Geology and Groundwater Supplies of
BOX BUTTE COUNTY, NEBRASKA

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Conservation and Survey Division
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The Conservation and Survey Division is the agency designated by statute to investigate and interpret the geologically related natural resources of Nebraska, 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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ABSTRACT

Box Butte County, an area of 1,066 square miles (2 750 km^2) is located on the upland plain of northwest Nebraska. Precipitation averages about 17 inches (430 mm) per year. Although the railroad industry has considerable input into the economy, agriculture is the principal industry. Dryland wheat is the major crop. In 1975, the main irrigated crops were corn, sugar beets, dry edible beans, and alfalfa. About 60,000 acres (2.43×10^8 m^2) of land were irrigated that year with water from about 600 wells.

Thirteen hydrologic units within 1,300 feet (3.95×10^2 m) of the land surface were defined by examination of test-hole samples and logs and by examining electric logs of oil and gas tests, drillers' logs of irrigation wells, and outcrops. Most of these hydrologic units could be correlated with established geologic units. The investigations disclosed that some of the previous stratigraphic interpretations are open to question.

Three of the hydrologic units--the Arikaree, Ogallala, and Runningwater--provide most of the groundwater in the county for irrigation, municipal, and industrial purposes. In other areas, a combination of hydrologic units is necessary to sustain high-yield wells. The Arikaree unit, the major aquifer in Box Butte County, contained an estimated 23 million acre-feet (28.5 km^3) of water in 1975. The Ogallala unit is second in importance, containing in 1975 an estimated 3.7 million acre-feet (4.59 km^3)

of water. The total amount stored in the Arikaree and overlying units was about 32 million acre-feet (39.4 km^3). An estimated 700,000 to 1,000,000 acre-feet (0.86 to 1.23 km^3) of groundwater was removed from storage from 1938 to 1975, probably half of this since 1964.

Recharge of the groundwater reservoir is principally from precipitation, averaging about 130,000 acre-feet (0.160 km^3) per year. The rate of recharge ranges from about 0.7 inch (17.8 mm) to about 6 inches (152 mm) per year. Although dependent on many factors, recharge from precipitation is greatly influenced by the hydrologic units at or near land surface. Evapotranspiration in areas with a shallow water table accounts for most of the groundwater discharged from the county. It is estimated that more than 150,000 acre-feet (0.185 km^3) of groundwater was discharged by evapotranspiration in 1938. Pumping of wells since then has lowered water levels and intercepted some of this discharge. Groundwater discharged from wells is estimated to have been 120,000 acre-feet (0.148 km^3) in 1975.

Geologic data and water-level measurements indicate that the groundwater supply is not significantly depleted anywhere in the county despite local water-level declines of more than 35 feet (10.7 m) in some areas between 1938 and 1975. However, some local problems are associated with these water-level changes, and water levels will continue to lower as wells are installed and water is pumped.

INTRODUCTION

Purpose and scope

Groundwater supplies began to be utilized for irrigation in Box Butte County in the 1930s. The use of this resource substantially increased after 1960 and prompted questions about the longevity of the supply and possible conflicts in use. The purpose of this report is to publish water resources information acquired by the Conservation and Survey Division through its continuing investigations of the geology and groundwater supplies of Nebraska and to describe the basic geologic and hydrologic situation in the county. Cooperating in the continuing investigations have been various federal and state agencies, most notably the Water Resources Division of the U.S. Geological Survey, and many local agencies. The Upper Niobrara-White Natural Resources District furnished the test-drilling funds as well as personnel for some of the work involved in the test-drilling program.

This report describes the relationship between the geology and the groundwater supplies in Box Butte County. It also evaluates the aquifers with respect to waterbearing characteristics and groundwater in storage. It further describes recharge to and discharge from the aquifers, outlines the movement of groundwater in the county, and summarizes the changes in groundwater storage that have occurred since the advent of irrigation in the county. Brief descriptions of the topography and drainage are included.

An evaluation of climatic data for Box Butte County and the Nebraska Panhandle is incorporated into this report and several observations are made about climate in relation to groundwater and the irrigation requirements of crops. Brief mention is made of the soils and agricultural activity in the county.

Location and extent of area

Box Butte County is in western Nebraska in the south-central part of the Upper Niobrara-White Natural Resources District (fig. 1). Nearly rectangular, the county measures 30 miles (48.5 km) in the north-south direction and nearly 36 miles (58 km) in the west-east direction. The area included within the county is 1,066 square miles or 682,240 acres (2 750 km^2). Box Butte County is bordered on the east by Sheridan County, on the north by Dawes County, and on the west by Sioux County. Morrill and Scotts Bluff counties border the county on the south.

Methods of investigation

Thirty-seven test holes were drilled in Box Butte County during fall 1975 and spring 1976 (fig. 2). Depths of the test holes ranged from 220 to 520 feet (67 to 158 m) and the average depth of the 37 holes was 404 feet (123 m). (See appendix A.)

Hydraulic rotary rigs were used for drilling the test holes. Representative samples of the cuttings, from each 10-foot (3.05-m) interval of depth or from each significantly different type of material less than 10 feet (3.05 m) thick, were collected. While

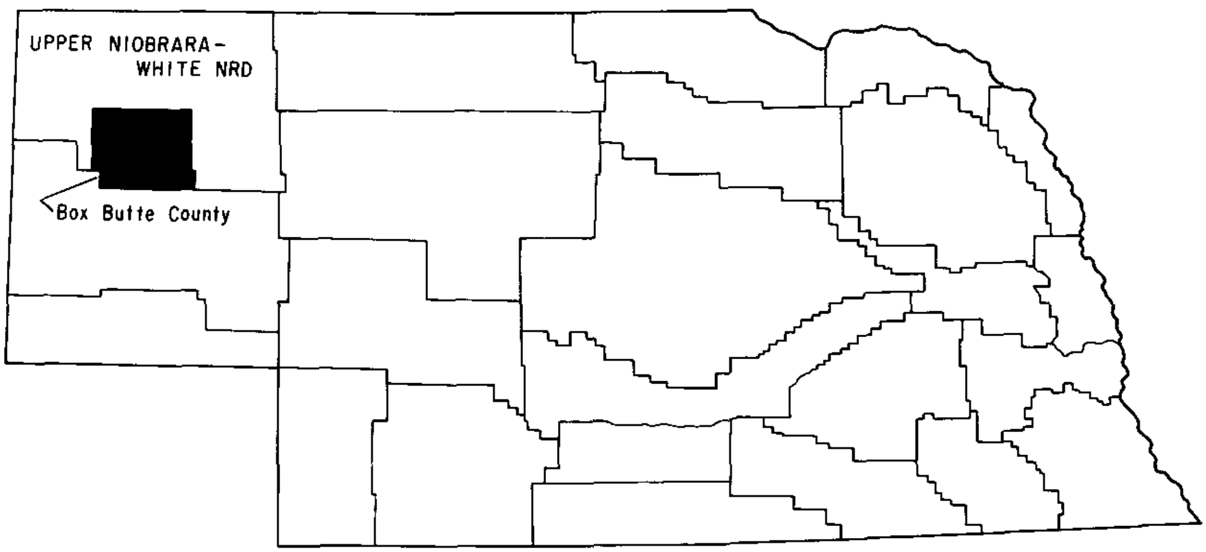


Fig. 1. Location of Box Butte County and Natural Resources District boundaries in Nebraska

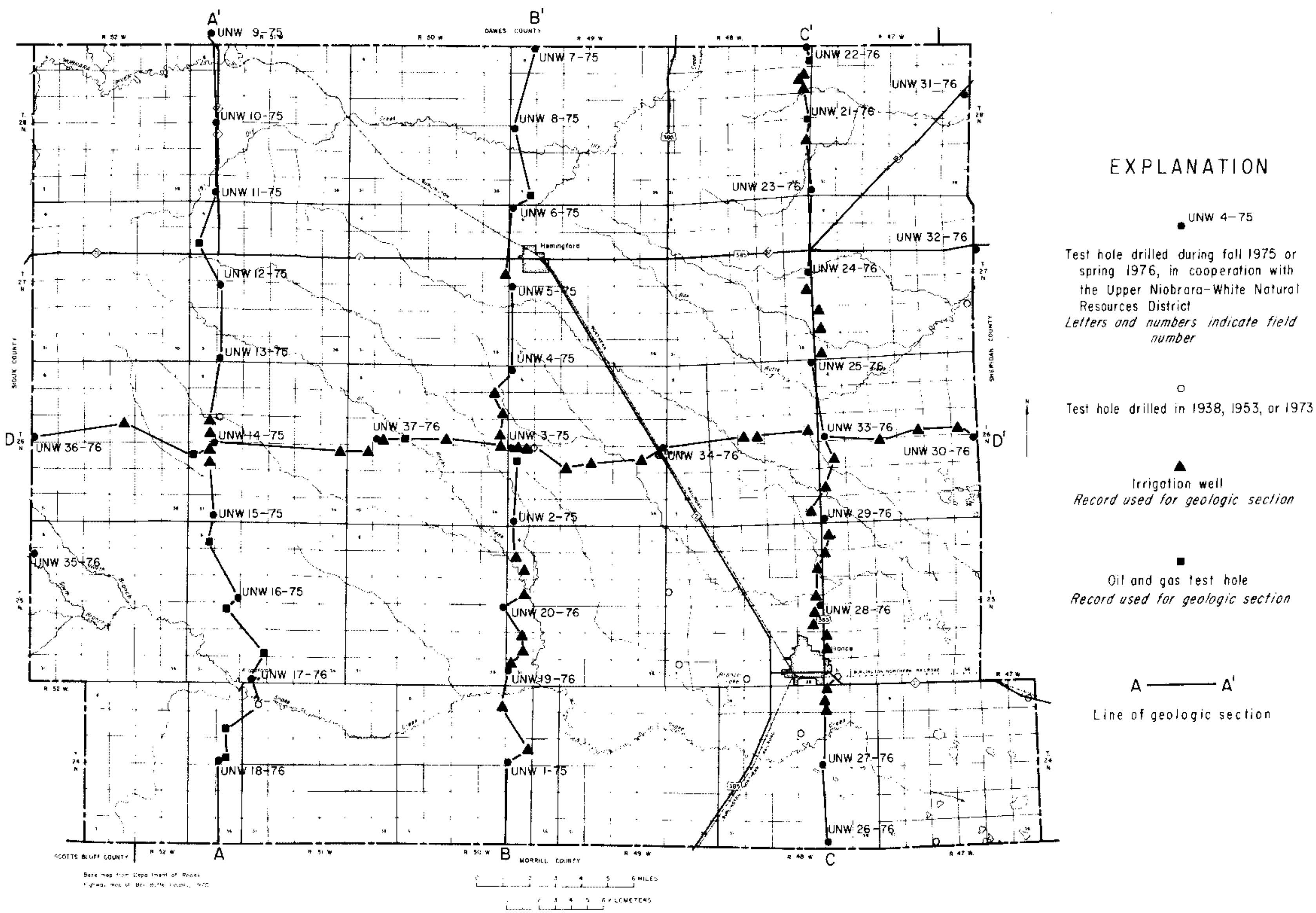


Fig. 2. Location of test holes and geologic sections

drilling was in progress, a geologist described the rocks penetrated and noted the drilling action and drilling time of each 10-foot (3.05-m) interval. An electric log was made of all but two holes where drilling problems prohibited logging. The electric logs are on file at Conservation and Survey Division offices, Lincoln and Scottsbluff, and at the Upper Niobrara-White Natural Resources District office in Chadron.

The depth to water was measured with a steel tape in 30 of the holes within three to 25 days after the completion of the drilling of each hole and after the water level in the test hole had stabilized (see appendix B). Seven of the test holes had caved in or the water level was not measurable. All holes but one were plugged after the water-level measurement, or attempted measurement, was made. Most of the holes were plugged by setting a wooden plug at a depth of about 4 feet, adding two to three shovelfulls of dry cement, and mixing wet cuttings with the cement. The hole was then filled to land surface and firmly tamped. The one hole that was not plugged was in a wheat stubble field that had been plowed after the time of drilling. That hole could not be found. Land surface altitudes were estimated from U.S. Geological Survey 7.5-minute and 15-minute topographic maps.

After the test-drilling program had been completed, most of the test-hole samples were examined with a binocular microscope in the laboratory. The field and laboratory descriptions, along with the electric logs, were used as the basis for identifying the geologic formations and assessing their water-bearing characteristics.

Each of the authors independently identified all hydrologic units. If significant differences in identification occurred, all three examined the samples together and decided on a suitable geologic identity for the materials.

One hundred twenty samples from 14 test holes were selected for a petrographic study to determine if the mineralogical composition could be used to characterize certain formations and hydrologic units. Preliminary analysis indicated that the percentage of volcanic glass shards in the very fine sand sized fraction of each sample would provide a quick and significant means for mineralogically identifying many units. The very fine sand sized fraction was used to reduce the effect of mineralogical changes as a function of grain size. It was also a size common to both the sandstones and siltstones in the study. The samples were gently disaggregated and sieved in a mechanical shaker for 10 minutes. Most grains in the samples had thin clay coatings, which made it difficult to identify them. Therefore, each sieved sample was gently agitated for 20 seconds in 3 percent hydrofluoric acid, which effectively removed most of the clay coatings. The samples were also treated with 10 percent hydrochloric acid to remove carbonate cement. After oven drying, the samples were hand sieved for 1 minute and mounted on slides with the use of Lakeside 70. The slides were then examined under a petrographic microscope and 300 grains per slide were counted with the use of a line count technique. Grain categories counted were volcanic glass, volcanic rock fragments, heavy minerals, and other grains.

For the purposes of this report only the percentages of volcanic glass are reported.

Most of the maps in this report are based on information obtained from the test drilling. Supplemental information consisted of drillers' logs of irrigation wells, records of previous drilling done by the Conservation and Survey Division in cooperation with the Water Resources Division of the U.S. Geological Survey, and electric logs of oil and gas tests. Water-level measurements made by the Upper Niobrara-White Natural Resources District and the Box Butte County Irrigator's Association were used. These measurements were supplemented by those made in Box Butte County by the Nebraska Department of Water Resources as a part of the statewide program of water-level monitoring in cooperation with the Conservation and Survey Division and the U.S. Geological Survey. The Water Resources Division, U.S. Geological Survey, furnished copies of records of a well inventory made in 1938.

Test-hole and well-numbering system

Each test hole and well referred to in this report is identified by a number indicating its location in the U.S. Bureau of Land Management's survey of Nebraska. The figure preceding N (for "north") indicates the township, the figure preceding W (for "west") indicates the range, and the figure preceding the lowercase letters indicates the section. The lowercase letters denote location within the section. As shown in figure 3, the

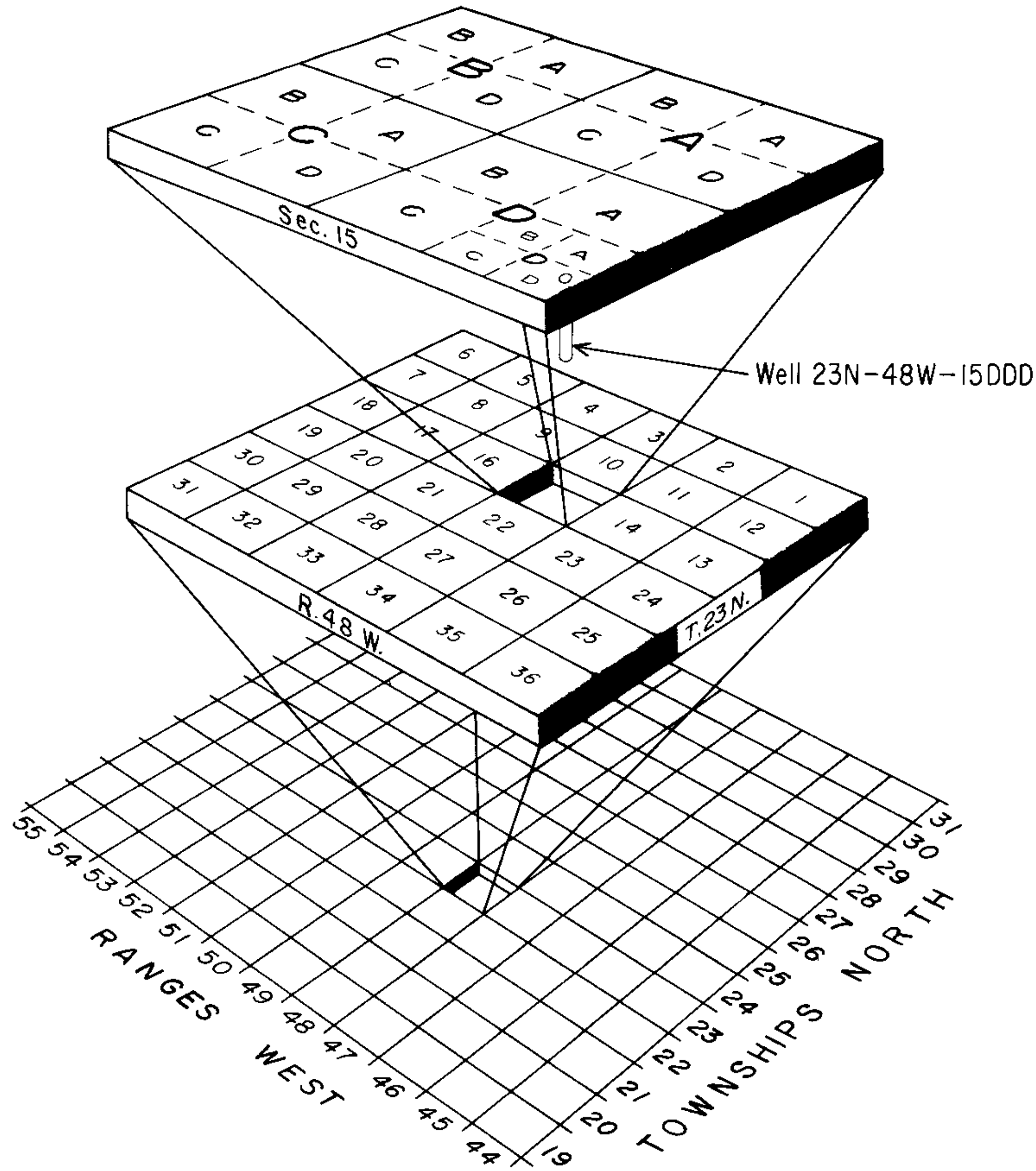


Fig. 3. System used for identifying test holes and wells according to their location

first of these letters indicates the quarter section, the second the quarter-quarter section, and the third the quarter-quarter-quarter section. Thus, in this system of numbering, a test hole or well in the SE 1/4 SE 1/4 SE 1/4 section 15, Township 24 North, Range 49 West, is identified by the number 24N-49W-15ddd.

Each test hole is also identified by a field number. It consists of the letters UNW (for Upper Niobrara-White), a sequential designation, and the year in which the hole was drilled. Thus, field number UNW 20-76 indicates the twentieth hole drilled for the Upper Niobrara-White project in 1976.

Previous groundwater investigations in Box Butte County

The U.S. Geological Survey conducted two previous investigations of all or part of Box Butte County. The earlier investigation was conducted in cooperation with the Conservation and Survey Division and the latter supplemental investigation was carried out in cooperation with the U.S. Bureau of Reclamation.

Cady and Scherer (1946) did extensive fieldwork in the county in 1938. They evaluated the geologic and hydrologic conditions in the county, published a map showing the configuration of the water table, a geologic map, and geologic sections. Calculations of recharge to, discharge from, and underflow within the groundwater system were made. Unfortunately, the study lacked sufficient subsurface information. Nevertheless, the results of the investigations by Cady and Scherer are extremely important to any later work because the water-level measurements were made prior to heavy usage of groundwater supplies.

The report of Cady and Scherer was supplemented by a report on groundwater for irrigation in the county by Nace (1953). The fieldwork was done in 1946, additional water-level measurements were made, and water was sampled for chemical analysis. The emphasis of the report was on the Alliance area. This report, like the first, lacked substantial subsurface information but did broaden and amplify hydrologic knowledge of the county. As a partial fulfillment for a Master of Science degree in Agricultural Engineering, Ralph Waddington (1971) constructed an electric-analog model of the groundwater system of Box Butte County and studied the effects of pumping on the system. Waddington's data came primarily from driller's logs of irrigation wells but lacked comprehensive subsurface information needed for constructing accurate groundwater models. Waddington nevertheless contributed to the understanding of the dynamic interactions of pumping and water-level change in Box Butte County. His work suggested that, while water levels would continue to lower throughout the county as a result of irrigation development, the groundwater supply was in no short-term danger of severe depletion.

Acknowledgments

Glen Nelson of Nelson Wells, Inc., operated the drill rig at 17 sites and John Skeen drilled the remaining holes. Helping in the drilling operations at various times were Earl Sowders, Marshall Rogers, Ted Hemphill, and George Sexton. The drilling program would have been impossible without the cooperation of these men.

John Boellstorff and Hal DeGraw, geologists with the Conservation and Survey Division, provided valuable information for the geology section of this report. Special recognition is due John Williams, manager of the Upper Niobrara-White Natural Resources District, who obtained permission from land owners to drill on their land.

Encouragement and support for this project came from throughout Box Butte County and from other parts of western Nebraska. It is impossible to name all who offered help in one way or another. The financial assistance for test-drilling by the Upper Niobrara-White Natural Resources District and the encouragement given the project by the Board of Directors of the district were essential. The encouragement and support of the Box Butte County Irrigators' Association; the assistance of David Evertson, former County Extension Agent of Box Butte County; and the help of Gene Youngman, former District Conservationist, Soil Conservation Service, Alliance, Nebraska, are all gratefully acknowledged. The Panhandle Station, University of Nebraska-Lincoln, whose director is Dr. John Weihing, furnished office space and support for the Conservation and Survey Division and this is greatly appreciated. Finally, thanks are due the landowners who permitted drilling on their land.

GEOGRAPHY

The topography of a region greatly influences the use of its land and water resources; this is especially true for agricultural uses of land that requires irrigation. In this respect, Box Butte County is fortunate in that the county is part of the high plain, or tableland, which lies between the Pine Ridge escarpment to the north and the North Platte valley to the south (fig. 4). Much of the land on this plain is suitable for irrigated agriculture.

The Pine Ridge escarpment is a west- to east-trending topographic feature that abruptly rises 600 to 1,000 feet (183 to 305 m) above the drainage areas of the White and Cheyenne rivers to the north. The relief between the tableland and the North Platte River ranges from 500 to 800 feet (152 to 244 m).

This broad plain, called Box Butte Table in the vicinity of Box Butte County, is bordered on the east by the Sand Hills region and rises westward in east-central Wyoming to a north-south chain of hills generally known as the Hartville Mountains. The headwaters of the Niobrara River originate on this plain in the vicinity of Lusk, Wyoming. This river crosses the plain from west to east in the Nebraska Panhandle and is approximately parallel to the Pine Ridge escarpment.

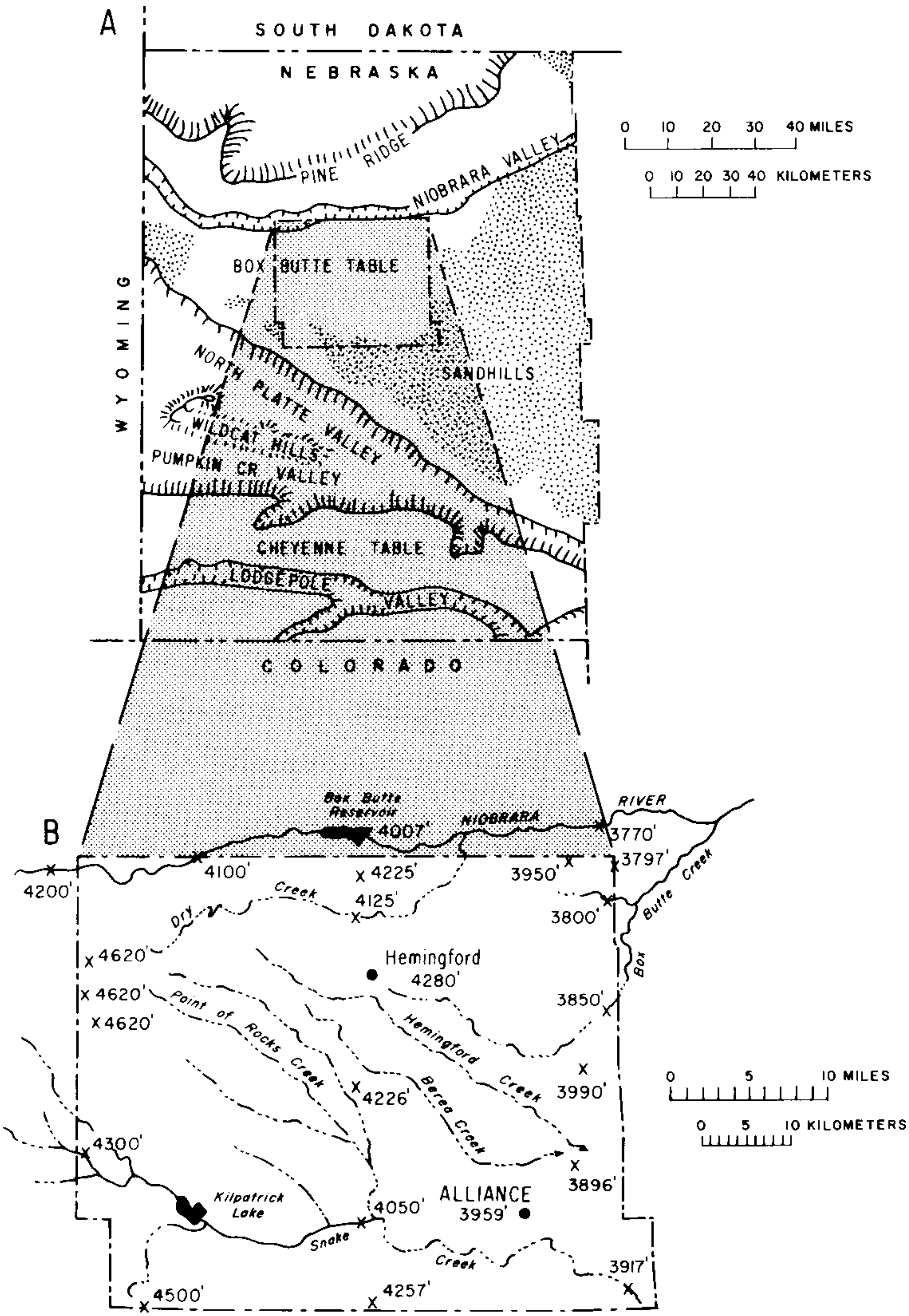


Fig. 4. Major topographic features of the Nebraska Panhandle and Box Butte County

The width and depth of the Niobrara River vary considerably throughout its reach across the panhandle. For example, the river lies nearly 400 feet (122 m) below the tableland where the stream crosses the northwestern corner of Box Butte County, but it is less than 150 feet (45.5 m) below the surface of the plain immediately north of the northeastern part of the county. The differences in the elevation between the river and the surface of the plain could be due to the erosional history of the plain and the deformation of the tableland surface by structural forces.

The plain slopes from west to east in Box Butte County in the area between Snake Creek and the Niobrara River (fig. 4) except south of Snake Creek where the plain slopes northeastward toward the creek. The slope of the tableland on a west-to-east line through Hemingford is not uniform but averages about 23 feet per mile (4.35 m/km). In the northwestern part of the county, the eastward slope of the plain is less than 20 feet per mile (3.80 m/km), while several miles east of Hemingford the slope exceeds 30 feet per mile (5.7 m/km). In comparison, the average eastward slope of the Niobrara River valley along the northern edge of Box Butte County is between 10 and 11 feet per mile (1.89 to 2.08 m/km). The highest points have an altitude of slightly more than 4,260 feet (1 410 m) and occur along the Sioux-Box Butte county line west of Hemingford. The lowest points in the county are in the northeast corner at an altitude slightly less than 3,800 feet (1 160 m).

The irregular surface of most of the tableland between Snake Creek and the Niobrara River is a result of dissection of the surface by small, ephemeral streams. These widely spaced streams have cut small valleys that trend southeast. In their middle and lower reaches, they have flat and relatively wide floors nearly 100 feet (30.5 m) below the tableland surface.

Snake Creek and its tributaries in southwest Box Butte County have relatively small, well defined valleys bordered by rolling to rough topography. To the east, the relief from the tableland to Snake Creek valley decreases markedly. The gradient of the Snake Creek valley at the Sioux-Box Butte county line is about 29 feet per mile (5.5 m/km) but decreases rapidly to the east. The gradient is 14 to 15 feet per mile (2.65 or 2.85 m/km) near Kilpatrick Lake and only 5 feet per mile (0.95 m/km) in the southeastern part of the county.

The eastern part of the county is the lowest part of the Box Butte Table with sand dunes rising to higher elevations to the east in Sheridan County. Buttes and hills, which are most numerous in the east-central part of Box Butte County, rise above the lowlands and probably represent remnants of the tableland to the west.

Sand hills occur in the southeastern and south-central parts of the county, with a few occurring in the southwestern part. Most of these hills are sand dunes, but the original dune form has been modified by wind and water erosion. The dunes, now stabilized by a cover of grass, brush, and yucca, are inactive except where blowouts (associated with cattle trails, watering tanks, or vehicle trails) have formed.

More than one-half the land in the county does not drain to any major through-flowing stream. Snake Creek, originating in Sioux County, crosses the county from west to east and finally disappears in front of the sand hills in the southeast part of the county. Snake Creek flows the year around from west of the Box Butte county line to east of Kilpatrick Lake. East of there it is an ephemeral stream, flowing only after heavy rains. The major tributary to Snake Creek in Box Butte County is Point of Rocks Creek. This creek and its numerous tributaries drain the tableland in the central and western parts of the county (fig. 4). Point of Rocks Creek is an ephemeral stream.

The headwaters of Berea and Hemingford creeks are in central Box Butte County. These ephemeral streams drain to the southeast where they disappear in front of the sand hills northeast of Alliance. There are several undrained depressions in southwest Box Butte County that receive surface runoff from small watershed areas. Lowlands in the vicinity of Alliance contain both ephemeral and perennial lakes, none of which drains directly to any stream.

Streams in the northern part of the county flow to the Niobrara River. Dry Creek (or Dry Creek-Sand Canyon), originates on the tableland in northwest Box Butte County and trends parallel to the course of the Niobrara River before turning north and entering the river below Box Butte Reservoir (fig. 4). Dry Creek, an ephemeral stream, is deeply entrenched below the tableland surface in its lower reach.

The headwaters of Box Butte Creek, which drains to the southeast, are on the tableland just east of Hemingford. In the eastern part of the county, the creek turns north-northeast to the Niobrara River and in this reach the stream may flow intermittently during part of the year. Several other small drainages occur throughout the county, but the areas drained by these streams are small.

The Niobrara River is a perennially flowing stream within a large valley. Near the upstream end of Box Butte Reservoir, the average annual discharge of the river for the 28 years prior to September 1974 was 31 cubic feet (0.88 m^3) per second, or 22,460 acre-feet (2.75 x 10^7 m^3) per year. The maximum discharge during this period was estimated to be 4,950 cubic feet (140 m^3) per second on July 28, 1951, and the minimum daily discharge was 1.6 cubic feet (0.045 5 m^3) per second on September 25, 1953 (anonymous 1974). The flow of the stream during dry periods is maintained by groundwater.

About 340,000 acres (1.38 x 10^9 m^2), or more than half the land in the county, is probably suitable for some type of farm operations and much of this land is suitable for irrigation. The rougher land along drainages and in the sand hill areas is suitable for livestock grazing.

CLIMATE

Weather and climate, as well as topography, influence the use of a region's land and water resources. The climate of Box Butte County is characterized by the large seasonal extremes typical of the Great Plains, low average annual precipitation, high rates of evaporation, and a wide range of temperature. The weather can be quite variable from year to year, season to season, and even day to day. Thunderstorms, sometimes accompanied by hail, occur during the summer and at times blizzards occur during the winter. Strong winds, common in early spring, can occur at any time of the year. Summer days can be hot, but the low relative humidity and high altitude combine to provide cool nights. Extremely cold temperatures usually occur each winter, but periods of mild days and mild nights can also occur. Some of these mild periods are due to dry, westerly winds called chinooks.

The National Weather Service collects climatological data at three stations in the county. Precipitation has been recorded at Alliance since 1890, except for the years 1893-94 and 1920-25. Temperature measurements are also made at Alliance and, as of 1975, 72 years of temperature records were available for the station. Since 1931, precipitation, temperature, and evaporation have been measured on a relatively consistent basis at the Box Butte Experiment Station four miles northwest of Alliance.

Precipitation and temperature have been recorded at Hemingford since 1964.

Some measurements of wind velocity are made in association with the evaporation pan at the Box Butte Experiment Station. Prevailing winds are from the south during the summer months and from the northwest during the winter months, but frequently they blow from other directions. Maximum wind velocities can exceed 60 miles per hour (96 km/hr), and velocities of 30 miles per hour (48 km/hr) are not unusual. Strong southerly winds during the summer months are often accompanied by high temperatures and very low humidity, all of which cause rapid loss of soil and plant moisture by evapotranspiration.

Table 1 shows the normal monthly and annual mean temperature at Alliance and at the Box Butte Experiment Station. The mean annual temperature in the area of the two stations is about 47°F (16.1°C). January is the coldest month and July and August are the hottest months. Temperatures of more than 100°F (37.5°C) commonly occur in summer and in winter they often drop below zero. Summer highs greater than 110°F (43.5°C) and winter lows below -40°F (-40°C) have been recorded.

The average growing season at Alliance is 137 days. May 14 is the average date of the last 32°F (0°C) reading in the spring and the average date of the first 32°F (0°C) reading in the fall is September 28 (Neild and Webb 1973). Even with irrigation, the growth of the row crops common to eastern and central Nebraska is restricted in Box Butte County by the short growing season and cool summer nights.

TABLE 1

Normal Monthly and Annual Temperature at Alliance and Box Butte Experiment Station, in Degrees Fahrenheit, 1941-70

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Alliance	24.9	29.1	33.5	45.5	55.6	64.9	72.6	71.1	60.3	49.3	35.6	27.9	47.5
Box Butte Experiment Station	23.2	27.4	31.9	44.4	54.3	63.8	72.3	70.9	60.0	48.9	34.7	26.5	46.5

TABLE 2

Normal Monthly and Annual Precipitation at Alliance and Box Butte Experiment Station, in Inches, 1941-70

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Alliance	0.43	0.42	0.78	1.64	3.39	3.55	2.22	1.68	1.37	0.68	0.43	0.36	17.13
Box Butte Experiment Station	0.33	0.34	0.64	1.45	3.06	3.34	2.01	1.65	1.34	0.86	0.38	0.28	15.68

TABLE 3

Annual and Mean Annual Precipitation at Alliance, Box Butte Experiment Station, and Hemingford, in Inches, 1964-75

Station	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	Annual
Alliance	8.67	21.73	16.48	19.73	18.51	16.42	16.14	18.22	18.35	22.04	14.10	13.34	16.98
Box Butte Experiment Station	8.40	18.71	14.67	16.48	16.34[1]	14.17[1]	16.06	20.69	16.77[1]	21.66[1]	12.03[1]	11.03[1]	15.59
Hemingford	12.57	20.97	16.29	23.54	18.30	20.06	18.78	20.65	18.58	24.59	12.49	13.77	18.38

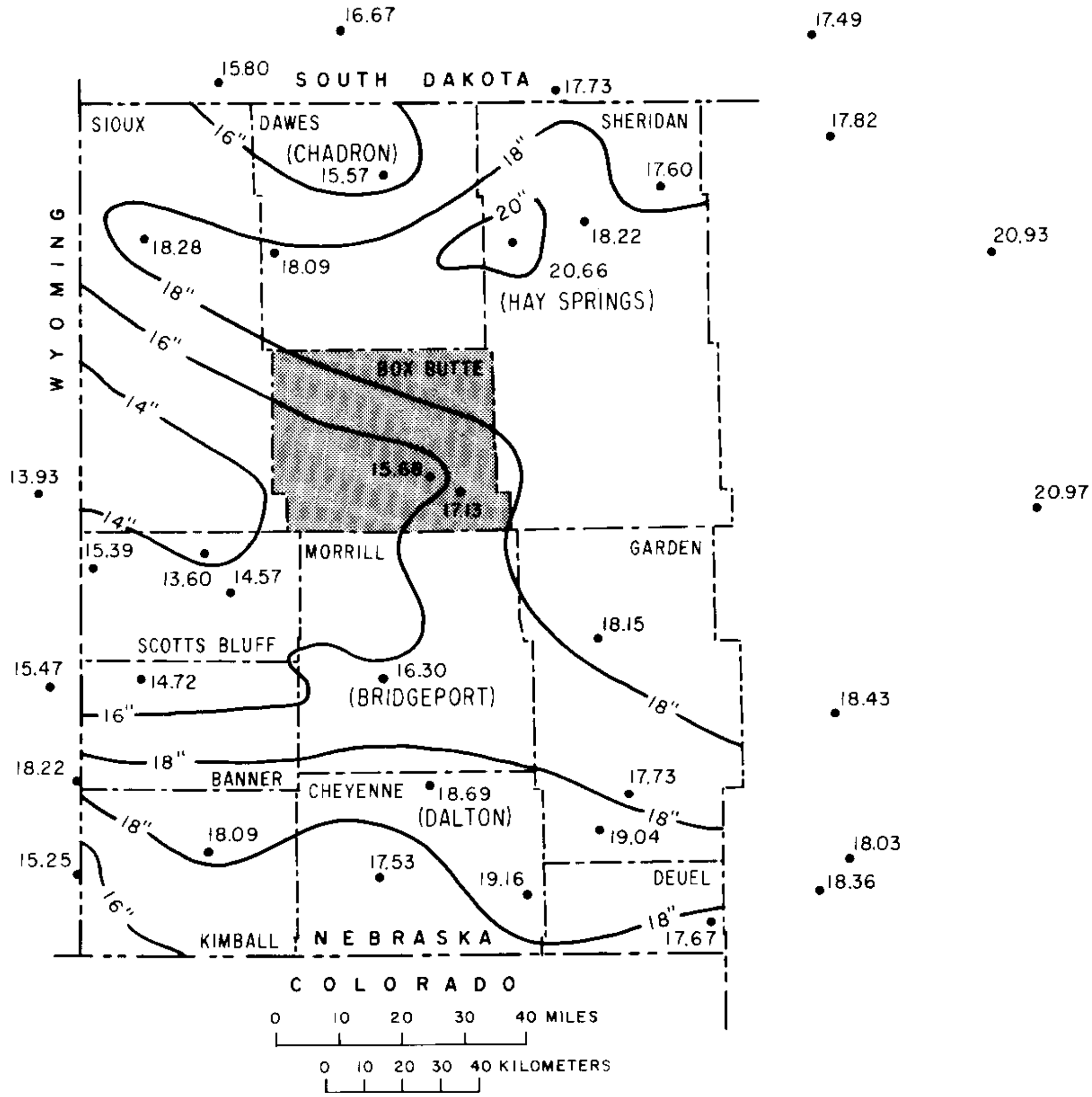
1. Precipitation estimated for one or more months of the year.

Normal monthly and annual precipitation at Alliance and the Box Butte Experiment Station is listed in table 2. Normal climatic figures are based on the 30-year sample record for the period 1941-70. Normal annual precipitation at Alliance is 17.13 inches (435 mm), 1.45 inches (37.0 mm) more than at the Box Butte Experiment Station. At both stations, more than 60 percent of the annual precipitation normally comes in the form of local showers during May, June, July, and August; and more than 80 percent of the annual precipitation at both places normally occurs in the six-month period of April through September. About one-third of the annual precipitation normally occurs in March, April, and May, the months when conditions generally are most favorable for precipitation to recharge the aquifers of the county.

The daily, monthly, and annual precipitation varies considerably from place to place throughout the county. Table 3 shows that the annual precipitation since 1964 was 16.98 inches (430 mm) at Alliance, 18.38 inches (465 mm) at Hemingford, and 15.59 inches (395 mm) at the Box Butte Experiment Station between Alliance and Hemingford. Colville and Myers (1965, p. 4) postulate that two important factors affecting precipitation in Nebraska are the Rocky Mountains to the west of the Nebraska border and the distance and direction from the Gulf of Mexico. The mountains, for the most part, block Pacific Ocean moisture from reaching the state and the Gulf of Mexico is the source of moisture-laden air that supplies the state with most of its precipitation. As the moist air moves northward from the Gulf of Mexico, it generally turns slowly eastward, often moving over eastern Nebraska and missing the western portion of the state. Normal annual precipitation thus gradually increases from less than 14 inches (355 mm) in parts of western Nebraska to more than 36 inches (910 mm) in the extreme southeast corner of the state.

The isohyetal lines in figure 5 show the normal annual precipitation in the panhandle and suggest that regional or local influences modify the principal factors affecting precipitation. The lines indicate that belts of relatively high precipitation are associated with Pine Ridge and the northern part of the Cheyenne Table. An area of low precipitation coincides with the North Platte River lowlands. Another area with relatively small amounts of precipitation occurs north of Pine Ridge in northeastern Sioux County and northern Dawes County. The map in figure 5 thus suggests some long-term differences in annual precipitation can be associated with the topography of the panhandle.

To illustrate the differences topography may have on precipitation, the records of two pairs of stations with different topographic settings are given. Table 4 compares the normal monthly and annual precipitation at Dalton with that at Bridgeport, while table 5 compares the normal monthly and annual precipitation at Hay Springs with that at the Chadron Airport. Dalton is on the northern rim of the Cheyenne Table about 19.5 miles (31.5 km) south of Bridgeport, which is in the North Platte valley. The altitude of the station at Dalton is 4,273 feet (1 300 m) and is 613 feet (187 m) higher than Bridgeport. Hay Springs is near the edge of the Pine Ridge escarpment 22 miles (35.5 km) southeast of



EXPLANATION

17.13

Climatic station and mean annual precipitation, in inches

16"

Isohyetal line showing mean annual precipitation, in inches
Interval is 2 inches

Mean annual precipitation based on the 30-year sample record, 1941-1970

Fig. 5. Normal annual precipitation in the Nebraska Panhandle

the Chadron Airport. The altitude of the station at Hay Springs is 3,855 feet (1 180 m) and is 555 feet (169 m) higher than the airport. Dalton normally receives 2.39 inches (61 mm) more precipitation each year than Bridgeport, while the normal annual precipitation at Hay Springs exceeds that of the Chadron Airport by slightly more than 5 inches (127 mm).

Examination of the normal monthly precipitation records at Dalton and Bridgeport and the precipitation ratio of Dalton to Bridgeport (table 4) suggests that precipitation at Dalton is significantly greater in the fall, winter, and early spring months. Except for the month of August, normal late spring and summer precipitation is about the same for the two stations. Normal precipitation at Hay Springs exceeds that at the Chadron Airport in all months of the year. However, the precipitation at Hay Springs for November to March and for August significantly exceeds that at the airport. At times during the fall, winter, and spring, snow or rain can be observed falling on Pine Ridge, Wildcat Ridge, or the northern part of the Cheyenne Table at the same time that none is falling at the lower elevations.

Box Butte County is situated midway between the two largest topographic features of the panhandle: Pine Ridge lies to the north of the county and the North Platte River lowlands lie to the south. Figure 5 suggests that the northern and northeastern parts of Box Butte County receive more precipitation than the rest of the county. Over the long term, the annual precipitation in the northeastern part of the county may exceed that in the southwest corner by as much as 4 inches. On the average, this difference

TABLE 4

Normal Monthly and Annual Precipitation at
Dalton and Bridgeport, in Inches, 1941-70

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Dalton	0.46	0.47	1.10	1.72	3.34	3.65	2.33	1.70	1.59	1.16	0.69	0.48	18.69
Bridgeport	0.35	0.29	0.72	1.42	3.10	3.67	2.40	1.38	1.42	0.83	0.38	0.34	16.30
Dalton minus Bridgeport	0.11	0.18	0.38	0.30	0.24	-0.02	-0.07	0.32	0.17	0.33	0.31	0.14	2.39
Ratio: Dalton/Bridgeport	1.31	1.62	1.53	1.21	1.08	0.99	0.97	1.23	1.12	1.40	1.82	1.41	1.15

TABLE 5

Normal Monthly and Annual Precipitation at
Hay Springs and Chadron, in Inches, 1941-70

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Hay Springs	0.71	0.67	1.23	2.09	3.54	4.18	2.72	1.47	1.65	1.05	0.70	0.65	20.66
Chadron (Airport)	0.41	0.38	0.70	1.67	2.98	3.32	2.16	0.97	1.33	0.83	0.43	0.39	15.57
Hay Springs minus Chadron	0.30	0.29	0.53	0.42	0.56	0.86	0.56	0.50	0.32	0.22	0.27	0.26	5.09
Ratio: Hay Springs/Chadron	1.73	1.76	1.76	1.25	1.19	1.26	1.26	1.51	1.24	1.27	1.63	1.67	1.32

in annual precipitation probably means that irrigated crops in southwest Box Butte County would require one or more additional irrigation applications per season than irrigated crops in northeast Box Butte County.

The difference in the normal amounts of annual precipitation at the Box Butte Experiment Station and at Alliance does not appear to be readily explicable. The difference of 1.45 inches (37.0 mm) in annual precipitation within 4 miles (6.4 km) seems unusual, especially since local topography is about the same. The records for the Box Butte Experiment Station do show that monthly precipitation totals have had to be estimated more frequently there than at the Alliance station. Estimates, however, do not appear to be so numerous as to indicate the record is in error.

Precipitation varies not only from place to place in the county but also from year to year. Figure 6 is a graph showing annual precipitation at Alliance since 1890, except for the years 1892-94 and 1920-25. The precipitation at Alliance for these years was estimated by averaging the precipitation recorded at Hay Springs and Scottsbluff. Although marked differences in precipitation may occur from year to year, the record shows that periods of several years of less-than-average precipitation are generally followed by periods of several years when precipitation exceeds the long-term average. These below- and above-average periods recur throughout the record, but neither the lengths of the periods are the same nor is the degree of wetness or dryness of these periods precisely repeated.

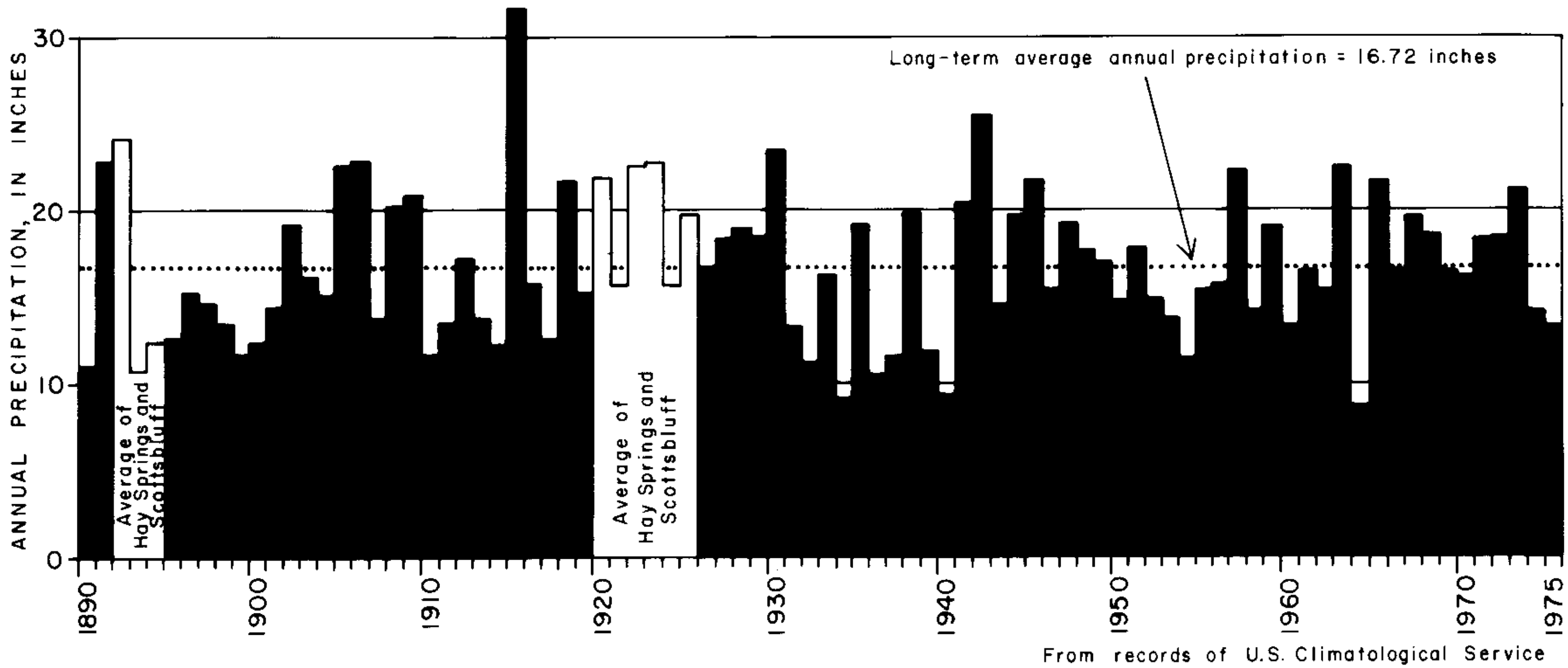


Fig. 6. Annual precipitation at Alliance, 1890-1975

Figure 7 summarizes the various wet, dry, and average periods at Alliance. The years from 1893 through 1901 were extremely dry years because the average annual precipitation for this period is estimated to have been only 13.01 inches (330 mm). This is nearly 4 inches (102 mm) below the long-term average, or less than 80 percent of the long-term average.

The three years from 1902 through 1904 were ones of average precipitation. Annual precipitation for the period averaged 16.72 inches (425 mm), the same as the long-term average. From 1905 through 1909, average annual precipitation was 120 percent of the long-term average, or 20.06 inches (510 mm) per year. This period was followed by a dry period, less severe than the 1890s, from 1910 through 1914. Average annual precipitation for this dry period was about 82 percent of the long-term average.

In the year 1915, 31.73 inches (810 mm) of precipitation fell at Alliance, the wettest year on record. This year signaled the inauguration of a prolonged period of above-average precipitation. Average annual precipitation from 1915 through 1930 is estimated to have been 116 percent of the long-term average.

The great drought of the 1930s is well documented in the precipitation record at Alliance. Beginning in 1931 and lasting through 1940, the average annual precipitation for the 10 years was only 13.17 inches (335 mm), or 79 percent of the long-term average. Only 9.01 inches (229 mm) of precipitation fell in 1934, 10.50 inches (265 mm) in 1936, and 9.39 inches (239 mm) in 1940. Like earlier dry periods, this drought was succeeded by several wetter-than-average years. Average annual precipitation from 1941 through 1949 was 114 percent of normal.

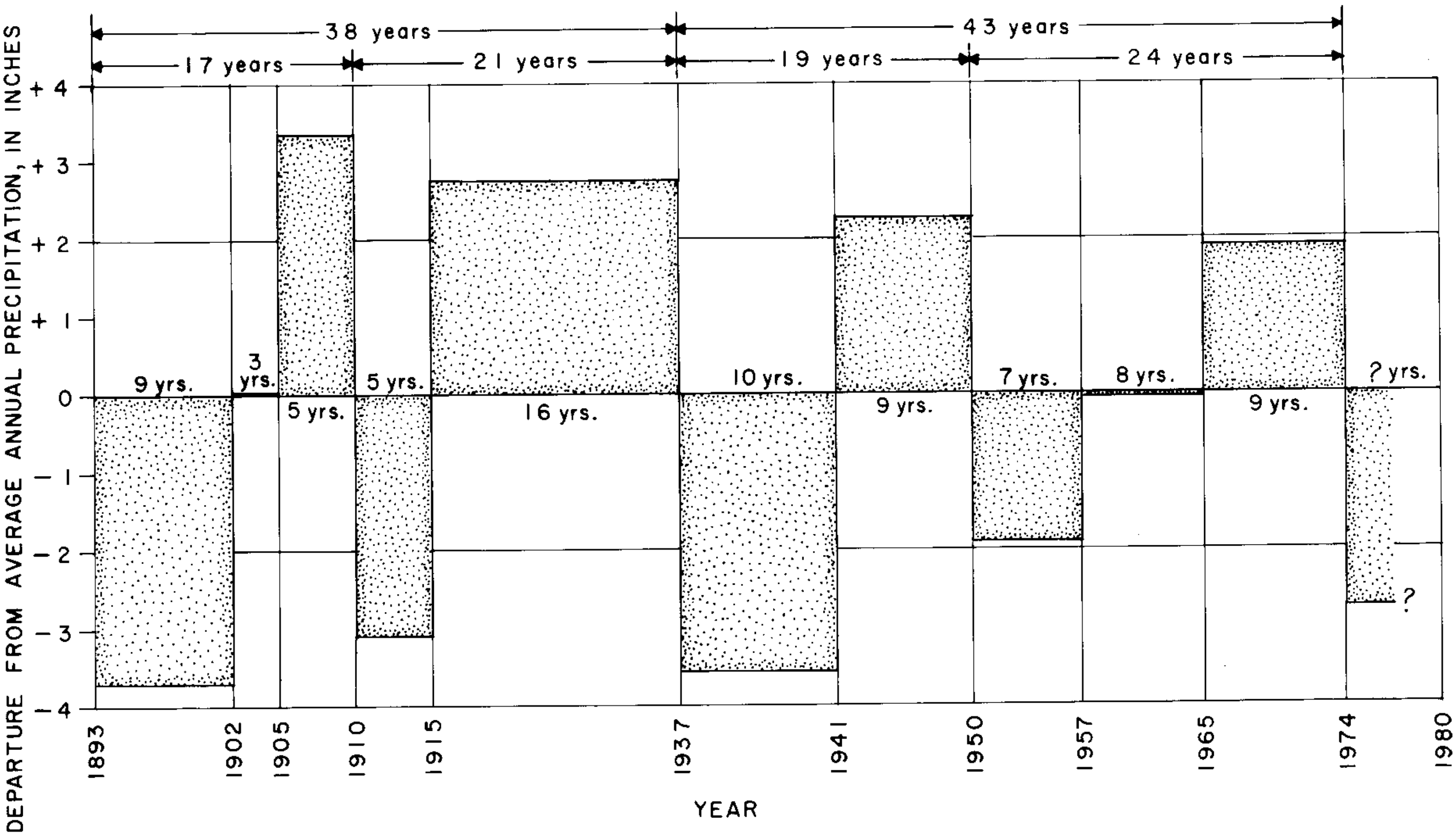


Fig. 7. Departure from average annual precipitation at Alliance

A dry period, less severe than the 1890s or 1930s and somewhat comparable to that from 1910-14, occurred at Alliance from 1950 through 1956 when 89 percent of the average precipitation fell. This dry period was followed by one in which the year to year precipitation varied considerably but in which, over an eight-year span from 1957 through 1964, the average annual precipitation was 16.46 inches (420 mm), or 98 percent of the long-term average. The year 1964 was, however, the driest one ever recorded at Alliance and only 8.67 inches (220 mm) of precipitation were measured.

Most of the years from 1965 through 1973 were again wetter-than-average and precipitation for the period was 111 percent of the long-term average. Dry conditions returned in 1974 and continued through 1975 and 1976. Average annual precipitation these three years amounted to only 13.96 inches (355 mm).

The duration and severity of this latest of the recurring dry periods at Alliance cannot be accurately forecast. Previous dry periods, generally confined to odd-numbered decades, have ranged from five to 10 years in length (fig. 7) and, except for the 1890s, included at least one year of above-average precipitation (fig. 6). The severe dry periods of the 1890s and 1930s were, respectively, nine and 10 years long. Less severe dry periods of the 1910s and 1950s were, respectively, five and seven years long.

It is too early to tell whether the current dry period is similar to that of the 1890s and 1930s, to that of the 1910s and 1950s, or whether it has a character of its own. The 85-year record at Alliance does suggest that the beginnings of the dry periods are approximately 20 years apart and that severely dry periods could occur at about 40-year intervals (fig. 7). If the past record is a guide, and if the patterns of the past 85 years tend to repeat, then the current dry period could be lengthy and severe, possibly not terminating until the early 1980s, and a subsequent, less severe, dry period could recur in the 1990s. Such predictions, however, are quite speculative and the reader is reminded that wetter-than-average years have occurred during dry periods, that wetter-than-average periods of years occur just as dry periods do, that it is hazardous to make long-term predictions on only 85 years of record, and that there is no assurance past climatic patterns are infallible indications of future climatic patterns.

The distribution of precipitation throughout the year and periods of high temperature, high wind velocity, and low relative humidity are the principal climatological factors that determine irrigation requirements. A wetter-than-average year may have a significant dry period in July and August, thus creating a large irrigation requirement. A drier-than-average year may have timely rains and favorable temperatures during critical growing periods and irrigation requirements might be less than normal. Over the long term, however, water requirements for irrigation are probably greater during the recurring dry periods than at other times. Recharge from precipitation to the aquifers would likewise be less during the dry periods, and the combination of increased water use and decreased recharge indicate water-level lowerings would be increased during the dry periods.

The high rates of evaporation in Box Butte County are shown in table 6. These figures represent measurements made in the evaporation pan at the Box Butte Experiment Station. The average evaporation for the five-month period of May to September for more than 30 years is 43.10 inches (1 090 mm). Evaporation from a free-water surface, such as a lake or stream, would be about 70 percent of that in the pan, or about 30 inches (760 mm) for the five-month growing season. Evaporation during the colder months is not measured but significant amounts of water can be evaporated during these months, especially in April and October. It is estimated that evaporation from a free-water surface averages more than 45 inches (1 140 mm) per year in the county. Consequently, on the average, the potential for evaporation from a lake, sub-irrigated meadow, or heavily irrigated field exceeds the precipitation by about 30 inches (760 mm) per year and by about 18 inches (455 mm) for the May to September period in the area around Alliance. Selected crops, such as alfalfa or sugar beets, would thus require an average of 18 inches (455 mm) of supplemental water during the growing season to reach maximum production. Other crops, such as corn and dry beans, would require less supplemental water.

Soils

The soils over much of the tableland between the Niobrara River and Snake Creek formed in wind-deposited silt. These soils have a silty texture and a moderately deep to deep root zone. The soils are moderately permeable to air and water and at field

TABLE 6

Average Pan Evaporation, in Inches, at Box Butte Experiment Station*

Month	Number of years used to average	Average pan evaporation
May	33	7.60
June	34	8.46
July	34	10.54
August	34	9.48
Sept.	34	7.03
Total, May through September		43.10

*Sample record 1941-75, not all years included.

capacity have from 5 to 6 inches (127 to 152 mm) of water available to plants in 3 feet (0.91 m) of soil. For the most part, these soils are well suited for irrigation. In places where consolidated rock crops out or where the slope steepens near the numerous drainages, the soils are not as well suited for farming and irrigation. In selected localities in the vicinity of Hemingford, drainage problems can occur because the soil is underlain by relatively impermeable clayey silt.

Soils along and for some miles distant on either side of Snake Creek in southwest Box Butte County are developed in sandstone bedrock or in wind-deposited sand. Much of the topography is rolling to rough, the permeability of the soils to air and water is moderately rapid to rapid and their water-holding capacity is limited. The soils are not generally well-suited to irrigation unless special management procedures are undertaken. Sprinkler irrigation appears most suitable to the soils of this area. Somewhat similar soil conditions occur in the lowlands northeast and south of Alliance and in the northeastern part of the county. The slopes in these parts of the county, in contrast to those of the southwestern part, are generally much gentler.

The soils of the sandhill areas in southern and southeastern Box Butte County are very sandy, very permeable, and have very limited water-holding capacity. These soil conditions, along with the very irregular slopes of the hills, are unfavorable for irrigation. Within the sandhill areas, selected tracts of land with gentler slopes can be irrigated, usually with sprinkler-type systems, if care is taken in the management of the land and water.

Rough, broken land occurs along the south side of the Niobrara valley, locally along Dry Creek at a few places in the southwestern part of the county, and along the lower reaches of streams draining the central part of the county. Many rock outcrops occur in these areas but generally good growths of grass make the land well suited for grazing.

Agriculture, municipalities, and industry

Agriculture is the predominant industry in Box Butte County. By far the leading crop in the county is winter wheat, of which 114,000 acres (460 km^2) were harvested in 1975. Since most of the wheat is grown on land that has lain fallow the previous year, more than 200,000 acres (810 km^2) of land in the county were devoted to winter wheat culture. Very little of the wheat acreage is irrigated. Corn is second to wheat in total acreage with 20,400 acres (83 km^2) of corn harvested in 1975. Most of the corn was grown for grain, but some was harvested for silage. More than 90 percent of this crop was irrigated. Other grains grown are oats, barley, and rye. There were 7,000 acres (28.5 km^2) of these crops harvested in 1975, but oats was seeded also with alfalfa to serve as a cover crop and rye was also used for pasture. Millet and sorghum are also grown in the county, but their combined acreages in 1975 probably were less than 5,000 acres (20.2 km^2).

Sugar beets, dry edible beans, and potatoes are important irrigated crops in Box Butte County. Approximately 13,050 acres (53 km^2) of sugar beets and 17,400 acres (70 km^2) of beans were harvested in 1975. Potato acreage is small and not listed in the agricultural statistics. An estimated 16,800 acres (68 km^2) of alfalfa and other tame hay were harvested in 1975 and many of these acres were probably irrigated. An estimated 10,000 acres (40.5 km^2) of wild hay were harvested in 1975. All the foregoing information on crop acreages was obtained from the Nebraska Crop and Livestock Reporting Service (1977).

Some 601 irrigation wells had been registered in the county as of December 31, 1975, and about 60,000 acres (243 km^2) of land were estimated to be under irrigation. Much of this irrigation is accomplished through the use of pivot sprinklers. According to imagery provided by the National Aeronautics and Space Administration's Landsat Satellites, Hoffman and Edwards (1976) counted 266 pivot systems in the county in the latter part of 1975.

Cattle on farms and ranches in the county numbered about 57,300 head at the end of 1975. About 19,300 calves were born and about 25,800 were placed on grain feed that year. About 4,400 hogs and 4,400 sheep were on farms near the end of 1975.

Alliance and Hemingford are the only municipalities in the county. Alliance, the county seat, had a population of 6,862 in 1970. The population of Hemingford that year was 734.

Alliance is strategically located on rail lines that connect the Wyoming coal fields to central and south-central United States. Because of this location and the large increase in coal shipments from Wyoming eastward, additional railroad facilities and associated industries are being located in the city. The resurgence of railroad business, along with other industrial activity, is spurring the growth of Alliance.

GEOLOGY

Hydrologic units and their water-bearing properties

The hydrologic unit, an informal term, is used in this report to designate rock units in the study area. Results of test drilling and of recent geological work in the general area (Galusha 1975; Cook 1965; McKenna 1965; Hunt 1978) all indicate some of the earlier nomenclature used by the Nebraska Geological Survey (Condra and Reed 1959) is inadequate. A hydrologic unit consists of materials of generally similar water-bearing characteristics. The upper and lower limits of hydrologic units used in this report, with one possible exception, conform to boundaries of established members, formations, groups, or systems. The names assigned to these hydrologic units, however, do not always carry the same meaning as the names that have been applied in the past to the stratigraphic units in Box Butte County. In the use of hydrologic units in this text, geological names often used for these units will also be given. Figure 8 shows the relation of hydrologic units to stratigraphic units and time-stratigraphic units.

General geology

The hydrologic units at or near the land surface in Box Butte County consist of unconsolidated silt, sand, clay, and

Hydrologic unit	Stratigraphic units: Formation	Stratigraphic units: Group	Ash dates (m.y.B.P.)	Time-stratigraphic units: Series	Time-stratigraphic units: System
Quaternary					Quaternary
Ogallala		Ogallala		Pliocene?	
Sheep Creek	Sheep Creek		13.7±1.2		
Box Butte	Box Butte			Miocene	
Runningwater	Runningwater		16.6±1.3		
Upper Harrison	Upper Harrison-Marsland*		19.7±4.1		Tertiary
Arikaree		Arikaree	21.3 27.0±0.7		
Brown Siltstone				Miocene or Oligocene	
Whitney	Brule				
Orella		White River		Oligocene	
Chadron	Chadron				
Pierre	Pierre	Montana			
Niobrara	Niobrara				
Carlile	Carlile	Colorado		Upper Cretaceous	Cretaceous
Greenhorn	Greenhorn				
Graneros	Graneros				
Dakota		Dakota			

* Sensu McKenna (1965)

Fig. 8. Relation of hydrologic units to stratigraphic units and time-stratigraphic units

gravel of Quaternary age and of semiconsolidated silt, sand, gravel, and clayey silt of Tertiary age. The Tertiary rocks are 1,200 to 1,400 feet (365 to 425 m) thick and include the principal aquifers of the county. The hydrologic units of Tertiary age, from youngest (uppermost) to oldest (lowermost), are the Ogallala, Sheep Creek, Box Butte, Runningwater, Upper Harrison, Arikaree, Brown Siltstone, Whitney, Orella, and Chadron (fig. 8). Cretaceous age rocks underlie the Tertiary rocks in Box Butte County (DeGraw 1969) and are, from youngest to oldest, Pierre Shale, Niobrara Formation, Carlile Shale, Greenhorn Limestone, Graneros Shale, and Dakota Group.

The Cretaceous strata dip to the southwest. Prior to the deposition of the Chadron unit, the Cretaceous rocks were eroded to form an eastward-sloping surface. As a result, the Chadron lies on the older Cretaceous units in extreme northeast Box Butte County and on the Younger Pierre Shale throughout the remainder of the county.

Sedimentary rocks of Jurassic, Triassic, Permian, and Pennsylvanian age occur beneath the Cretaceous rocks and include shale, sandstone, siltstone, limestone, dolomite, anhydrite, and salt. These older sedimentary rocks are in turn underlain by igneous or metamorphic rocks of Precambrian age.

In Box Butte County, water supplies are probably obtained from the Brown Siltstone unit and all younger units except for the Box Butte unit. Large supplies are developed from the

Arikaree, Ogallala, and Runningwater units or from a combination of several hydrologic units. Units below the Brown Siltstone have not been tapped for water supplies largely because overlying units furnish sufficient water in most places in the county. Little is known about the water-bearing capacities of the units below the Brown Siltstone, but electric logs of oil and gas tests indicate that supplies probably are limited except in localities where the Chadron unit contains a significant thickness of sand. The Graneros, Greenhorn, and Carlile units are directly overlain by the Chadron only in the extreme northeast corner of the county at depths of 1,300 feet (395 m) or more (DeGraw 1969). The Graneros, Greenhorn, and Carlile do not appear to be favorable as sources of water. The underlying Dakota unit contains the principal oil and gas-bearing sands of western Nebraska, although these sands have not as yet been found to be commercially productive in Box Butte County. The permeable beds of this unit undoubtedly contain considerable water, but the depths to the Dakota and the high probability that the water in it is of very poor quality prohibit the development of this unit for water supplies.

Cretaceous system

(Upper Cretaceous series)

Niobrara unit

The Niobrara unit is composed of calcareous shale, chalk, and chalky limestone. It overlies shale of the Carlile unit and underlies the Chadron unit of Tertiary age in the northeast part of T. 28 N, R. 48 W.; the northwest, central, and southeast parts of T. 28 N., R. 47 W.; and the northeast part of T. 27 N., R. 47 W. (DeGraw 1969). Where it is present throughout the remainder of the county, it underlies shale of the Pierre unit. The Niobrara unit was entirely removed by erosion in the extreme northeast corner of the county sometime after the Pierre Shale was deposited and before deposition of the Chadron. The unit is equivalent to the Niobrara Formation as redefined by DeGraw (1975), who shows the thickness of the uneroded Niobrara to range from about 320 to 420 feet (98 to 128 m) in Box Butte County. The depth to the top of the unit where it directly underlies the Chadron unit of Tertiary age is probably 1,200 to 1,400 feet (365 to 425 m). Depth to the top of the unit increases greatly southwestward from northeast Box Butte County.

Nothing is known about the ability of the Niobrara unit to furnish water to wells in Box Butte County. Some stock wells may obtain water from this unit in northeast Dawes and northwest Sheridan counties, where the Niobrara is at or near land surface. Some stock, domestic, municipal, and irrigation wells obtain water from the Niobrara in northeast and south-central Nebraska where cracks, fractures, and solution channels in the chalky shale and limestone transmit water to wells. In northeast Box Butte County, the unit was exposed to weathering sometime after the deposition of the overlying Pierre unit and before the deposition of the Chadron unit. Consequently, the possibility exists that fractures, cracks, and solution channels could occur in the unit in the northeast corner of the county and the Niobrara could yield water to wells. It is doubtful, however, that the water would be of suitable quality for stock, domestic, or irrigation use.

Pierre unit

The Pierre unit is principally gray to black clay shale with some silty shale. It overlies the Niobrara unit and is the youngest Cretaceous unit in the county. Prior to the deposition of the Chadron, the Pierre was completely eroded from the northeast part of the county and partially eroded from the remainder. The thickness of the unit thus ranges from nil in northeast Box Butte County to 2,500 feet (760 m) in the southwest corner because the unit dips southwestward whereas the old erosion surface slopes generally eastward. The depth to the top of the unit in the county ranges from about 900 to 1,400 feet (275 to 425 m). The Pierre unit is essentially equivalent to the Pierre Shale Formation of the Nebraska Geological Survey (Condra and Reed 1959) with the lower boundary redefined in western Nebraska by DeGraw (1975).

The Pierre unit is not considered a source of water supply to wells because it is predominantly a fine-grained clay shale and has a very low permeability.

Tertiary system

(Oligocene series)

Chadron unit

Electric logs of 135 oil and gas tests in and immediately adjacent to Box Butte County indicate a distinctive unit, ranging in thickness from about 100 feet (30.5 m) to more than 250 feet (76 m), overlies the Cretaceous rocks in Box Butte County at depths of about 800 to 1,300 feet (244 to 395 m). The unit is designated the Chadron in this report and consists largely of bentonitic clay, silty clay, and clayey silt. Water-bearing sand, sandstone, and probably gravel generally occur in the unit west of R. 49 W. Where present, these permeable beds usually occur at the base of the unit beneath bentonitic clays and immediately above Cretaceous rocks, but they can be interlayered with clay and silt throughout a zone more than 100 feet (30.5 m) thick.

In Box Butte County, 35 of 42 oil and gas tests west of R. 49 W. showed the presence of sand or sandstone in the Chadron unit. Twenty-three of these tests were in the southwest part of the county in Tps. 24 and 25 N., Rs. 51 and 52 W. Nineteen of these 23 tests showed an indication of sand or sandstone. Electric logs indicate the depth to the top of the sand or sandstone beds in the western part of the county ranges from 820 to 1,260 feet (250 to 385 m) and the thickness ranges from 2 to 133 feet (0.61 to 40.5 m). Oil test 24N-51W-32da, near the

Morrill county line, had sand or sandstone and probably gravel from 1,010 to 1,143 feet (310 to 350 m).

The Chadron unit was deposited on an unevenly eroded, ancient landscape of Cretaceous rocks. Alluvial sand, gravel, silt, and clay, with large additions of volcanic ash, presumably were deposited in ancient valleys by low gradient streams while silt, clay, and ash probably were deposited on the uplands by wind. Reconstruction of these ancient valley systems is complicated, however, because structural movements resulting in the faulting and displacement of units appears to have occurred after the deposition of the Chadron. Circumstantial evidence derived from electric logs indicates that faults with displacements up to 200 feet (61 m) occur in the Chadron in southern Box Butte County. Faulting may also exist in the Chadron in eastern Box Butte County.

The Chadron unit, as interpreted in this report, is restricted to the bentonitic clay and silt and to the sand and sandstone in the basal part of the White River Group. The top of the unit is difficult to identify with consistency on electric logs, but generally it occurs a few feet to a few tens of feet below the "f" horizon as defined by DeGraw (1969). This would make the Chadron hydrologic unit about equivalent to the Chadron Formation of the White River Group in the North Platte Valley (Schultz and Stout 1955).

Water in the sands of the Chadron, confined beneath clays and silts, is probably under artesian pressure and would rise in wells above the level of the sands. Small-yield wells, such as stock and domestic wells, could be developed where several feet of sand are present. Where the sand or sandstone exceeds 50 feet (15.2 m) in thickness, wells yielding several hundred gallons per minute probably could be developed. Such wells, however, might require a drawdown of the water level in the well of 200 to 500 feet (61 to 152 m) to maintain yields. Such a large drawdown would affect the water pressure in the aquifer over several square miles.

No wells tap Chadron sands in Box Butte County but some do in Scotts Bluff, Banner, and Morrill counties. Water from wells in these counties is high in sodium and can be hazardous to soils when used for irrigation. The quality is suitable for stock and domestic purposes in these counties.

Orella unit

Overlying the Chadron throughout Box Butte County is a unit called the Orella, which is composed largely of clayey siltstone and, in a few places, thin beds of sandstone. Thin beds of volcanic ash occur in similar sediments in the North Platte valley. The thickness of the Orella ranges from about 200 to 500 feet (61 to 152 m). The depth to the top of the unit ranges from about 500 feet (152 m) to more than 1,000 feet (305 m). Test drilling did not reach the unit in the county, but the electric logs of oil and gas tests and outcrops of similar beds in the North Platte valley suggest that the unit is a complicated sequence of stream- and wind-deposited sediments. The top of the unit is a few feet to a few tens of feet below the "h" horizon as defined by DeGraw (1969) and its base is at the top of the clays of the Chadron unit. The Orella unit is approximately equivalent to the Orella member of the Brule Formation, White River Group, of the North Platte valley (Schultz and Stout 1955).

The depth to the unit and the fine-grained nature of the materials do not make the Orella unit attractive for the exploitation of water supplies in Box Butte County. However, the unit is an aquifer supplying water to irrigation, municipal, stock and domestic wells in parts of northeastern Colorado, Lodgepole Creek valley and Sidney Draw, Pumpkin Creek valley, North Platte valley and Wildcat Ridge, Goshen Hole in Wyoming, and at the foot of Pine Ridge. In these places, the capacity of the unit to transmit water appears to be mostly related to cracks, fractures, and fissures in the unit.

Whitney unit

This unit is mostly a brown to reddish-brown, well-sorted, clayey siltstone. Examination of the very fine sand and coarse silt fraction of three samples of the Whitney from one test hole showed volcanic glass shards made up an average of 43 percent of the material and ranged from 38 to 48 percent (table 7). Sedimentary rocks containing significant percentages of volcanic material (such as glass shards, glass-coated mineral grains, and volcanic rock fragments) can be described by the term volcaniclastic.

In this study, the Whitney is the oldest unit reached by test drilling. Five test holes probably reached it in the southwestern part of the county. Three of the four geologic sections in figures 9 and 10 show the relationship of the Whitney unit to overlying units. The depth to the top of the unit is about 200 feet (61 m) below the Niobrara River in the northwestern part of the county and slightly more than 250 feet (76 m) along the South Branch of Snake Creek in the vicinity of test hole 25N-51W-17ddd. The depth to the top of the unit is perhaps as much as 600 feet (183 m) in other parts of the county. The thickness of the Whitney unit ranges from about 150 feet (45.5 m) in southwest Box Butte County to perhaps as much as 300 feet (91 m) in other parts of the county.

DeGraw (1969) recognized in the southern Nebraska Panhandle two reference horizons, "i" and "h," on electric logs in materials similar to those of the Whitney unit. He correlated these horizons with two distinct ash beds exposed in the North Platte valley (upper and lower ash beds of Schultz and Stout 1955). Electric-log characteristics similar to DeGraw's "i" and "h" horizons can be detected in much of Box Butte County. The ash beds and the character of the material suggest that the Whitney unit is about equivalent to the Whitney member of the Brule Formation, White River Group (Schultz and Stout 1955).

The very fine grain size of the Whitney materials and the depth to the unit make it an unlikely source of water supply in Box Butte County.

TABLE 7

Percentages of Glass Shards in Very Fine Sand of Selected Test-Hole Samples[1]

UNW3-75		UNW5-75		UNW6-75		UNW8-75		UNW9-75		UNW10-75		UNW11-75		UNW13-75	
26N-49W-19bbb		27N-49W-19bbb		27N-49W-6bbb		28N-49W-19bbb		29N-51W-33cad		28N-51W-19aaa		28N-51W-31dad		27N-51W-32ccc	
Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)
						RUNNINGWATER									
						65-70	0.1					52-60	4.0		
						140-150	1.7					70-80	7.7		
						165-168	12.0					83-87	12.0		
						220-233	12.3					90-95	6.0		
												100-105	3.7		
												100-114	10.0		
												116-120	9.7		
												120-130	6.3		
												130-140	8.7		
												140-150	6.0		
												155-160	10.3		
												170-180	8.0		
						UPPER HARRISON (?)[2]									
		54-60	3.1											40-50	5.3
		75-80	5.1												
		90-95	9.1												
		110-120	11.7												
						UPPER HARRISON									
36-40	15.0	132-140	20.4	100-110	19.3									90-100	12.0
50-60	14.1	150-160	20.6	210-220	22.3										
80-90	19.3	170-180	19.7												
110-120	29.7	200-220	22.8												
154-160	31.3														
						ARIKAREE									
183-190	31.7	223-230	23.4	290-300	27.8							180-190	17.3	370-380	42.3
240-250	21.8	260-270	33.0												
300-310	28.8	330-340	37.5												
350-360	42.7	350-360	23.0												
390-400	25.3														
425-432	43.7														
						BROWN SILTSTONE									
440-450	58.5	369-380	48.3	370-380	67.0	250-260	49.3	80-90	74.3	60-70	55.7			440-450	36.1
470-480	80.7	400-410	56.4			280-290	70.3	130-140	81.7	210-220	47.0				
						350-360	61.0	190-200	50.0	250-260	76.7				
						390-400	60.0								
						410-420	38.3								
						440-450	56.7								
						WHITNEY									

1. See text introduction for explanation of procedure used to determine percentages of glass shards.

2. Sandy zone above typical brown sandy siltstone of Upper Harrison in many test holes in central and east-central parts of county. See text description of Upper Harrison.

TABLE 7 (continued)

Percentages of Glass Shards in Very Fine Sand of Selected Test-Hole Samples[1]

UNW16-75		UNW21-76		UNW23-76		UNW32-76		UNW33-76		UNW34-76		Total number of samples	Average glass shard percentage ($\bar{X}$) ± one standard deviation
25N-51W-17ddd		28N-48W-24aaa		28N-47W-31ccc		27N-46W-18bbb		26N-47W-18cdc		26N-49W-24aba			
Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)	Depth (feet)	Glass shards (percent)		
RUNNINGWATER													
		72-80	2.0	90-93	4.6	150-155	5.3					25	5.9 ± 3.7
		100-110	2.0	110-113	6.7	200-210	2.7						
		130-135	2.0										
		160-170	1.0										
		190-200	3.3										
UPPER HARRISON (?)[2]													
								50-54	1.3	46-50	3.0	8	5.4 ± 3.4
										50-60	4.3		
UPPER HARRISON													
		210-220	21.6	130-140	9.3	224-230	36.0	70-80	16.3	70-80	7.0	24	22.6 ± 8.3
		240-250	39.0	190-200	22.7	240-250	22.7	170-180	32.0	200-210	26.0		
				250-260	30.3	260-268	34.0						
ARIKAREE													
150-160	28.3					280-285	21.7	240-250	18.8	250-260	18.7	26	27.0 ± 7.8
280-290	21.0					340-345	29.0	290-300	20.3	290-300	24.3		
310-320	18.3							360-370	18.5	380-390	30.3		
389-392	28.7												
440-450	24.7												
BROWN SILTSTONE													
		280-290	51.8	290-300	70.7	380-390	50.2	410-420	48.8	430-440	48.3	26	58.0 ± 12.0
				350-360	54.0	417-420	58.0						
				400-410	59.3								
WHITNEY													
460-470	48.0											3	42.9 ± 5.0
470-480	38.0												
490-500	42.7												

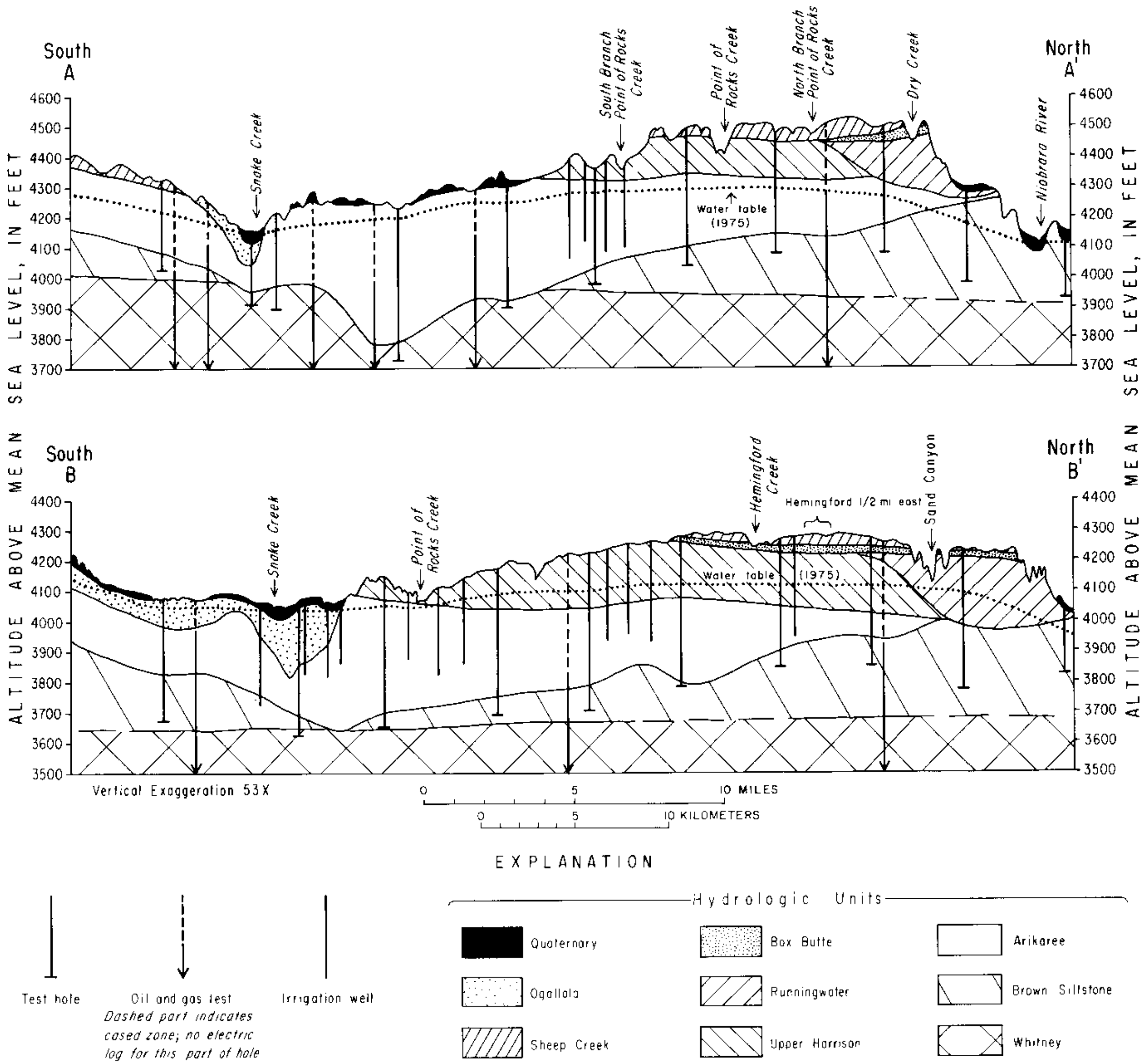


Fig. 9. Geologic sections A-A' and B-B'

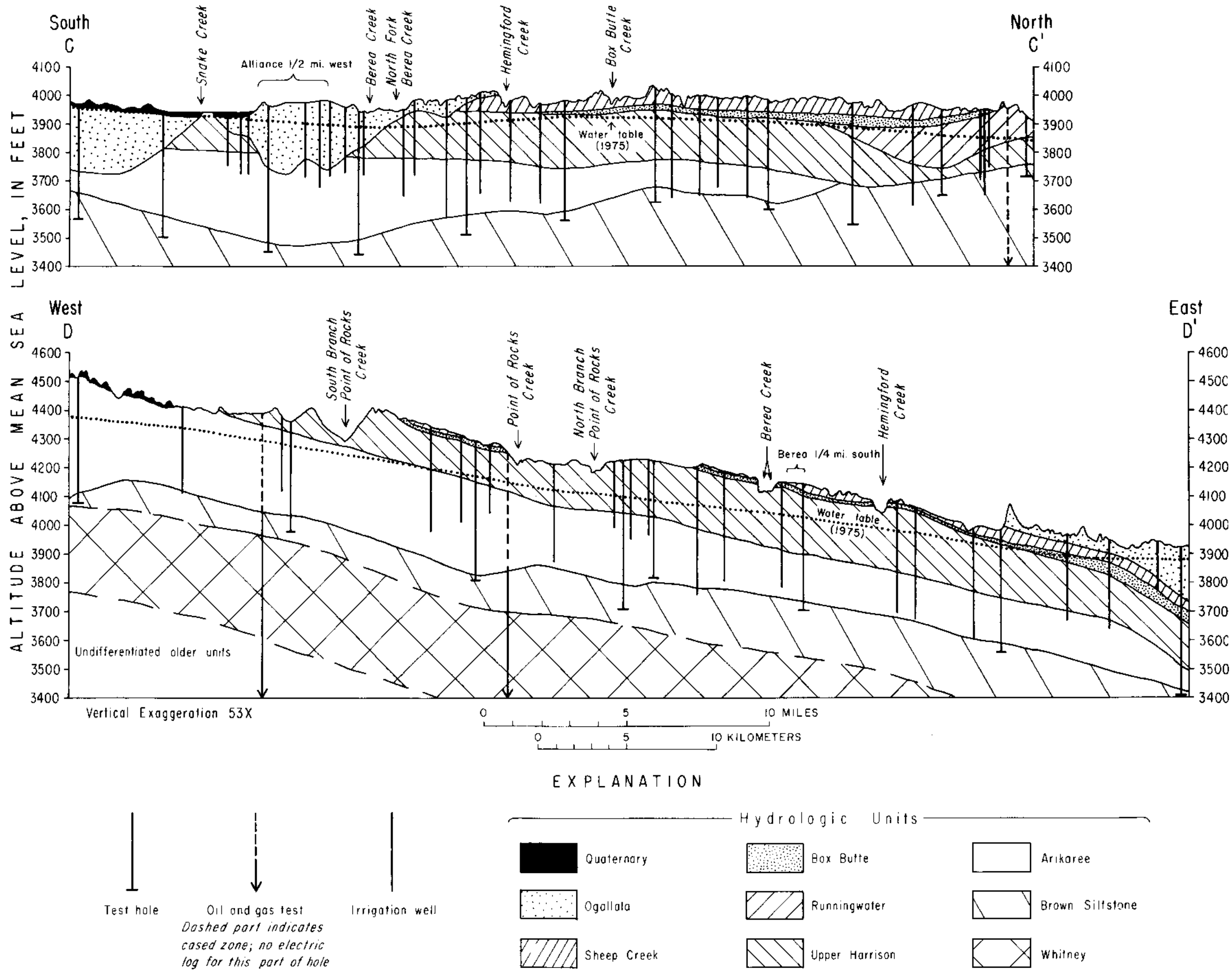


Fig. 10. Geologic sections C-C' and D-D'

Tertiary System

(Miocene or Oligocene series)

Brown Siltstone unit

Overlying the Whitney unit throughout most of the county is a thick sequence of light brown, well-sorted, sandy siltstone. For practical reasons of drilling and water supply, this thick section was separated from the other hydrologic units and called the Brown Siltstone unit. Much of the unit is calcareous and in some places contains hard, carbonate-cemented concretions. Twenty-six samples taken from the drill cuttings contained an average of 58 percent volcanic glass shards in the very fine sand-size fraction. The range was 36 to 81 percent (table 7). Nearly pure volcanic ash in this unit was penetrated in test hole 26N-49W-31ccd, 460 to 473 feet (140 to 144 m); test hole 26N-49W-19bbb, 492 to 510 feet (150 to 155 m); and test hole 28N-51W-19aaa, 280 to 300 feet (85 to 91 m). The ash drilled in these holes may represent the same bed; if it does, an additional horizon may be available for stratigraphic correlation in Box Butte County. The uniform massive character, very well sorted and fine grained nature, and high percentage of volcanic glass indicate that this unit probably was deposited by wind.

The Brown Siltstone unit is exposed along the Niobrara River valley in the extreme northwest corner of Box Butte County (fig. 11). The depth to the top of the unit ranges from zero to about 600 feet (183 m) in the southeastern part of the county. The unit attains its greatest thickness in the

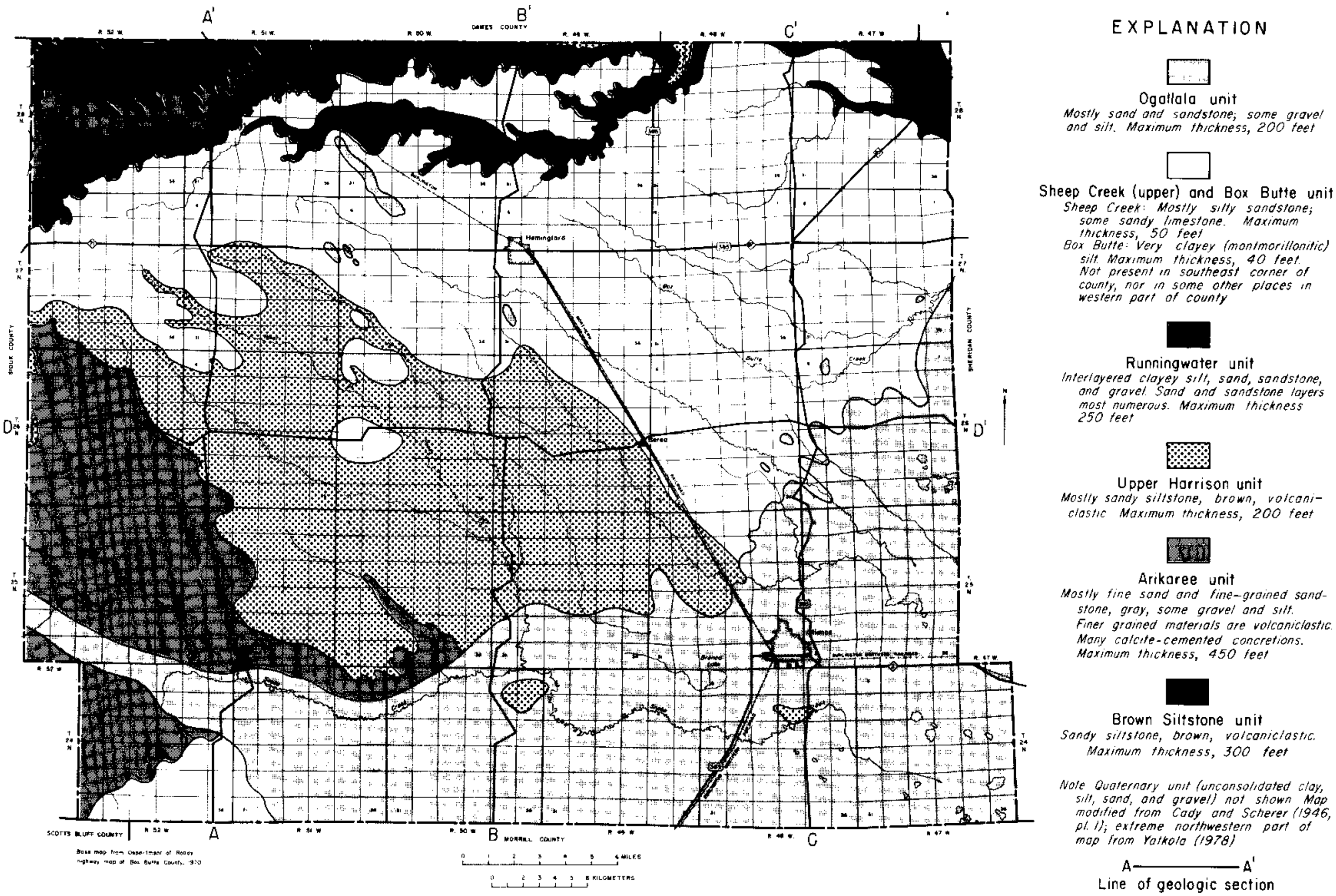


Fig. 11. Hydrologic units at or near land surface in Box Butte County

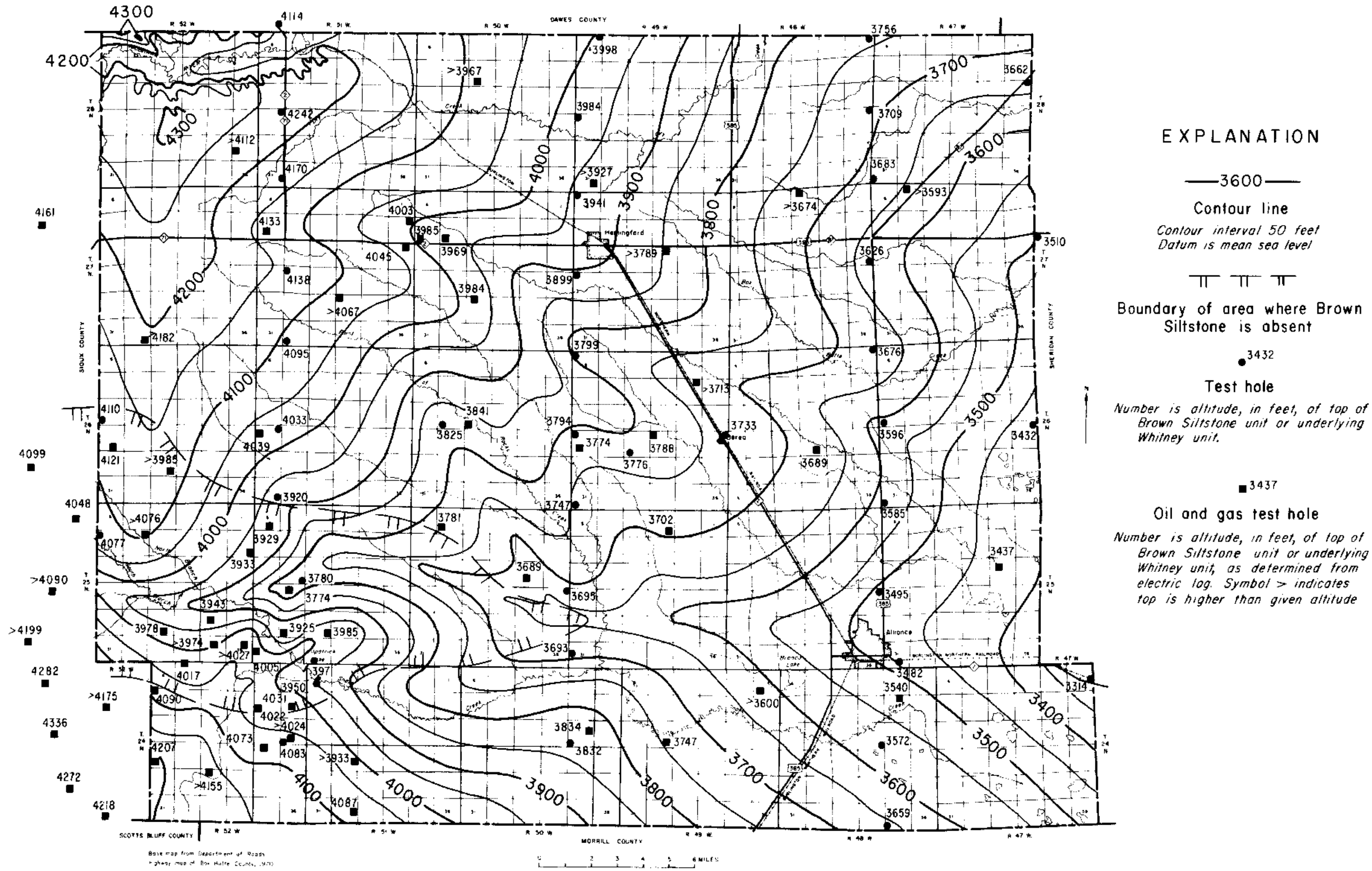


Fig. 12. Configuration of the top of the Brown Siltstone unit

northeastern part of the county where it may exceed 300 feet (91 m). The map in figure 12 shows the configuration of the top of the Brown Siltstone except for the area in the southwestern part of the county where the unit was removed by erosion prior to the deposition of younger units. The map is probably accurate to within 25 feet (7.6 m) in most places.

The electric log and samples from test hole 25N-49W-31bcc and the electric logs of more than 50 oil and gas tests in Box Butte County suggest that the sediments of the Brown Siltstone grade downward into the finer grained, more clayey materials of the Whitney unit. Subsurface information thus suggests that the contact between the Brown Siltstone and the underlying Whitney unit is a gradational one. The contact between the Brown Siltstone and the next-younger hydrologic unit, the Arikaree, is relatively sharp. This contact is generally an easy one to identify from drill samples and electric logs because the Arikaree is coarser, grayer, and contains more calcium carbonate and significantly less volcanic material than the Brown Siltstone. Thirty-one test holes penetrated the contact between the two units in Box Butte County. After the samples were examined, there were only four holes in which the placing of the contact was questionable.

Geologic sections A-A' and B-B' (fig. 9) show the relationship of the Brown Siltstone to the underlying Whitney unit and overlying Arikaree unit as interpreted from test-hole information and electric logs of oil and gas tests. These sections indicate that significant erosion occurred in Box Butte County after the deposition of the Brown Siltstone but that little or no erosion appears to have occurred before its deposition. If these interpretations are valid, then the most important break (unconformity) in sedimentation from the time of deposition of the Whitney unit through the time of deposition of the Arikaree unit occurred following the deposition of the Brown Siltstone unit. The gradational Brown Siltstone-Whitney contact, the similarity of materials in the two units, and the break in sedimentation after deposition of the Brown Siltstone implies that the Brown Siltstone and the Whitney are a closely associated group of rocks. Since the Whitney unit is in the White River Group, it is suggested that the Brown Siltstone be included in this group also.

Some additional information is available to support this suggestion. Test hole 28N-51W-19aaa penetrated a volcanic ash bed in the Brown Siltstone unit at an altitude of 4,000 to 4,020 feet (1 220 to 1 230 m). Only 0.7 mile (1.13 km) away, the electric log of oil test 28N-51W-17ac shows DeGraw's "i" horizon may occur at an altitude of 3,733 feet (1 140 m) and his "h" horizon at an altitude of 3,634 feet (1 110 m). The "i" horizon is near the top of the Whitney unit. The general electric-log characteristics of the oil test and the difference in altitude between the "i" horizon and the ash in the test hole indicate they are not the same ash bed but two different ones separated by 270 feet (82 m) of the Brown Siltstone unit. An ash bed is exposed above the Brown Siltstone and near the base of the Arikaree unit in sec. 4, T. 28 N., R. 53 W., Sioux County, at an altitude of 4,297 feet (1.31 km). The late Daniel Yatkola sampled this ash in 1975. A preliminary age of 26.1 ± 0.5 (CI_{95} = ± 4.5)* million years before present (m.y. B.P.) was determined by Boellstorff and Spellman (personal communication 1977) using the fission-track method of dating volcanic glass (Boellstorff and Steineck 1975, pp. 144-145). At Helvas Canyon south of the North Platte valley, an ash near the base of the Arikaree Group (Carter Canyon Ash of Vondra et al. 1969) has been dated by various workers. Obradovich et al. (1973) determined a potassium-argon age of 27.0 ± 0.7 m.y. B.P. using biotite and a fission-track age of 27.8 ± 3 m.y. B.P. using zircon. Boellstorff (personal communication 1977) has determined a preliminary fission-track age for the ash of 27.9 ± 2.6 (CI_{95} = ± 6.5) m.y. B.P. using glass. These dates thus suggest that the Brown Siltstone is older than the Arikaree Group as it is described in the Wildcat Hills (Vondra et al. 1969).

Cady and Scherer (1946) assigned the materials comprising the Brown Siltstone unit of this report to the Monroe Creek Formation of the Arikaree Group. The evidence provided above raises a question as to the validity of this correlation. Sufficient test drilling and surface mapping has not been done to correlate the Brown Siltstone with outcrop areas in the North

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*The first ± value represents one standard deviation. CI_{95} is the 95 percent confidence interval of the mean (Swinehart and Boellstorff 1977). All subsequent fission-track glass dates in this report include the one standard deviation value and CI_{95}.

Platte valley or Pine Ridge to verify the establishment of a hitherto undescribed Tertiary stratigraphic unit in the northern panhandle.

The base of the principal aquifer in Box Butte County is the top of the Brown Siltstone unit, or the top of the Whitney unit where the Brown Siltstone is absent (fig. 12). The Brown Siltstone unit does have some permeability and is a source of water supply for stock and domestic wells in the northern part of the county. Irrigation wells could probably be developed in the unit if a considerable thickness, about 300 feet (91 m), is penetrated and the wells are developed over a long period of time by surging, back-flushing, and over-pumping. The yields of these wells would probably seldom exceed 700 gallons per minute (0.044 0 m^3/s) and the drawdowns required for obtaining these yields would be about 200 feet (61 m). There could be some problems in designing the wells: the wells probably would pump silt and fine sand along with the water; water cascading into the well could be encountered; and the well yields might decline during an irrigation season. Several irrigation wells in the northwestern part of the county seem to obtain at least part of their supply from this unit. On the whole, the unit is not attractive as a source of water supply if a well yield greater than a few hundred gallons per minute is required.

Tertiary system

(Miocene system)

Arikaree unit

Sand, sandstone, silty sand, sandy silt, and minor amounts of gravel comprise the Arikaree unit in Box Butte County. This unit, which occurs throughout most of the county, overlies the Brown Siltstone unit, and is the major aquifer. The unit is absent in much of the northern part of the county but may be thicker than 500 feet (152 m) in places in the southwestern part of the county north of Snake Creek. The Arikaree is at the land surface throughout most of southwest Box Butte County (fig. 11). Along the Box Butte-Sheridan county line, however, the top of the unit is deeper than 400 feet (122 m) in some places. The geologic sections (figs. 9 and 10) show the relationship of the Arikaree to other units and the variations in the thickness of the unit. Figure 13 shows the saturated thickness of the unit.

The Arikaree unit is predominantly a very fine to fine-grained sand throughout much of the county, with gray to brownish-gray colors predominating. The unit is a very fine grained, silty sand in the northeastern part of the county and in a strip trending east-southeast from west-central Box Butte County to just east of Berea. Medium sand to fine gravel occurs in the middle and lower parts of the Arikaree unit, with the major area of coarser grained Arikaree occurring where the unit is the thickest (fig. 13). Figure 12 shows that a large valley trending west to east was eroded across the county in T. 25 N. after the

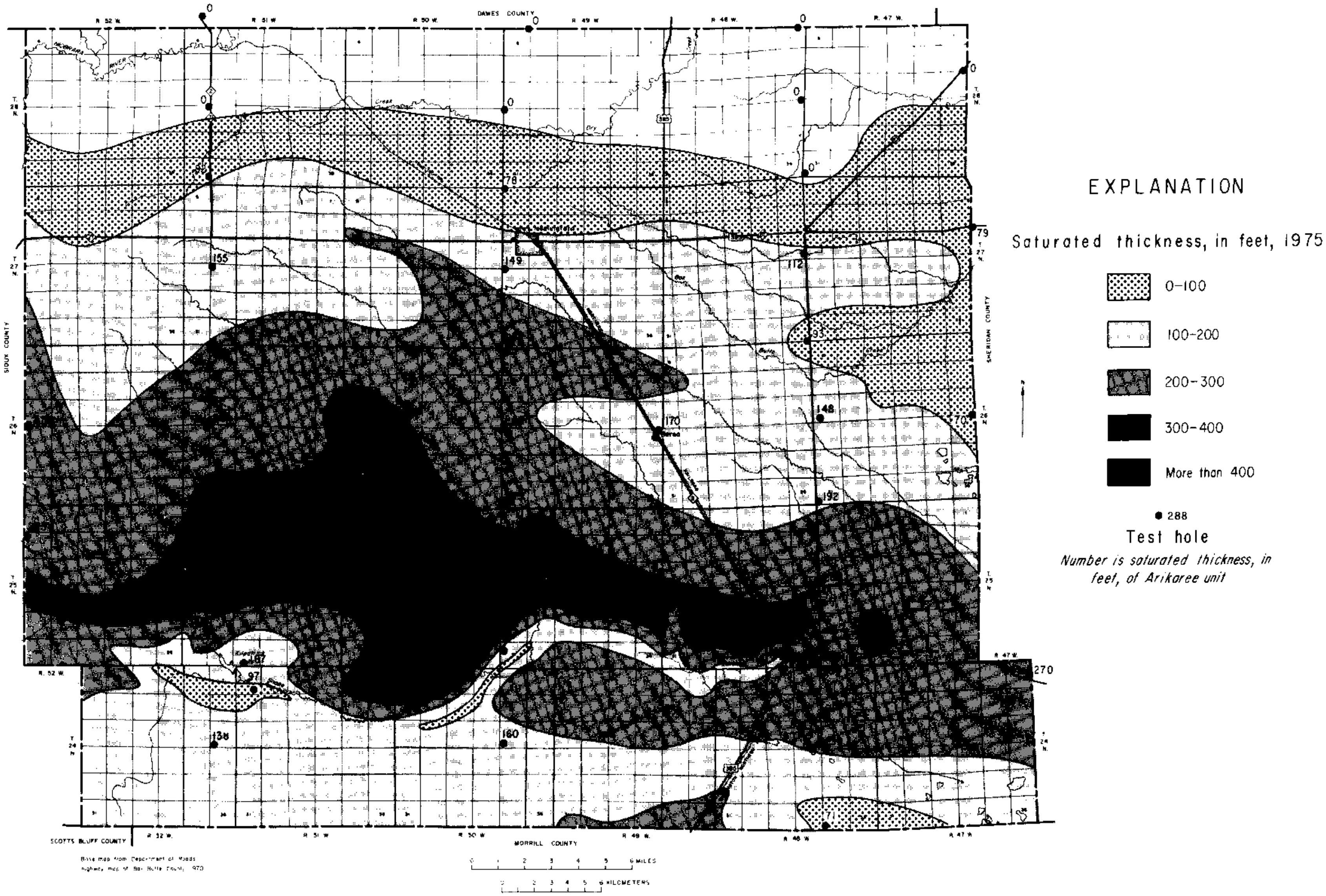

Fig. 13. Saturated thickness of the Arikaree unit

deposition of the Brown Siltstone. This valley was the location of a major river system during Arikaree time and most of the coarser Arikaree materials are associated with this valley. Test holes 25N-52W-7bbc, 25N-51W-17ddd, and 25N-50W-24aaa are good examples of test holes that penetrated the coarse Arikaree. The coarser materials are of two types: (1) igneous and metamorphic rock fragments derived from the Rocky Mountains, and (2) rock fragments, principally siltstone and claystone, derived from local Tertiary sediments. Where the Arikaree unit is a well-sorted, very fine to fine-grained sand, it contains significant amounts of materials derived from volcanic sources, including glass shards, plagioclase and sanidine feldspar, and euhedral hornblende and pyroxene. Denson (1969) studied the regional variations in hornblende, pyroxene, and other nonopaque heavy minerals of the White River, Arikaree, and Ogallala units. He noted a significant amount of volcanically derived material in the Arikaree. The percentage of glass shards in the very fine grained sand fraction of 26 Arikaree samples averages 27 percent, ranging from 17 to 44 percent (table 7). The presence of coarse sand to fine gravel indicates some of the Arikaree unit is composed of stream-deposited sediments while the high percentage of volcanic debris and the well-sorted nature of the fine-grained materials suggest that their mode of deposition may have been primarily by the wind. Consequently, the unit is viewed as a complex set of beds reflecting both alluvial and eolian deposition.

Beds of brown, clayey silt up to 40 feet (12.2 m) thick are interlayered with coarser grained sediments in the lower part of the Arikaree in the west-to-east trending paleovalley. Test hole 25N-51W-17ddd provides the best example of these silt beds. These beds often resemble material of the Whitney unit but, if examined closely, the material is more poorly sorted than the Whitney and often includes gravel-sized siltstone and claystone fragments. Consequently, the first brown silt encountered below a section of sandstone does not always signal the base of the Arikaree.

Coarse-grained Arikaree materials occur also near the base of the unit in the Hemingford area. Test holes 27N-49W-19bbb and 27N-49W-6bbb penetrated these materials, but their regional distribution could not be inferred from the test drilling. Most of those coarse-grained materials are locally derived silt-stone fragments.

The cementation and consolidation of the sediments of the unit varies in the extreme. Very loose, unconsolidated sands occur immediately beneath very hard, carbonate-cemented sandstone. Most of the unit displays some degree of consolidation. The extremely hard sandstones encountered in test drilling were probably the large pipy concretions described by many authors (Darton 1899; Schultz 1941a; Cady and Scherer 1946). Up to 10 feet (3.05 m) of continuously hard, well-cemented sandstones were drilled in the upper half or upper third of the unit. They were more common within the west-to-east trending paleovalley than in the northern part of the county. Small to large nodular concretions are more common in finer grained sediments in the lower half of the unit. Thin beds of soft, calcareous material can occur in the Arikaree in places.

The contact between the Arikaree unit and the next younger, overlying Upper Harrison unit cannot be reliably determined by field examination of drill cuttings. The upper part of the Arikaree is mostly silty, very fine grained sandstone which can be gray, brownish gray, or brown. During the course of drilling, the contact can usually be located within 10 to 30 feet (3.05 to 9.1 m) of the contact determined by laboratory examination of the samples. The Arikaree is usually coarser and grayer than the Upper Harrison and fewer thick, hard, calcite-cemented zones occur in the Upper Harrison.

Cady and Scherer (1946) assigned the Arikaree unit of this report to the Harrison Formation of the Arikaree Group. This group has traditionally been subdivided into the following formations: Gering at the base, Monroe Creek in the middle, and Harrison at the top (Lugn 1939). No attempt is made in this report to subdivide the Arikaree unit.

The Arikaree is capable of supplying from a few hundred to more than 1,000 gallons of water per minute (0.063 m^3/s) to wells throughout most of the area except in the northern part of the county where the Arikaree is fine grained, silty, and less than 100 feet (30.5 m) thick (fig. 13). Generally speaking, larger well yields can be obtained from the places where the unit is thick, provided the wells penetrate the entire thickness of the unit. The geologic sections (figs. 9 and 10) indicate that only a few irrigation wells penetrate the entire thickness of the unit except where it is thin and silty. The Arikaree unit is the major aquifer of the county and the lowest unit from which it is generally practical to develop irrigation supplies.

Upper Harrison unit

Overlying the Arikaree unit throughout much of Box Butte County is a relatively thick sequence of brown, well to moderately sorted, sandy siltstone called Upper Harrison in this report. The unit is mostly coarse silt to very fine sand with some clay and fine silt. The materials of the unit appear to be slightly coarser in the west-central part of the county than in the eastern part. Nodular, lime-cemented concretions can occur throughout the unit.

The Upper Harrison is exposed at the land surface throughout much of west-central Box Butte County (fig. 11) and dips to the east beneath younger units (section D-D', fig. 10). The maximum thickness of the Upper Harrison in the county, penetrated by test hole 26N-49W-24aba, is 200 feet (61 m). Where it is directly overlain by the Box Butte unit, the thickness is usually between 150 and 200 feet (45.5 and 61 m).

The texture and color of the Upper Harrison unit is quite similar to that of the Brown Siltstone, and where the intervening Arikaree unit is absent, the two units could not be separated in the field by examination of drill cuttings. Test holes 28N-47W-13aab, 28N-47W-31ccc, and 28N-48W-1aba were places where this situation occurred. Examination of the electric logs of the test holes narrowed the interval in which the contact of the two units could be selected, but precise determination of the contact required mineralogic data. Volcanic glass shards in 24 samples of the Upper Harrison siltstone average 23 percent, ranging from 7 to 39 percent (table 7). The average glass content in the very fine sand size fraction of the Upper Harrison is very similar to that of the Arikaree and is significantly lower than that in the Brown Siltstone.

Where the full thickness of the Upper Harrison unit is present, the upper 20 to 80 feet (6.1 to 24.4 m) is a calcareous silty sandstone (see test hole 26N-49W-24aba). Mineralogic data on eight samples of this interval show that an average of 5 percent (ranging from 3 to 12 percent) of the very fine sand fraction of this material is volcanic glass shards (table 7). The reason for the significant difference in glass content between the typical sandy siltstone of the Upper Harrison and this upper, sandier zone is not certain. It may simply be that the Upper Harrison contains less volcanic material in its uppermost part. On the other hand, this zone may not belong to the Upper Harrison unit. Galusha (1975) described silty sand beds (Red Valley member of the Box Butte Formation) occurring locally beneath the Box Butte unit of this report. It is also possible that this upper sandy zone is part of the younger Runningwater unit. However, since only an indistinct grain-size break was noted in the drill samples between this sandy zone and the main body of volcaniclastic Upper Harrison siltstone, it was included with the Upper Harrison. Field study and further mineralogic data in this interval would be necessary to resolve the problem.

Because the Arikaree and Upper Harrison units have similar quantities of volcanic glass shards, differentiation of the two units based on the content of shards does not appear feasible. The texture of the sediments, the high percent of volcanic glass in them, and the manner in which they mantle older units suggest that the Upper Harrison unit was deposited by wind. These considerations, along with the difficulty in picking a precise contact between the Upper Harrison and the Arikaree, suggest that the two units may be closely associated and may belong to the same group of rocks.

The geologic correlation of the brown, sandy siltstone unit overlying the Arikaree unit is in question. The Upper Harrison unit, as described in this report and shown on figures 9, 10, 11, and 14, is correlated with rocks in the Upper Niobrara valley in Sioux County, which were named the Upper Harrison beds by Peterson (1907, p. 22; 1909, p. 75). Schultz (1938, 1941b) renamed these beds the Marsland Formation and transferred the type section from the Upper Niobrara valley to exposures in secs. 23-27, T. 28 N., R. 52 W., and secs. 19 and 30, T. 28 N., R. 51 W., about 4 to 6 miles (6.4 to 9.7 km) southwest of Marsland (northwest of test hole 28N-51W-31dad). However, Cook (1965), McKenna (1965), and Skinner at al. (1977, pp. 292-94) indicate that the rocks exposed south of Marsland are not correlative with Peterson's Upper Harrison beds. The results of the test drilling in Box Butte County support the interpretation

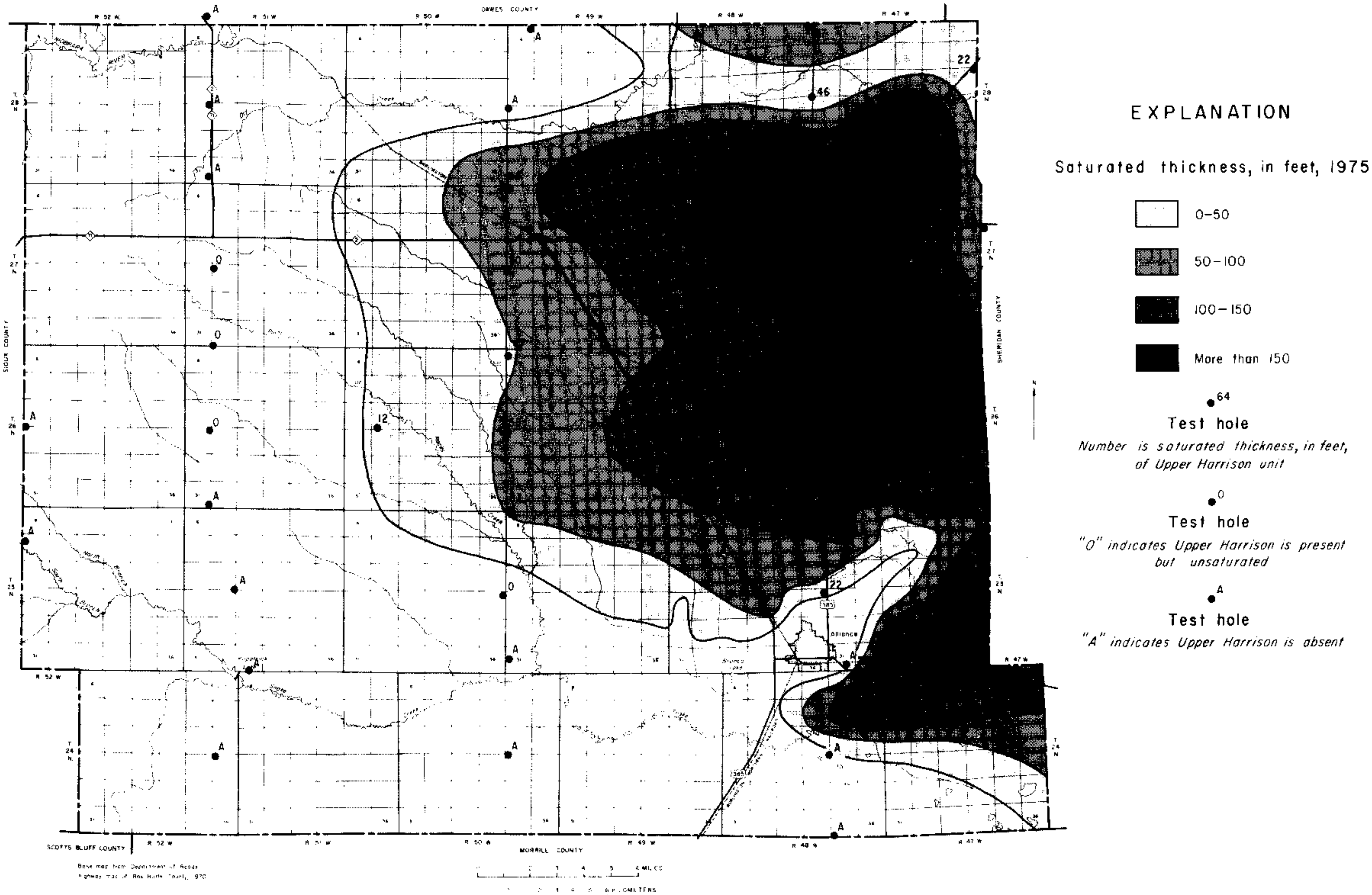

Fig. 14. Saturated thickness of the Upper Harrison unit

that the rocks assigned by Schultz to the type section of the Marsland Formation are really the materials of a younger valley-fill sequence, the Runningwater of Cook (1965), which are cut into rocks equivalent to Peterson's Upper Harrison beds (geologic sections A-A' and B-B' on figure 9 and C-C' on figure 10).

A volcanic ash bed occurs in N½ sec. 3, T. 28 N., R. 55 W., in Sioux County about 1 mile (1.61 km) north of the Agate Springs quarries. This ash bed is in the Arikaree and is projected to occur about 30 feet (9.1 m) below the Uppper Harrison sediments (Hunt 1978, fig. 17, and Everndon et al. 1964, p. 178). Everndon et al. report a postassium-argon date on biotite from this ash bed of 21.3 m.y. B.P.* A preliminary fission-track glass date of 21.6 $\pm$ 5.7 (CI_{95} = $\pm$ 6.0) m.y. B.P. was determined by Boellstorff (personal communication 1977) from the same ash bed. An ash bed occurs in Upper Harrison sediments north of Harrison, Nebraska, in sec. 27, T. 32 N., R. 56 W. (Hunt 1978, fig. 17). Boellstorff (personal communication 1977) obtained a preliminary fission-track glass date of 19.7 $\pm$ 4.1 (CI_{95} = $\pm$ 4.3) m.y. B.P. for this ash.

The sandy siltstone of the Upper Harrison unit, like the sandy siltstone of the Brown Siltstone unit, is permeable enough to make it a source of water for stock and domestic wells. According to Glen Nelson of Nelson Wells, Inc. (personal communication 1976), many stock and domestic wells in parts of the county obtain water solely from this unit. Nelson further related that one well was installed in the Upper Harrison unit to obtain

*No standard deviation reported

a water supply for the drilling of a large irrigation well. This supply well, after a lengthy period of well development, was eventually pumped at the rate of 100 gallons per minute (0.006 3 m^3/s). Geologic section D-D' (fig. 10) further suggests that a significant amount of the water pumped from some of the irrigation wells along the line of the section must be coming from the Upper Harrison because some of these wells appear to penetrate only 30 to 90 feet (9.1 to 27.5 m) of the Arikaree unit. The irrigation wells that penetrate only a small part of the Arikaree are usually older wells; more recent wells penetrate deeper into the Arikaree.

Runningwater unit

The Runningwater unit fills an ancient valley system trending west to east across the northern part of the county. The rocks in the unit are composed of interbedded clayey silt, siltstone, silty sandstone, coarse sand, and gravel. A large percentage of the coarse sand and gravel consists of igneous and metamorphic rock fragments from the Rocky Mountains. Some thin beds of volcanic ash and bentonitic clay occur within the unit. Test holes 28N-48W-24aaa and 28N-51W-31dad provide examples of the kinds of material in the unit. Geologic sections A-A', B-B', and C-C' (figs. 9 and 10) illustrate how these materials occur within a valley cut into or through the Upper Harrison unit. Figure 15 shows the location of the saturated part of the channel. The maximum thickness of the unit encountered in the test drilling was 225 feet (69 m).

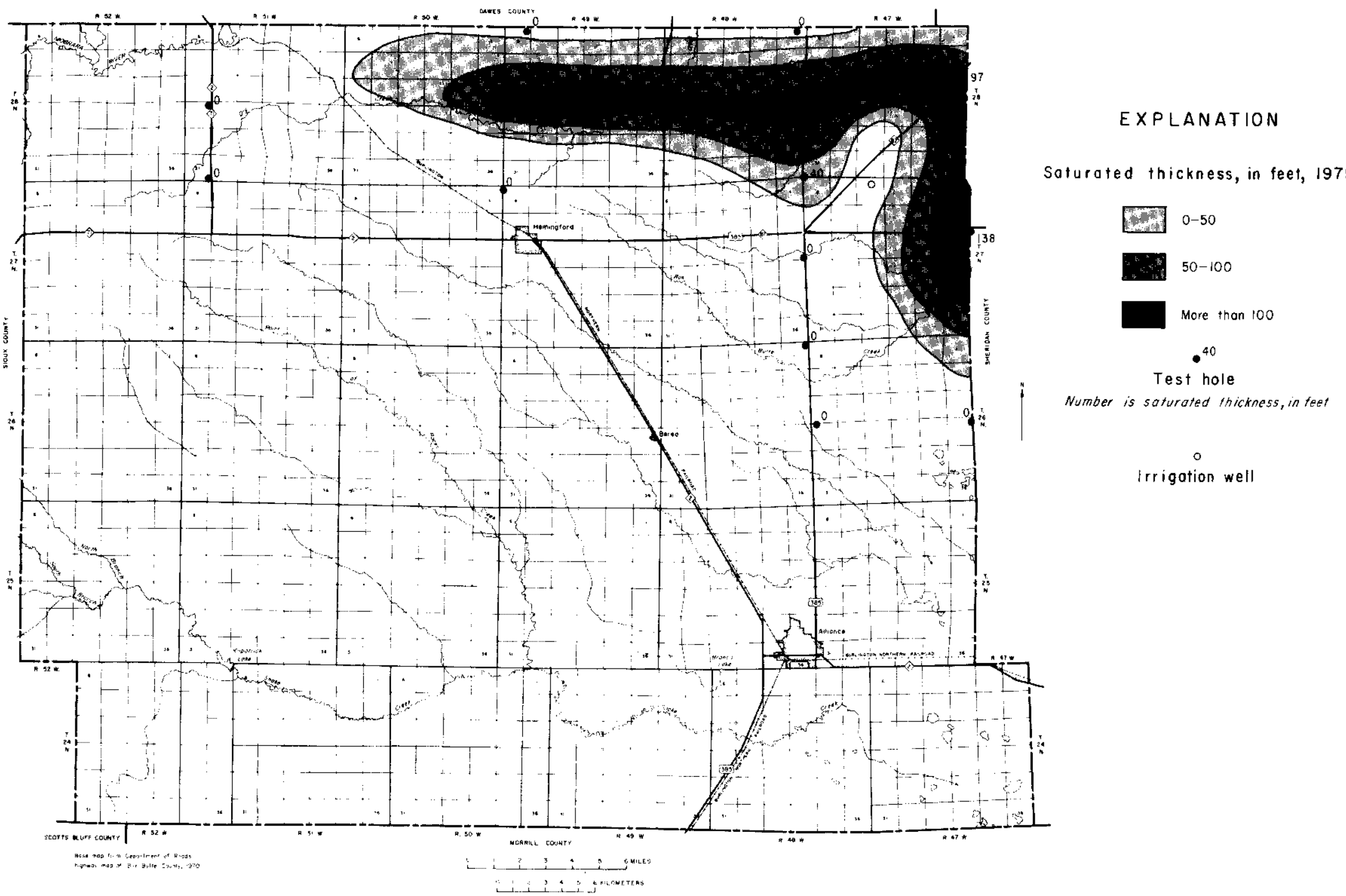

Fig. 15. Saturated thickness of the Runningwater unit

The wide range in texture, the presence of coarse material, and the interbedded nature of the Runningwater unit suggest that most of the sediments were deposited by streams. Twenty-five samples of the very fine grained sand fraction had an average of only 6 percent glass shards as compared with 23 percent in the samples from the Upper Harrison unit (table 7). This difference in mineralogy, the inferred differences in depositional environment, and the deep erosion of the Upper Harrison unit prior to the deposition of Runningwater sediments suggest that the Runningwater and Upper Harrison units are not geologically or hydrologically associated. The erosion prior to the deposition of the Runningwater unit probably represents a significant break in the sedimentary record of Tertiary rocks in Box Butte County.

The Runningwater unit of this report is essentially the same as the Runningwater Formation of Cook (1965). Skinner et al. (1977, fig. 1) show the general trend of the Runningwater paleovalley system in western Nebraska. A preliminary fission-track glass date of 16.6 ± 1.3 ($CI_{95} = \pm 1.6$) m.y. B.P. was determined by Boellstorff and Spellman (personal communication 1977) from a volcanic ash 33 feet (10.1 m) below the Box Butte-Runningwater contact in secs. 29 and 20, T. 28 N., R. 51 W. This ash occurs in rocks assigned to the type area of the Marsland Formation by Schultz (1941b).

The Runningwater unit is a source of water supply in the northern and northeastern parts of the county where the unit contains significant saturated thicknesses of sand, sandstone, and gravelly sand (fig. 15). The interval from 76 to 214 feet

(23.2 to 65 m), test hole 27N-46W-18bbb, is an example of a thick section of coarser grained sediments in the Runningwater. Figure 15, it should be emphasized, is based on limited information and the saturated thickness depicted includes silt and clay beds as well as sand, sandstone, and gravelly sand beds. Nevertheless, irrigation wells yielding from 400 to 800 gallons per minute (0.025 0 m^3/s to 0.050 m^3/s) for an irrigation season probably can be developed throughout much of the area where the saturated thickness of the unit is shown to exceed 100 feet (30.5 m).

Box Butte unit

A thin distinctive unit, called the Box Butte in this report, is present throughout much of the north, northeast, and east-central parts of Box Butte County. The unit is mapped together with the overlying Sheep Creek unit as shown in figure 11. The Box Butte is not known to occur with the Sheep Creek unit in the southwestern part of the county.

Textural analyses of samples from outcrops of the Box Butte unit in 28N-48W-7ada and 28N-51W-29bcb indicate that it is a very clayey silt. Colors in the unit are brown, reddish brown, gray, and greenish gray. Carbonate nodules up to 4 inches (102 mm) across occur throughout the unit. Dr. Warren Lynn, U.S. Soil Conservation Service, Lincoln, Nebraska, X-rayed outcrop samples and found the clay fraction to be predominantly montmorillonite, a swelling clay. Dr. Lynn indicated that the x-ray patterns suggested that the montmorillonite was detrital; that is, it was already in the form of montmorillonite when it was deposited and was not a product of in situ weathering. Drill cuttings from this unit were readily distinguished from the cuttings of other units and the Box Butte could be easily correlated from test hole to test hole. Because many drillers recognize this unit as "joint clay" or "slippery clay," driller's logs of irrigation wells are helpful in tracing this unit.

The Box Butte unit is at or near land surface throughout much of the area where it occurs (fig. 11) and is less than 1 foot (0.305 m) to slightly more than 40 feet (12.2 m) thick. The top of the Box Butte is 210 feet (64 m) deep in test hole 26N-47W-24aaa on the Sheridan county line. The depth of the Box Butte unit in this hole is interpreted on geologic section D-D' (fig. 10) as being solely due to the greatly increased eastward dip of the bed in eastern Box Butte County. However, vertical displacement of beds by faulting cannot be ruled out as an explanation for the depth of the Box Butte unit in the test hole.

The Box Butte unit was originally described and named by Cady (1940) and has recently been studied in detail by Galusha (1975). The Box Butte of this report is essentially the same as Galusha's Dawes Clay member of the Box Butte Formation. In this formation, Galusha also described the Red Valley member locally underlying the Dawes Clay member in northern Box Butte County. If the Red Valley member was encountered during the test drilling, it was not recognized as such.

The Box Butte unit is not a source of water to wells. The principal hydrologic significance of the unit is its effect on the downward movement of water and the problems it can cause in the drilling of wells and test holes. Materials with a significant percentage of montmorillonite swell when wetted and become very sticky. If such material is drilled too rapidly, the sticky cuttings collect in large masses along the wall of the borehole and partially plug the hole. Contractors have experienced some trouble drilling large-diameter holes with reverse-circulation rigs in eastern Box Butte County where the Box Butte may be entirely saturated.

The montmorillonite makes the Box Butte an effective barrier to the downward movement of moisture, which means that a perched water table is customarily associated with it. Because of the small scale of the illustrations, this perched water table is not shown on the geologic sections (figs. 9 and 10) but it would occur within or just above the Box Butte unit. The effects of this unit on recharge from precipitation to the principal aquifers is discussed more fully in the section on recharge.

The perched zone of saturation, commonly called "surface water" or "sheet water" by local residents, causes some problems in the Hemingford and Berea areas, especially during a wet spring. Wet basements, poor structural conditions for foundation footings, and wet, boggy areas in fields are some of the problems associated with such a perched water table.

Sheep Creek unit

The Sheep Creek unit of this report refers to a thin sequence of light gray, greenish gray, and light brown siltstone and silty sandstone beds mantling the Box Butte unit in much of northern and east-central Box Butte County. Similar rock types occur in the extreme southwest corner of the county (fig. 11). White to very light gray calcareous cemented sandstone and sandy limestone often occur in this unit. The thickness of the unit is generally less than 40 feet (12.2 m).

The unit was not studied in detail and Galusha's (1975, p. 50) assignment of the sediments of this unit to the Sand Canyon member of the Sheep Creek Formation is followed. In many respects, the unit is very similar to parts of the Ogallala unit in Box Butte County and elsewhere in the panhandle. Cady and Scherer (1946, p. 33) and Galusha (1975, fig. 13F) described a volcanic ash bed in sediments of the Sheep Creek unit in sec. 26, T. 28 N., R. 52 W., occurring 28 feet (8.5 m) above the top of the Box Butte unit. Boellstorff and Spellman (personal communication 1977) determined for this ash a fission-track glass date of 13.7 + 1.2 ($CI_{95} = \pm$ 1.1) m.y. B.P. This ash and the dated ash in the Runningwater unit are stratigraphically superimposed and thus the deposition of the Box Butte unit probably occurred sometime between 14 and 16 m.y. B.P.

The Sheep Creek unit is not of major importance to ground-water supplies in the county. The perched water table created by the Box Butte unit causes the Sheep Creek to be saturated in its lower part in some places. Glen Nelson of Nelson Wells, Inc., and Lawrence Grabher, a local farmer, (personal communication 1976) report that some shallow stock and domestic wells obtain their water supply from this saturated zone in northeastern Box Butte County.

Ogallala unit

The Ogallala unit occurs in south-central and southeastern Box Butte County (fig. 11) and is up to 200 feet (61 m) thick (figs. 9, 10, and 16). Thin remnants of the Ogallala, commonly calcareous cemented sandstone and silty sandstone, cap some hills and buttes in the northern and east-central parts of the county.

Sand, sandstone, and gravel are the major constituents of the unit, but some sandy silt and clayey silt also occur. The coarser grained sediments include igneous and metamorphic rock fragments derived from the Rocky Mountains. Test holes 25N-28W-24aaa, 25N-49W-31bcc, and 26N-47W-24aaa penetrated thick sections of the Ogallala.

Figure 16 shows a major buried valley system in the southern part of the county. One valley extends from the center of T. 24 N., R. 50 W., to the southeast corner of the county. North of this valley, and separated from it by a ridge of rocks of the Upper Harrison unit, is another narrow, sinuous, and west-to-east trending valley. Both valleys are filled with material of the Ogallala unit. In places, these valleys are less than 2 miles (3.20 km) wide and more than 200 feet (61 m) deep. The materials that fill the valleys are the coarsest, most permeable materials encountered in the county.

The Ogallala unit of this report is considered to be equivalent to at least part of the Ogallala Group as defined by Condra and Reed (1959). Results of test drilling in Box Butte County indicate that the hydrologic units from the Runningwater through the Ogallala are a closely associated group of rocks.

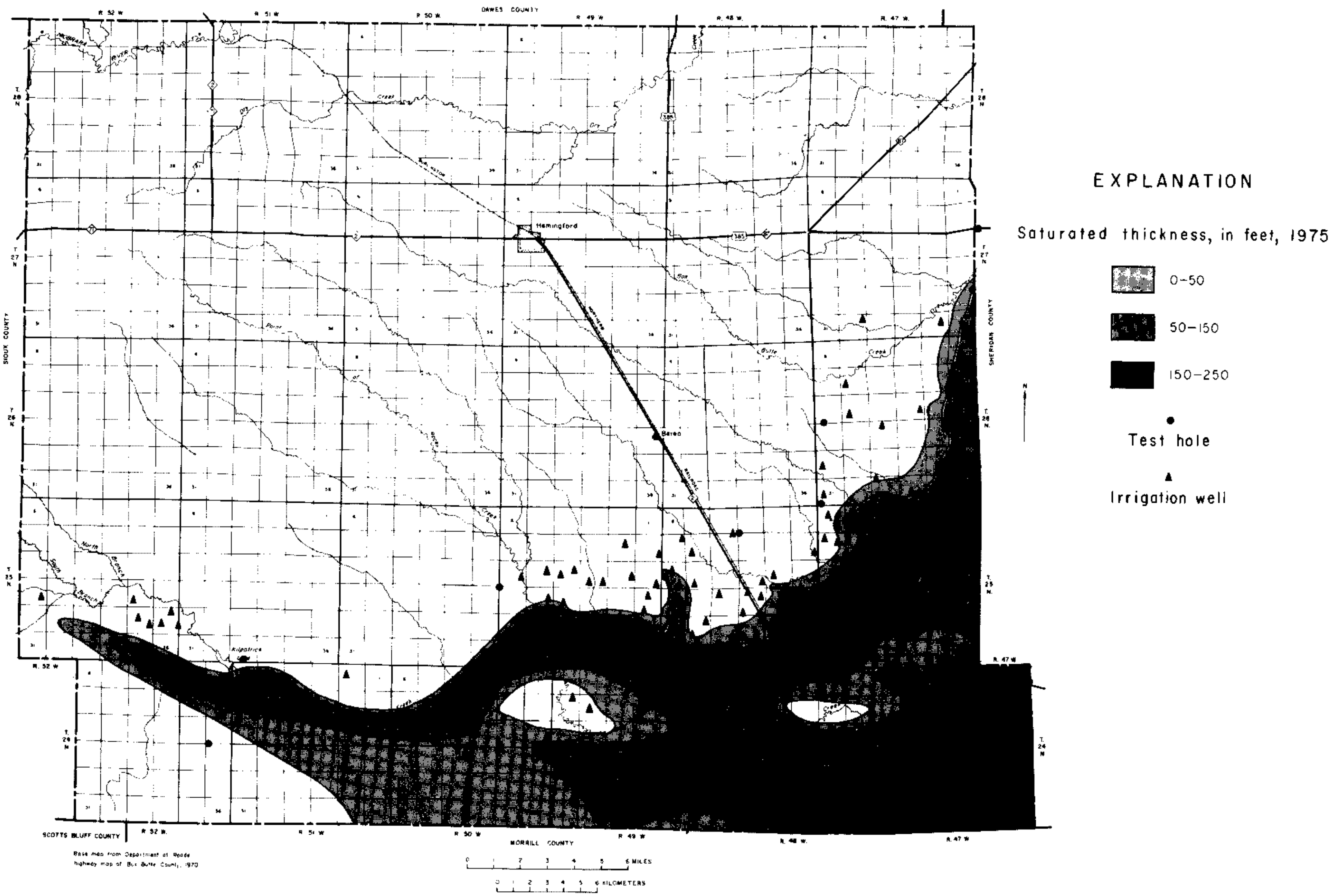

Fig. 16. Saturated thickness of the Ogallala unit

They include a wide range of textures, a low percentage of volcanic glass shards disseminated throughout the sediments, and a significant percentage of material derived from the Rocky Mountains.

The Ogallala is the second most important aquifer in the county and wells yielding 1,000 gallons per minute (0.063 m^3/s) or more are probably obtainable from the unit in some places. Many irrigation wells in the Alliance area, especially the older ones, obtain water only from the Ogallala unit. Other irrigation wells tap the Ogallala and part of the underlying units. Figures 13 and 16 show that the area of thickest Ogallala largely coincides with the area of thickest Arikaree. In southwestern Box Butte County, the areas may be related to possible faulting in deeper beds. The west to east belt of thick Arikaree and Ogallala across southern Box Butte County is the most favorable place in the county for obtaining large-yield wells.

Quaternary system

Quaternary unit

Up to 20 feet (6.1 m) of wind-deposited sand (dune sand) and silt (loess) mantle the tablelands and benches of Box Butte County. Stream-deposited sand with some silt and gravel, up to 20 feet (6.1 m) thick, occur beneath the valleys and some of the benches along the Niobrara River and Snake Creek. Silt, clay, fine sand, and sand and gravel, less than 20 feet (6.1 m) thick, underlie other stream valleys of the county. These relatively young materials of Quaternary age are for this report combined in a Quaternary unit. The relationship of these materials to the variously named lithologic units of the Quaternary system was not investigated.

The principal hydrologic importance of this unit is its ability to absorb precipitation and transmit it downward. Shallow stock and domestic wells in the Niobrara River and Snake Creek valleys may obtain water from the Quaternary unit.

GROUNDWATER

Principles of occurrence

All water beneath the surface of the earth is termed subsurface water. Below some level beneath the land surface the permeable rocks generally are saturated with water under hydrostatic or other pressure. The subsurface water in this zone of saturation is called groundwater. If there are not beds of clay, shale, fine silt, or other relatively impermeable rocks to confine this zone of saturation, the water is called unconfined groundwater. The upper limit of a body of unconfined groundwater is the water table, the surface at which the pressure on the water is equivalent to the atmosphere. Water in the zone of saturation is under greater than atmospheric pressure because of the weight of the water. Confined groundwater, or artesian water, is under significantly greater than atmospheric pressure. The upper limit of a body of confined groundwater is the bottom of the overlying confining bed.

The zone between the land surface and the water table is defined as the unsaturated zone. Characteristically, this zone contains liquid water under less than atmospheric pressure and water vapor and air or other gases usually at atmospheric pressure. The unsaturated zone includes the capillary fringe, a region immediately above the water table in which all or some of the open spaces in the rock or sediment are filled with water that is under less than atmospheric pressure and that is continuous with the water below the water table. The water is held above the water table by surface tension. The capillary fringe is typically saturated to some distance above its base at the water table; upward from the saturated part progressively fewer open spaces are filled with water and the upper limit of the fringe is indistinct. The thickness of the capillary fringe is greater in fine-grained material than in coarse-grained material. Perched zones of saturation may exist within the unsaturated zone. This perched groundwater is held up by a bed of low permeability, called a perching bed; and because the groundwater is unconfined, its water table is called a perched water table.

Unconfined groundwater, artesian groundwater, and perched groundwater occur in Box Butte County. Groundwater in the permeable beds of the Brule, Chadron, and deeper units is probably confined and will rise above the top of the beds containing the water. Most of the groundwater in the units younger than the Brule is considered to be unconfined. However, there may be local areas where there are confining beds in the Arikaree, Runningwater, and Ogallala units and thus some confined, or artesian, groundwater can occur locally in these units. Perched groundwater is often found above the Box Butte unit throughout the north-central and northeastern parts of the county.

The ultimate source of the unconfined groundwater in the Box Butte County is precipitation that falls within the county or immediately south and west of the county. Most of the water that falls as rain or snow evaporates or is transpired by growing vegetation and part of it is carried away by surface runoff to be discharged as streamflow. In the northern part of the county, the surface runoff can eventually reach the Niobrara River and be discharged away from the area. In the central and southern parts of the county, however, the streams lose water back to the subsurface or discharge into lakes, lagoons, or flats where the water is evaporated (see section on topography and drainage). A small part of the precipitation escapes runoff, evaporation, and transpiration. This part percolates slowly downward through the soil and underlying unsaturated zone and eventually joins the body of groundwater in the zone of saturation.

The rocks that form the upper part of the crust of the earth generally are not solid throughout but contain numerous open spaces, or voids, called pore spaces or interstices. It is in these spaces that groundwater is contained. The voids range in size from microscopic openings between small grains to large caverns developed in massive limestones. The ratio, expressed as a percentage or decimal fraction, of the volume of pore spaces to the total volume of the rock is the porosity of the rock. When considering problems of groundwater supply, knowledge of the porosity of the water-bearing materials is desirable; however, the permeability of the materials, rather than their porosity, controls the amount of water that can move through them. The permeability of a rock is its capacity for transmitting water and is governed by the size, shape, and arrangement of the pores. A bed of fine silt or clay, for example, may have a relatively high porosity; but because of the small size of the particles, individual pores are very small. Since molecular attraction holds a thin layer of water on the surface of each grain, these films of water are not free to move and they may fill or almost fill the pores of fine-textured sediments. Thus the permeability, or hydraulic conductivity of the material, is very low even though its porosity, or water-holding capacity, is quite high. Likewise, larger pores that are not connected may produce high porosity and low permeability. Water moves most freely through a rock that has relatively large and well-connected pores (Keech and Dreeszen 1959, Lohman et al. 1972).

Water Table and direction of groundwater movement

The water table is not level but generally is an irregular, sloping surface. Groundwater moves very slowly through the pores in the rocks, usually at right angles to the slope of the water table. The slope of the water table is controlled by the hydraulic conductivity and thickness of the water-bearing materials, the stratigraphy and structure of the rock formations, the topography, and local variations in the quantity of recharge and discharge. Groundwater is eventually discharged through evaporation and transpiration, through seeps into streams, and through springs or wells.

Irregularities in the slope of the water table are caused by several factors. In places where the amount of recharge is exceptionally high, the water table may rise and form a mound or low ridge from which the water slowly spreads out. In material of low permeability, these mounds or ridges may be pronounced, but in very permeable material they are generally small. Depressions in the water table may indicate places where the groundwater is discharging, as along streams or in places where water is withdrawn by wells or vegetation.

Figure 17 shows the shape and slope of the water table in Box Butte County in the summer of 1938, a time when only 11 irrigation wells were located in the county (Cady and Scherer 1946). Figure 18 shows the configuration of the water table in Box Butte County in the spring of 1975.

Configuration of water table, summer 1938

In the summer of 1938, water levels were measured in 216 wells in and adjacent to Box Butte County by members of the staffs of the U.S. Geological Survey and Conservation and Survey Division. Altitudes of the measuring points at these wells were determined with an aneroid barometer because reliable topographic maps were not available for Box Butte County until 1948. These water-level measurements and altitudes were used to make the water-table map in the report by Cady and Scherer (1946, plate 8). However, another water-table map (fig. 17) showing the 1938 conditions had to be made for the present report in order to compare the configuration of water table in 1938 with that of 1975 because the 1975 water-table map is based on altitudes determined from post-1948 topographic maps. Altitudes selected from topographic maps are generally more accurate than altitudes determined by the barometer. The Water Resources Division, U.S. Geological Survey, furnished copies of the 1938 field records

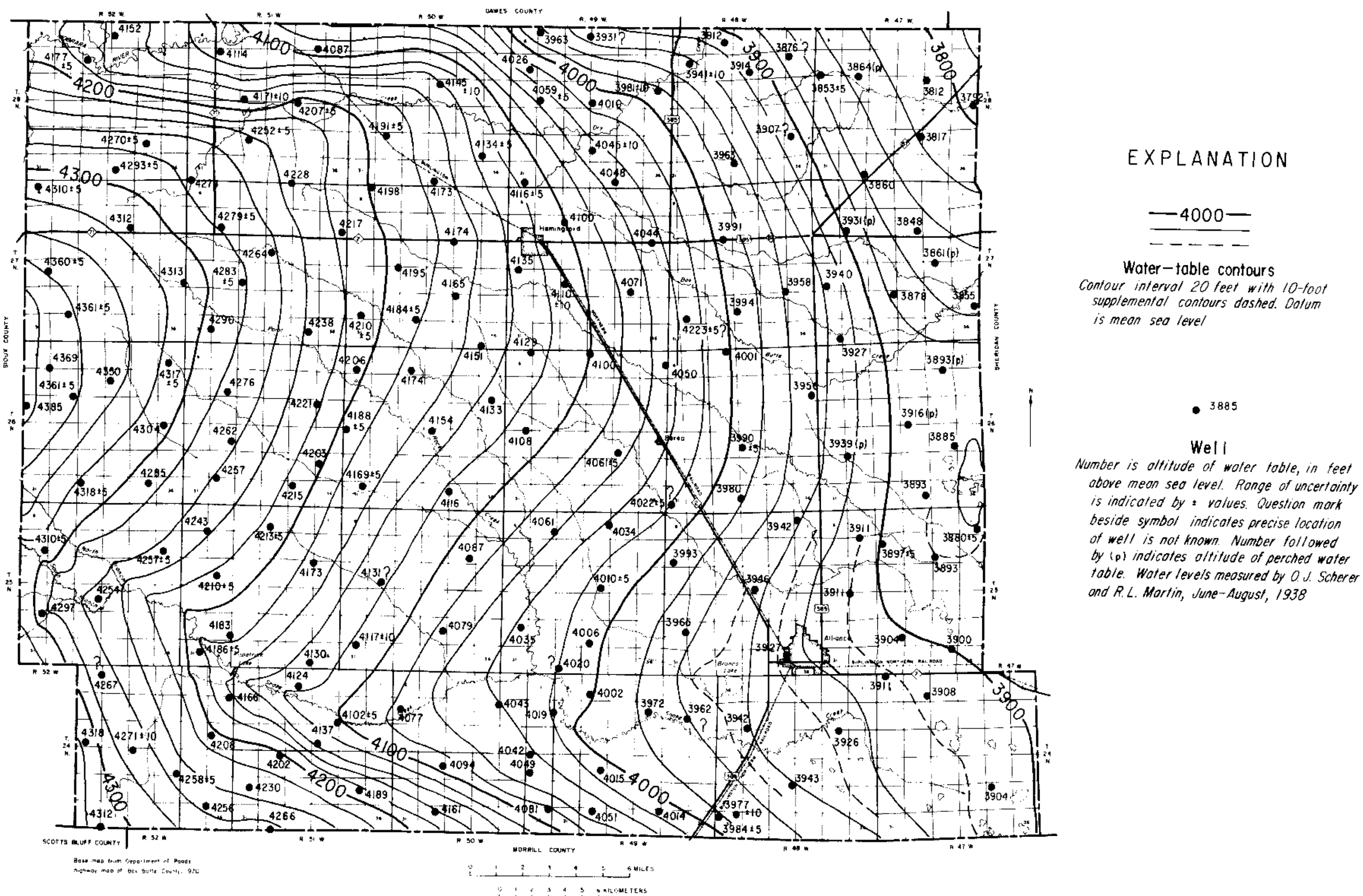

Fig. 17. Configuration of the water table, summer 1938

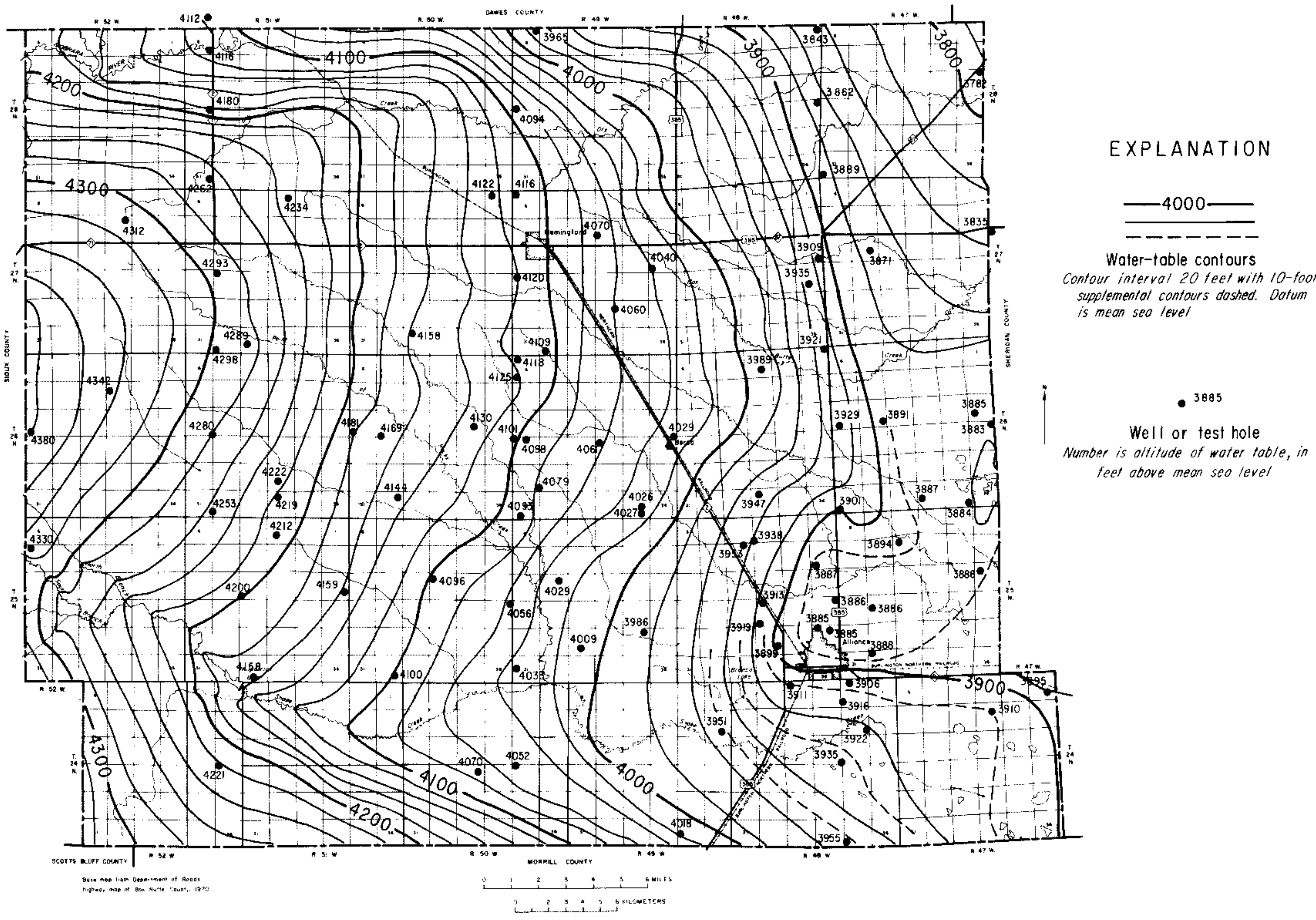

Fig. 18. Configuration of the water table, spring 1975

and these were used to locate many of the sites of water-level measurements on 7.5-minute and 15-minute topographic maps.

Some difficulties were encountered in reconstructing the water-table map for 1938. Descriptions of well locations on the field records were not always sufficient to assign with confidence a map location and altitude. Of the 216 records of measurement, 186 sites were located precisely enough to be used with confidence. The precise locations of the remaining 30 sites in figure 19 can be questioned, although the altitude of the water table is accurate. Other measurement sites show a range in value indicating an uncertainty about the water-table altitude. A more serious problem for accurate mapping, however, is caused by the geologic and hydrologic conditions which occur north of Alliance and east of U.S. Highway 385. Here, the Box Butte unit dips to the east beneath an eastward-thickening cover of younger units. The perched water table associated with the Box Butte unit is within several feet or tens of feet of the regional water table in this area and locally probably coincides with the regional water table. Determining whether a water-level measurement represented the perched water table or the regional water table was difficult, especially in T. 27 N., R. 47 W., and the north half of T. 26 N., R. 47 W.

The configuration of the contour lines in figure 17 resembles that of the contour lines on the original map of Cady and Scherer. When examined closely, however, figure 17 indicates that in some places the Cady and Scherer map showed the water table as much as 20 feet (6.1 m) too high and in other places nearly 15 feet (4.55 m) too low. Differences this large are significant because the maximum water-level change in the county between 1938 and 1975 is slightly less than 40 feet (12.2 m). It is assumed that the altitudes determined with the aneroid barometer in 1938 were not sufficiently accurate for detailed mapping of the water table and that figure 17 is now the most reliable reference available for showing the configuration of the water table in Box Butte County prior to the development of irrigation on a large scale.

Beneath the central tableland of the county, as shown in figure 17, the water table in 1938 generally sloped to the east at an average gradient of 15 or 16 feet per mile (2.85 to 3.05 m/km). At the north edge of the tableland in the northwestern part of the county, the slope of the water table was to the north toward the Niobrara River and the gradient was very steep, averaging more than 40 feet per mile (7.6 m/km) and, in places, exceeding 50 feet per mile (9.5 m/km). The Niobrara River was 100 to 200 feet (30.5 to 61 m) lower than the water table at the north edge of the tableland and groundwater was being discharged into the river and by evapotranspiration on the floodplain.

A trough occurred in the water table in the vicinity of Snake Creek in the southwestern part of the county. The contour lines of the map in this area are V-shaped near the creek and in the lower reaches of its tributaries. The point of each of the V-shaped contours is centered on the creek and directed upstream. This configuration of contour lines indicates groundwater was being discharged into the creek and consumed by vegetation through evapotranspiration along its banks and in the adjacent floodplain. In places along the stream, the principal means of groundwater discharge may have been through evapotranspiration by vegetation, with the result that very little groundwater may have actually reached the stream. Figure 17 indicates that groundwater was discharged along Snake Creek from the Sioux county line eastward to sec. 3, T. 24 N., R. 50 W., and then again in secs. 7 and 18, T. 24 N., R. 49 W. The contour lines suggest that groundwater discharge was probably balanced by recharge along Snake Creek from sec. 18, T. 24 N., R. 49 W., east to a point south of Alliance. Along the creek east of this point, the contour lines of the map bulge eastward in the downstream direction. This configuration suggests that, on an annual basis, Snake Creek lost water to the subsurface. This interpretation appears reasonable because the creek disappears in a sandy lowland in southeast Box Butte County. South of Snake Creek the water table sloped northeast toward the creek and lowlands. The gradient of the water table in this part of the county differed considerably from place to place.

In 1938, a shallow trough occurred in the water table from Alliance northeast to a closed depression on the Sheridan county line. This trough and depression coincides with the lowland northeast of Alliance where the water table was shallow and where there were several perennial and ephemeral lakes. This trough was caused by groundwater discharge to vegetation and lakes in the region and to municipal wells at Alliance (Cady and Scherer 1946). The contour lines west of Bronco Lake, southwest of Alliance, indicate that the lake was fed by groundwater in addition to surface runoff.

Configuration of water table, spring 1975

Figure 18 shows the spring 1975 configuration of the water table in Box Butte County, 37 years after the measurements were made for the water-table map shown in figure 17. During these 37 years, nearly 600 irrigation wells were installed and put into operation in the county.

Ninety-seven water-table values were used to draw the contour lines in figure 18. Six of these values represent estimates of water levels in test holes. The estimates are based on the projection of the water table from one test hole to another on the geologic sections and are supported by water-level measurements reported by drillers of nearby irrigation wells. Two of the water-table values used in figure 18 represent depths at which test holes caved. These holes are south and southwest of Alliance in areas where the water table is shallow and the materials are sand. Test holes usually cave at or near the water table in sandy material. Four additional water-table values represent depths to water determined from electric logs of test holes. If the water table occurs in sand or sandstone beds, which it did in these four cases, the electric-log characteristics of the unsaturated and saturated materials differ. Depths to the regional water table were measured in 25 of the test holes.

The large depression in the 1975 water table at and north of Alliance appears in figure 19 as a large area where the water table has declined as much as 25 feet (7.6 m) or, in places, more than 35 feet (10.7 m). Other areas where the water table has declined more than 25 feet (7.6 m) are west-southwest of Hemingford, along Nebraska Highway 2 between Hemingford and Berea, and east of U.S. Highway 385 in Tps. 26 and 27 N., R. 47 W. The large water-level declines near Hemingford, Berea, and east of U.S. Highway 385 occur where the Upper Harrison unit is being dewatered. Removal of relatively small amounts of water causes relatively large water-level declines in this hydrologic unit. Because it was difficult to map the water table in the area east of U.S. Highway 385, the large decline there is more conjectural than in other places noted above. Figure 19 indicates that the water table has declined 5 or more feet (1.52 m) throughout one-third of the county from 1938 to 1975.

Outside the irrigated areas, the water level was the same or slightly higher in 1975 than in 1938. This is not surprising because six of the seven years preceding 1938 were ones of below-normal precipitation and five of these years were extremely dry. The average annual precipitation at Alliance from 1931 through 1937 was only 12.94 inches (330 mm). On the other hand, four of the seven years preceding 1975 were ones of above-normal precipitation and the average annual precipitation for these seven years at Alliance was 17.68 inches (450 mm).

The water table appears to have risen more than 5 feet (1.52 m) beneath the tableland in the northwestern corner of

385 north of Alliance. The configuration of the water table from the north edge of the tableland to the Niobrara River in northwest Box Butte County and along Snake Creek in the southwestern part of the county is probably about the same as that of 1938. Some differences in the water-table positions can be noted in the lower reach of Snake Creek south of Alliance, but little or no differences are apparent south of Snake Creek. The differences south of Alliance are probably due to the discharge of groundwater by irrigation wells since 1938. The shallow trough in the 1938 water table northeast of Alliance has been deepened and broadened, as noted earlier, by the discharge of groundwater by wells at and north of Alliance. The closed depression still occurs in the water table along the Sheridan county line northeast of Alliance. Satellite imagery (Seevers 1973) indicates that perennial lakes still occur in this lowland area. The contour lines in figure 18 indicate that the water table is below the floor of Bronco Lake and the bed of the stream entering the lake from the west, which means that the lake is no longer fed with groundwater.

Water-level changes from 1938 to 1975

During the period from 1938 to 1975, cropping and cultivating practices changed throughout the county and the use of groundwater for irrigation increased dramatically. Figure 19 shows the amount the water table changed in Box Butte County from the summer of 1938 to the spring of 1975. This map was made by overlaying figures 17 and 18 and connecting points of equal change in the water table.

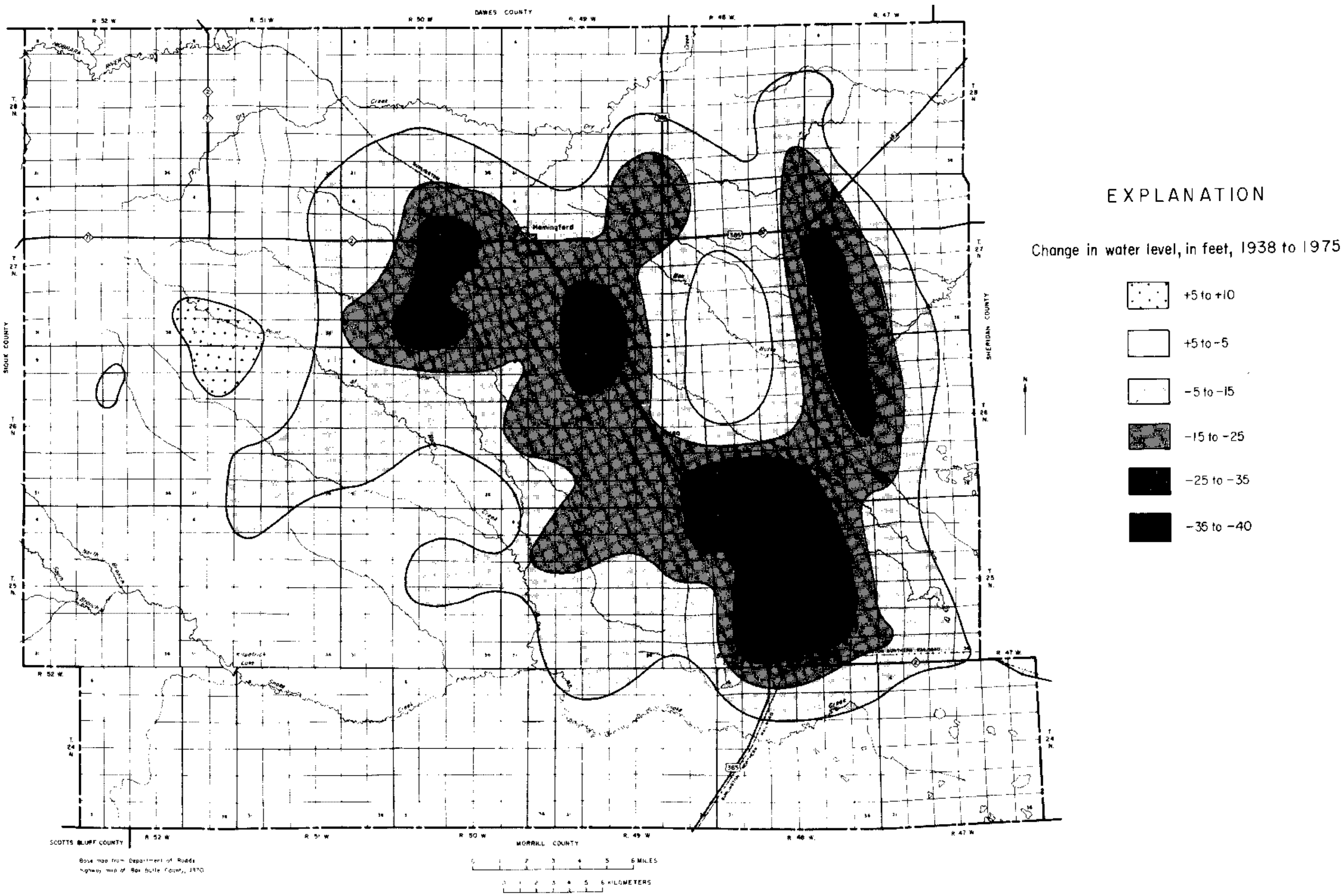

Fig. 19. Water-level changes from 1938 to 1975

T. 26 N., R. 51 W., and the southwestern part of T. 27 N., R. 51 W. While there were not repeated water-level measurements in the same well from 1938 to 1975 to validate this rise, there was good control for contouring both the 1938 and 1975 water-table maps. The configuration of the two water-table maps suggest that the water table may have risen nearly 8 feet (2.44 m) in this small area. The land use map of Box Butte County (Land Use Map 1975) indicates that there is only one irrigation well in this area of water-table rise, although irrigation wells are present immediately northeast and south of the area. The land use map further indicates that about one-half of the land in the area of the rise is cultivated, presumably with wheat and as summer-fallow land, and about half is still in pasture. Similar rises in water table from the mid-1930s to the 1970s have been noted beneath uplands in other semi-arid parts of Nebraska (Ellis and Pederson 1976, pp. 36, 44, and 45). The plowing of the rangeland and the practice of fallow-wheat cropping, combined with more favorable precipitation from 1942 to 1973, may account for this rise in the water table in Box Butte County from 1938 to 1975.

Hydrologic properties of water-bearing materials

Porosity, specific yield, and storage coefficient

The amount of water that can be stored in an aquifer depends upon the porosity of the aquifer. The porosities of the materials making up the aquifers in Box Butte County are estimated to range from less than 15 percent to more than 35 percent. However, part of the water in all rocks is held by the force of molecular attraction, which in fine-grained rocks is great enough to hold most of the water against the force of gravity. Consequently, the amount of groundwater stored within an unconfined aquifer may be considered to be one of two quantities: (1) the total amount of water within the pore spaces of the aquifer, or (2) the amount of stored water that will move out of the pore spaces under the force of gravity. The quantity of water described by (2) is of most concern with regard to an unconfined aquifer because this describes the amount of stored water that may be available to wells, springs, and streams. When quantities of groundwater in storage are discussed in this report, they are those described by (2).

The specific yield of an aquifer indicates the relation between the amount of water that will drain from the aquifer by gravity and the amount of water that is held fixed in the rock by molecular attraction. The specific yield of a rock is defined as the ratio of the volume of water the saturated rock will yield by gravity to the volume of the rock. The definition implies gravity drainage is complete (Lohman and others 1972, Keech and Dreeszen 1959). Laboratory and field tests (Prill et al. 1965, Johnson 1967) show that the rate of drainage varies with the length of time the material is drained and that the time needed for gravity drainage to be complete may be quite long for some materials. The idea of specific yield may be illustrated as follows: If 1 cubic foot (0.028 5 m^3) of saturated, water-bearing material will yield 0.20 cubic foot (0.005 7 m^3) of water by gravity drainage, then the specific yield of that material is 20 percent. A 1 foot (0.305 m) lowering of the water table in an aquifer of this material indicates a loss of water equivalent to a thickness of water of 0.20 foot (0.061 m) distributed over the area of decline. Conversely, recharge of 0.20 foot (0.061 m) of water over an area of an aquifer of this material would raise the water table 1 foot (0.305 m), or perhaps slightly more than 1 foot (0.305 m) because air could be entrapped within the zone of saturation.

For an unconfined body of groundwater, the specific yield is virtually the same as the storage coefficient. The storage coefficient is a more general concept than specific yield, which can include confined aquifers in a definition of groundwater storage. The storage coefficient is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In a confined body of groundwater, the water derived from storage with decline in head comes from the expansion of the water and compression of the aquifer. In an unconfined body of groundwater, however, the amount of water derived by expansion of the water or compression of the aquifer generally is negligible compared to the amount derived from gravity drainage, hence the storage coefficient of an unconfined aquifer is virtually equal to the specific yield (Lohman et al. 1972). Complications in the process of gravity drainage apply to the idea of storage coefficient as well as to specific yield.

Accurate values for storage coefficients or specific yields are difficult to determine and no tests have been conducted in Box Butte County to determine these values. Various laboratory and field methods are available for measuring storage coefficients but all the methods have some shortcomings, especially when the heterogeneous collection of materials containing groundwater in Box Butte County is considered. On the other hand, investigations of storage coefficients both in the laboratory and in the field by means of neutron probes, aquifer tests, and detailed water budgets show that storage coefficients of unconfined aquifers range from about 0.05 to 0.30 and that the range for many aquifers is from about 0.10 to 0.25. The texture and shape of the aquifer materials furthermore provide information that is helpful in evaluating storage coefficients since the size, shape, and connections of the pores largely determine the storage coefficient. Thus, close examination of drill cuttings and rock outcrops together with knowledge of storage coefficients for aquifer materials in other areas provide a basis for estimating the storage coefficients of the various aquifers in Box Butte County.

With long periods of drainage, the storage coefficient of the Arikaree probably ranges from less than 0.15 where the unit is composed of very sandy siltstone and silty, very fine grained sandstone to nearly 0.30 where it is relatively coarse grained. The average storage coefficient of the unit is probably about 0.20. The Upper Harrison unit is mostly sandy siltstone and its storage coefficient is probably lower than that of the Arikaree, probably ranging from 0.10 to 0.20. An average coefficient of

0.15 is assumed for this unit. The texture and character of the beds in the Runningwater unit are quite different and thus the ease with which they yield water is significantly different. An average storage coefficient of 0.20 is probably a reasonable estimate. The average storage coefficient of the Ogallala unit is probably about 0.25 after long periods of drainage. The Brown Siltstone unit, although not considered to be an aquifer from which it is practical to develop large supplies of water, can undoubtedly release water from storage and take water into storage.

Hydraulic conductivity and transmissivity

The rate at which a given rock will transmit water under given hydraulic forces is determined by the size, shape, and degree of interconnection of the pores in the rock (intrinsic permeability) and the viscosity of the water. The intrinsic permeability is determined by several factors: the size, shape, arrangement, and degree of sorting of individual grains; the amount of cementation on, around, and between the grains; the number of cracks, fractures, and fissures present in the rock; and the number of openings, which are largely traceable to organic activity in the past and to chemical solution of the rock materials. In most cases pertaining to groundwater supply, the viscosity is primarily a function of water temperature. Because it is difficult or even impossible to measure all the factors that determine the permeability of a rock, the concept of hydraulic conductivity is used to describe the rate at which a given rock will transmit water. The hydraulic conductivity of a rock or porous medium is the volume of water, at the existing vicosity, that will move in a unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Lohman et al. 1972).

Gravel deposits of uniform texture make excellent aquifers because they have large, well connected pores that provide high hydraulic conductivity, high specific yield, and high porosity. Beds of sand are also good aquifers; but because the pores are smaller, water is conducted less readily and a smaller proportion of water is yielded to wells. Cementation of the particles and a mixture of grain sizes can sharply reduce the hydraulic conductivity, whereas fractures and cracks can sometimes increase the conductivity.

The rate at which an aquifer can transmit water is determined by its transmissivity. Transmissivity is defined as the rate at which water, at the prevailing viscosity, is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to the sum of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths or to the product obtained by multiplying the average hydraulic conductivity of the aquifer by the saturated thickness of the aquifer.

The hydraulic conductivity of water-bearing materials and the transmissivities of aquifers may be approximated by laboratory tests of samples of the materials, by tests to determine the groundwater velocity in the field, by pumping tests made on wells that withdraw water from or introduce water into the aquifers, and by analysis of detailed water budgets for a given aquifer. The results of these tests and analysis, however, are often difficult to interpret or to apply to an aquifer throughout its area of occurrence and for extended lengths of time.

Cady and Scherer (1946) report the results of three pumping tests in Box Butte County. The tests were made by measuring the recovery of water levels in wells that had been pumped from one to 17 hours, a very short time for such tests. The depth of one well was not known and the other two wells did not penetrate the entire thickness of the aquifers. The transmissivity for a well in sec. 10, T. 26 N., R. 52 W., was reported to be 54,000 gallons per day per foot (670 m^2/day) and the average hydraulic conductivity was estimated to be 225 gallons per day per square foot (9.2 m/day). The aquifer in this area is the Arikaree unit. An abnormally high transmissivity was calculated for a well in sec. 24, T. 24 N., R. 50 W. Cady and Scherer report a transmissivity here of 144,000 gallons per day per foot (1 790 m^2/day) and an average hydraulic conductivity of 394 gallons per day per square foot (16.1 m/day). The aquifers here are the Ogallala, Upper Harrison, and Arikaree. The transmissivity for a well of unknown depth in sec. 9, T. 25 N., R. 47 W., was computed to be 105,800 gallons per day per foot (1 310 m^2/day) and the average hydraulic conductivity was estimated to be 235 gallons per day per square foot (9.6 m/day). The aquifers here are also the Ogallala, Upper Harrison, and Arikaree, although it is not known in which aquifers the well was screened. All these results seem to give values for transmissivities that are too high except possibly for the test in T. 25 N., R. 47 W. Difficulties in evaluation of such short tests and lack of observation wells make an interpretation of these tests difficult if not impossible.

A three-hour pumping test was conducted on an irrigation well in sec. 9, T. 26 N., R. 47 W., by the Agricultural Engineering Department, University of Nebraska-Lincoln, in June 1976. In the irrigation well registration, the depth of the well is reported to be 400 feet (122 m). That depth would indicate that the aquifers penetrated were the Upper Harrison, 130 feet thick (39.5 m); Arikaree, 100 feet thick (30.5 m); and Brown Siltstone, 100 feet thick (30.5 m). The results of this short-term test are, again, difficult to evaluate. They do indicate the transmissivity of the aquifers at this site may be somewhere between 8,000 and 10,000 gallons per day per foot (99 to 124 m^2/day) and the average hydraulic conductivity for the materials may be about 30 gallons per day per square foot (1.22 m/day). The Upper Harrison and the Brown Siltstone are composed of sandy siltstone while the Arikaree is composed of a very fine to fine-grained sandstone to a sandy siltstone in this area. The results of the test seem too low, but not significantly so. However, all values determined by the tests conducted in county are considered unreliable.

To approximate the transmissivities of aquifers, the late E. C. Reed, former state geologist of Nebraska, devised a method based on many tests made in Nebraska in connection with the cooperative statewide drilling program. Piskin (1971) refined and revised the method. It has proven reliable in many cases in predicting yields of wells developed in the unconsolidated aquifers of Quaternary age. Piskin's revisions appear applicable to the unconsolidated and semiconsolidated rocks of Tertiary age which occur in Box Butte County. The method works as follows: Each layer of material drilled in the test hole is closely examined with a hand lens in the field and generally with a microscope in the laboratory. Each layer is classified and assigned a value for hydraulic conductivity. The hydraulic conductivity is multiplied by the thickness, in feet, of that material to get a transmissivity value for the layer. The sum of the transmissivities of all saturated beds is the estimated transmissivity of the aquifer or aquifers at the test-hole site.

For this report, Souders and Smith independently estimated transmissivities for each of the 37 test holes. Estimates of hydraulic conductivities ranged from near-zero for hard, well cemented sandstones and some clayey silts to more than 1,000 gallons per day per square foot (40.5 m/day) for some sand and gravel beds in the Ogallala unit.

Transmissivities for the Ogallala, Runningwater, Upper Harrison, and Arikaree aquifers were estimated from test-hole information. Maps of the transmissivities for these aquifers were made by using these estimates and the maps showing saturated thicknesses of the aquifers (figs. 13, 14, 15, and 16). The four transmissivity maps were then combined into one map showing the total transmissivity of the aquifer or aquifers above the Brown Siltstone unit (fig. 20).

Rate of groundwater movement

The rate of movement of groundwater is proportional to the hydraulic conductivity of the water-bearing materials and the slope of the water table. Even in sand and gravel the water percolates along irregular paths between grains and the rate of movement under natural conditions is very slow.

If the average hydraulic conductivity and the porosity of the water-bearing materials is known and the slope of the water table has been determined, the average velocity of the water percolating through the materials can be computed by the use of the following formula:

$$v = \frac{KI}{p},$$

where

v = velocity, in feet per day

K = hydraulic conductivity, in feet per day

I = slope, a dimensionless ratio

p = porosity.

The transmissivity at test-hole site 25N-50W-24aaa was estimated to be 95,000 gallons per day per foot (1 180 m^2/day) or 12,700 square feet per day. The saturated thickness of the aquifer at this site was 360 feet (110 m). The average hydraulic conductivity is the transmissivity divided by the saturated

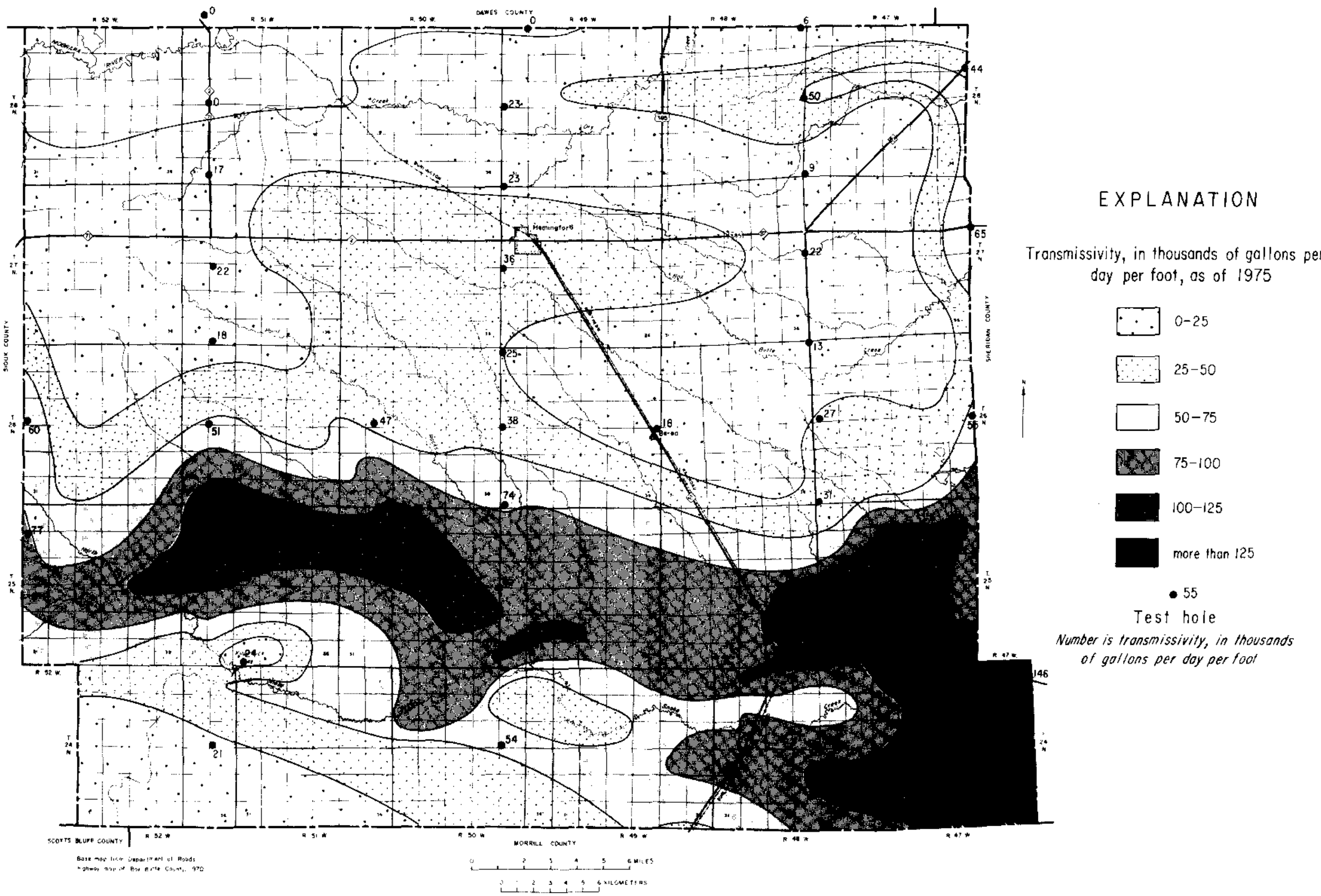

Fig. 20. Transmissivity of aquifer or aquifers above the Brown Siltstone unit

thickness, or 35 feet per day (10.7 m/day). The slope of the water table in this area is 0.003 (fig. 18) and the porosity is estimated to be 0.30. By substituting these values in the formula, the average velocity is computed as 0.35 foot per day (0.107 m/day), or 128 feet (39.0 m) per year, or 2.4 miles (3.85 km) per century. Average rates of flow probably range from less than 50 feet (15.2 m) per year in some parts of the county to more than 200 feet (61 m) per year in other parts.

When a well is pumped, a depression is formed in the water table around the well and a hydraulic gradient is established toward the well from all directions. This gradient is steep near the well and causes the water to move toward the well much more rapidly than under natural conditions.

Groundwater in storage and change in storage, 1938 to 1975

The rocks beneath the Box Butte County make up a groundwater reservoir that absorbs water chiefly during periods of precipitation surplus and gradually releases it to seeps, springs, wells, and areas of evapotranspiration. This reservoir has been drawn upon for more than 30 years to supplement the precipitation for growing crops.

The Arikaree, Upper Harrison, Runningwater, and Ogallala are the units within the groundwater reservoir that can be most readily developed. Water is also stored in the Brown Siltstone and older units, but it is generally more difficult or less practical to withdraw the water stored in these units. The groundwater contained in the Arikaree, Upper Harrison, Runningwater, and Ogallala units is not known to be confined, except possibly in very local areas, so it is assumed that unconfined conditions prevail. The storage coefficients discussed in the section "Porosity, specific yield, and storage coefficients" and the maps showing saturated thicknesses (figs. 13, 14, 15, and 16) can thus be used to estimate the quantity of groundwater stored in these units in Box Butte County.

The estimated, saturated volume of each hydrologic unit in the county in 1975 is listed below. The estimated volume of water that may be extracted from this volume of rock by long-term, gravity drainage is also given.

Hydrologic Unit	Volume of saturated rock (acre-feet)	Volume of Water (acre-feet)
Brown Siltstone	(not calculated)	(not calculated)
Arikaree	115,000,000	23,000,000
Upper Harrison	30,000,000	4,500,000
Runningwater	6,000,000	1,200,000
Ogallala	14,000,000	3,700,000
Totals (Arikaree and younger)	165,000,000	32,400,000

Some groundwater is stored in the Sheep Creek unit in eastern Box Butte County, but the unit is thin, the water is not easily accessible, and the amount of water is limited. The volume of groundwater stored in units younger than the Brown Siltstone exceeds 30 million acre-feet (37.0 km^3) and the Arikaree contains more than two-thirds of this quantity.

Cady and Scherer (1946, pp. 61-63) estimated that 31 million acre-feet of groundwater (38.0 km^3) was stored in the county.

Their estimate, however, was based on only a very general idea of the thickness of the hydrologic units in the county and included water stored in the Brown Siltstone unit. If the average thickness of the Brown Siltstone unit is about 150 feet (45.5 m) (fig. 10), and if the storage coefficient is about 0.05, then another 4 to 5 million acre-feet (4.95 to 6.2 km^3) of water is stored in this unit. This amount added to the 32 million acre-feet (39.4 km^3) computed for the units overlying the Brown Siltstone makes a total of about 36 million acre-feet (44.6 km^3) of groundwater stored in the county in units above the Whitney. This groundwater is not uniformly distributed throughout the county nor can it be completely recovered, even if that were desirable. There is a physical limitation on the amount of water that may be withdrawn from aquifers by wells. Each pumping well, in order to furnish water, has to establish a water-table gradient toward the well. Thus, a cone of depression must form around each well for it to be productive. A certain amount of water level lowering at the well, termed drawdown, is necessary. Drawdowns for large-yielding wells, such as irrigation wells, can be large. When static water levels decline to the point where sufficient drawdown is not available to maintain economically suitable yields for large-capacity wells, the groundwater reservoir has become depleted for such wells even though significant quantities of water may remain in the reservoir. Low-yielding wells, such as stock and domestic wells, have very small drawdowns and can continue to operate under these conditions but the cost of obtaining the water is somewhat greater.

The preceding paragraph indicates that there is also an economic limit to the amount of groundwater withdrawn from storage and this limit can change as crop prices, energy costs, labor costs, and other cost factors change. As water levels decline, pumping lifts increase or well yields decrease. If the costs of obtaining water supplies under these conditions become so great that little or no economic gain can be made or foreseen, then the groundwater reservoir has become depleted for some economic purposes. Suppose crop prices are extremely low in relation to energy, materials, and services needed to produce crops and little or no economic gain can be foreseen in using groundwater for irrigation. Farmers would then stop irrigating crops. However, industrial or municipal users of groundwater, although facing higher costs, might well be able to continue to use the supplies quite profitably.

There may also be a social limit, for lack of a better term, on the amount of water that may be withdrawn from the groundwater reservoirs. This limitation--defined in large measure by public opinion--is extremely vague and variable. It pertains to the conflicts arising between groundwater users as water levels decline, to the social cost of adjusting these conflicts, and to changing social attitudes toward water supplies. Such a limitation probably cannot be precisely defined, but that fact does not establish its nonexistence. The physical, economic, and social limitations are all interrelated to some degree.

The use of groundwater by irrigators, municipalities, and industries has lowered water levels in the county and decreased the amount of stored groundwater. The amounts of water that have been removed from storage from the different hydrologic units from 1938 to 1975 can be estimated by using the map showing changes in the water level (fig. 19) and the storage coefficients already assigned to the units. The areas of water-level decline were examined and the amount of dewatering of each hydrologic unit affected by the water-level lowerings was determined.

The estimated dewatered volume of each hydrologic unit (from 1938 to 1975) is listed below along with the estimated volume of water obtained from the dewatering.

Hydrologic unit	Dewatered volume of rock (acre-feet)	Volume of water (acre-feet)
Brown Siltstone	(none)	(none)
Arikaree	190,000	38,000
Upper Harrison	3,410,000	512,000
Runningwater	(negligible)	(negligible)
Ogallala	770,000	192,000
Totals	4,370,000	742,000

The calculations indicated that 700,000 to 800,000 acre-feet (0.86 to 0.99 km^3) of water was removed from storage in the county between 1938 and 1975. The volume of dewatered material in the Upper Harrison unit is largest because many wells are located in areas where the unit is saturated, the unit overlies the major aquifer of the county, and the storage coefficient of the unit is relatively low. Most of the dewatering of the Upper Harrison unit has occurred in the Hemingford, Berea, and Alliance areas since the mid-1960s, whereas most of the dewatering of the Ogallala unit has taken place in the Alliance area since the early- to mid-1950s.

Additional data could change the estimates of the volume of groundwater in storage, dewatered material, and groundwater depletion. The amount of depletion estimated from geologic information and water-level changes does not agree with the amount of depletion estimated by assessing withdrawals from wells. This matter is discussed at greater length in the section "Groundwater discharge by wells." However, both methods of estimating groundwater depletion indicate that the quantity of stored groundwater declined only 2 to 3 percent from 1938 through 1974. Half of this reduction probably occurred since 1964.

Groundwater recharge

Recharge is the addition of water to the groundwater reservoir and is accomplished in several ways. The groundwater reservoir beneath Box Butte County is recharged primarily by infiltration of local precipitation through the soil and subsoil strata. Other sources of recharge in the county are seepage from ephemeral streams, or water ponded in depressions and subsurface inflow from areas to the west and southwest. A very small amount of water entering the county as stream flow may contribute some water to the zone of saturation, although the quantity is negligible. Once water becomes a part of the groundwater body, it moves slowly in the direction of the slope of the water table and is discharged downgradient.

Recharge by underflow

The maps showing configuration of the water table in 1938 and in 1975 (figs. 17 and 18) indicate that groundwater enters Box Butte County by underflow from Sioux County on the west and Morrill County on the south. Underflow from Sioux County into Box Butte County takes place from about Nebraska Highway 71 in northwest Box Butte County southward to Scotts Bluff County. Underflow from Morrill County into Box Butte County takes place throughout nearly all the length of the southern boundary of Box Butte County. In 1938, a very small amount of groundwater moved west from Sheridan County into Box Butte County in secs. 1, 12, and 13, T. 26 N., R. 47 W., and secs. 24 and 25, T. 26 N., R. 47 W. These sections are at the northeast and southeast sides of the closed depression in the water table along the boundary of Sheridan and Box Butte counties. By 1975, groundwater was entering Box Butte County from the east along most of the county line between Sheridan and Box Butte counties in T. 25 N. One evidence for such movement was that the trough in the water table from Alliance northeastward to the closed depression deepened since 1938.

The amount of groundwater moving into the county can be estimated by use of the formula:

$$Q = TIL$$

where

Q = quantity of water moving through aquifer(s)

T = transmissivity of the aquifer(s)

I = hydraulic gradient

L = length of cross section through which groundwater moves.

Using the 1975 water-table map (fig. 18), the transmissivity map (fig. 20), and the foregoing formula, the following amounts of underflow into Box Butte County in 1975 were computed: 15,000 acre-feet (1.85×10^7 m^3) per year from Sioux County; 28,000 acre-feet (3.45×10^7 m^3) per year from Morrill County; 1,000 acre-feet (1.23×10^6 m^3) per year from Sheridan County. The total is 44,000 acre-feet (5.4×10^7 m^3) per year. The estimates of underflow, particularly that from Morrill County, cannot be considered very accurate because only one test hole was drilled on the Morrill county line and only two were drilled on the Sioux county line. Cady and Scherer (1946, pp. 52 and 57) made similar estimates of underflow into the county, even in the absence of subsurface information. Interpretation of their calculations indicates that they estimated about 90,000 acre-feet (1.11×10^8 m^3) of water enters the county by underflow from the west and south each year, with 73,700 acre-feet (9.1×10^7 m^3) coming from Morrill County.

The limited amount of subsurface information, especially along the Morrill County line, makes it difficult to determine transmissivity values and the amount of underflow. These computations are presented, however, in order to give some idea of the magnitude of underflow into Box Butte County. The water obtained by underflow does not add appreciable amounts to storage in the county because groundwater also moves out of the county by underflow to the north and east.

Recharge from precipitation

The annual precipitation in Box Butte County averages 17 inches (430 mm) and only a small part of that water reaches the zone of saturation. The configuration of the water table in 1938 (fig. 17) indicates, however, that precipitation on the land surface must account for most of the water in the groundwater reservoir. To illustrate this, figure 21 was constructed. This figure shows the principal contour lines on the water table beneath the central tableland. The direction of groundwater movement is shown by flow lines drawn at right angles to the contour lines. The two sets of lines form a grid, or net; blocks within the grid are lettered. The 1938 water-table map was used as the basis for figure 21 because the 1975 water-table map contains many irregularities traceable to the discharge of groundwater by wells.

The flow lines in the central tableland are divergent eastward from the western part of the county. This divergence could be due to one or a combination of the following conditions: a progressive increase in the amount of groundwater passing contour lines of successively lower altitude; a progressive eastward decrease in transmissivity of the aquifers; or a progressive eastward decrease in hydraulic gradient. Figures 17 and 21 indicate that the hydraulic gradient beneath the central tableland is fairly constant and may increase slightly in an eastward direction. Differences in transmissivity from west to east across the county are small compared to the large differences from north to south. Consequently, most divergence must be

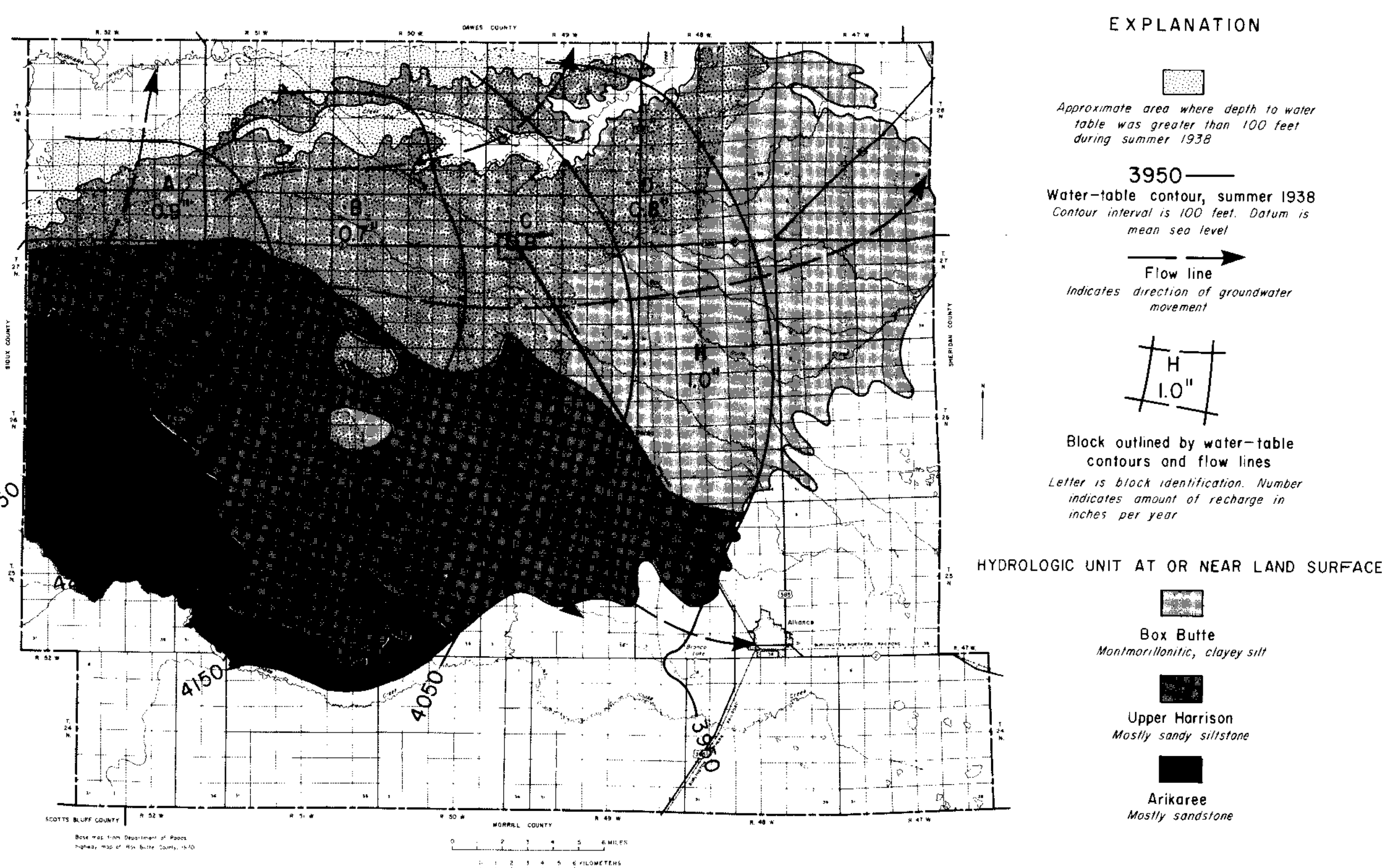

Fig. 21. Average annual rate of groundwater recharge from precipitation

related to an increase in the quantity of water passing successive contour lines and this eastward increase must be due primarily to recharge from precipitation.

The amount of water contributed by recharge from precipitation can be approximated. Underflow entering each block (fig. 21) can be computed by using the formula Q = TIL. For each block, transmissivity values (T) are derived from figure 21, hydraulic gradients (I) are obtained from figure 17, and lengths of aquifer cross section (L) are obtained from figure 21. Underflow leaving each of the blocks can be computed in the same manner. If the underflow leaving a block is greater than the underflow leaving each of the blocks can be computed in the same manner. If the underflow leaving a block is greater than the underflow entering that block, water has been added to the groundwater system within the block. The only sources of recharge water on the central tableland are precipitation or, in some places, seepage from the beds of ephemeral streams during surface flow. Recharge can be computed by dividing the gain in underflow by the area of the block and converting to inches. Recharge amounts within each of the blocks in figure 21 are listed in the following table:

TABLE 8

Precipitation Recharge to Aquifer Beneath Central Tableland

Block	Underflow in (acre-ft/yr)	Underflow out (acre-ft/yr)	Net gain (acre-ft/yr)	Area (acres)	Average annual recharge (inches)
A	520	3,000	2,480	31,900	0.9
B	1,930	3,300	1,370	24,800	0.7
C	3,300	4,970	1,670	24,500	0.8
D	4,970	6,860	1,890	30,000	0.8
E	450	2,420	1,970	15,200	1.6
F	2,420	4,980	2,560	26,900	1.1
G	4,980	9,420	4,400	42,200	1.3
H	6,090	10,140	4,050	48,600	1.0
I	700	5,320	4,620	13,200	4.2
J	5,320	7,960	2,640	15,400	2.0
K	1,410	5,820	4,410	8,800	6.0

Table 8 indicates that the average annual rate of recharge is significantly different in various parts of central Box Butte County. The amount of precipitation that eventually recharges the groundwater reservoir is dependent upon many factors. Some of these are: the time of the year precipitation occurs, the duration and intensity of rainstorms, the freezing and thawing of the soil column, the wetting and drying of the soil column, the slope of the land, the vegetative cover, cultural practices on the land, biological activities of plants and animals in the soil, the texture and permeability of the soil columns, and the vertical hydraulic conductivity of subsoil strata in the unsaturated zone. The depth to the water table has little to do with the average annual rate of recharge from precipitation; although the greater the depth to water, the more likely the presence of materials of low permeability above the water table. One geological factor that influences the rate of recharge from precipitation in Box Butte County is the hydrologic unit that occurs at or near the land surface.

Figure 21 shows the average annual rates of recharge in the central part of the county and the hydrologic units that occur at or near the land surface there. The recharge rates are noticeably low where the Box Butte unit occurs over substantial portions of the blocks. For example, 0.7 inch (17.8 mm) of recharge occurs each year in block B, a block in which the Box Butte unit occurs at or near land surface throughout virtually the entire area. In blocks E and J, the Upper Harrison is present at or near land surface and the rates of recharge there appear to be more than double those in which the Box Butte unit is at or near the land surface. The computations suggest block K has the highest rate of recharge, an average of 6.0 inches (152 mm) per year. Block K is in the area where the permeable sandstones of the Arikaree unit are exposed. The soils in this area are quite sandy and the sandy beds of the ephemeral streams in the area are quite porous. The combination of sandy soils, porous stream beds, and exposed permeable rock provide favorable conditions for rapid infiltration of precipitation and storm runoff. Consequently, recharge to the groundwater reservoirs appears to be quite large in the area of block K despite the fact that the average annual precipitation there is only about 15 inches (380 mm).

Although the recharge rates are low in the areas where the Box Butte unit occurs, they are not as low as one might expect on the basis of the materials composing the unit. The Box Butte is comprised of montmorillonitic, clayey silt that swells when wetted. The vertical hydraulic conductivity of the unit must be low because a perched body of groundwater is associated with this unit throughout much of the north-central and northeastern parts of the county. This perched groundwater appears to be permanent in some places in the vicinity of Hemingford because the growth of water-loving vegetation, such as cattails and willows, is sustained by the discharge of groundwater. A small amount of streamflow not due to surface runoff occurs in some reaches of Box Butte and Hemingford creeks, at least for part of the year, and this base flow must be groundwater discharged from the perched groundwater body because the regional water table is several tens of feet to more than 100 feet (30.5 m) below the stream beds.

In other places, however, perched groundwater appears to be seasonally associated with the Box Butte unit. The largest amount of perched water apparently occurs in the spring after snow has melted and rains have begun. At this time, the weather is still cool and vegetation has not attained a lush growth. In some places, areas that are too wet to farm in the spring have dried out by July or August and farming is possible. The intermittent recharge is not great enough or frequent enough to prevent the perched water from disappearing as a result of drainage or as a result of the lateral movement to areas of discharge to streams and vegetation. Where the perched water is seasonal, the clayey silt can dry, shrink, and develop cracks. Some of the water may then seep through the cracks and percolate downward to the regional water table. The Box Butte unit is furthermore quite thin in some places and locally stream valleys have eroded through the unit (section D-D', fig. 10). These areas would be favorable ones for recharge water to pass through the unit to the regional water table.

Figure 21 indicates that the depth to the water table is not a significant factor in the average annual rate of recharge. Block A and block H have a similar proportion of the same hydrologic units at or near the land surface and similar rates of recharge. The average depth to the water table in block A, however, is about twice as great as the depth to water in block H. The depth to water in block E is substantially greater than in block H, but the rate of recharge is greater in E than in H. The difference, of course, is that the Box Butte unit is at or near the land surface throughout more than one-half of block H and is not present in block E.

Figure 21 also indicates that the hydrologic units at or near the land surface, and probably the soils as well, influence average annual recharge more significantly than the amount of annual precipitation. Average annual precipitation in the vicinity of blocks C and D is about 18 inches (455 mm), but the average annual recharge to the groundwater reservoir probably is less than 1 inch (25.5 mm), or less than 5 percent of the precipitation. Average annual precipitation in the vicinity of blocks I and K is about 15 inches (380 mm), but the average annual recharge is probably from 4 to 6 inches (102 to 152 mm), or more than 25 percent of the precipitation.

The rates of recharge computed for the central tableland area of Box Butte County are not precise. These computations do, however, provide estimates of recharge based on available data. The principal difficulty with the computations occurs at the point of determining an accurate value for the transmissivity, especially in the area just north of Snake Creek where the Arikaree unit varies considerably in thickness and texture over short distances in a north-south direction. Sufficient test holes are not available for accurate definition of these variations. Nevertheless, the computed recharge rates are the best guides presently available for estimating recharge from precipitation throughout the county.

Average annual recharge from precipitation in areas where the Box Butte unit is at or near the land surface is probably from 0.5 to 1 inch (12.7 to 25.5 mm), averaging about 0.7 inch (17.8 mm). Where the Upper Harrison and the Runningwater are at or near land surface, the rate of recharge is probably from 1.5 to 2 inches (38 to 51 mm) per year, averaging 1.8 inches (45.5 mm) per year. The rate of recharge is from 4 to 6 inches (102 to 152 m) per year, averaging at least 5 inches (127 mm) per year, in areas where the Arikaree unit is at or near the land surface. In areas where sand hills overlie the Ogallala unit, conditions for recharge are even more favorable than in the areas where the Arikaree unit is present. In places where the Ogallala is not overlain by sand hills, the soils are still quite sandy and recharge rates are probably comparable to those of the Arikaree. An average annual rate of recharge of 5 inches (127 mm) seems reasonable, or perhaps conservative, for all the areas in which the Ogallala occurs. Little or no recharge probably occurs in the rough, broken land south of the Niobrara River because the steepness of the land causes rapid surface runoff. Using the average recharge rates and the hydrologic unit map (fig. 11), the authors estimate that precipitation adds an average of 130,000 acre-feet (1.60×10^8 m^3) of water per year to the groundwater reservoir in Box Butte County. This estimate is probably conservative; total average annual recharge may exceed 150,000 acre-feet (0.185 km^3) per year.

Figure 21 and table 8 show that recharge from precipitation is the important source of recharge for the central tableland area of the county and that underflow from the west is insignificant. The computed underflow into blocks A, E, I, and K was 3,080 acre-feet (3.80×10^6 m^3) per year. Of this amount, half the water moving into block A is diverted northward to discharge areas along the Niobrara River and water entering blocks I, K, and part of E is diverted southeastward toward discharge areas in the Snake Creek valley. This leaves only about 700 acre-feet (8.6×10^5 m^3) entering the central tableland area through parts of blocks A and E. The computed underflow east out of blocks D and H is 16,000 acre-feet (1.97×10^7 m^3) per year. Of this water, only 700 acre-feet (8.6×10^5 m^3), or less than 5 percent, is derived from underflow beneath the west boundary of Box Butte County. The remainder is due to recharge from precipitation within the central tableland area.

Recharge from seepage

Recharge to the groundwater reservoir from ephemeral streams whose beds are above the water table can occur during the brief period in which these streams flow after rains. In this report, recharge from ephemeral streams as well as the very small amount of recharge that comes from water ponded in depressions are both considered to be part of the recharge from precipitation. A small stream trending southeast from Alliance to the lowlands carries water discharge from the Alliance power plant. Some of the water in the stream is used for irrigation but southeast of the city some probably seeps to the water table. No net gain in groundwater storage in the county is achieved, however, because the source of the water is groundwater from wells in Alliance. In fact, net loss to the groundwater reservoir occurs with this operation because some water is lost to evaporation and transpiration in the lowlands.

Snake Creek flows year-round at the Sioux-Box Butte county line, adding a very small amount of water to the county each year. The stream sinks beneath the ground to the east and some of the water may reach the water table. Groundwater is discharged into the Niobrara River in northwest Box Butte County and the river probably seldom serves as a source of recharge.

Recharge from irrigated lands

Kilpatrick Lake is a privately owned reservoir on Snake Creek in southwest Box Butte County. A small amount of land is irrigated with water stored in this reservoir and a negligible amount of groundwater recharge may occur by the seepage from these lands. Part of the waste water from the Alliance power plant is used to irrigate a few acres southeast of Alliance, the seepage from which probably also reaches the water table. Some irrigation may occur with water from the Niobrara River but the amount of recharge from this source is probably negligible. Except for these few places, all irrigation in the county is with water pumped from wells. Some of this irrigation water from wells, probably less than 10 percent, may return to the water table.

Groundwater discharge

Water is discharged from the groundwater reservoir in Box Butte County by evaporation, transpiration through vegetation, underflow, streams, and wells. The rate at which it is discharged varies with many factors, most important of which is the season of the year. Local differences in hydrologic conditions cause more groundwater to be discharged in some parts of the county than in others. For example, more water is discharged in areas where lakes occur and more water is pumped from wells in some areas than in others.

Discharge by evaporation and transpiration

Evaporation and transpiration account for the discharge of the largest amounts of groundwater in the county. Water is evaporated from lakes fed primarily by groundwater and from areas where the capillary fringe is at the land surface. Evaporation at these sites takes place in all but the coldest months, and some evaporation or sublimation may occur even then. Groundwater is also discharged through transpiration by plants that have roots in the zone of saturation or in the capillary fringe. Discharge of groundwater through transpiration occurs only when the plants are growing. The combination of evaporation and transpiration is called evapotranspiration.

Discharge of groundwater by evapotranspiration can occur only where the depth to the water table is relatively shallow. The shaded portions of figure 22 indicate the parts of Box Butte County where the water table is relatively shallow, generally

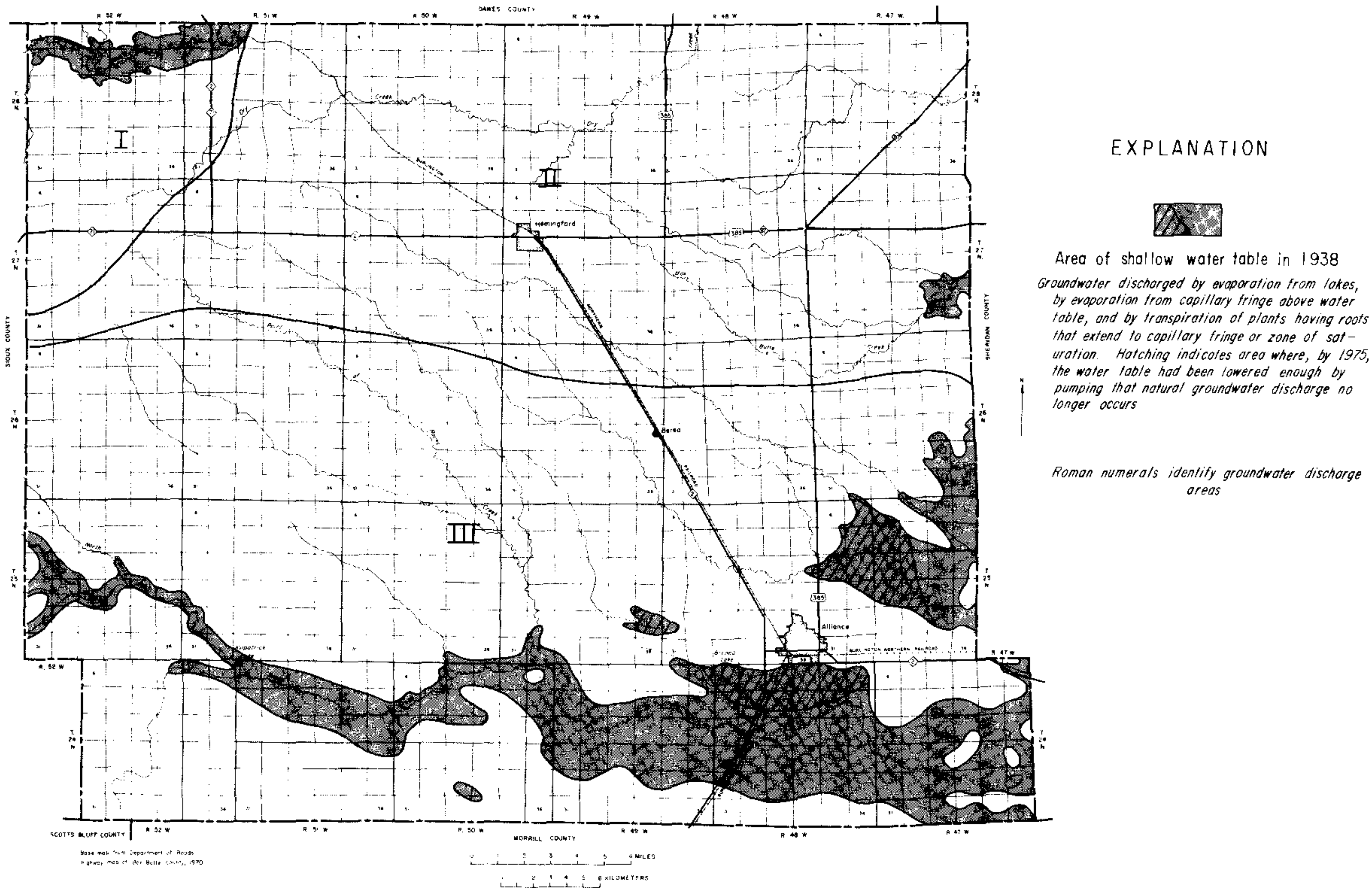

Fig. 22. Areas of shallow water table

less than 10 feet (3.05 m). Locally, the land is too wet for crops requiring cultivation and is used for hay or pasture. Cattails, rushes, and sedges grow where water is at or very near land surface. According to Dr. James Stubbendieck, range management specialist, University of Nebraska-Lincoln (personal communication 1977), grasses native to the wetter sites, but not necessarily restricted to them, are alkali sacaton, inland salt grass, prairie sand reed, sand bluestem, tall dropseed, alkali cordgrass, and American slough grass. Some forbs common to these sites are arrowgrass, goldenrod, and horsetail. Plants that have been introduced and thrive here include Kentucky bluegrass, reed canary grass, redtop, alsike clover, and sweet clover. Alfalfa is grown in places where the water table is shallow and, where not irrigated, probably derives some of its water supply from groundwater.

Some of these plants are classified as phreatophytes by Robinson (1958). A phreatophyte is a plant that depends for its water supply upon groundwater that lies within reach of its roots. Alkali sacaton and salt grass are two such plants identified by Robinson, but many of the other plants described by Stubbendieck must derive at least part of their water supply from groundwater.

Studies on the amount of groundwater transpired by salt grass (Robinson 1958, p. 56) show the amount decreases with increasing depth to the water table. Rates of evapotranspiration for salt grass range from two-thirds to three-fourths of the pan evaporation where the water table is at a depth of less than 1 foot (0.305 m) to insignificant amounts where the water table is deeper than 8 feet (2.44 m). Many other grasses and forbs undoubtedly behave in a similar manner.

The amount of groundwater discharged by evapotranspiration can be approximated for 1938, a time when irrigation with groundwater was insignificant. Groundwater discharge by evapotranspiration at that time would have been about equivalent to groundwater recharge from underflow and precipitation minus groundwater leaving the county by underflow, the limited amount of withdrawals from wells by agricultural, municipal, and industrial users, and the small amount of groundwater entering into the Niobrara River. It is assumed that no significant changes in groundwater storage had occurred in the county up to 1938.

In figure 22, Box Butte County is divided into three areas that differ with respect to groundwater discharge. Discharge of groundwater in area I is by evapotranspiration in the Niobrara River valley, seepage to the river, and by several stock and domestic wells. By 1975, three irrigation wells were reported to be in the river valley and only a few were reported to be on the tableland part of the area. Otherwise, the conditions in 1975 and 1938 are similar. The amount of water withdrawn by wells in the area is probably not much more than 500 acre-feet (6.2×10^5 m^3) per year. It is difficult to estimate the underflow into the Niobrara River valley because all the water must move through the Brown Siltstone unit at the edge of the tableland. Underflow, however, may be in the magnitude of 1,500 acre-feet (1.85×10^6 m^3) per year. If an average of 3 inches

(76 mm) of precipitation recharges the groundwater reservoir north of the rough land at the edge of the table, then an additional 3,000 acre-feet (3.70 x 10^6 m^3) of groundwater, and a total of about 4,500 acre-feet (5.5 x 10^6 m^3), must be discharged each year in the valley by evapotranspiration or seepage to the river. The shaded part of area I (fig. 22) represents about 6,000 acres (24.3 km^2) of land where the water table is relatively shallow. If total evapotranspiration averages 24 inches (610 mm) per year in this area and precipitation averages 18 inches (455 mm) per year, then discharge by evapotranspiration is about 3,000 acre-feet (3.70 x 10^6 m^3) per year, leaving about 1,500 acre-feet (1.85 x 10^6 m^3) per year to be discharged into the Niobrara River. These discharge values are crude estimates at best.

Groundwater discharge from area II (fig. 22) was principally by underflow out of the county to the north and east in 1938 except possibly for a small area along Box Butte Creek near the Sheridan county line. The area of possible evapotranspiration is quite small and the quantity of groundwater discharged would have been only an insignificant part of the total quantity discharged from area II.

In 1938, groundwater discharge in area III occurred by evapotranspiration (as depicted by the shaded portions of figure 22); by a small amount of underflow out of the extreme southeastern corner of the county; by the withdrawals of a few irrigation, municipal, and industrial wells; and by the withdrawals of many stock and domestic wells. Groundwater did, and still does, discharge into Snake Creek in places in the western half of the county, but none of this groundwater leaves the county as surface runoff.

The amount of recharge to the groundwater reservoir by underflow in area III in 1938 is estimated to have been 43,000 acre-feet (5.3×10^7 m^3) per year (see section on recharge by underflow). Recharge to the groundwater reservoir by precipitation is estimated to have been 112,000 acre-feet (1.38×10^8 m^3) per year, according to the rates of recharge determined above. Thus the total recharge in area III was approximately 155,000 acre-feet (1.91×10^8 m^3) per year. Discharge by underflow out of the southeastern corner of the county is estimated to have been 4,000 acre-feet (4.95×10^6 m^3) per year. Cady and Scherer (1946) estimated that 1,900 acre-feet (2.34×10^6 m^3) of groundwater per year was pumped from the wells in the southern two-thirds of the county. They assumed some of this groundwater came from storage because they considered the shallow depression in the water table in Alliance to be caused by discharge of groundwater from wells. This amount of pumpage, furthermore, is relatively insignificant in view of the much larger amounts of water discharged by other means. Total recharge of 155,000 acre-feet per year (1.91×10^8 m^3) minus discharge by underflow of 4,000 acre-feet per year (4.95×10^6 m^3) and discharge by wells of about 1,000 acre-feet per year (1.23×10^6 m^3) equals the amount of groundwater discharged by evapotranspiration, or about 150,000 acre-feet per year (1.85×10^8 m^3).

Cady and Scherer (1946, p. 59) made an estimate of groundwater discharged by evapotranspiration in the same part of the county as area III. Their estimate of total evapotranspiration in the parts of area III where the water table is relatively shallow was 318,450 acre-feet per year (3.95×10^8 m^3). This figure includes evapotranspiration from temporary ponds and soil moisture; that is, water from precipitation that never reached the groundwater reservoir. Using their figures with the methods used in this report, their estimate of groundwater discharge by evapotranspiration becomes 175,680 acre-feet per year (2.17×10^8 m^3). The 25,680 acre-feet (3.15×10^7 m^3) difference between their figure and the one given here is principally due to recent subsurface information. Their estimate of recharge by underflow was about double that of this report. Rates of recharge from precipitation used in this report, however, are higher than those used by Cady and Scherer, and this partially compensates for their large estimate of recharge by underflow.

The computed amount of groundwater discharged by evapotranspiration is similar to the computed amounts of groundwater recharge and storage presented earlier. The amounts are estimates that include considerable judgment and are not precise measurements. The amounts are given, however, to show the magnitudes of groundwater recharge, discharge, and storage. These estimated quantites should be revised if additional information is acquired.

Discharge of groundwater by evapotranspiration in the eastern lowlands of Box Butte County and adjacent parts of Sheridan County was the source of minerals for the short-lived potash industry in the area during World War I (Condra 1918). Cady and Scherer (1946, p. 81) and Durum (in Nace 1953, pp. 11-17) show that minerals are in solution in the groundwater. Condra (1918) and Rainwater (in Bradley 1956) also give chemical analyses and discuss the relationship of groundwater to mineral accumulation. Evaporation from lakes fed by groundwater, evaporation from the capillary fringe, and transpiration of groundwater through plants concentrate these minerals in the lakes, soil, and the upper part of the zone of saturation. As groundwater is discharged, more groundwater moves laterally and upward into the discharge areas, bringing a fresh supply of minerals to be added to the existing supply. With enough time, significant concentrations can accumulate in the discharge areas.

Many irrigation wells have been installed in area III (fig. 22) since 1938. A significant number of these wells are located where the water table is relatively shallow. The lowering of the water level by pumping has resulted in salvaging at least part of the water formerly lost in evapotranspiration. The groundwater pumped from these wells is used to grow corn, beans, sugar beets, potatoes, and alfalfa instead of supporting the growth of grasses, rushes, and sedges. In some places, such as around Bronco Lake, the lowering of the water level by pumping has been large enough to intercept all the groundwater that formerly was discharged by evapotranspiration. These places are shown in figure 22 by a cross-hatch pattern.

Discharge by springs and seeps

A relatively small amount of water from the regional groundwater reservoir is discharged by springs and seeps along the

Niobrara River and Snake Creek. A very small quantity of groundwater may also be discharged into Box Butte Creek in a similar manner. The total amount of groundwater seeping into the Niobrara River and leaving the county may be as much as 1,500 acre-feet per year (1.85×10^6 m^3). Springs and seeps also occur in the northern part of the county, but the source of groundwater here is the perched zone of saturation associated with the Box Butte unit.

Discharge by underflow

Just as groundwater moves into Box Butte County by underflow from the west and south, so also it moves out of the county by underflow to the north and east. Within the county, groundwater percolates slowly in the direction of the maximum slope of the water table and toward areas of discharge. Groundwater that is not used within the county or is not intercepted in the discharge areas along the Niobrara River, Snake Creek, or the lowlands in the eastern part of the county percolates north into Dawes County or east into Sheridan County.

Area II (fig. 22) is the area from which most of the groundwater is discharged by underflow. The amount of water that moves north and northeast out of this area into Dawes County is estimated to be about 13,000 acre-feet per year (1.60×10^7 m^3) under conditions similar to those in 1938. The amount of water that moves out of northeastern Box Butte County into Sheridan County is estimated to be about 4,000 acre-feet per year (4.95×10^6 m^3) under similar circumstances. Inspection of the

1938 and 1975 water table maps (figs. 17 and 18) indicates that the water-table gradient along the Dawes County and Sheridan County borders is about the same for both years. Thus, groundwater discharge from area II by underflow in 1975 was probably the same as that in 1938 despite the large number of irrigation wells now located in area II.

Groundwater discharge by underflow from southeast Box Butte County into Sheridan County is estimated to be about 4,000 acre-feet per year (4.95×10^6 m^3) under conditions similar to those in 1938. A similar quantity is probably now discharged from the same part of the county.

The total quantity of groundwater moving out of the county by underflow is about 21,000 acre-feet per year (2.60×10^7 m^3) and the amount probably has not changed significantly since 1938. The amount of groundwater discharged from the county by underflow is about half the amount of recharge to the groundwater reservoir by underflow. Most of the recharge by underflow, however, comes from Morrill County to the south, and the majority of this is eventually discharged by evapotranspiration in the Snake Creek valley and the lowlands around Alliance. Most of the groundwater discharged from the county by underflow originates as recharge from precipitation on the central and northern tablelands of the county.

Groundwater discharge by wells

The most obvious discharge of groundwater in Box Butte County is through wells, but the amount of groundwater discharged in this manner is less than that discharged by evapotranspiration. Most of the water for livestock and all the domestic, municipal, and industrial water supplies are pumped from wells. Most of the water pumped in the county, however, is used for irrigation. Of all the water that is pumped, perhaps only 10 to 20 percent returns to the groundwater reservoir. Most of the remainder is transpired by crops or evaporated from the soil or standing bodies of water.

Cady and Scherer noted that eight wells had been used for irrigation in Box Butte County during the summer of 1938, a ninth irrigation well was drilled that year, and two wells designated as irrigation wells had not been used. They said: "Irrigation in Box Butte County is at present [1938] in either a pioneering or an abortive stage, depending on its future development" (Cady and Scherer 1946, p. 76). It appears now that the owners* of the 11 irrigation wells in 1938 were truly pioneers inasmuch as 601 irrigation wells were registered in Box Butte County as of December 31, 1975 (irrigation-well registrations, Nebraska Department of Water Resources).

Figures 23 and 24 show the locations of irrigation wells in Box Butte County in 1945, 1955, 1965, and 1975. Figure 25 shows the cumulative number of wells from 1938 through 1975. From the latter part of the 1930s through World War II (1938 through

*The well owners listed by Cady and Scherer (1946, pp. 76-79) were Koester Brothers, E. W. Purington, Nels Peterson, George Smith, O. A. Odel, Ferdinand Trenkle, Herman Bauer, Louis Bauer, P. L. Johnson, G. E. Dyer, and L. R. Hughes.

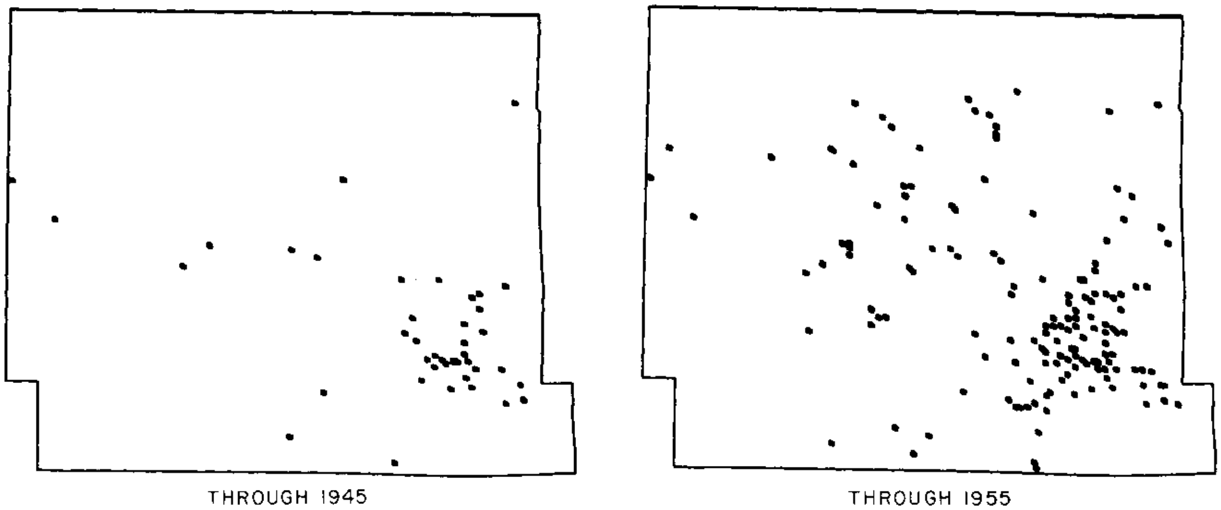

Fig. 23. Location of irrigation wells, 1945 and 1955

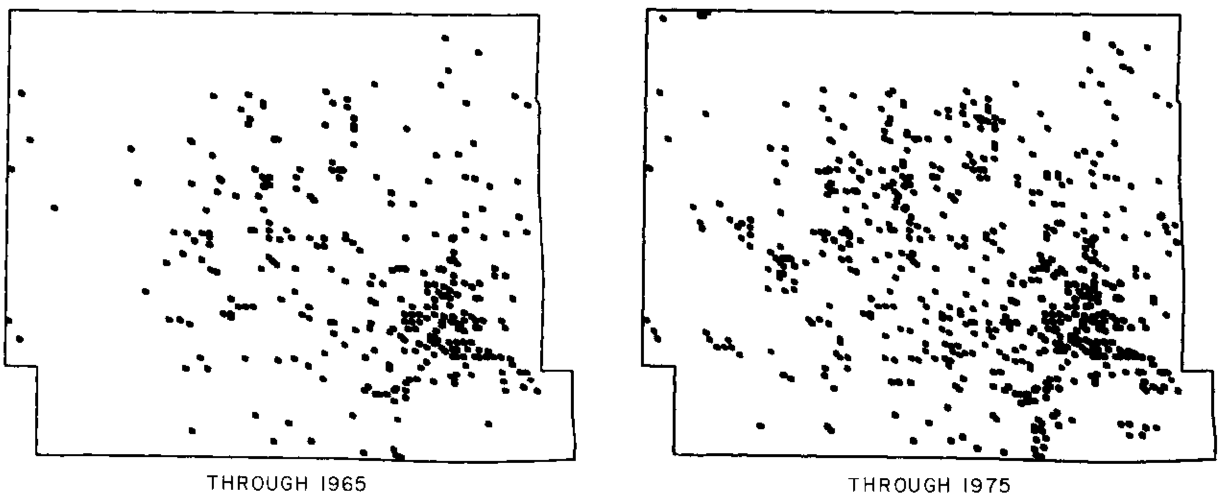

Fig. 24. Location of irrigation wells, 1965 and 1975

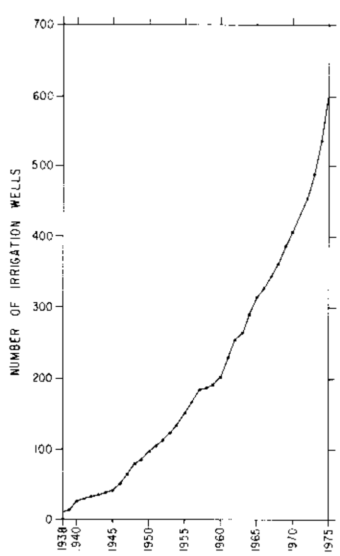

Fig. 25. Cumulative number of irrigation wells, 1938-75

1945), an average of about four wells per year were installed. The development of irrigation with wells increased steadily but not spectacularly during the 15 years following the war. From 1946 through 1960, an average of 11 wells per year were installed. Beginning in 1961, the installation of new irrigation wells increased significantly. An average of 21 wells per year were drilled each year from 1961 through 1972. In 1973, 1974, and 1975, a total of 148 wells were installed, which made an average of 49 wells each year. The number of irrigation wells in the county doubled from 1964 to 1975.

High commodity prices in 1973 and good prices in 1974 and 1975, combined with the onset of dry weather in 1974, created a large demand for new irrigation systems, especially pivot sprinklers. Landowners' concerns about future controls on well installations may also have been a factor in this large increase in well installations. Commodity prices dropped sharply in 1976. The lower crop prices and the greatly increased costs in practically all phases of agriculture, especially energy, indicate that the economic outlook for the expansion of irrigation in the country has changed since 1974. Therefore, a long-range prediction of new well installations at this time would be of little value. Economic and social considerations rather than the water-supply situation are more likely to determine whether irrigation with groundwater will expand, remain about the same, or become less.

The amount of land irrigated with wells is not known precisely, nor is it easy to estimate. Information on the irrigation-well registrations through 1975 indicates these wells were intended to irrigate between 88,000 and 99,000 acres (3.55×10^8 m^2 and 4.00×10^8 m^2). However, according to the Nebraska Crop and Livestock Reporting Service (1977), the acreage in the county that could be irrigated with systems existing in the county in 1975 was 78,000 acres (3.15×10^8 m^2). The same report indicates that 27,000 acres (1.09×10^8 m^2) of irrigated corn, sorghum, wheat, and alfalfa were harvested. It indicates also that 30,450 acres (1.23×10^8 m^2) were planted to dry edible beans and sugar beets and it is probable that most, if not all, of this acreage was irrigated. All of the small but important potato acreage was irrigated but was not reported in the agricultural statistics. Some of the 7,000 acres (2.85×10^7 m^2) of oats, barley, and rye harvested in the county in 1975 may have been irrigated. Similarly, some tame hay other than alfalfa may have been irrigated, but the acreage probably was small. Therefore, a crop by crop examination of the preliminary estimates for 1975 indicates that 60,000 to 64,000 acres (2.43×10^8 m^2 to 2.60×10^8 m^2) was irrigated in Box Butte County in 1975.

The amount of water pumped from the groundwater reservoir in 1975 to irrigate crops in the county is even more difficult to estimate than the amount of land irrigated in 1975. The Alliance weather record shows that precipitation was below normal throughout the 1975 growing season and that temperatures were above normal in July and August. These departures from normal indicate that more water probably was applied to each acre than in wetter and cooler growing seasons.

Irrigation-well registrations indicate about 580 irrigation wells were in the county during the 1975 growing season. About 245 of these wells delivered water through center-pivot sprinklers. On the average, about 135 acres are irrigated by such a system in Box Butte County, so an estimated 33,000 acres (1.34×10^8 m^2) were irrigated by this method in 1975. Average water application per acre was probably 1.33 acre-feet per acre (0.405 m^3/m^2) or a total of 44,000 acre-feet (5.4×10^7 m^3) (personal communication 1977, Walter Trimmer, district extension irrigation engineer, University of Nebraska Panhandle Station, and based on irrigation scheduling programs in cooperation with Panhandle Rural Electrification Association, Alliance, Nebraska). Most of the remaining 335 wells were used to irrigate 27,000 to 31,000 acres (1.09×10^8 m^2 to 1.25×10^8 m^2) of land by gravity methods.

John Schrunk, College of Agriculture, University of Nebraska, surveyed irrigation wells in Box Butte County in 1949. He found that during the 1949 season the average amount of water withdrawn from 55 wells was 206 acre-feet (2.55×10^5 m^3) per well (Conservation and Survey Division files). These wells presumably served gravity-irrigation systems. L. F. Kulish, an engineer appraiser for the Federal Land Bank of Omaha, estimated that the average seasonal pumpage from 1959 to 1962 was 207 acre-feet (2.55×10^5 m^3) per well (based on 80 to 89 wells). Using records from 224 to 321 wells, he estimated the average seasonal withdrawal per well from 1963 to 1967 was 200 acre-feet (2.47×10^5 m^3). Kulish's estimates were based on known hours of pumping and an estimated average yield of 900 gallons per minute (5.7×10^{-2} m^3/s) per well (Conservation and Survey Division files). The wells probably furnished water to gravity-irrigation systems. Schrunk's survey and Kulish's records suggest that the average withdrawal of a well supplying water for irrigation by gravity methods is about 200 acre-feet (2.47×10^5 m^3) during an average year. Precipitation during the 1975 growing season was only about 75 percent of normal. Consequently, it is assumed that the average withdrawal per well was 220 acre-feet (2.71×10^5 m^3) in 1975. This amount, multiplied by 335 wells, is about 74,000 acre-feet (9.1×10^7 m^3). Addition of this pumpage to pumpage by center-pivot systems of 44,000 acre-feet (5.4×10^7 m^3) makes total irrigation withdrawals of 118,000 acre-feet (1.45×10^8 m^3) in 1975.

Precipitation from April through September 1975 amounted to 9.36 inches (238 mm) at Alliance. Supplemental water requirements for good crop yields were about 7 inches (178 mm) for dry edible beans, 18 inches (455 mm) for corn, 21 inches (530 mm) for sugar beets, and more than 30 inches (760 mm) for alfalfa. If the crop proportions on land irrigated by gravity systems was about the same as that reported for all irrigated cropland in the county, then an average of nearly 1.5 acre-feet of irrigation water per acre (0.455 m^3/m^2) was needed. Transmission, runoff, deep percolation, and evaporation losses probably totaled 0.5 acre-feet per acre (0.152 m^3/m^2). Additional water was probably pumped because of difficulties in scheduling irrigation to utilize rainfall to full advantage. This management problem probably increased pumpage by an average of 0.2 acre-feet (6.1×10^{-2} m^3/m^2) per acre. Average well withdrawals of 2.2 feet per acre (0.67 m^3/m^2) for 27,000 to 31,000 acres (1.09×10^8 m^2 to 1.25×10^8 m^2) is 59,400 to 68,200 acre-feet (7.3×10^7 m^3 to 8.4×10^7 m^3). This amount, added to that estimated to have been pumped through center-pivot systems gives total irrigation withdrawals of 103,000 to 112,000 acre-feet (1.27×10^8 m^3 to 11.38×10^8 m^3) in 1975, a quantity somewhat less than estimated previously.

A third method of estimating withdrawals is to use agricultural statistics and supplemental-water requirements for crops. With this method, the supplemental-water requirements for irrigated corn, sorghum, winter wheat, alfalfa, edible beans, and sugar beets came to 82,400 acre-feet (1.02×10^8 m^3) in 1975. The irrigated acreage for potatoes, tame hay, pasture, and other small grains is not known but is assumed to be 6,000 acres (2.43×10^7 m^2). If the supplemental-water requirement for these crops average 1 foot (0.305 m), then 6,000 acre-feet (7.4×10^6 m^3) added to 82,400 (1.02×10^8 m^3) acre-feet makes the total supplemental-water requirements in the county about 88,400 acre-feet (1.09×10^8 m^3). If an average of one-third acre-foot of water per acre (0.101 m^3/m^2) is assumed to have been lost because of management problems, evaporation and other transmission losses, deep percolation, and runoff, then 20,000 to 21,000 acre-feet (2.47×10^7 m^3 to 2.60×10^7 m^3) should be added to the supplemental needs to determine total pumpage for irrigation in the county. This third method yields 109,000 acre-feet (1.34×10^8 m^3) of total withdrawals for irrigation in 1975.

None of the three methods of estimating pumpage for irrigation is precise. Nevertheless, all methods indicate that pumpage for 1975 probably fell in the range of 100,000 to 120,000 acre-feet (1.23×10^8 m^3 to 1.48×10^8 m^3). Therefore 110,000 acre-feet (1.36×10^8 m^3) may be a reasonable estimate of irrigation-well withdrawals in Box Butte County in 1975.

Additional amounts of groundwater were pumped for stock, domestic, municipal, and industrial uses. The quantity of water pumped for these uses in 1975, including the needs of the Alliance power plant, was probably between 7,000 and 11,000 acre-feet (8.6×10^6 m^3 to 1.36×10^7 m^3). Estimated total withdrawals of groundwater from wells in Box Butte County in 1975 is about 120,000 acre-feet (1.48×10^8 m^3), or somewhat less than the quantity of groundwater discharged by evapotranspiration.

A large volume of groundwater has been withdrawn from wells in the county since 1938. This volume can only be roughly estimated because few surveys of water usage have been made. The irrigation-well registrations, Schrunk's survey, Kulish's records, Trimmer's programs, and the number of center-pivot systems derived from satellite images provide some bases for estimating the total amount of water withdrawn from wells. From these data it was calculated that 1,300,000 to 1,600,000 acre-feet (1.60 to 1.97 km^3) of water were withdrawn from wells from 1938 through 1974. Of these withdrawals, 90 percent was used for irrigation. Half of these withdrawals probably occurred from 1964 through 1974 and more than one-quarter probably occurred from 1970 through 1974.

Of the total amount of groundwater withdrawn, 150,000 to 300,000 acre-feet (1.85 x 10^8 m^3 to 3.70 x 10^8 m^3) probably returned to the aquifers by deep percolation. An additional 100,000 to 200,000 acre-feet (1.23 x 10^8 m^3 to 2.47 x 10^8 m^3) may have been salvaged by lowering the water table in areas where natural discharge by evapotranspiration occurred. Moreover, the lowering of the water table in these areas probably created conditions which permitted some recharge from precipitation to take place, although this quantity was undoubtedly small. In addition, recharge from precipitation could have increased throughout the irrigated lands because of cultural practices associated with irrigation. Thus, withdrawal of water from wells from 1938 through 1974 probably diminished the supply of groundwater stored in the county by 900,000 to 1,200,000 acre-feet (1.11 to 1.48 km^3).

In the above section "Groundwater in storage and change in storage, 1938-1975," it was estimated that 4,400,000 acre-feet (5.4 km^3) of rock in the county had been dewatered and that the yield was 700,000 to 800,000 acre-feet (8.6 x 10^8 m^3 to 9.9 x 10^8 m^3) of water, or 60 to 90 percent of the amount considered to have been derived from storage based on estimates of well withdrawals. The lack of agreement can be attributed to several things.

First, the data base for making the estimates by either method may not be sufficiently detailed; that is, more water-level measurements (especially in 1975) and more water-use inventories could have made the estimates more precise and eliminated some or all of the discrepancy.

Second, accurate values for storage coefficients, or specific yields, after several years or decades of drainage have not been determined for different kinds of materials. Although the storage coefficients used in this report probably are on the high side, the possibility exists that, with long-term drainage, the specific yield of sandstone may approach the porosity of the rock, thus giving specific-yield values of 30 percent or more. Fine-grained rocks, such as siltstones, can be highly porous. The specific yield of these rocks, while not approaching the porosity, may be much greater than it was formerly thought possible. For example, if the specific yield of the Ogallala and Arikaree units is 30 percent and the Upper Harrison is about 20 percent after long periods of drainage, the amount of water withdrawn from these units from 1938 through 1974 would approximate 1,000,000 acre-feet of water (1.23 km^3).

Third, little information is available for determining how much irrigation water applied to fields returns to aquifers via deep percolation. Because most hydrologists assume a value of 10 to 20 percent, 15 percent was assumed in this report. However, the quantities of recharge from precipitation estimated in this report indicate that, in some areas, the soil and subsoil conditions are especially favorable for the intake of water and more deep percolation of irrigation water may take place than was assumed.

Fourth, little or no information is available to assess the effects of the cultural practices of irrigation on recharge from precipitation. A rise in water levels in areas of southwest Nebraska and possibly in one small area in Box Butte County may be associated with changes in the cultural practices of dryland farming on the semi-arid plains. These practices could have created conditions favorable for increasing recharge from precipitation. Similarly, cultural practices associated with irrigation may have done the same thing but the effects of these practices are masked by the lowered water levels due to pumping.

Fifth, the amount of water salvaged in Box Butte County by lowering water levels in areas of natural discharge was estimated in a very general way. The estimate of such saving might be increased if the subject were studied in detail.

In summary, all five points discussed above could have contributed to the discrepancy that resulted when the amount of groundwater depletion was estimated by two different methods. The magnitudes of the volumes of well withdrawals and dewatered rock, compared to the quantities involved in salvage and recharge from precipitation, suggest that the major discrepancies are due to insufficient information about water use, water levels, storage coefficients, and return flow via deep percolation.

CHEMICAL QUALITY OF THE WATER

The chemical quality of the groundwater in Box Butte County was a subject of only minor investigation for this report. Cady and Scherer (1946) and Durum (in Nace 1953) reported the results of chemical analyses of groundwater and briefly discussed the chemical quality of groundwater in the county. Cady and Scherer did not list the geological source of the water in their table of analyses (Cady and Scherer 1946, p. 82, table 11), but Durum did assign geological sources (Nace 1953, p. 12, table 2). Most of the analyses from their earlier reports plus later analyses of water from one observation well are presented in table 9. The analyses are grouped under the hydrologic units that are the probable sources of water. The geological sources of water in table 9 generally differ from those of Durum because information from test drilling suggested changes in the interpretation of the geology.

Water samples from municipal wells in Alliance and Hemingford have been collected and analyzed by the Nebraska State Department of Health (anonymous 1973). The College of Agriculture, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln, has analyzed samples from several wells.

The few samples collected and analyzed by different agencies are probably insufficient for drawing detailed conclusions about the chemical quality of groundwater in the county. The analyses

TABLE 9

Chemical Analyses and Related Physical Measurements of Water

[Results in milligrams per liter, except as indicated. See footnotes for explanation of numbers in parentheses.]

Well number, lake name, or lake location	Date of collection	Well depth (feet)	Temperature (°F)	pH	Specific conductance (micromhos at 25°C)	Silica (SiO2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO3)
NIOBRARA VALLEY ALLUVIUM												
28-52-9cb·······	10- 2-38	26	---	---	-----	--	----	52	9.8	26		-----
OGALLALA												
24-52-12aa·····	10- 3-38	45	---	---	-----	--	----	64	12	16		-----
25-47-17cc·····	8-26-47	170	53	8.4	419	61	----	34	16	28	9.0	10
25-48-36d······	10- 3-38	165	---	---	-----	--	----	107	32	152		0
OGALLALA AND UPPER HARRISON												
24-47-4ba······	8-26-27	200	52	8.5	615	63	0.10	23	22	77	9.0	12
OGALLALA, UPPER HARRISON, AND ARIKAREE												
25-47-32bb·····	8-26-47	280	52	8.4	1,030	58	0.50	41	23	156	7.0	10
25-47-4bb······	8-26-47	297	55	7.8	459	64	0.12	29	20	26	16	0
OGALLALA AND ARIKAREE												
24-48-6da1·····	4-18-47	200	52	7.7	535	--	0.09	74	13	22		0
24-48-6da2·····	7-14-47	200	55	8.1	539	36	----	41	12	46	15	0
25-48-36bc·····	4-15-47	307	53	8.2	550	42	----	60	16	24	20	0
RUNNINGWATER												
27-46-18ba·····	10- 3-38	72	---	---	-----	--	----	42	9	9.8		-----
28-47-14bc	10- 3-38	92	---	---	-----	--	----	53	10	21		-----
UPPER HARRISON												
27-47-17db·····	8-26-47	160	53	8.3	458	64	----	28	10	54	7	5
27-48-16aa	10- 2-38	168	---	---	-----	--	----	72	10	44		
UPPER HARRISON AND ARIKAREE												
25-47-5bb······	4-17-47	280	55	7.8	450	52	----	38	20	7.0	31	5
25-48-12cc·····	11-19-70	194	54	7.7	472	48	0.65	60	11	24	9	0
25-48-22cc·····	8-27-47	408	54	8.5	454	64	0.11	42	15	25	17	11
25-48-27db2····	4-17-47	236	54	7.7	490	42	----	58	16	5.0	20	0
26-49-6cc······	7-13-77	254	---	7.6	328	33	0.06	38	8	14	6.6	0
26-49-19aa·····	10- 3-38	250	---	---	-----	58	----	42	14	13	6.9	-----
26-49-18aa····· (Hemingford public supply well)	10- 2-38	300	---	---	-----	63	----	55	14	24	6.6	-----
ARIKAREE												
25-50-31ab·····	11-23-36	110	---	---	-----	--	----	55	11	18		-----
26-51-32bb·····	10- 3-38	108	---	---	-----	--	----	59	11	4.7		-----
26-52-10bc·····	10- 2-38	198	---	---	-----	--	----	44	11	8		-----
26-52-10bc·····	8-26-47	198	55	8.4	302	58	0.10	42	8.0	9.6	1.0	6
SURFACE WATER												
Bronco Lake····	4-19-47	---	---	8.9	3,200	--	0.02	27	61	691		149
Unnamed lake in eastern part of county········	10- 3-38	---	---	---	-----	--	----	--	----			1,692

(1) From U.S. Geological Survey Water-Supply Paper 969, table 11, p. 82.
(2) From U.S. Geological Survey Circular 166, table 2, p. 12.

TABLE 9 (continued)

Chemical Analyses and Related Physical Measurements of Water

[Results in milligrams per liter, except as indicated. See footnotes for explanation of numbers in parentheses.]

Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids (Residue at 180°C)	Hardness as $CaCO_3$		Percent sodium	Source of analysis	Remarks
							Total	Noncar-bonate			
NIOBRARA VALLEY ALLUVIUM											
239	15	3.5	1.8	7.5	----	293	170	--	--	(1)	
OGALLALA											
234	19	11	0.4	19	----	296	209	--	--	(1)	May include water from Snake Creek alluvium
179	43	6.0	0.8	1.9	0.36	303	151	0	27	(2)	
370	309	68	0	11	----	950	399	96	33	(1)	Labeled "Burlington Railroad"
OGALLALA AND UPPER HARRISON											
215	109	6.0	0.8	0.2	0.20	418	148	0	51	(2)	
OGALLALA, UPPER HARRISON, AND ARIKAREE											
274	230	41	0.8	1.3	0.26	702	197	0	62	(2)	Most of the water probably from Ogallala
204	45	5.0	0.3	6.7	0.14	314	155	0	24	(2)	Most of the water probably from Upper Harrison and Arikaree
OGALLALA AND ARIKAREE											
250	65	8.0	1.0	0.1	0.00	350	238	33	17	(2)	Most of water probably from Ogallala
248	53	7.0	1.1	0.4	0.09	337	152	0	37	(2)	Do.
254	62	9.8	0.8	6.0	0.09	374	216	8	18	(2)	Do.
RUNNINGWATER											
174	7.4	2.8	0	11	----	234	142	--	--	(1)	
216	26	4.2	0	11	----	290	174	--	--	(1)	
UPPER HARRISON											
138	91	6.0	2.0	7.8	0.11	347	111	0	49	(2)	
297	67	24	0	14	----	428	221	--	--	(1)	
UPPER HARRISON AND ARIKAREE											
226	26	4.5	0.4	6.0	0.08	299	177	0	7	(2)	
230	31	17	0.9	8.2	0.05	341	197	9	20	(3)	Observation well
196	44	8.0	1.1	8.1	0.00	320	166	0	22	(2)	
224	41	10	1.0	6.0	0.10	332	211	27	5	(2)	Most of water from Arikaree
180	13	2.0	1.3	3.2	0.04	208	130	0	18	(4)	Observation well
192	24	2.1	1.8	8.2	----	265	162	--	--	(1)	
246	37	3.4	0.4	9.6	----	338	195	--	--	(1)	
ARIKAREE											
186	25	18	0.7	20	----	304	183	--	--	(1)	
218	6.4	3.9	1.1	11	----	276	193	--	--	(1)	
178	8.6	6.8	0	10	----	243	155	--	--	(1)	
143	7.0	5.0	0.4	12	0.07	225	138	10	13	(2)	
SURFACE WATER											
1,040	483	144	5.5	0.2	0.70	2,080	318	0	83	(2)	
2,265	2,500	300	---	0	----	-----	12	--	--	(1)	

(3) From Water Resources Data for Nebraska, U.S. Geological Survey Annual Report.
(4) Unpublished data from Lincoln, Nebraska, office of U.S. Geological Survey.

do suggest that throughout most of the county the groundwater has a mineral concentration of less than 500 milligrams per liter. The water is generally a hard, silica-calcium-bicarbonate type and suitable for most irrigation, stock, domestic, industrial, and municipal purposes.

Analyses of samples from irrigation wells 24-47-4ba and 25-47-32bb (table 9), from municipal wells in Alliance (Nebraska State Department of Health 1973), and from irrigation wells immediately east of Alliance (personal communication 1977, Louis A. Daigger, agronomist, Panhandle Station, University of Nebraska-Lincoln) indicate that there is an area around Alliance in which the concentrations of sodium, sulfate, and total dissolved solids are significantly greater than in the rest of the county. Alliance is located in a region where much groundwater is discharged by evapotranspiration. A cone of depression has existed in the water table in the vicinity of Alliance for nearly 40 years. It is not known whether these two factors are part of the cause for the poorer quality of water. The poorer quality of water and a deepening cone of depression suggest, however, that the water quality in the Alliance area should be monitored.

Cady and Scherer (1946) reported the partial analysis of water from "a lake in the eastern part of the county" and Durum (in Nace 1953) reported an analysis of water from Bronco Lake. These analyses are included in table 9. These lakes, fed by groundwater seepage and surface runoff, are undrained. The analyses show that evaporation increases the salt content of the lakes.

Rainwater (*in* Bradley 1956, pp. 44-49) describes the chemical quality of lake water and groundwater in the closed-basin area of Sheridan County, an area adjoining eastern Box Butte County. Reports by Condra (1918) and Keech and Bentall (1971, pp. 15-16) also discuss the chemical quality of the lakes and lake hydrology in the area. Durum (*in* Nace 1953) presents a more thorough discussion of the chemical quality of groundwater in Box Butte County and its suitability for various uses. Engberg (1973) mentions the occurrence of selenium in groundwater in the county.

SUMMARY

Information gained from test drilling, electric logs of oil and gas tests, and drillers' logs of irrigation wells provide a basis for delineating the aquifers of Box Butte County and for defining a practical lower limit of potential aquifers capable of supplying water to large-yield irrigation, municipal, and industrial wells. Thirteen hydrologic units are herein defined and their water-bearing characteristics described. These units, from oldest to youngest, are: Niobrara, Pierre, Chadron, Orella, Whitney, Brown Siltstone, Arikaree, Upper Harrison, Runningwater, Box Butte, Sheep Creek, Ogallala, and Quaternary.

The hydrologic units in the county generally conform to geologically established members, formations, groups, or systems. The Niobrara and Pierre units are chalk and shale of Cretaceous age and are deeper than 900 feet (275 m). The Chadron unit, the oldest Tertiary unit in the county, unconformably overlies Cretaceous rocks and is composed of clay, silt, and some sand and gravel. The Chadron underlies the entire county at depths greater than 800 feet (244 m) and ranges in thickness from 100 feet (30.5 m) to 250 feet (76 m). The Orella unit overlies the Chadron throughout the county and is mostly clayey siltstone with local occurrences of thin beds of sandstone. The Orella ranges from 200 to 500 feet (61 to 152 m) in thickness and occurs at depths greater than 500 feet (152 m). Reddish brown, well-

sorted, clayey siltstone of the Whitney unit overlies the Orella throughout the county. The thickness of the Whitney ranges from 150 to 300 feet (45.5 to 91 m) and the depth to the top of the unit is from 200 to 600 feet (61 to 183 m). The Brown Siltstone unit overlies the Whitney except in an area around Snake Creek in the southwest part of the county. The Brown Siltstone is light brown, well-sorted, sandy siltstone with large amounts of volcanic glass shards. The unit, exposed in northwest Box Butte County, lies at a depth of 600 feet (183 m) in the southeast part. The maximum thickness of the unit is about 300 feet (91 m) and occurs in the northeast part of the county. The character of the Brown Siltstone is similar in many respects to the Whitney unit and appears to overlie it conformably, thus suggesting that the Brown Siltstone should be grouped with the Whitney and older Tertiary rocks in the area.

The Arikaree unit, mostly gray, very fine to fine-grained volcaniclastic sandstone that is locally silty to gravelly, occurs throughout all but extreme northern Box Butte County and unconformably overlies the Brown Siltstone or Whitney units. The Arikaree is exposed throughout much of the southwestern part of the county but the depth to the top of the unit increases to more than 400 feet (122 m) in places along the eastern border of the county. The maximum thickness is nearly 500 feet (152 m) in the southwestern part.

The Upper Harrison unit is mostly brown, well-sorted, sandy volcaniclastic siltstone that appears to overlie the Arikaree unit conformably. The Upper Harrison is exposed throughout much of west-central Box Butte County, but the depth to the top of this unit is nearly 250 feet (76 m) in at least one place on the eastern border. The maximum thickness of the unit is 200 feet (61 m). The Upper Harrison unit and fine-grained rocks of the Arikaree contain similar quantities of volcanic glass and probably were deposited by the wind. It is suggested the two units belong to the same major group of rocks.

Following deposition of the Upper Harrison unit, considerable erosion occurred in northern Box Butte County and a large, west-to-east valley system was cut into or through the Upper Harrison and Arikaree. Sediments of the Runningwater unit, ranging in grain size from clay to gravel, fill this valley system and reach a thickness of at least 225 feet (69 m).

A thin, distinctive, clayey silt unit, the Box Butte overlies the Runningwater and Upper Harrison units throughout much of the northern and east-central parts of the county. The Box Butte is at or near land surface throughout much of the county but dips eastward to depths of more than 200 feet (61 m) along the county line in the east-central part. The maximum thickness of the unit is slightly more than 40 feet (12.2 m).

Light gray, greenish gray, and brown siltstone, sandstone, and limestone of the Sheep Creek unit, generally less than 40 feet (12.2 m) thick, occur above the Box Butte in most of the northern and east-central parts of the county. Similar rock types occur in the southwestern corner.

The Ogallala unit occurs in south-central and southeastern Box Butte County. The grain size of the unit ranges from silt to gravel, with sand predominating. The sediments occupy ancient, west-to-east valley systems and reach thicknesses of 200 feet (61 m). Hydrologic units from the Runningwater through the Ogallala appear to have several common petrographic and depositional characteristics and thus may form a closely associated group of rocks. Small amounts of dune sand and loess of the Quaternary unit mantle the tablelands and benches, while small amounts of stream-deposited sediments (alluvium) are associated with the drainages of the county.

The Arikaree unit is considered to be the oldest hydrologic unit from which it is practical to develop large-yield wells, although the underlying Brown Siltstone unit is capable of supplying some water to wells. The Arikaree occurs throughout most of the county and is the major aquifer. The Ogallala unit is the next most important aquifer and occurs in the southern and southeastern parts of the county. Of secondary importance as an aquifer is the Runningwater unit in northern and northeastern Box Butte County. The Upper Harrison unit in the central and eastern parts of the county is capable of contributing water to wells but is, in itself, not an aquifer for large-yield wells.

Water-level measurements for 1938 and 1975 were used to map the water table and to show changes during the intervening period. In an area of about 8 square miles north of Alliance, the water level in wells lowered more than 35 feet (10.7 m) between 1938 and 1975.

The geologic data and the water-table maps were used to estimate the amount of recharge to the groundwater reservoir, the amount of groundwater discharged by evapotranspiration, and the amount of groundwater in storage. The amount of groundwater discharged by wells in 1975 was estimated on the basis of agricultural statistics and weather records.

An average of slightly less than 1,000,000 acre-feet (12.3 km^3) of precipitation falls on the county each year. Of this amount, approximately 130,000 acre-feet (1.60 x 10^8 m^3) recharges the groundwater reservoir. Underflow into the county is estimated to be 44,000 acre-feet (5.4 x 10^7 m^3) per year while underflow out of the county is about 21,000 acre-feet (2.60 x 10^7 m^3) per year. Groundwater discharged from the county by streams is small, probably between 1,000 and 2,000 acre-feet (1.23 x 10^6 m^3 to 2.47 x 10^8 m^3) per year. Evapotranspiration accounts for most of the groundwater discharged in Box Butte County. Under conditions similar to 1938, groundwater discharged by evapotranspiration would be approximately 155,000 acre-feet (1.91 x 10^8 m^3) per year. Because the lowering of water levels by pumping has intercepted some of this water, the amount of groundwater discharged in 1975 by evapotranspiration was less than that prior to large-scale irrigation. The number of irrigation wells registered in the county by the end of 1975 was 601. An estimated 60,000 acres (2.43 x 10^8 m^2) were irrigated with about 110,000 acre-feet (1.36 x 10^8 m^3) of water pumped from these wells. The number of irrigation wells virtually doubled from 1964 to 1975.

An estimated 32 million acre-feet (39.4 km^3) of groundwater is stored in the Arikaree and younger hydrologic units. Of this total amount, 23 million acre-feet (28.5 km^3) of water is stored in the Arikaree unit, 3.7 million acre-feet (4.59 km^3) in the Ogallala unit, and the remainder in other units. The decrease of groundwater in storage from 1938 to 1975 is estimated to be 700,000 to 1,000,000 acre-feet (0.87 to 1.24 km^3).

Despite what appears to be serious water-level declines in some areas of the county, there is no Box Butte area in which the groundwater supply is severely depleted. That is not to say there are no problems associated with the large-scale development of groundwater supplies or that all parts of the county are uniformly blessed with a bountiful water supply. The largest supplies are available along and north of Snake Creek in southwest Box Butte County and in the south-central and southeastern parts of the county.

It is estimated that the amount of groundwater in storage has decreased 2 to 3 percent since 1938 and perhaps one-half of this decrease has occurred since 1964. Though not uniform throughout the county, the decrease was concentrated in four areas: west-southwest of Hemingford, between Hemingford and Berea, 9 to 15 miles (14.5 to 24.1 km) north of Alliance and east of U.S. Highway 385, and immediately north of Alliance. Three of these areas lie outside the region of the most abundant groundwater supplies. The most serious water-level declines are at immediately north of Alliance in an area where the groundwater resource is large. This area has the highest concentration of irrigation wells and is also the oldest irrigated part of the county. Therefore, it is doubtful that future expansion of irrigation will be as great in this area as in other parts of the county. The large water supply, the degree of water-supply development, and decreased natural discharge (evapotranspiration) suggest that the past rate of water-level lowering might not continue into the future in the area immediately north of Alliance.

While the groundwater supply has not been severely depleted in any area, various shallow stock, domestic, and possibly some irrigation wells have had to be deepened because of lowered water levels. Many of the stock and domestic wells, especially the older ones, probably were drilled into only the upper part of the aquifers and a slight lowering of water levels was enough to cause problems. Some of the older, relatively shallow irrigation wells probably now have reduced yields or pump air because of the more serious water-level lowerings. Reduced yields and pumpage of air, however, does not always indicate a lowered water table. The same problem can also be caused by clogging of well screens with sand or chemical precipitates and inadequate well design and development.

The largest water supplies generally occur where much of the land is less suitable for irrigation because of soil type and terrain. There will be continued development of land suitable for irrigation provided economic and social conditions are favorable.

The most asked questions concerning water in Box Butte County is, "How long will the water supply last?" This report did not attempt to answer this question. It is, furthermore, an impossible one for a water-resources specialist to answer because economic considerations and social attitudes are as important in answering this question as is the water supply. The hydrologist can answer more restricted questions such as, "Assuming economic conditions are favorable, well installations increase at a given rate in the next 20 years, irrigation technology remains the same, and people continue to feel the use of groundwater for irrigation is valuable, what will the water-level lowerings be in the next 20 years?" Techniques are available for making reliable predictions in response to such questions. Information about water levels under these or other assumed conditions would show where deeper wells would be needed, where changes in groundwater storage would be most significant, where problems of decreased yields or increased pumping depth would likely occur, and what control procedures might be most effective. To make a reliable prediction about water levels under such assumed economic, social, and technical conditions would require the collection of additional hydrologic data in Box Butte County. The most important information needed is water-use data collected through selective metering of wells. Additional information on storage coefficients and transmissivities would be helpful in much of the county and necessary in parts of it. Acquiring this information would require further test drilling as well as laboratory and field tests of aquifer materials. More detailed work on the amount of groundwater discharged by evapotranspiration would be very helpful along with a more complete knowledge of the variations in precipitation throughout the county.

Perhaps the only reply that can therefore be made to the question, "How long will the water supply last?" is "Indefinitely."

Although utilization of groundwater will become more costly, the water supply throughout most of the county is sufficient for many decades to come if the economic situation justifies the cost of pumping the water. Economic and social limitations on the use of the groundwater reservoir in Box Butte County are probably more restrictive than any physical limitations, although all three limitations are interrelated. This is simply another way of saying that analysis of the assumptions made in the question of the previous paragraph are probably more critical to knowledge about the longevity of the water supply in the county than is an analysis of the water supply itself.

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Appendix A

LOGS OF TEST HOLES

The sample descriptions and identification of hydrologic units were based on both field and laboratory descriptions along with electric log characteristics. Colors were determined by comparing the wet sample with the Munsell soil color chart. The term lithic used in the sample descriptions refers to sand and gravel particles composed of sedimentary rocks, primarily siltstone and claystone.

Test hole 24N-48W-15ddd
(Field No. UNW 27-76)

Location: 48 ft. north and 57 ft. west of southeast corner of sec. 15, T. 24 N., R. 48 W
Ground altitude: 3,941 ft. (Alliance 7.5 minute-quadrangle)
Depth to water: 5.7 ft. (April 9, 1976)

	Depth, in feet From	To
Quaternary:		
No sample	0	3
Silt, very sandy, slightly clayey, brown; finer grained and olive below 10 ft	3	14
Ogallala:		
Sand, very fine to medium; gravelly from 14 to 20 ft.; some thin silt beds and root casts	14	60
Sand, very fine to coarse, in part some very coarse sand and some silt beds; a trace of fine gravel below 90 ft.	60	110
Silt, very sandy, olive gray; some sandstone beds	110	120
Sandstone, very fine to medium, olive; interbedded with silt	120	130
Arikaree:		
Marl, sandy, light gray; interbedded with sandstone	130	140
Sandstone, very fine to fine, brown; some marly zones, calcareous sandstone and limestone; dark grayish brown below 160 ft	140	300
Sand, very fine to medium, in part a trace of coarse sand.	300	320
Sand, gravelly, very fine sand to medium gravel	320	325
Sand, very fine to coarse, some very coarse	325	369
Brown Siltstone:		
Silt, sandy, clayey, light brownish gray, slightly calcareous; contains some calcareous nodules; light yellowish brown below 400 ft	369	440

Test hole 24N-48W-35ccc
(Field No. UNW 26-76)

Location: 31 ft. north and 12.5 ft. east of southwest corner of sec. 35, T. 24 N., R. 48 W.
Ground altitude: 3,967 ft. (Alliance 7.5-minute quadrangle)
Depth to water: unknown; test hole caved at 11.9 ft. (April 9, 1976)

	Depth, in feet From	To
Quaternary:		
No sample	0	5
Ogallala:		
Silt, slightly clayey, slightly sandy, moderately calcareous, pale olive	5	11
Sand, very fine to coarse, gravelly; gravel is mostly fine but some is medium to coarse	11	20
Sand, very fine to coarse; contains some fine to medium gravel	20	30
Sand, very fine to coarse, gravelly, mostly medium with some coarse gravel	30	40
Sand, very fine to very coarse, some fine gravel; some silt layers below 60 ft.	40	70
Sand, very fine to medium, some coarse; contains some silt layers	70	80
Silt, moderately clayey, greenish gray to pale yellow	80	90
Sandstone, very fine to fine, silty, dark greenish gray; contains some silt beds	90	104
Silt, very sandy, slightly clayey, light brownish gray	104	110
Sandstone, very fine to medium, very dark greenish gray to brown; very silty below 120 ft.	110	134
Sand, very fine to fine, slightly silty, pale olive	134	148
Silt, very sandy, moderately clayey, pale brown	148	176
Sand, very fine to fine, silty; sand is very fine to very coarse below 180 ft. and contains some fine gravel	176	237
Arikaree:		
Silt, very sandy, yellowish brown	237	240
Sand to sandstone, very fine to fine; contains some silty zones and hard calcareous concretions	240	308
Brown Siltstone:		
Silt, clayey, sandy, light brownish gray to pinkish gray; contains some calcareous zones	308	400

Test hole 24N-50W-14ccc
(Field No. UNW 1-75)

Location: 141 ft. north and 131.9 ft. east of southwest corner of sec. 14, T. 24 N., R. 50 W.
Ground altitude: 4,072 ft. (Hemingford 4 SE 7.5-minute quadrangle)
Depth to water: unknown; test hole caved at 19.5 ft. (October 16, 1975)

Test hole 24N-50W-14ccc - continued

	Depth, in feet From	To
Quaternary:		
Sand, very fine to medium, some coarse, moderately silty, some lithic material	0	8
Sandstone, very fine to medium, some coarse to very coarse, light gray	8	10
Sand, very fine to medium, very silty	10	15
Ogallala:		
Silt, very sandy, slightly clayey, pale olive; slightly calcareous	15	20
Sand, very fine to coarse; sand below 70 ft. very fine to medium, trace of coarse, trace of fine to medium gravel, few rootlets	20	80
Arikaree:		
Sandstone, very fine to fine, some medium silty, grayish brown, in part lime cemented; light gray below 106 ft...	80	108
Silt, slightly clayey, sandy, light gray, calcareous	108	110
Sandstone, very fine to fine with some medium, light brownish gray, some lime-cemented sandstone	110	117
Silt, slightly clayey, sandy, light brownish gray, calcareous	117	120
Sandstone, very fine to medium, some coarse light brownish gray, in part lime cemented; grayish brown from 130-230 ft., light brown below 230 ft; trace of gravel below 210 ft.	120	240
Brown Siltstone:		
Silt to siltstone, clayey, sandy, yellowish brown, in part calcareous	240	320
Sand, very fine to fine, some medium, very silty	320	330
Silt to siltstone, sandy, clayey, yellowish brown, slight to in part moderately calcareous	330	400

Test hole 24N-52W-13ccc
(Field No. UNW 18-76)

Location: 271 ft. north and 79 ft. east of southwest corner, sec. 13, T. 24 N., R. 52 W.
Ground altitude: 4,323 ft. (Kilpatrick Lake 15-minute quadrangle).
Depth to water: 102.3 ft. (March 30, 1976).

	Depth, in feet From	To
Quaternary:		
Silt, very sandy, slightly clayey, dark grayish brown	0	4
Silt, very sandy, slightly clayey, pale yellow	4	13
Sheep Creek:		
Sandstone, very fine to medium, very silty, pale olive; some rootlet casts; in part calcareous	13	30

Test hole 24N-52W-13ccc - continued

	Depth, in feet From	To
Arikaree:		
Sandstone, very fine to medium, grayish brown and olive gray; in part calcareous	30	54
Sandstone, very fine to fine, some medium; olive, some white and brown; in part calcareous	54	110
Sandstone, very fine to medium, dark grayish brown, some brown; in part calcareous	110	180
Silt, very sandy, slightly clayey, brown; in part very calcareous; some calcareous nodules	180	240
Brown Siltstone:		
Silt, clayey, sandy, yellowish brown; in part calcareous	240	300

Test hole 25N-48W-24aaa
(Field No. UNW 28-76)

Location: 43 ft. south and 107 ft. west of northeast corner, sec. 24, T. 25 N., R. 48 W.
Ground altitude: 3,943 ft. (Berea Creek East 7.5-minute quadrangle).
Depth to water: 57.2 ft. (March 21, 1976).

	Depth, in feet From	To
Quaternary:		
Silt, very sandy, very dark grayish brown	0	4
Ogallala:		
Sand to sandstone, very fine to medium, in part very fine to fine, light gray, brownish gray and brown; in part calcareous and silty	4	60
Silt, very sandy, slightly clayey, pale olive to light gray; sand layers from 68 to 70 ft.; some gravel grains below 74 ft	60	75
Clay, sandy, some gravel grains, pale yellow	75	80
Sand, very fine to medium, some gravel grains; no medium sand below 100 ft	80	101
Silt, very sandy, greenish gray	101	106
Gravel, sandy; very fine sand to coarse gravel	106	110
Sand, gravelly; very fine sand to medium gravel, some coarse gravel, in part silty; slightly finer, much lithic material below 120 ft	110	137
Upper Harrison:		
Silt, very sandy, yellowish brown to brown; in part calcareous, some calcareous nodules	137	160
Arikaree:		
Sandstone, very fine to fine, some medium sand and lithic gravel, brownish gray to brown; some calcareous sandstone	160	290
Silt, very sandy, gray to olive gray, some grayish brown; some sandstone beds	290	310

Test hole 25N-48W-24aaa - continued

	Depth, in feet From	To
Sand, gravelly; very fine sand to fine gravel, some medium to coarse gravel; much lithic material...........	310	320
Sand, very fine to medium, very silty; some lithic gravel.	320	337
Sand, very fine to coarse, much lithic material...........	337	350
Sand, gravelly; very fine sand to fine gravel, some coarse to very coarse gravel; much lithic material.............	350	370
Sand, very fine to coarse, some marly zones; less coarse sand below 380 ft....................................	370	390
No sample..	390	400
Sand, very fine to coarse, some coarse to very coarse, trace of gravel; much lithic material; very fine to very coarse in calcareous zone below 410 ft.............	400	420
Sand, gravelly; very fine sand to medium gravel with some coarse gravel; much lithic material; very fine sand to fine gravel below 430 ft..............................	420	448
Brown Siltstone:		
Silt, sandy, clayey, light yellowish brown; coarse silt to very fine sand; some calcareous zones, some calcareous nodules..	448	500

Test hole 25N-49W-31bcc
(Field No. UNW 19-76)

Location: about 2,552 ft. south and 65 ft. east of northwest corner, sec. 31, T. 25 N., R. 49 W.
Ground altitude: 4,065 ft. (Hemingford 4 SE 7.5-minute quadrangle)
Depth to water: 32 ft. (electric log) (March 30, 1976)

	Depth, in feet From	To
Quaternary:		
No sample..	0	3
Sand, gravelly; very fine sand to coarse gravel...........	3	15
Ogallala:		
Silt to siltstone, clayey, sandy, light gray..............	15	24
Sand, gravelly; very fine sand to medium gravel; some silt below 30 ft..	24	40
Sand, very fine to medium, some coarse; some gravel grains, sandstone and siltstone fragments..............	40	100
Sand, very fine to medium, some coarse to very coarse, trace of sandstone....................................	100	110
Sand, very fine to coarse, some very coarse sand to fine gravel; trace of calcareous nodules; sand is very fine to very coarse in center of fine gravel below 120 ft.; slightly finer texture below 190 ft; some sandstone and siltstone material below 190 ft....................	110	206

Test hole 25N-49W-31bcc - continued

	Depth, in feet From	To
Arikaree:		
Limestone, sandy, brown and gray; sand is very fine to fine; some marly zones	206	280
Silt, very sandy, brownish gray, some grayish brown; slight to very calcareous	280	310
Sandstone, very fine to fine, slightly silty, grayish brown, very calcareous	310	340
Silt, very sandy, slightly clayey, grayish brown, very calcareous	340	350
Sandstone, very fine to medium, silty, grayish brown, very calcareous to in part very calcareous, few lithic gravels	350	372
Brown Siltstone:		
Clay, silty, brown, very calcareous	372	380
Silt, very sandy, grayish brown	380	410
Whitney:		
Silt, very sandy, slightly clayey, brown	410	440

Test hole 25N-50W-24aaa
(Field No. UNW 20-76)

Location: 137 ft. south and 69 ft. west of northeast corner, sec. 24, T. 25 N., R. 50 W.
Ground altitude: 4,149 ft. (Hemingford 4 NE 7.5-minute quadrangle)
Depth to water: 93.5 ft. (March 30, 1976)

	Depth, in feet From	To
Quaternary:		
No sample	0	3
Upper Harrison:		
Limestone, sandy, white, some brown; sand is very fine; some marly zones	3	43
Silt to siltstone, very sandy, slightly clayey, grayish brown, in part light brown; some marly zones	43	52
Siltstone, very sandy, slightly clayey, olive; some limy ledges, marl zones and calcareous nodules	52	70
Arikaree:		
Siltstone, very sandy, slightly clayey, olive brown; some marl zones, calcareous ledges, and calcareous nodules	70	80
Sandstone, very fine, in part fine, slightly silty, brownish gray, some grayish brown; in part calcareous, with ledges	80	100
Sandstone, very fine to fine, light brown; in part calcareous, in part calcareous with ledges	100	120

Test hole 25N-50W-24aaa - continued

	Depth, in feet From	To
Sandstone, very fine to fine, grayish brown to brownish gray; some marl zones, some limestone lenses; trace of coarse to very coarse sand below 330 ft.	120	340
Sandstone, very fine to medium, some coarse to very coarse, rare gravel, grayish brown; sand is very fine to medium from 360-370 ft.; sand is very fine to coarse below 380 ft.	340	390
Sand, gravelly; very fine sand to fine gravel, trace of medium gravel; sand is very fine to coarse, with a trace of fine gravel below 400 ft.	390	420
Sand, gravelly; very fine sand to fine gravel; some lithic material	420	454
Brown Siltstone:		
Silt, sandy, slightly clayey, brown, some grayish brown, moderately calcareous	454	500

Test hole 25N-51W-17ddd
(Field No. UNW 16-75)

Location: 41 ft. north and 260 ft. west of southeast corner, sec. 17, T. 25 N., R. 51 W.
Ground altitude: 4,230 ft. (Kilpatrick Lake 15-minute quadrangle)
Depth to water: unknown, estimated 30 ft. (November 12, 1975)

	Depth, in feet From	To
Arikaree:		
Sandstone, very fine to fine, in part some medium, grayish brown; some calcareous ledges and calcareous sandstone.	0	198
Sand, very fine to fine, very silty, some calcareous sandstone	198	200
Silt, moderately sandy, slightly clayey, light gray, calcareous	200	203
Sandstone, very fine to fine, light gray to pale olive, moderately calcareous; some calcareous grains; some medium sand below 210 ft.	203	217
Clay, silty, pale yellow	217	220
Sandstone, very fine to fine, some medium with a little coarse to very coarse, pale olive; in part iron-cemented; sand is very fine to medium, little coarse below 230 ft.	220	260
Sand, very fine to medium, little coarse, rare fine gravel; sand is very fine to coarse, little very coarse sand to fine gravel, trace of lithic material below 280 ft.	260	290

Test hole 25N-51W-17ddd - continued [d]

	Depth, in feet From	To
Sand, gravelly; very fine sand to fine gravel; trace of medium gravel, some lithic material; trace of coarse gravel below 310 ft.	290	330
Silt to siltstone, sandy, clayey, pink to light brown, slightly calcareous, in part moderate to very calcareous; trace of coarse to very coarse sand below 343 ft.	330	360
Sand, very fine to very coarse, rare fine gravel, some lithic material	360	370
Sand, gravelly; very fine sand to fine gravel, much lithic material	370	377
Silt to siltstone, clayey, sandy, brown, some pink and yellowish gray, moderately calcareous; in part very to slightly calcareous	377	410
Sand, very fine to medium, some coarse, trace of very coarse	410	414
Silt to siltstone, clayey, sandy, brown, slightly calcareous; in part moderately calcareous	414	440
Sand, gravelly; very fine sand to fine gravel, little medium gravel; principally lithic gravel with some granitic gravel	440	450
Whitney:		
Silt to siltstone, clayey, sandy, pink and yellowish brown, very calcareous, in part moderately calcareous	450	500

Test hole 25N-51W-33cdd
(Field No. UNW 17-76)

Location: about 2,150 ft. east and 108 ft. west of southwest corner, sec. 33, T. 35 N., R. 51 W.
Ground altitude: 4,215 ft. (Kilpatrick Lake 15-minute quadrangle)
Depth to water: 57.4 ft. (March 30, 1976)

	Depth, in feet From	To
Quaternary:		
No sample	0	3
Sandstone, very fine to fine, some medium, grayish brown, some gray; in part calcareous	3	128
Silt, very sandy, slightly clayey, brown, very calcareous, in part moderately calcareous, some sandstone	128	140
Sand, very fine to fine, some medium, silty; some sandstone	140	170
Sandstone, very fine to medium, some coarse, in part silty and calcareous, grayish brown	170	196
Silt, very sandy, slightly clayey, yellowish brown, moderately calcareous; some silty sandstone fragments	196	244

Test hole 25N-51W-33cdd - continued

	Depth, in feet From	To
Whitney:		
Silt to siltstone, clayey, sandy, light brown, some yellowish brown, in part slight to very calcareous.......	244	320

Test hole 25N-52W-7bbc
(Field No. UNW 35-76)

Location: 954 ft. south and 138 ft. east of northwest corner of sec. 7, T. 25 N., R. 52 W.
Ground altitude: 4,365 ft. (Kilpatrick Lake 15-minute quadrangle)
Depth to water: 35.3 ft. (May 5, 1976)

	Depth, in feet From	To
Quaternary:		
No sample..	0	2
Sand, very fine to fine, some medium.....................	2	10
Arikaree:		
Sandstone, very fine to fine, some medium, moderately silty, brown; in part calcareous cemented..............	10	70
Limestone, sandy, grayish brown; interbedded with sandstone..	70	80
Sandstone, very fine to fine, in part some medium, dark brown, some calcareous zones..........................	80	110
Sandstone, very fine to medium, some coarse, brown; some lithic material......................................	110	140
Sand, very fine to medium, some coarse to very coarse, sand and fine gravel; some lithic material.............	140	153.5
Sand, slightly gravelly, very fine sand to fine gravel, some lithic material; some medium gravel below 180 ft...	153.5	200
Sandstone, very fine to fine, in part very silty, some lithic material, brown................................	200	230
Sand, gravelly, very fine sand to fine gravelly; much lithic material..	230	250
Silt to siltstone, clayey, brown; interbedded with some sandstone..	250	258
Sand, very fine to coarse................................	258	260
Silt, moderately sandy, slightly clayey, some lithic material, dark gray to yellowish brown, contains some sandstone beds and calcareous zones................	260	288
Whitney:		
Silt to siltstone, sandy, clayey, light brown............	288	340

Test hole 26N-47W-18cdc
(Field No. UNW 33-76)

Location: 1,358 ft. east and 73 ft. north of southwest corner of sec. 18, T. 26 N., R. 47 W.
Ground altitude: 3,981 ft. (Berea Creek East 15 minute-quadrangle).
Depth to water: 52.2 ft. (May 5, 1976).

	Depth, in feet	
	From	To
Quaternary:		
Silt, moderately clayey, moderately sandy, dark gray......	0	4
Silt, moderately sandy, slightly clayey, moderately calcareous, brownish gray..............................	4	9
Sheep Creek:		
Sandstone, gravelly, very fine sand to fine gravel, some medium gravel..	9	10
Sandstone, very fine to fine, very silty, pale yellow; silt layers from 12 to 14 ft.; calcareous below 25 ft...	10	26
Silt to siltstone, sandy, clayey, some calcareous zones, pale brown...	26	42
Box Butte:		
Clay, silty, moderately sandy, some calcareous zones, pale yellow..	42	46
Upper Harrison:		
Limestone, white...	46	50
Sandstone, very fine to fine, moderately silty, brownish yellow to brown, silt layer from 54 to 57 ft...........	50	60
Silt to siltstone, very sandy, yellowish brown with some brown; in part contains calcareous nodules and zones....	60	237
Arikaree:		
Silt, very sandy, slightly clayey, light gray; in part contains some sandstone beds and calcareous zones.......	237	270
Sandstone, very fine, gray; in part calcareous............	270	275
Silt, very sandy, light gray; contains many hard calcareous zones......................................	275	290
Sandstone, very fine, light gray; some hard calcareous zones..	290	308
Silt, very sandy, light gray; some sandstone layers.......	308	315
Sand, very fine to fine, very silty; silt, very sandy from 335 to 340 ft..................................	315	385
Brown Siltstone:		
Silt to siltstone, clayey, yellowish brown; in part contains calcareous nodules............................	385	420

Test hole 26N-47W-24aaa
(Field No. UNW 30-76)

Location: 54 ft. south and 58 ft. east of northeast corner of sec. 24, T. 26 N., R. 47 W.
Ground altitude: 3,922 ft. (Antioch 15-minute quadrangle)
Depth to water: 38.9 ft. (April 23, 1976)

	Depth, in feet	
	From	To
Quaternary:		
Silt, very sandy, slightly clayey, dark grayish brown.....	0	4
Ogallala:		
Volcanic ash, light gray..................................	4	5
Sand to sandstone, very fine to fine, some medium, yellowish brown to brown; some root casts..............	5	25
Sand, very fine to medium, trace of coarse, very silty....	25	40
Silt, very sandy, slightly clayey, light gray............	40	43
Sand, very fine to medium; some silty zones and root casts; some coarse sand below 140 ft..................	43	178
Sheep Creek:		
Silt, very sandy, slightly clayey, pale yellow to pale olive; some calcareous zones..........................	178	210
Box Butte:		
Clay, silty, light brown to yellowish brown; some calcareous nodules.....................................	210	248
Upper Harrison:		
Silt, very sandy, moderately to very calcareous, pale olive to brown; some interbedded sandstone.............	248	294
Silt, sandy, brownish yellow and brown; in part some calcareous nodules and zones..........................	294	420
Arikaree:		
Sand, very fine to fine, very silty, pale brown; some calcareous zones.......................................	420	430
Silt, very sandy, calcareous, white......................	430	440
Sandstone, very fine to fine, much lithic material, pale brown; some hard calcareous zones.....................	440	457
Silt, very sandy, pale brown; moderately sandy from 457 to 462 ft.; some calcareous zones.....................	457	490
Brown Siltstone:		
Silt, sandy, clayey, yellowish brown; some calcareous zones and nodules......................................	490	520

Test hole 26N-47W-31ccc
(Field No. UNW 29-76)

Location: 58 ft. north and 62 ft. east of southwest corner of sec. 31, T. 26 N., R. 47 W.
Ground altitude: 3,933 ft. (Berea Creek East 7.5-minute quadrangle)
Depth to water: 91.8 ft. (April 21, 1976)

Test hole 26N-47W-31ccc - continued

	Depth, in feet From	To
Quaternary:		
Silt, moderately sandy, slightly clayey, dark grayish brown, pale brown below 2 ft...........................	0	5
Gravel, coarse sand to coarse gravel, most of the gravel clasts are composed of limestone........................	5	11
Ogallala:		
Sandstone, very fine to medium, some coarse; very calcareous, light gray.................................	11	21
Sheep Creek:		
Silt, very clayey, sandy, pale yellow, white and yellowish brown, some sandstone beds and calcareous zones.....	21	42
Sandstone, very fine to fine, some medium, light gray; some marly layers....................................	42	48
Silt, very sandy, slightly clayey, light gray to brown.....	48	62
Upper Harrison:		
Silt, very sandy, slightly clayey, pale brown; in part some calcareous nodules and zones.......................	62	70
Silt, very sandy, slightly clayey; pinkish gray to brown..	70	100
Silt to siltstone, sandy, clayey, brown to yellowish brown; in part some silty sandstone and calcareous zones and nodules..	100	216
Arikaree:		
Silt, moderately sandy, calcareous, pale brown with some yellowish brown.................................	216	220
Sand to sandstone, very fine to fine, light gray to grayish brown; in part some hard calcareous sandstone...	220	320
Silt, very sandy, very calcareous, light gray.............	320	357
Sand, very fine to fine, some medium, very silty; silt layer from 367 to 370 ft...............................	357	376
Sand, very fine to medium, some coarse, very silty; sand, very fine to coarse with a trace of very coarse below 380 ft.; some calcareous zones.........................	376	390
Sand, gravelly, very fine to very coarse sand, some fine gravel and a trace of medium gravel, moderately silty...	390	408
Brown Siltstone:		
Silt, very sandy, brown to yellowish brown; some calcareous zones...	408	480

Test hole 26N-48W-1aaa
(Field No. UNW 25-76)

Location: 130 ft. south and 232 ft. west of northeast corner of sec. 1, T. 26 N., R. 48 W.
Ground altitude: 4,026 ft. (Box Butte 7.5-minute quadrangle)
Depth to water: 43.3 ft. (perched water level) (April 9, 1976)

Test hole 26N-48W-1aaa - continued

	Depth, in feet From	To
No sample	0	3
Sheep Creek:		
Silt, very sandy, pale brown to brownish gray	3	12
Sandstone, very fine to medium, moderately silty, pale olive; some calcareous zones	12	18
Silt, very sandy, moderately clayey, pale yellow; some sandstone layers; calcareous below 30 ft	18	35
Sandstone, very fine to fine, pale brown; some calcareous zones	35	48
Silt, sandy, calcareous, white, some pinkish gray; some limestone beds	48	56
Box Butte:		
Clay, silty, slightly sandy, pale yellow, some pinkish gray	56	68
Upper Harrison:		
Silt, sandy, calcareous, white	68	72
Sandstone, very fine to fine, silty, white; some calcareous zones	72	78
Silt to siltstone, clayey, sandy, moderately calcareous, pale brown; some silty sandstone beds	78	100
Silt to siltstone; clayey, sandy, light yellowish brown; some calcareous nodules and zones	100	257
Arikaree:		
Silt, very sandy, very calcareous, light gray with some yellowish brown; some silty sandstone beds	257	300
Silt, very sandy, moderately to very calcareous, pale yellow to light gray	300	310
Sand, very fine to medium; some calcareous zones	310	320
Silt, very sandy, calcareous, light gray to pale brown	320	350
Brown Siltstone:		
Silt, slightly clayey, slightly sandy, yellowish brown; some calcareous zones	350	400

Test hole 26N-49W-6bbc
(Field No. UNW 4-75)

Location: 1,233 ft. south and 71 ft. east of northwest corner of sec. 6, T. 26 N., R. 49 W.
Ground altitude: 4,281 ft. (Hemingford 7.5-minute quadrangle)
Depth to water: 162.9 ft.

	Depth, in feet From	To
Quaternary:		
Silt, very sandy, some claystone fragments, very dark gray.	0	4

Test hole 26N-49W-6bbc - continued

	Depth, in feet From	To
Sheep Creek:		
Sandstone, very fine to fine, calcareous, pale brown......	4	7
Box Butte:		
Clay, silty, slightly sandy, pale yellow..................	7	17
Upper Harrison:		
Sandstone, very fine to medium, some coarse, slightly to very silty, pale brown; some hard calcareous sandstone..	17	40
Siltstone, very sandy, light yellowish brown.............	40	54
Sandstone, very fine to fine, very silty, yellowish brown; moderately calcareous below 60 ft................	54	70
Siltstone, very sandy, yellowish brown; some calcareous material...	70	90
Sandstone, very fine to fine, very silty, yellowish brown; moderately calcareous, light gray to pale brown below 110 ft., some hard calcareous sandstone................	90	137
Silt to siltstone, very sandy, slightly clayey, slightly calcareous, light yellowish brown; some calcareous zones..	137	210
Arikaree:		
Sandstone, very fine to fine, light gray with some grayish brown, some calcareous zones; very calcareous below 313 ft...	210	320
Silt, slightly clayey, slightly sandy, slightly calcareous, light yellowish brown, light gray and some brownish gray....................................	320	435
Silt, very sandy, very calcareous to moderately calcareous, light gray to grayish brown...	435	482
Brown Siltstone:		
Silt to siltstone, moderately sandy, slightly clayey, very to moderately calcareous, yellowish brown..........	482	500

Test hole 26N-49W-19bbb
(Field No. UNW 3-75)

Location: 81 ft. south and 75 ft. east of northwest corner of sec. 19, T. 26 N., R. 49 W.
Ground altitude: 4,226 ft. (Hemingford 4 NE 7.5-minute quadrangle)
Depth to water: 125.4 ft. (November 7, 1975)

	Depth, in feet From	To
No sample...	0	4

Test hole 26N-49W-19bbb - continued

	Depth, in feet From	To
Upper Harrison:		
Limestone, sandy, white	4	9
Sandstone, very fine to fine, some medium, dark yellowish brown to pale brown and white; some calcareous sandstone	9	30
Silt to siltstone, moderately sandy, slightly clayey, light yellowish brown	30	36
Silt, very sandy, slightly clayey with some sand, very silty; pale brown	36	71
Silt to siltstone; very sandy, slightly clayey with some sand, very silty; pale brown; some hard calcareous sandstone	71	93
Sandstone, very fine to fine, calcareous; light gray	93	130
Silt, very sandy, to sand, very silty, slightly calcareous, yellowish brown; some calcareous sandstone; pale brown below 170 ft	130	183
Arikaree:		
Silt, very sandy, slightly clayey, very calcareous, light gray; some calcareous sandstone	183	194
Sandstone, very fine to fine, in part some medium, very silty, in part moderately to very calcareous, light gray with some yellowish brown and grayish brown; some marl	194	378
Sand, very fine to medium	378	380
Sandstone, very fine to fine, silty, slightly clayey, light brownish gray	380	384
Silt to siltstone, clayey, in part sandy, very calcareous, light gray	384	390
Sandstone, very fine to medium, some coarse to very coarse, a trace of fine gravel, very silty, very calcareous, light brownish gray	390	406
Sand, slightly gravelly, very fine sand to fine gravel, slightly silty, some lithic material	406	410
Sand, very fine to medium, some coarse to very coarse, a trace of fine gravel composed of lithic clasts	410	420
Sandstone, very fine to fine, very silty, very calcareous, a trace of lithic material, light gray	420	432
Brown Siltstone:		
Silt to siltstone, very to moderately sandy, slightly clayey, very to moderately calcareous, brown; in part calcareous; volcanic ash from 492 to 510 ft	432	520

Test hole 26N-49W-24aba
(Field No. UNW 34-76)

Location: 1,580 ft. west and 383 ft. south of northeast corner of sec. 24, T. 26 N., R. 49 W.
Ground altitude: 4,143 ft. (Berea Creek West 7.5-minute quadrangle)
Depth to water: 113.6 ft. (May 5, 1976)

	Depth, in feet From	To
No sample	0	3
Sheep Creek:		
Silt, very clayey, very sandy, very calcareous, light gray; pale yellow below 15 ft	3	17
Sandstone, very fine to medium, light gray to yellowish brown; some hard calcareous zones	17	27
Limestone, sandy, pinkish gray to light gray	27	33
Box Butte:		
Clay, silty, pinkish gray with some light gray	33	40
Upper Harrison:		
Silt, very clayey, light gray, some calcareous zones	40	46
Sandstone, very fine to medium, yellowish brown; some calcareous zones	46	68
Silt to siltstone, clayey, sandy, yellowish brown with some light gray; in part some calcareous zones	68	240
Arikaree:		
Silt, very sandy, light gray; some sandstone beds and calcareous zones	240	250
Sandstone, very fine to fine, moderately silty, brown; in part calcareous	250	260
Silt, very sandy, slightly clayey, light gray; in part calcareous	260	270
Sandstone, very fine to fine, very calcareous, grayish brown	270	280
Silt, very sandy, in part moderately clayey, grayish brown with some gray; some hard calcareous zones; some silty sand below 310 ft	280	410
Brown Siltstone:		
Silt, moderately clayey, moderately sandy, pinkish gray to yellowish brown; some calcareous zones	410	440

Test hole 26N-49W-31ccd
(Field No. UNW 2-75)

Location: 79 ft. north and 719 ft. east of southwest corner of sec. 31, T. 26 N., R. 49 W.
Ground altitude: 4,170 ft. (Hemingford 4 NE 7.5-minute quadrangle)
Depth to water: 77.4 ft. (October 16, 1975)

Test hole 26N-49W-31ccd - continued

	Depth, in feet From	To
No sample	0	3
Upper Harrison:		
Sandstone, very fine to fine, some medium, moderately calcareous, light gray; in part some coarse sand with a trace of very coarse; non-calcareous and light gray from 3 to 5 ft	3	28
Limestone, sandy, white	28	30
Silt, slightly clayey, slightly sandy, very calcareous, pale brown, some calcareous sandstone	30	33
Sandstone, very fine to fine, silty, very calcareous, light yellowish brown and light gray	33	100
Silt, very sandy, calcareous, light gray	100	110
Sandstone, very fine to fine, calcareous, light gray	110	130
Arikaree:		
Sandstone, very fine to fine, in part some medium to coarse, in part silty, grayish brown to light gray; much calcareous sandstone	130	340
Sand, very fine to very coarse, rare fine gravel, rare lithic material; sand is very fine to coarse with some very coarse below 360 ft	340	367
Sand, gravelly, very fine sand to fine gravel, some medium gravel, gravel primarily composed of lithic material	367	380
Sand, very fine to coarse, some very coarse sand to fine gravel, gravel primarily composed of lithic material; the sand is slightly finer grained below 390 ft	380	423
Brown Siltstone:		
Silt to siltstone, moderately sandy, slightly clayey, mostly very calcareous, pale brown; in part non-calcareous; volcanic ash from 460 to 473 ft	423	480

Test hole 26N-50W-17ccc
(Field No. UNW 37-76)

Location: 503 ft. east and 60 ft. north of southwest corner of sec. 17, T. 26 N., R. 50 W.
Ground altitude: 4,292 ft. (Hemingford 4 NW 7.5-minute quadrangle)
Depth to water: 122.9 ft. (May 5, 1979)

	Depth, in feet From	To
Quaternary:		
Silt, very sandy, slightly clayey, dark grayish brown	0	3

Test hole 26N-50W-17ccc - continued

	Depth, in feet From	To
Sheep Creek:		
Silt, very sandy, slightly clayey, light gray	3	8
Box Butte:		
Clay, silty, light gray to pinkish gray with some olive; some calcareous nodules	8	22
Upper Harrison:		
Limestone, sandy, white	22	30
Silt, very sandy, slightly clayey, brown; some calcareous zones	30	40
Silt, very sandy, brown and pinkish white, some calcareous zones and nodules	40	63
Silt to siltstone, very sandy, brown; some calcareous zones	63	80
Sand, very silty, brown, some calcareous zones	80	90
Silt, very sandy, slightly clayey, brownish gray to yellowish brown; some calcareous zones	90	120
Sandstone, very fine to fine, dark yellowish brown; some calcareous zones	120	135
Arikaree:		
Sandstone, very fine to fine, dark brown; grayish brown from 150 to 200 ft., some calcareous zones and concretions	135	300
Sand, very fine to fine, slightly silty, calcareous zones	300	338
Silt, calcareous; light gray; some sand beds	338	350
Sand, very fine to fine, interbedded with silt layers, very sandy; some lithic material; some calcareous zones	350	384
Sand, very fine to medium, slightly silty, some coarse to very coarse sand below 390 ft., in part some calcareous silt layers and some lithic material	384	420
Sand very fine to coarse, slightly silty; many calcareous zones below 430 ft	420	440
Silt, very sandy, brownish gray to light gray	440	454
Sand, gravelly, very fine sand to fine gravel, moderately silty; some calcareous zones below 457 ft	454	467
Brown Siltstone:		
Silt, clayey, sandy, brownish yellow to brown; a trace of calcareous material	467	485

Test hole 26N-51W-19aaa
(Field No. UNW 14-75)

Location: 137 ft. south and 60 ft. west of northeast corner of sec. 19, T. 26 N., R. 51 W.
Ground altitude: 4,360 ft. (Kilpatrick Lake 15-minute quadrangle)
Depth to water: 79.9 ft. (December 4, 1975)

	Depth, in feet	
	From	To
Quaternary:		
No sample	0	2
Sand, very fine to fine, some medium	2	15
Gravel, sandy, coarse sand to coarse gravel, gravel composed principally of lithic material	15	20
Arikaree:		
Sandstone, very fine to fine, trace of medium to coarse, slightly silty, grayish brown; in part some hard calcareous sandstone; some very coarse sand to fine gravel composed of lithic material below 125 ft	20	160
Sandstone, very fine to fine, some medium grained, grayish brown; some lithic material; some medium to very coarse sand below 240 ft	160	270
Sand, gravelly, very fine sand to fine gravel; some lithic material and root casts	270	310
Sand, very fine to very coarse, trace of fine gravel; sand is slightly finer grained below 320 ft; much lithic material	310	330
Sand, slightly gravelly, very fine sand to fine gravel, much lithic material	330	340
Sand, very fine to fine, very silty	340	360
Sand, very fine to very coarse, some fine gravel, much lithic material	360	370
Sand, gravelly, very fine sand to coarse gravel, much lithic material	370	400
Whitney (?):		
Silt to siltstone, sandy, clayey, very calcareous, pale brown and light yellowish brown	400	420

Test hole 26N-51W-31dda
(Field No. UNW 15-75)

Location: Approximately 900 ft. north and 80 ft. west of southeast corner of sec. 31, T. 26 N., R. 51 W.
Ground altitude: 4,320 ft. (Kilpatrick Lake 15-minute quadrangle)
Depth to water: 66.7 ft. (December 4, 1975)

Test hole 26N-51W-31dda - continued

	Depth, in feet From	To
Quaternary:		
No sample	0	2
Sand, very fine to fine, some medium	2	15
Gravel, sandy, coarse sand to coarse gravel, gravel made up principally of lithic clasts	15	20
Arikaree:		
Sandstone, very fine to fine, trace of medium to coarse, slightly silty, grayish brown; in part some hard calcareous sandstone; some very coarse sand to fine gravel below 125 ft., mostly composed of lithic clasts	20	160
Sandstone, very fine to fine, some medium, grayish brown, in part some lithic material; some medium to coarse sand below 240 ft	160	270
Sand, gravelly, very fine sand to fine gravel, some lithic material and root casts	270	310
Sand, very fine to very coarse, trace of fine gravel; sand is finer grained below 320 ft.; abundant lithic material	310	330
Sand, slightly gravelly, very fine sand to fine gravel, much lithic material	330	340
Sand, very fine to fine, silty	340	360
Sand, very fine to very coarse, some fine gravel, much lithic material	360	370
Sand, gravelly, very fine sand to coarse gravel, much lithic material	370	400
Brown Siltstone:		
Silt to siltstone, sandy, clayey, very calcareous, pale brown and light yellowish brown	400	420

Test hole 26N-52W-18ccc
(Field No. UNW 36-76)

Location: 156 ft. west and 12 ft. east of southwest corner of sec. 18, T. 26 N., R. 52 W.
Ground altitude: 4,510 ft. (Kilpatrick Lake 15-minute quadrangle)
Depth to water: 130.2 ft. (May 5, 1976)

	Depth, in feet From	To
Quaternary:		
Silt, very sandy, slightly clayey, dark grayish brown	0	3
Arikaree:		
Limestone, sandy, light gray	3	16

Test hole 26N-52W-18ccc - continued

	Depth, in feet From	To
Sand, very fine to fine, slightly silty; some sandstone and limestone layers and calcareous nodules............	16	60
Sandstone, very fine to fine, slightly silty, grayish brown; some hard calcareous layers and nodules; fewer hard calcareous layers below 130 ft....................	60	305
Silt, very sandy, some lithic material, light gray........	305	310
Sand, very fine to fine, some medium, some lithic material, grayish brown, some calcareous zones..................	310	330
Sand, very fine to medium, trace of coarse to very coarse, slightly silty, some lithic material; some calcareous zones below 370 ft..................................	330	385
Sand, very fine to coarse, with some fine gravel, some lithic material...	385	390
Sand, slightly gravelly, very fine sand to fine gravel, with some medium gravel, in part silty, some lithic material...	390	400
Brown Siltstone (?):		
Silt to siltstone, clayey, moderately sandy, brownish gray; some calcareous zones............................	400	430

Test hole 27N-46W-18bbb
(Field No. UNW 32-76)

Location: 28 ft. south and 7 ft. east of northwest corner of sec. 18, T. 27 N., R. 46 W.
Ground altitude: 3,867 ft. (Skunk Lake 15-minute quadrangle)
Depth to water: 32 ft. (May 5, 1976)

	Depth, in feet From	To
Quaternary:		
Silt, very sandy, slightly clayey, dark grayish brown.....	0	5
Silt, very sandy, slightly clayey, pale brown............	5	14
Sheep Creek:		
Sand, very fine to medium, some hard calcareous sandstone layers; some sandy siltstone below 23 ft...............	14	30
Siltstone to silt, sandy, pale brown.....................	30	38.5
Sandstone, very fine to fine, calcareous.................	38.5	44
Silt to siltstone, light brown...........................	44	46
Box Butte:		
Clay, silty, light gray to pinkish gray, some olive; in part some calcareous nodules and layers.............	46	76

Test hole 27N-46W-18bbb - continued

	Depth, in feet From	To
Runningwater:		
Sand to sandstone, very fine to very coarse with some fine gravel, grayish brown; some calcareous zones.......	76	120
Sand, slightly gravelly, fine sand to fine gravel.........	120	140
Sand, fine to coarse, some very coarse..................	140	168
Sand, very fine to medium, some coarse, a trace of very coarse; in part slightly silty.........................	168	214
Upper Harrison:		
Silt, very sandy, pale brown; in part interbedded with calcareous, silty sandstone...........................	214	230
Silt to siltstone, clayey, sandy, yellowish brown; some calcareous zones......................................	230	278
Arikaree:		
Silt, moderately sandy, pale brown; many calcareous zones...	278	280
Limestone, sandy, light gray..............................	280	285
Sandstone, very fine to fine, light gray; in part calcareous..	285	300
Silt to siltstone, clayey, sandy, pale yellow............	300	310
Sand, very fine to fine, calcareous; in part some medium sand; interbedded with silty sand...............	310	340
Silt, very sandy, brown; some calcareous zones............	340	357
Brown Siltstone:		
Silt, sandy, clayey, yellow brown with some brownish gray, white from 417 to 420.5 ft.; some calcareous zones...	357	440

Test hole 27N-48W-13dda
(Field No. UNW 24-76)

Location: 676 ft. north and 175 ft. west of southeast corner of sec. 13, T. 27 N., R. 48 W.
Ground altitude: 3,981 ft. (Box Butte 7.5-minute quadrangle)
Depth to water: 21.1 ft. (perched water-level) (April 9, 1976)

	Depth, in feet From	To
Quaternary:		
Silt, very sandy, slightly clayey, dark grayish brown.....	0	2
Sheep Creek:		
Silt, very sandy, light gray............................	2	10
Sandstone, very fine to medium, light gray to white; contains some hard and some soft calcareous layers......	10	31

Test hole 27N-48W-13dda - continued

	Depth, in feet From	To
Silt, very sandy, pale brown; in part some soft calcareous zones	31	40
Box Butte:		
Clay, silty, pinkish gray to light gray; contains some calcareous nodules and layers	40	59
Silt to siltstone, calcareous, white	59	60
Upper Harrison:		
Limestone to marl, white	60	62
Sand to sandstone, very silty, calcareous	62	82
Sandstone, very fine to medium, light olive gray; contains some calcareous nodules and zones	82	85
Silt, very sandy, slightly clayey, pale olive to brownish gray; in part moderately calcareous	85	90
Silt to siltstone, sandy, very calcareous, brown	90	100
Silt to siltstone, clayey, sandy, light yellowish brown to brown; contains some calcareous nodules and zones	100	243
Arikaree:		
Silt, very sandy, slightly clayey, very calcareous, white to light gray; contains some calcareous sandstone	243	260
Sandstone, very fine to medium, light gray; contains some very calcareous zones and limestone layers; some coarse sand below 270 ft.	260	300
Sandstone, very fine to medium, light gray; in part silty; some calcareous zones	300	336
Silt, very sandy, slightly clayey, pale brown; some siltstone and sandstone layers; calcareous below 340 ft.	336	350
Sandstone, very fine to fine, olive gray; in part calcareous	350	355
Brown Siltstone:		
Silt to siltstone, sandy, clayey, yellowish brown; in part slightly calcareous	355	380

Test hole 27N-49W-6bbb
(Field No. UNW 6-75)

Location: 32 ft. south and 139 ft. east of northwest corner of sec. 6, T. 27 N., R. 49 W.
Ground altitude: 4,269 ft. (Hemingford 7.5-minute quadrangle)
Depth to water: 50.4 ft. (perched water level) (November 7, 1975)

	Depth, in feet From	To
Quaternary:		
Silt, very sandy, slightly clayey, dark grayish brown; moderately calcareous below 2 ft.	0	4

Test hole 27N-49W-6bbb - continued

	Depth, in feet From	To
Sheep Creek:		
Sandstone, very fine to fine, pale olive.................	4	12
Silt, sandy, calcareous, pale yellow.....................	12	15
Sandstone, very fine to fine, very calcareous, light gray.	15	26
Silt, very sandy, slightly clayey, very calcareous, light gray..	26	27
Box Butte:		
Clay, silty, light brown to light gray and pale yellow; in part calcareous.....................................	27	50
Runningwater:		
Sandstone, very fine to fine, some medium silty, white to pale brown; in part calcareous......................	50	70
Upper Harrison:		
Silt to siltstone, moderately sandy, slightly clayey, yellowish brown to brownish yellow; in part slightly to very calcareous.....................................	70	130
Sandstone, very fine to fine, very silty, moderately calcareous, yellowish brown............................	130	150
Silt to siltstone, very sandy, slightly clayey, very calcareous, yellowish brown with some brownish yellow; in part slightly to moderately calcareous.......	150	250
Arikaree:		
Sandstone, very fine to fine, moderately silty, very calcareous, light gray................................	250	300
Silt, very sandy, slightly clayey, very calcareous, light gray..	300	310
Sandstone, very fine to fine, very silty, contains some lithic fragments, moderately calcareous, pale yellow...	310	320
Sand, slightly gravelly, very fine sand to fine gravel, some lithic fragments.................................	320	328
Brown Siltstone:		
Silt, very sandy, slightly clayey, slightly calcareous, brownish yellow to yellowish brown; contains some calcareous nodules..................................	328	420

Test hole 27N-49W-19bbb
(Field No. UNW 5-75)

Location: 270 ft. south and 49 ft. east of northwest corner of sec. 19, T. 27 N., R. 49 W.
Ground altitude: 4,268 ft. (Hemingford 7.5-minute quadrangle)
Depth to water: 63.7 ft. (perched water level) (November 7, 1975)

Test hole 27N-49W-19bbb - continued

	Depth, in feet From	To
No sample	0	3
Sheep Creek:		
Limestone and calcareous sandstone, very fine to medium, some coarse, light gray with some pale yellow and pale olive	3	25
Box Butte:		
Clay, silty, in part slightly sandy, light yellowish brown and pale brown; in part calcareous	25	50
Upper Harrison:		
Silt, moderately clayey, moderately sandy, very calcareous, light yellowish brown	50	54
Sandstone, very fine to fine, in part some medium, moderately to very silty, pale brown; some calcareous sandstone	54	100
Silt, very sandy, slightly clayey, very calcareous, pale brown	100	110
Sandstone, very fine to fine, very silty, very calcareous, pale yellow with some pale brown and light yellowish brown	110	132
Siltstone, very sandy, slightly clayey, very calcareous, light yellowish brown	132	170
Sandstone, very fine to fine, very silty, slightly to very calcareous, light yellowish brown	170	200
Siltstone, very sandy, slightly clayey, very calcareous, light yellowish brown	200	220
Arikaree:		
Sandstone, very fine to fine, slightly to very silty, light olive gray; light gray to light brownish gray above 240 ft	220	330
Sandstone, very fine to fine with some medium to coarse, light olive brown; sand is very fine to coarse with some very coarse sand and fine gravel composed of lithic material below 350 ft	330	360
Sand, very fine to fine, some medium to coarse, a trace of very coarse	360	369
Brown Siltstone:		
Silt to siltstone, very sandy, slightly clayey, very calcareous, light yellowish brown, contains some calcareous sandstone layers	369	420

Test hole 27N-51W-20bbc
(Field No. UNW 12-75)

Location: 793 ft. south and 130 ft. east of northwest corner, sec. 20, T. 27 N., R. 51 W.
Ground altitude: 4,480 ft. (Marsland 15-minute quadrangle)
Depth to water: 186.5 ft. (December 4, 1975)

	Depth, in feet	
	From	To
Quaternary:		
Silt, very sandy, slightly clayey, very dark gray.........	0	4
Sheep Creek:		
Silt, very sandy, slightly clayey, brown to yellowish brown..	4	20
Sandstone, very fine to fine, little medium, slightly silty, yellowish brown, slightly calcareous.............	20	24
Silt to siltstone, moderately sandy, slightly clayey, yellowish brown, in part moderately calcareous..........	24	36
Upper Harrison:		
Sandstone, very fine to fine, pale brown; lime cemented...	36	44
Silt to siltstone, slightly clayey, slightly sandy, in part moderately to very sandy, yellowish brown..........	44	70
Sandstone, very fine to fine, very silty, yellowish brown, some pale brown; in part lime cemented...........	70	91
Silt, moderately sandy, slightly clayey, light brown to yellowish brown, slightly calcareous; some calcareous nodules...	91	156
Arikaree:		
Sand to sandstone, very fine to fine, yellowish brown to brown; in part lime cemented; marl below 195 ft.........	156	197
Sandstone, very fine to fine, light gray to brown; in part lime cemented; some marl..........................	197	270
Sandstone, very fine to fine, grayish brown to light gray; some marl.......................................	270	282
Silt, sandy, light gray, some marl.......................	282	288
Sandstone, very fine to fine, moderately silty, brownish gray to grayish brown..................................	288	300
Silt, moderately sandy, slightly clayey, brownish gray to light gray, slightly calcareous.....................	300	320
Sandstone, very fine to fine, very silty, brownish gray, very calcareous...	320	335
Silt, moderately sandy, slightly clayey, light gray, in part very calcareous...................................	335	342
Brown Siltstone:		
Silt to siltstone, moderately sandy, in part slightly sandy, yellowish brown, moderately calcareous, in part slightly calcareous.......................................	342	400

Test hole 27N-51W-32ccc
(Field No. UNW 13-75)

Location: 9 ft. north and 56 ft. east of southwest corner, sec. 32, T. 27 N., R. 51 W.
Ground altitude: 4,495 ft. (Marsland 15-minute quadrangle)
Depth to water: 194 ft. (electric log) (November 12, 1975)

	Depth, in feet	
	From	To
Quaternary:		
No sample	0	3
Sheep Creek:		
Sandstone and limestone, very fine to fine sand, light gray; in part non-calcareous	3	10
Sandstone, very fine to fine, some medium, trace of coarse, rare gravel, light gray to yellowish brown, moderately calcareous, in part very calcareous; non-calcareous below 20 ft	10	26
Upper Harrison:		
Sandstone, very fine to fine, some medium, yellowish brown; some lithic gravel below 15 ft	26	56
Silt, moderately sandy, in part very sandy, slightly clayey, pale brown, some yellowish brown; in part slightly to very calcareous	56	110
Sandstone, very fine to fine, moderately silty, pale brown, moderately calcareous	110	120
Silt, very sandy, in part sandy, very silty, yellowish brown, in part moderately calcareous; some calcareous sandstone	120	150
Arikaree:		
Sandstone, very fine to fine, yellowish brown to brown, moderately calcareous; in part slightly calcareous	150	179
Silt, slightly sandy, light gray; some marl	179	182
Sandstone, very fine to fine, yellowish brown, calcareous.	182	192
Silt, slightly clayey, slightly sandy, light gray, very calcareous	192	210
Sandstone, very fine to fine, yellowish brown, light gray, and pale brown; in part moderately calcareous	210	238
Silt, slightly clayey, slightly sandy, light gray, very calcareous; some marl zones	238	270
Sand, very silty, brownish gray, very calcareous; sand is very fine to fine; some lime-cemented sandstone	270	280
Silt, very sandy, slightly clayey, light gray, very calcareous; some lime-cemented sandstone	280	292
Sandstone, very fine to fine, yellowish brown, slightly calcareous; some olive silt	292	298
Silt, slightly clayey, slightly sandy, in part moderately sandy, pale brown to light gray; some limy zones	298	400

Test hole 27N-51W-32ccc - continued

	Depth, in feet From	To
Brown Siltstone:		
Silt to siltstone, slightly sandy, yellowish brown, very calcareous	400	460

Test hole 28N-47W-13aab
(Field No. UNW 31-76)

Location: 1 ft. south and 785 ft. west of northeast corner, sec. 13, T. 28 N., R. 47 W.
Ground altitude: 3,842 ft. (Box Butte NE 7.5-minute quadrangle)
Depth to water: 63.3 ft. (May 5, 1976)

	Depth, in feet From	To
Quaternary:		
Silt, moderately sandy, slightly clayey, dark grayish brown	0	2
Silt, very sandy, light gray to pale yellow, moderately calcareous	2	3
Runningwater:		
Sandstone to limestone, sandy, light gray; sand is very fine to medium	3	10
Silt, very clayey, pale yellow, slightly to moderately calcareous; calcareous nodules and calcareous zones	10	17
No sample	17	20
Sand, very fine to medium, some coarse, slightly silty, root casts; some very coarse sand, trace of fine gravel and calcareous ledges below 45 ft	20	63
Sandstone, very fine to medium, some coarse, very silty, olive, thin calcareous ledges; sand is very fine to very coarse, little fine gravel below 90 ft	63	102
Silt, very sandy, slightly clayey, pale yellow; sand is very fine to very coarse	102	106
Sand, gravelly; very fine sand to fine gravel	106	112
Sand to sandstone, very fine to very coarse	112	120
Sand, gravelly; very fine sand to fine gravel, some medium gravel; some lithic material; some silt lenses	120	136
Silt, to siltstone, clayey, sandy, pale yellow; sand is very fine to coarse	136	140
Sand, gravelly; very fine sand to fine gravel; trace of coarse gravel below 150 ft	140	158

Test hole 28N-47W-13aab - continued

	Depth, in feet From	To
Upper Harrison:		
Silt, clayey, sandy, light gray and brown.................	158	180
Brown Siltstone:		
Silt to siltstone, clayey, sandy, brown; some calcareous nodules and zones....................................	180	260

Test hole 28N-47W-31ccc
(Field No. UNW 23-76)

Location: 1 ft. north and 65 ft. east of southwest corner, sec. 31, T. 28 N., R. 47 W.
Ground altitude: 3,969 ft. (Box Butte 7.5-minute quadrangle)
Depth to water: unknown (Test hole plowed over April 9, 1976)

	Depth, in feet From	To
Quaternary:		
No sample...	0	4
Sheep Creek:		
Sandstone, very fine to medium, in part silty, light gray to pale olive; in part calcareous......................	4	18
Silt, moderately clayey, sandy, pale yellow, very calcareous; some medium sand...........................	18	21
Sandstone, very fine to medium, pale yellow, pale brown and pinkish gray; moderate to very calcareous; some limestone ledges and marl zones........................	21	40
Box Butte:		
Clay, silty, sandy, pinkish gray; pale yellow to light gray below 60 ft.......................................	40	76
Runningwater:		
Silt, very clayey, moderately sandy, light brownish gray, moderate to very calcareous; some calcareous zones..	76	80
Sandstone, very fine to medium, light brown to light gray; silty from 88 to 90 ft...........................	80	93
Silt to siltstone, clayey, sandy, pale brown to light gray; some calcareous nodules and zones, some medium sand...	93	107
Sandstone, very fine to coarse, light gray; in part calcareous...	107	114
Upper Harrison:		
Silt to siltstone, clayey, sandy, yellowish brown, in part moderately calcareous; some calcareous nodules, ledges, and marl zones................................	114	286

Test hole 28N-47W-31ccc - continued

	Depth, in feet From	To
Brown Siltstone:		
Silt to siltstone, clayey, sandy, yellowish brown, in part very calcareous; some marl zones, calcareous nodules and ledges	286	420

Test hole 28N-48W-1aba
(Field No. UNW 22-76)

Location: About 1,870 ft. west and 6.9 ft. south of northeast corner, sec. 1, T. 28 N., R. 48 W.
Ground altitude: 3,926 ft. (Box Butte NE 7.5-minute quadrangle)
Depth to water: 83.1 ft. (April 2, 1976)

	Depth, in feet From	To
Quaternary:		
Sand, very fine to medium, very silty	0	3
Runningwater:		
Sandstone, very fine to medium, in part very fine to coarse with a little fine gravel, slightly silty, pale yellow, some pale olive, in part very to slightly calcareous; some rootlet casts	3	75
Upper Harrison:		
Siltstone, sandy, clayey, yellow brown; some calcareous nodules and zones	75	110
Silt to siltstone, sandy, clayey, yellow brown; some medium sand; some clacareous zones, some lime-cemented sandstone; pale brown below 120 ft	110	130
Sandstone, very fine to fine, silty, dark yellow brown; some calcareous nodules and zones	130	140
Siltstone, very sandy, dark yellow brown; some medium sand; some calcareous nodules and zones	140	170
Brown Siltstone:		
Silt to siltstone, sandy, clayey, yellow brown; some calcareous nodules and zones, some silty sandstone	170	200

Test hole 28N-48W-24aaa
(Field No. UNW 21-76)

Location: 229 ft. south and 50 ft. west of northeast corner, sec. 24, T. 28 N., R. 48 W.
Ground altitude: 3,951 ft. (Box Butte NE 7.5-minute quadrangle)
Depth to water: 14.9 ft. (perched water level) (April 2, 1976)

	Depth, in feet	
	From	To
Quaternary:		
No sample	0	2
Sheep Creek:		
Silt, very sandy, slightly clayey, light gray, moderately calcareous	2	3
Sandstone, very fine to medium, moderately silty, light gray, some white, moderately calcareous	3	31
Siltstone, sandy, white, very calcareous	31	40
Box Butte:		
Clay, silty, pale brown	40	58
Runningwater:		
Limestone, sandy, white; sand is very fine to fine; some sandy siltstone below 59 ft	58	60
Sandstone, very fine to medium, light gray, slightly calcareous; some calcareous fragments	60	70
Silt, sandy, marly, white; some siltstone, sandstone lenses; some gravel grains	70	84
Sandstone, very fine to medium, little coarse; sand is very fine to very coarse with a trace of fine gravel below 90 ft	84	100
Sand, slightly gravelly, fine sand to fine gravel; silty below 115 ft	100	120
Marl, silty, sandy, white	120	132
Sand, very fine to medium, silty; some marl	132	140
Sand, very fine to very coarse, trace of fine gravel; sand is very fine to medium with a trace of coarse below 150 ft	140	160
Sand, very fine to very coarse; sand is very fine to medium with a trace of coarse from 170 to 190 ft.; trace of fine gravel below 190 ft	160	204
Upper Harrison:		
Silt to siltstone, very sandy, clayey, pale brown, slightly calcareous; some calcareous zones, ledges and sandstone below 242 ft	204	300

Test hole 28N-49W-6aaa
(Field No. UNW 7-75)

Location: 62 ft. south and 70 ft. west of northeast corner, sec. 6, T. 28 N., R. 49 W.
Ground altitude: 4,046 ft. (Box Butte Reservoir East 7.5-minute quadrangle)
Depth to water: 80.9 ft. (November 1, 1975)

	Depth, in feet	
	From	To
Quaternary:		
Sand, very fine to medium, trace of coarse sand to fine gravel, very silty....................................	0	3
Sand, very fine to coarse, trace of very coarse sand to fine gravel..	3	10
Silt, moderately sandy, slightly clayey, dark brown, slightly calcareous; little medium sand................	10	20
Runningwater:		
Sand, gravelly; very fine sand to very coarse gravel......	20	30
Limestone, sandy; light brown silty; sand is very fine....	30	33
Siltstone, slightly clayey, slightly sandy, brown to yellowish brown; few calcareous and siliceous fragments.	33	48
Brown Siltstone:		
Limestone, sandy, light gray.............................	48	58
Silt, moderately sandy, slightly clayey, brown to yellow brown, moderately calcareous; some calcareous nodules; some silty sandstone, brown below 80 ft................	58	100
Sandstone, very fine, yellowish brown; some calcareous material..	100	108
Silt, slightly clayey, slightly sandy, yellow brown, in part moderately calcareous..........................	108	117
Silt to siltstone, slightly clayey, slightly sandy, brown, in part very calcareous; some calcareous material; some sandstone lenses from 206 to 214 ft......	117	220

Test hole 28N-49W-19bbb
(Field No. UNW 8-75)

Location: 77 ft. south and 54 ft. east of northwest corner of sec. 19, T. 28 N., R. 49 W.
Ground altitude: 4,233 ft. (Box Butte Reservoir East 7.5-minute quadrangle)
Depth to water: 138.8 ft. (November 7, 1975)

	Depth, in feet	
	From	To
Quaternary:		
Silt, very sandy, slightly clayey, very dark gray.........	0	4

Test hole 28N-49W-19bbb - continued

	Depth, in feet From	To
Sheep Creek:		
Sandstone, very fine to fine with some medium, very silty, slightly calcareous, pale brown.................	4	6
Box Butte:		
Clay, silty, moderately sandy, pale brown with some light gray..	6	25
Runningwater:		
Silt, very sandy, moderately to very clayey, light brown; some calcareous zones below 32 ft......................	25	40
Clay, moderately sandy, pink, some sandstone beds.........	40	50
Silt, very sandy, moderately to very clayey, in part very calcareous..	50	102
Sand, very fine to fine with a trace of medium, very silty..	102	110
Silt, very sandy, moderately clayey, pale yellow..........	110	120
Sand, very fine to coarse, some very coarse, a trace of fine gravel, slightly silty............................	120	126
Sand, slightly gravelly, very fine sand to fine gravel; most gravel composed of lithic material................	126	140
Sand, very fine to medium with some coarse; some silt beds..	140	150
Clay, silty, sandy, pale yellow..........................	150	158
Sand, very fine to medium, some coarse, some lithic material..	158	160
Silt, very clayey, moderately sandy, pale yellow; sand from 165 to 168 ft..................................	160	170
Sand, very fine to medium, in part some coarse sand to fine gravel..	170	202
Silt, very sandy, slightly clayey, pale yellow to pale olive..	202	210
Sand, very fine to medium, some coarse, trace of lithic material, sand is very fine to fine with some calcareous sandstone below 220 ft................................	210	233
Sandstone, very fine, silty, light gray; some calcareous sandstone..	233	250
Silt, very sandy, slightly clayey, very calcareous, light yellowish brown................................	250	260
Silt, very sandy, slightly clayey, very calcareous, pale brown; some calcareous sandstone..................	260	300
Silt, very sandy, slightly clayey, very calcareous, yellowish brown; in part slightly to non-calcareous.....	300	460

Test hole 28N-51W-19aaa
(Field No. UNW 10-75)

Location: 146 ft. south and 256 ft. west of northeast corner of sec. 19, T. 28 N., R. 51 W.
Ground altitude: 4,300 ft. (Marsland 15-minute quadrangle)
Depth to water: 119.7 ft. (November 13, 1975)

	Depth, in feet From	To
Quaternary:		
Sand very fine to fine, some medium, a trace of coarse sand to fine gravel....................................	0	10
Runningwater:		
Sand, very fine to medium, a trace of coarse to very coarse, rare fine gravel, in part some sandstone, rare root casts; slightly finer grained below 30 ft..........	10	47
Arikaree:		
Sandstone, very fine, some fine, calcareous, light gray...	47	58
Brown Siltstone:		
Silt to siltstone, very sandy, slightly clayey, pale brown to light yellowish brown; some calcareous zones..	58	90
Silt to siltstone; very sandy, moderately calcareous, light brown; moderately sandy below 140 ft..............	90	170
Silt to siltstone, slightly clayey, slightly sandy, slightly to moderately calcareous, yellowish brown......	170	250
Silt to siltstone; moderately clayey, slightly sandy, brown with some yellowish brown; some calcareous material; volcanic ash 280 to 300 ft....................	250	320

Test hole 28N-51W-31dad
(Field No. UNW 11-75)

Location: about 1,635 ft. north and 92 ft. west of southeast corner of sec. 31, T. 28 N., R. 51 W.
Ground altitude: 4,498 ft. (Marsland 15-minute quadrangle)
Depth to water: 236 ft. (from electric log) (November 5, 1975)

	Depth, in feet From	To
Quaternary:		
Silt, very sandy, slightly clayey, dark grayish brown, some fine to medium gravel composed principally of lithic material..	0	2
Sheep Creek:		
Sandstone, very fine to fine, in part some medium, light brownish gray to light yellowish brown and light gray..	2	20

Test hole 28N-51W-31dad - continued

	Depth, in feet From	To
Box Butte:		
Clay, silty, sandy, light gray with some pinkish gray, in part slightly to moderately calcareous	20	50
Silt, moderately to very sandy, slightly clayey, very calcareous, white	50	52
Runningwater:		
Sandstone, very fine to medium, pale yellow to pale brown with some light gray; calcareous from 60 to 63 ft.; slightly silty below 63 ft	52	80
Sandstone, very fine to fine, slightly silty, moderately calcareous, light gray to yellowish brown and pale brown; some medium to coarse sand below 87 ft	80	90
Sandstone, very fine to medium, light gray to yellowish brown; in part some calcareous zones; some coarse to very coarse sand below 110 ft	90	120
Sand, very fine to very coarse, a trace of fine gravel	120	130
Sandstone, very fine to medium, slightly silty, calcareous, light gray	130	140
Sandstone, very fine to fine, slightly silty, yellowish brown with some brown; in part calcareous	140	160
Silt, moderately sandy, slightly clayey, moderately calcareous, brownish gray to brown; some calcareous sandstone	160	168
Sandstone, very fine to fine, moderately silty, moderately calcareous, yellowish brown	168	180
Arikaree:		
Sandstone, very fine to fine, moderately to very calcareous, brownish gray to grayish brown; in part some concretions	180	290
Marl, sandy, light gray	290	300
Sandstone, very fine to fine, grayish brown; some silt beds	300	328
Brown Siltstone:		
Silt, very sandy, slightly clayey, grayish brown to yellowish brown with some brown; in part calcareous	328	345
Silt to siltstone, clayey, sandy, moderately to very calcareous, yellowish brown; finer grained below 410 ft.	345	420

Test hole 29N-51W-33cad
(Field No. UNW 9-75)

Location: 2,460 ft. east and 1,430 ft. north of southwest corner of sec. 33, T. 29 N., R. 51 W.
Ground altitude: 4,150 ft. (Marsland 15-minute quadrangle)
Depth to water: 37.9 ft. (November 13, 1975)

	Depth, in feet	
	From	To
Quaternary:		
Silt, very sandy, slightly clayey, moderately calcareous, pale brown	0	1
Gravel, sandy, fine sand to coarse gravel; gravel is composed principally of lithic material	1	36
Brown Siltstone:		
Silt to siltstone, very sandy, brown; in part moderately to slightly sandy; in part very calcareous with some calcareous nodules	36	140
Sandstone, very fine to fine, slightly silty, slightly calcareous, brown	140	147
Silt to siltstone, slightly clayey, slightly sandy, brown; in part slightly to moderately calcareous	147	220

Appendix B

WATER-LEVEL MEASUREMENTS USED FOR WATER TABLE CONFIGURATION (Figure 18)

Part A. Water-levels measured or estimated in test holes drilled fall 1975-spring 1976

Test hole location	Altitude of land surface (ft.)	Depth to water table below land surface (ft.)	Date of measurement	Altitude of water table above mean sea level (rounded to nearest ft.)
24N-48W-15ddd	3,941	5.74	4- 9-76	3,935
24N-48W-35ccc	3,967	11.9 (c)	4- 9-76	3,955
24N-50W-14ccc	4,072	19.5 (c)	10-16-75	4,052
24N-52W-13ccc	4,323	102.25	3-30-76	4,221
25N-48W-24aaa	3,943	57.24	4-21-76	3,886
25N-49W-31bcc	4,065	32 (e)	3-24-76	4,033
25N-50W-24aaa	4,149	93.49	3-30-76	4,056
25N-51W-17ddd	4,230	30 (est.)	11-21-75	4,200
25N-51W-33cdd	4,215	57.39	3-30-76	4,158
25N-52W- 7bbc	4,365	35.27	5- 5-76	4,330
26N-47W-18cdc	3,981	52.20	5- 5-76	3,929
26N-47W-24aaa	3,922	38.89	4-23-76	3,883
26N-47W-31ccc	3,993	91.80	4-21-76	3,901
26N-48W- 1aaa	4,026	105 (est.)	4- 2-76	3,921
26N-49W- 6bbc	4,281	162.94	11- 2-75	4,118
26N-49W-19bbb	4,226	125.35	11- 7-75	4,101
26N-49W-24aba	4,143	113.6	5- 5-76	4,029
26N-49W-31ccd	4,170	77.43	10-16-75	4,093
26N-50W-17ccc	4,292	122.89	5- 5-76	4,169
26N-51W-19aaa	4,360	79.90	12- 4-75	4,280
26N-51W-31dda	4,320	66.66	12- 4-75	4,253
26N-52W-18ccc	4,510	130.18	5- 5-76	4,380
27N-46W-18bbb	3,867	32.07	5- 5-76	3,835
27N-48W-13dda	3,981	72 (est.)	4- 1-76	3,909
27N-49W- 6bbb	4,269	153 (est.)	10-22-75	4,116
27N-49W-19bbb	4,268	148 (est.)	10-21-75	4,120
27N-51W-20bbc	4,480	186.55	12- 4-75	4,293
27N-51W-32ccc	4,495	197 (e)	11-11-75	4,298
28N-47W-13aab	3,842	60.30	5- 5-76	3,782
28N-47W-31ccc	3,969	80 (est.)	3-30-76	3,889
28N-48W- 1aba	3,926	83.09	4- 2-76	3,843
28N-48W-24aaa	3,951	89 (e)	3-26-76	3,862
28N-49W- 6aaa	4,046	80.97	11- 1-75	3,965
28N-49W-19bbb	4,233	138.81	11- 7-75	4,094
28N-51W-19aaa	4,300	119.74	11-13-75	4,180
28N-51W-31dad	4,498	236 (e)	11- 5-75	4,262
29N-51W-33cad	4,150	37.86	11-13-75	4,112

Note: (c) test hole caved here, probably the water-table top
(e) water level estimated from electric log
(est.) water level estimated from geologic and irrigation data

Part B. Water levels measured as part of the U.S. Geological Survey--Conservation and Survey Division statewide water-level monitoring program*

Well location	Altitude of land surface (ft.)	Depth to water table below land surface (ft.)	Date of measurement	Altitude of water table above mean sea level (rounded to nearest ft.)
24N-47W- 1db	3,909.4	14.22	10-14-75	3,895
24N-48W- 2bba	3,940	34.15	10-14-75	3,906
24N-48W- 4bb	3,948	36.54	4- 9-74	3,911
24N-48W-11dd	3,930.2	7.86	10-14-75	3,922
25N-48W- 4ddd	4,032.95	94.48	10-28-75	3,938
25N-48W-12cc	3,952	64.98 (A)	10-28-75	3,887
25N-48W-25bb	3,990.8	106.02	10-28-75	3,885
25N-48W-27db	4,001.37	102.34	10-28-75	3,899
26N-47W-17dd	3,985.32	93.99	10-28-75	3,891
26N-47W-35dd	3,900.9	16.98	10-28-75	3,884
26N-49W- 6cc	4,270	145.20 (A)	10-28-75	4,125
26N-52W-10bc	4,436	94.49	10-28-75	4,342
28N-51W- 6dd	4,120 (est.)	4.47	10-28-75	4,116

Note: (*) measurements made by Nebraska Department of Water Resources, Bridgeport office
(A) measurement in automatic water-level recorder well
(est.) water level estimated from geologic and irrigation data

Part C. Water level measured as part of the Box Butte County Irrigator's Association and Upper Niobrara-White Natural Resources District water-level monitoring program

Well location	Altitude of land surface (ft.)	Depth to water table below land surface (ft.)	Date of measurement	Altitude of water table above mean sea level (rounded to nearest ft.)
24N-47W-10acc	3,940	30.18	3-17-75	3,910
24N-48W- 2ccb	3,937	20.58	3-17-75	3,916
24N-49W-12dcb	3,969	18.27	3-19-75	3,951
24N-49W-35cbb	4,049	31.44	4-11-74	4,018
24N-50W-21aac	4,094	23.84	3-19-75	4,070
25N-47W- 9bb	3,926	32.44	3-18-75	3,894
25N-47W-13b	3,915	27.47	3-17-75	3,888
25N-47W-20bc	3,944	58.16	3-17-75	3,886
25N-47W-32bbb	3,968	79.97	3-17-75	3,888
25N-48W- 9abb	4,061	108.48	3-18-75	3,953
25N-48W-22bba	4,008	94.96	3-18-75	3,913

25N-48W-22ccc	4,046	127.31	4-30-76	3,919
25N-48W-25abc	3,988	103.34	3-17-75	3,885
25N-49W-17acb	4,110	80.76	3-19-75	4,029
25N-49W-26aba	4,010	23.51	3-19-75	3,986
25N-49W-28cad	4,059	50.10	3-19-75	4,009
25N-50W-15bcb	4,243	146.79	3-19-75	4,096
25N-50W-32dcb	4,191	90.5	5- 5-76	4,100
25N-51W- 3cbd	4,300	88.26	3-19-75	4,212
25N-51W-13dbd	4,239	79.77	3-19-75	4,159
26N-47W-13c	3,938	52.72	3-16-75	3,885
26N-47W-21baa	3,970	52.34 (p)	3-16-75	3,918 (p)
26N-47W-34cbb	3,921	33.86	3-16-75	3,887
26N-48W- 3dcb	4,054	65.45	3-18-75	3,989
26N-48W-34b	4,072	124.64	3-18-75	3,947
26N-49W-19bab	4,227	128.99	3-20-75	4,098
26N-49W-22bbc	4,193	131.60	4-10-74	4,061
26N-49W-30dd	4,215	136.34	3-20-75	4,079
26N-49W-35dcb	4,141	113.94	3-20-75	4,027
26N-49W-35dbc	4,140	113.74	3-20-75	4,026
26N-50W-14dbb	4,240	109.74	3-21-75	4,130
26N-50W-18ccc	4,334	152.71	3-20-75	4,181
26N-50W-32abd	4,265	120.71	3-20-75	4,144
26N-51W-27cad	4,350	127.98	3-20-75	4,222
26N-51W-34b	4,312	92.80	3-20-75	4,219
27N-47W-17dbd	3,960	88.60	3-18-75	3,871
27N-48W-24cda	4,030	95.38	4- 7-74	3,935
27N-49W- 2ab(?)	4,175(?)	174.86(?)	3-18-75	4,000(?)
27N-49W-10cbb	4,213	143.32	3-18-75	4,070
27N-49W-13ccc	4,168	127.96	3-18-75	4,040
27N-49W-27abc	4,205	144.51	3-21-75	4,060
27N-49W-32ccd	4,242	133.24	3-18-75	4,109
27N-50W- 1bbd	4,305	182.88	3-18-75	4,122
27N-50W-33bdb	4,324	165.99	3-21-75	4,158
27N-50W- 3acd	4,462	227.96	3-21-75	4,234
27N-51W-33cbd	4,420	131.37	3-21-75	4,289
27N-52W-10a	4,527	214.72	3-21-75	4,312

Note: (p) perched water table, value not used for 1975-76 water-table map
(?) altitude or location possibly in error for this well, value not used for 1975-76 water-table map