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GEOLOGY AND GROUND-WATER RESOURCES OF BOX BUTTE COUNTY, NEBRASKA

BY

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Prepared in cooperation with the
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By R. C. Cady and O. J. Scherer

ABSTRACT

Box Butte County is situated in the northwestern part of Nebraska, on the upland divide between the North Platte and Niobrara Rivers. It is adjacent to Sioux County, which adjoins Wyoming and South Dakota, and is also adjacent to Dawes County, which adjoins South Dakota. The area of Box Butte County is 1,076 square miles. Within the past few years several areas of farm land have been irrigated with ground water obtained from wells, and the study of the possibility of expanding the use of ground water for farming has been emphasized.

The northern part of Box Butte County lies in the Niobrara Valley or on its upper slopes. Snake Creek crosses the southern part of the county from west to east and ends in an undrained depression in the southeastern part. Sand hills border the county on the east and south. Within the valleys of the Niobrara River and Snake Creek are some of the terraces and terrace surfaces identified previously in the North Platte Valley.

The geologic formations exposed in the county are the Monroe Creek and Harrison sandstones of the Arikaree group, the Marsland formation, and the Box Butte member of the Sheep Creek formation—all of Miocene age. The Ogallala formation of Pliocene age is also exposed and has filled a valley that was cut into the older formations in the southern and eastern parts of the county. The formations below the Ogallala dip toward the east at a somewhat greater rate than the land surface. The aggregate thickness of water-bearing formations is 500 feet in the eastern part of the county but only about 200 feet in the western part. In the Niobrara Valley it is still less.

Field coefficients of permeability of the aquifers were determined by means of three pumping tests, and it was found that the Ogallala is the most permeable of the aquifers and that the Marsland formation is the least permeable. The Harrison and Monroe Creek sandstones are moderately permeable. The Quaternary alluvial valley fill in the valleys of the Niobrara River and Snake Creek is fine-grained and probably not very permeable.

Ground water is moving at a rate of about 100 feet a year. The water table lies at shallow depth below the lowlands, but it increases to a maximum of 275 feet in depth beneath the uplands in the western part of the county.

Ground water is entering the county by underflow from areas outside the county on the south and west, but most of it is diverted into the areas of ground-water discharge along the Niobrara River and Snake Creek before it reaches the eastern part of the county. The conclusion is reached that recharge from the land surface on the central uplands of the county is considerable—more than 4 inches of water a year in some upland areas. In other upland areas it is little more than 1 inch a year. Recharge in the lowlands, where the water table is nearer the land surface, is greater.

The ground water beneath the southern two-thirds of the county is discharged into the atmosphere by evaporation and transpiration from seep areas in the

Snake Creek Valley and from other lowlands in the eastern part of the county. It is computed that more than 144,000 acre-feet of ground water a year is so discharged from the uplands, in addition to 174,000 acre-feet a year that falls as rain and snow on the undrained lowlands and hence is discharged into the atmosphere by evaporation and transpiration. The total amount of water discharged into the atmosphere from the seep areas amounts to 2.55 feet a year.

It is estimated that about 31,000,000 acre-feet of water, or more than 30 times the amount that normally falls in a year on the county as rain and snow, is stored within the Miocene and Pliocene aquifers beneath Box Butte County. The records of observation wells indicate that this amount is rather constant, for, although the ground water is frequently replenished or depleted to a slight degree, the water levels have not indicated any notable long-term increase or decrease in ground-water storage.

The ground water in the county is a moderately hard calcium and magnesium bicarbonate water that is chemically favorable for most uses.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

This account of the geology and ground-water resources is in a sense another progress report in the long-term cooperative program of study that was begun in 1930 by the Geological Survey, United States Department of the Interior, and the Conservation and Survey Division, University of Nebraska, and that has been continued without interruption ever since. (See fig. 1.) It is the fourth of the series of detailed local investigations to be made by the two agencies.[1] Several reports that deal with special phases of the investigations have been published separately.[2] In addition, hydrologic data obtained in Nebraska during these investigations have been treated in a number of other papers published by the Federal and State surveys and in technical journals. In 1934 several hundred wells scattered over the State were chosen for observation and were equipped for periodic measurements of water level. Records of these measurements, which are still being made, have been tabulated and published by the Federal Survey in its annual water-supply papers dealing with measurements of water levels and artesian head in observation wells in the United States.[3]

Until rather recently, ground water in Box Butte County was used chiefly for domestic and stock supplies, and demands for large amounts

[1] Lugn, A. L., and Wenzel, L. K., Geology and ground-water resources of south-central Nebraska, with special reference to the Platte River Valley between Chapman and Gothenburg: U. S. Geol. Survey Water-Supply Paper 779, 242 pp., 1938. Wenzel, L. K., and Waite, H. A., Ground-water resources of Keith County, Nebr.: U. S. Geol. Survey Water-Supply Paper 848, 68 pp., 1941. Wenzel, L. K., Cady, R. C., and Waite, H. A., Geology and ground-water resources of Scotts Bluff County, Nebr.: U. S. Geol. Survey Water-Supply Paper 943 (in press).

[2] Wenzel, L. K., The Thiem method for determining permeability of water-bearing materials and its application to the determination of specific yield—results of investigations in the Platte River Valley, Nebr.: U. S. Geol. Survey Water-Supply Paper 679–A, 57 pp., 1936; The problem of overdevelopment of ground-water supplies with special reference to conditions at Grand Island, Nebr.: U. S. Geol. Survey Water-Supply Paper 836–E, 49 pp., 1940.

[3] See U. S. Geol. Survey Water-Supply Papers 777, 817, 840, 845, 886, 908, 938, 946, and 988.

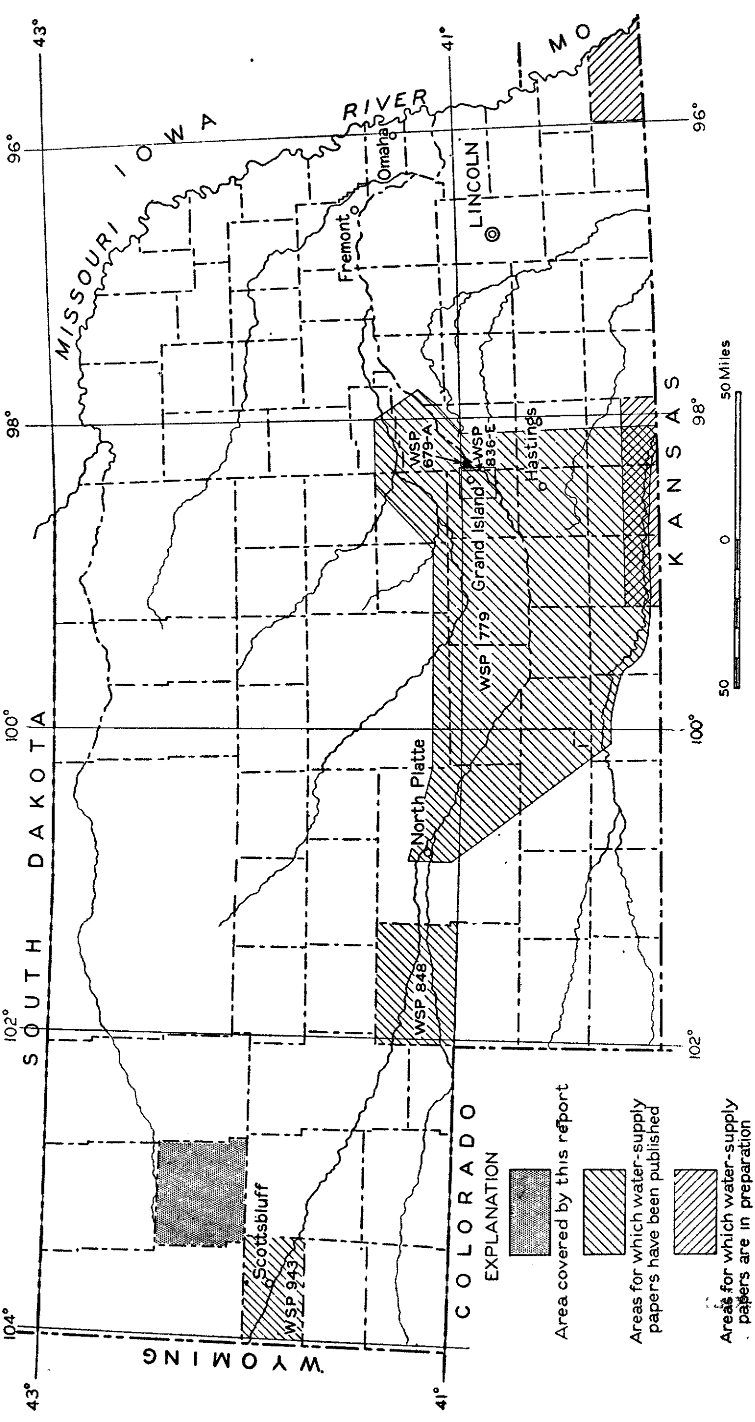

Figure 1.—Index map of Nebraska showing areas covered in ground-water investigations since 1930.

were not numerous. Ground water is abundant and not hard to obtain, although it is deep lying in many localities. Municipal supplies at Alliance and other communities and a supply for the Chicago, Burlington & Quincy Railroad shops represented the greatest withdrawal of ground water in the area. However, within the past few years a number of enterprising farmers have put down irrigation wells and have operated them with apparent success. Not many places are irrigated with water from wells on the upland plains of Nebraska, but as Box Butte County is likely to be irrigated with water from such wells, considerable interest has arisen regarding the geologic and hydrologic conditions there. As a consequence, the present report, like others of its kind, contains information concerning the nature of the geologic formations, with special reference to their water-bearing properties; their distribution over the surface of the county; their thickness and depth below the land surface; the depth at which the water table lies beneath the ground; the direction of the movement of ground water; the places where recharge to the zone of saturation occurs and where the ground water finds its escape at the land surface; the amount and causes of the water-level fluctuations in wells; the uses to which ground water is put, and the detailed construction and performance of existing wells; and the chemical nature of the ground water in relation to its usefulness. This incomplete statement in part means that from the viewpoint of the individual user or prospective user of water an attempt is being made to answer such essential questions as: Where can ground water of good quality be obtained, how much is available, and what will be the pumping lift? From the viewpoint of the community an effort is made to provide the means, or a part of the means, for evaluating the prospects of utilizing an important natural resource. With reference to irrigation, which is only a preliminary stage of development, the present study provides base data that may prove useful in the future, for the operation of a ground-water irrigation project is likely to raise many special quantitative problems. Lastly, the ground-water conditions in Box Butte County may be taken to represent conditions in other hitherto-unexplored parts of a physiographic subdivision of the State—the high western table lands.

The geologic and hydrologic information on Box Butte County was collected during the period between mid-June and early October 1938. Geologic formations were mapped, sections were measured, and the material was carefully described. Detailed records of more than 200 wells were collected, readings of the water levels in them taken, and the approximate altitude of the measuring points above sea level was determined by means of surveying aneroids. Ten test holes were drilled with the project-owned drilling rig, and well samples were collected down to maximum depths of more than 500 feet. Samples of ground water from selected wells and samples of surface water were collected for chemical analysis in the laboratory of the Geological Survey. In addition, 17 wells were selected for close observation, and their water levels were measured about every 10 days. Automatic water-stage recorders were installed on some of them for a time. Measurements were made of the discharge of some of the irrigation wells and of the rate of recovery of the water levels when pumping was stopped.

PERSONNEL AND ACKNOWLEDGMENTS

The cooperative ground-water investigation in Nebraska upon which this report is based was conducted under the direction of O. E. Meinzer, geologist in charge, Division of Ground Water, Federal Geological Survey, G. E. Condra, director, Conservation and Survey Division, University of Nebraska, and L. K. Wenzel, of the Federal Survey, engineer in charge of ground-water investigations in Nebraska. R. C. Cady carried on the geologic studies in the field and wrote the chapters on geography, land forms, and geology. O. J. Scherer collected most of the hydrologic data and collaborated in writing some of the chapters dealing with ground-water hydrology. The test holes were drilled by Howard Haworth and Robert Lawrence, of the Nebraska Conservation and Survey Division, and by C. S. Osborn, assisted by Messrs. Shannon and O'Meara, of the Central Nebraska Public Power and Irrigation District. E. L. Marlin assisted in collecting well data for a short time. The water samples were analyzed by Margaret D. Foster, of the Federal Survey.

Besides those who have officially contributed to the present investigation are the following, whose voluntary cooperation has been of material aid: E. C. Reed, assistant State geologist of Nebraska; A. L. Lugn, professor of geology, University of Nebraska; M. K. Elias, of the Nebraska Geological Survey; C. B. Schultz, of the Nebraska State Museum; Grayson Meade; and Albert Potter. To these men thanks are due for assistance and suggestions.

City officials, land owners and tenants, operators of irrigation wells, and well drillers have willingly contributed to the progress of the investigation, and their contribution is acknowledged.

GEOGRAPHY

AREA AND POPULATION

Box Butte County lies in the northwestern part of Nebraska, in what is known as the panhandle. It is bounded on the north by Dawes County, which is adjacent to South Dakota; on the west by Sioux County, which is the most northwestern county of the State; on the south by Morrill County and about 2 miles of the north boundary of Scotts Bluff County; and on the east by Sheridan County. Box Butte

County is rectangular in shape, with six townships in the east-west direction and five townships in the north-south direction. It has an area of 1,076 square miles.

The population of Box Butte County was 11,861 in 1930. Alliance, with 6,669 inhabitants, was the largest community and the county seat; Hemingford had a population of 1,025; Berea 75; and Nonpareil 20.

Farming and ranching are by far the most important industries in Box Butte County. According to the census of 1930 there were 914 farms of all types in the county, with a total area of 675,210 acres, and there were 424 "cash grain" farms. Most farms in the county are large—a necessity dictated by the semiarid climate. Cattle ranches are the largest and average 6,975 acres; animal specialty farms are next largest and average 998 acres; general farms average 605 acres; cash-grain farms 657 acres; and crop specialty farms 375 acres. Farm units of all types average 739 acres.

The distribution of the general types of farming follows in a rough way the distribution of the geologic formations. (See pl. 1.) On the central upland underlain by the Marsland formation and the Box Butte member of the Sheep Creek formation, grain and specialty crops are mostly raised. Cattle are raised mostly in the southwestern part of the county, which is underlain by soft sandstone of Harrison age. This sandstone country is rough, and the soil, although not desirable for farming, supports a good growth of grass.

The chief agricultural products are wheat, rye, oats, corn, feed sorghum, quality seed potatoes, beans, beef cattle, and dairy products. Grass in the main lowlands is cut for hay.

Industry is relatively unimportant. Nine industrial establishments employing 138 people produced goods valued in 1929 at $1,060,929. Many of the people in Alliance are employed by the Chicago, Burlington & Quincy Railroad, of which Alliance is a division point.

COMMUNICATIONS

Box Butte County is traversed by the Billings, Mont., branch of the Chicago, Burlington & Quincy Railroad, which enters the county directly east of Alliance and, on reaching that town, turns toward the northwest and passes through Berea, Hemingford, and Nonpareil. The Casper, Wyo., branch starts from a junction point at Alliance and goes southwestward toward Bridgeport. State Highway 19 follows the railway into the county from the southwest to Alliance, thence goes northward to Chadron. State Highway 2, which enters the county from the east and parallels the railway, continues along the railway to Hemingford, where it goes westward 12 miles and then turns north to the county line. State Highway 84 crosses the county from east to west 8 miles south of the north boundary. Highway 19 is paved a part of the way across the county, but the other highways are graveled. Many of the section lines are marked by roads or trails. These are best and most numerous in the central parts of the county and poor or nonexistent about the periphery.

CLIMATE

The climate of Box Butte County is typical of the Great Plains—rigorous and variable. In summer the heat sometimes becomes extreme, exceeding 100°F.; in winter minimum temperatures of zero and lower occur rather frequently. Table 1 shows the monthly mean temperature at three stations in and near Box Butte County in 1938. Table 2 shows that most months in 1938 were warmer than normal, with the greatest difference in temperature in the winter. In the summer a few days were very hot, the daily temperature reaching its seasonal maximum as usual during the hot dusty winds that sometimes prevail. Table 2 shows that the station at Lake Minatare is warmer than that at Alliance. As the station at Minatare is on a south slope and is somewhat protected from the northerly winds of winter, the greatest difference between temperatures recorded at these two stations comes in winter. In 1938 the last killing frost at all stations came on May 9, and the first of the following autumn came on October 18. The interval provided an exceptionally long growing season.

Most of the rain in Box Butte County falls during showers of high intensity, chiefly in the warm months of the year. May, June, and July are normally the wettest months. Tables 3 and 4 show that the year 1938, in addition to being warmer than normal, was also wetter. Precipitation in April, May, and September was conspicuously above normal. A phenomenon was observed in the summer of 1938 that, if common, has a favorable bearing on the climate of Box Butte County. On more than six occasions when a southwesterly wind was elevated by the topography of southern Sioux County, the writers saw thunderstorms forming from clusters of small cumulus clouds above the north slope of the North Platte Valley. Most of these storms were immature as they crossed into Box Butte County but attained a stage of high intensity as they reached the central meridian of the county. One of them, in passing over the west boundary of the county, failed to drop rain but caused floods in the vicinity of Hemingford that were large enough to make travel impossible. If the north slope of the North Platte Valley is a breeding ground for summer storms, then the central and eastern parts of Box Butte County may be favored localities.

TABLE 1.—*Monthly mean temperature, in degrees Fahrenheit, in Box Butte County and adjacent areas, 1938*

Station	Altitude (feet above sea level)	January	February	March	April	May	June	July	August	September	October	November	December	Total for year
Alliance	3,971	28.8	30.2	39.8	45.6	55.4	67.4	73.0	74.6	64.7	54.6	32.6	28.5	49.6
Box Butte Experimental Farm	4,900	27.2	29.5	38.6	44.0	53.8	66.0	72.0	74.4	63.6	52.9	32.4	28.3	48.6
Lake Minatare	4,127	30.2	31.6	42.2	48.3	56.2	67.7	73.8	75.3	66.2	55.8	35.9	30.4	51.1

TABLE 2.—*Normal monthly temperature, in degrees Fahrenheit, in Box Butte County and adjacent areas*

Station	Altitude (feet above sea level)	January	February	March	April	May	June	July	August	September	October	November	December	Total for year
Alliance	3,971	23.6	25.6	34.0	45.5	55.1	66.2	72.4	70.6	60.3	47.4	35.0	23.5	46.8
Lake Minatare	4,127	25.1	29.6	36.2	48.7	55.5	66.4	73.2	71.2	61.6	49.7	36.3	26.5	48.3

TABLE 3.—*Monthly precipitation, in inches, in Box Butte County and adjacent areas, 1938*

Station	Altitude (feet above sea level)	January	February	March	April	May	June	July	August	September	October	November	December	Total for year
Alliance	3,971	0.41	0.50	1.83	3.17	3.29	2.42	2.98	0.51	3.07	0.08	1.37	0.32	19.95
Box Butte Experimental Farm	4,900	.79	.59	1.90	4.29	3.61	2.32	2.20	.76	2.72	.08	1.17	.27	20.70
Lake Minatare	4,127	.20	.23	1.08	2.71	4.56	3.36	1.37	.86	2.48	Trace	.56	.08	17.49

TABLE 4.—*Normal monthly precipitation, in inches, in Box Butte County and adjacent areas*

Station	Altitude (feet above sea level)	January	February	March	April	May	June	July	August	September	October	November	December	Total for year
Alliance	3,971	0.41	0.50	0.70	2.06	2.62	2.64	2.70	1.87	1.26	1.14	0.44	0.39	16.73
Lake Minatare	4,127	.38	.44	.71	1.90	2.72	2.12	2.46	1.68	1.58	1.12	.40	.48	15.99

Although some recharge of the ground water took place in the summer of 1938 as a consequence of the abnormal rainfall, it is not generally the rains of high intensity that most benefit the ground-water supplies. Slow autumn rains and the melting of winter snow are favorable for replenishment of the soil moisture and ground water. Table 4 reveals the unfortunate fact that the autumn and winter are comparatively dry. Snow falls sparsely as a rule and is ablated greatly by the sun and wind before it melts.

Evaporation from free water surfaces in Box Butte County far exceeds the precipitation during the year. Table 5 shows the evaporation for the warm months of 1938, as measured in an evaporation pan of the Bureau of Plant Industry.

TABLE 5.—*Evaporation, in inches, from a free water surface at the Box Butte Experimental Farm, Box Butte County, 1938*

Month	Inches
May	7.35
June	8.59
July	7.90
August	9.45
September	5.87
Total for the 5 months	39.18

It must be noted, however, that these data are a measure only of total evaporation from a limited area of exposed free water surfaces. They are not a measure of loss from the ground-water reservoir, and they are not a basis for comparison of total loss and recharge of the ground water.

SOILS AND VEGETATION

As the soils of Box Butte County have already been mapped and described,[4] there is no need to paraphrase those descriptions in this report.

In a general way the soil series conform to the outcrop areas of some of the geologic formations in the area. Soils of the Rosebud, Dunlap, and Scott series, in order of descending area, have been developed on the outcrop areas of the Harrison sandstone, the Marsland formation, and the Box Butte member of the Sheep Creek formation. (See pl. 1.) Those areas that are underlain by sands of Ogallala age are characterized by Valentine soils or by dunesand. Soils of the Tripp, Yale, and Laurel series have been developed in the bottoms of the valleys of the larger streams. This is only the roughest kind of generalization, for soil boundaries cannot be used to define geologic boundaries, nor are the soil series rigidly limited to the formations on whose outcrops they abound.

The vegetation in Box Butte County tends toward uniformity because most of the county is a high treeless plain. Sandgrass, grama, needle-

[4] Hayes, F. A., and Agee, J. H., Soil survey of Box Butte County, Nebr., U. S. Dept. Agr., Bur. Soils., advance sheets of Field Operations for 1916, 1918.

grass or Stipa, red-topped bunchgrass, bluestem, western wheatgrass, buffalo grass, blackroot, a sedge, and wire grass cover much of the top of the plain, but they vary somewhat with the type of soil. Although many of these species grow lush in the moist lowlands as wild hay, the most important hay grasses are grama, bluestem, western wheatgrass, buffalo grass, and wire grass. In the sand hills of Box Butte County and adjacent areas the longleaf reedgrass, redfeldia, and needlegrass are most abundant. Yucca grows on sandy soils and rough land; sage covers some of the sand hills; and willow, ash, cottonwood, aspen, hackberry, elm, chokecherry, and scrub pine grow on the rough land or along the larger streams of an otherwise treeless country.

TOPOGRAPHY AND DRAINAGE

Box Butte County lies almost entirely on the upland divide between the North Platte and Niobrara valleys. This upland is a part of the western Nebraska High Plains that is called the Box Butte Table. The rest of the Box Butte Table is mainly in southern Sioux County. The Niobrara River cuts across the northwest corner of the county and, after leaving the county, runs parallel with the north boundary. The northern part of the county is rough and slopes steeply toward the Niobrara Valley, which in the western part of the county is between 300 and 350 feet deep. The drop from upland plain to river takes place over a linear distance of about 4½ miles, but as the grade of the valley is less than that of the surface of the plain, the relief decreases eastward.

The edge of the Niobrara Valley limits the Box Butte Table on the north. The Box Butte Table is limited on the east by the sand-hills region, the west limit of which almost coincides with the east boundary of the county. Another area of sand hills extends across northern Morrill County, and its north limit nearly coincides with the south boundary of Box Butte County. The tableland has been dissected by many streams and possesses a diverse topography. Snake Creek, which crosses the southern part of the county from the west-northwest, has eroded a lowland to a depth of about 150 feet below the surface of the upland. The Snake Creek lowlands extend far out from the confines of the inner stream valley. Because the courses of Snake Creek and the Niobrara River diverge, the upland plain surface in the central part of the county is roughly triangular, with its apex to the west. The highest part of the upland plain is the northwest corner, about 10 miles south of the Dawes County line. Here the highest altitude recorded—4,612 feet—is at a United States Coast and Geodetic Survey bench mark. The surface slopes approximately southeastward to an altitude of about 3,900 feet near the Sheridan County line in the east. The grade of this slope is thus about 700 feet in a linear distance of a little less than 40 miles, or 17.5 feet to the mile. However, the grade is not everywhere the same and ranges from a maximum of 21 feet to the mile on the upland to a minimum of 11.5 feet to the mile along Snake Creek Valley.

Most of the central upland plain is rolling, because of the dissection by small, ephemeral streams. These streams are not very closely spaced. They have cut gullies that are from 20 to 50 feet deep except near the larger valleys and that have flat, rather wide floors, and sides that in most places are graded and covered with sod. A resistant "cap rock" at the top of the Marsland formation imparts a rigidity and angularity to the topography in the central upland. The top of the plain is likely to approach a gully with only a slight slope and then break abruptly at the point where the ledgelike cap rock intersects the gully wall. Most of these gullies drain toward the southeast so that the depth of the dissection diminishes in their headwaters region toward the northwest.

The outer valley of Snake Creek is hilly and rough near its axis but smoothes out somewhat as it rises toward the central upland. The lowland along Snake Creek is 5 to 8 miles wide but involves much more territory in the western part of the county, where the creek branches This lowland is separated from the central upland by a perceptibly steeper slope that is not properly an escarpment.

The eastern part of the county is underlain by soft sandstone and has been eroded into a lowland. In the vicinity of Alliance this lowland is 6 to 8 miles wide, but it grows narrower toward the north. It is separated from the central upland by a definite escarpment. Buttes and hillocks, which are numerous, reach upward to about the level that would be attained by the central upland. Wild Horse Butte and Box Butte are prominent examples.

The few sand hills in the county possess a distinctive topography. Their outlines are smooth and graceful, but the small, steep hills give a jumbled appearance and in the distance they resemble mountains Between many of them are undrained depressions where lakes may form, or swales, or salt flats. Although many of the sand hills are dunes, the perfect dune shape has been modified in most places. Except where blow-outs have been formed, they are now sodded over and inactive.

The drainage has been discussed incidentally with the topography. So numerous are the streams and so few are the names for them that no detailed catalog of them is possible, even if it were desirable. However, certain features about the drainage must be noted. The Niobrara River in Box Butte County is a small stream in a large valley. At Dunlap, due north of Alliance, in Dawes County, its mean monthly discharge varied between 70 second-feet in March 1938 and 11 second-feet in August 1938. In June of the same year its daily discharge reached a minimum of 3 second-feet. During such periods of low flow, its supply

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comes from underground sources, and the water is clear. In September 1937 it reached a flood discharge of 1,060 second-feet. The stream meanders over a flood plain that is about ¾-mile wide.

Snake Creek is a perennial stream with a small discharge except during floods. Near Alliance it loses itself on a broad lowland 3 or 4 miles wide. Its flood plain varies in width. Halfway to the west boundary of the county it is about 1 mile wide, but west of Kilpatrick Lake it is only a few yards wide. Near the west boundary of the county Snake Creek and its valley break up into three tributaries. Box Butte Creek originates east of Hemingford, flows toward the southeast for a distance of 10 miles or more, and then turns toward the northeast. It continues in this direction as far as the county line, but beyond it turns northward toward the Niobrara. In the extreme eastern part of the county Box Butte Creek becomes an intermittent stream, but in certain moist years it may be even perennial. Dry Creek occupies a deep rugged valley that is parallel to the Niobrara River across the county. It rises in the northwestern part of the county, not over 5 or 6 miles from the river, trends almost due eastward past Hemingford, then turns more and more toward the north, and enters the Niobrara Valley in sec. 4, T. 28 N., R. 48 W. As it crosses the county line it is trending almost directly northward. It is a perennial stream, or at least intermittent, in this stretch.

The great maze of small ephemeral streams on the central upland of Box Butte County trend from the northwest toward the southeast. Apparently this arrangement is very ancient, for a glance at the geologic map (pl. 1) will show that the central upland is not a stratigraphic surface, but one that cuts across the geologic formations. Streams in the vicinity of Hemingford have removed Ogallala sediments and flow upon sediments of the Sheep Creek formation; streams south of Hemingford have removed Sheep Creek sediments and flow upon Marsland sediments. A drainage with a southeasterly trend probably has long been flowing from the old erosional surface developed on the Box Butte Table. The streams from the northwest antedate those that, flowing in another direction, have modified this ancient arrangement by piracy. Box Butte Creek, for instance, must certainly have been intercepted by a younger stream that worked southward from the Niobrara Valley. The stream that enters Snake Creek from the north in sec. 32, T. 25 N., R. 49 W., probably modified its course from southeast to south as Snake Creek widened its valley. Some of the creeks north of Kilpatrick Lake seem to be situated on a land surface younger than the top of the plain, and it is believed that their northwesterly alinement is due to the action of wind, as will be pointed out later. Dry Creek is probably younger than these southeastward-trending streams. The streams flowing northward into the Niobrara River are obviously more recent than those on the upland whose headwaters will some day be pirated.

The minor streams on the upland are entirely dry except after heavy rains; then they quickly flood, but they quickly subside after the rain has ceased. There are three destinations to which nearly all of them carry their runoff. The Niobrara River, either directly or by way of Box Butte and Dry Creeks, is the destination of the northern streams; and Snake Creek is the destination of the streams in the southern and central parts of the county; but a few streams in the eastern part of the county simply carry their water to the lowland at the end of the sand hills and empty it into small lakes. Some of the larger lakes are shown on maps of the county. (See pls. 1 and 8.) In this respect, however, Snake Creek is similar to the smaller streams, for it ends in the southeast corner of Box Butte County and only under exceptionally moist conditions does water ever spill over the divides into basins of the sand hills. But when this happens it is merely a lake at the end of Snake Creek that is spilling and not Snake Creek itself. Other streams empty into very local undrained depressions of which Bronco Lake is an example. Small streams in the western part of the county a few miles north and northwest of Kilpatrick Lake also empty into local small undrained depressions.

LAND FORMS

LAND FORMS RESULTING FROM STREAM ACTIVITY

The Niobrara River and Snake Creek possess terraces that reveal something of the history of the development of their valleys. The terraces of these streams, and hence their histories, correspond to some of the terraces of the North Platte River in Scotts Bluff County, as has been pointed out in an earlier report.[5] The correlation of the terraces from one valley to another can be made by comparison of the elevation of their surfaces above the valley floor. In western Nebraska, however, the terraces have certain characteristics that might be called stratigraphic, which thus substantiate the correlation. In the North Platte Valley the terraces were numbered from the lowest to the highest, and the lowest, most recent terrace was called number one. The same system is followed in Box Butte County.

Upland surface.—The highest and most ancient land surface in Box Butte County is the central upland plain. It slopes toward the east and southeast at a rate of about 17 feet to the mile, and transects the outcropping Tertiary formations in the north-south direction and also in the east-west direction. (See pl. 1.) The cap rock at the top of the Marsland formation in places defends the upland surface, but the upland

[5] Wenzel, L. K., Cady, R. C., and Waite, H. A., Geology and ground-water resources of Scotts Bluff County, Nebr.: U. S. Geol. Survey Water-Supply Paper 943, 150 pp., 1946.

surface as a whole is not related to the position of the cap rock. However, too little is known of the surface to assign it a number with the implication of a correlation. No doubt it is continuous with one of the erosion surfaces on the north wall of the North Platte Valley. A careful study of the topography of the upland surface was not possible, as no topographic map exists for Box Butte County; hence it is not certain that the upland is a simple erosion surface developed in a single cycle. It is suspected that the 6th and possibly the 7th erosion surfaces of the North Platte Valley are present on the central upland and its peripheral areas.

Fourth terrace.—The highest of the identifiable terraces in the valleys of the Niobrara River and Snake Creek is the fourth. In T. 28 N., R. 51 W., near the point where State Highway 2 crosses the Niobrara, this terrace can be seen plainly on the south valley wall. Spurs or interstream divides slope down toward the river, steeply farther up, but flattening out to a gentler grade near the bottom of the slope. Because of the gradient of this terrace surface the height of the remnants above the flood plain is indefinite, depending upon the distance from the river of the part measured. However, it is more than 100 feet at its lowest points. No trace of alluvial gravel was found on any remnants of this terrace. In Snake Creek Valley the long slope down from the central upland levels off near the edge of the inner valley to form a terrace that in several localities is well preserved. Near Kilpatrick Lake it is possible to ascend the scarp from the third terrace and see across the dissected fourth surface to the uplands in the distance. In an area 3 to 5 miles northwest of Kilpatrick Lake the fragments of this dissected surface conform to a slope that is concave upward and that levels off near the stream into a definite terrace. The terrace stands more than 100 feet above the flood plain of Snake Creek.

In the Scotts Bluff County report [6] it was shown that the fifth and fourth terraces of the North Platte Valley possibly belong to the same erosion cycle. One of the reasons for considering such a possibility was that topographic profiles across the Niobrara Valley in Sioux County showed no sufficient vertical interval to accommodate the fifth erosion surface. A somewhat similar situation prevails in the headwater region of Snake Creek, in eastern Sioux County, where the Quaternary valley of Snake Creek was cut directly into the seventh erosion surface during the fourth or combined fourth-fifth terrace cycle.

Third terrace.—The third terrace can be recognized in both the Niobrara and the Snake Creek Valley. Along the former stream it exists as a bench cut on Tertiary sandstone and runs back into the reentrants between the remnant spurs of the fourth terrace. Its slope

[6] Wenzel, L. K., Cady, R. C., and Waite, H. A., op. cit.

is less than that of the fourth terrace, and upstream on the tributaries of the Niobrara it becomes a narrow terrace. Where State Highway 2 crosses the Niobrara the third terrace stands about 70 feet above the flood plain. In many localities it can be seen unmistakably, but in others it is likely to be poorly preserved. It is not well preserved on the north side of the Niobrara River near Marsland, in Dawes County.

Gravel, composed partly of local sandstone and partly of crystalline pebbles, is scattered over the terrace surface in the valley of Snake Creek. In the northern part of sec. 22, T. 24 N., R. 52 W., a channel that was cut to a depth of 60 feet into the terrace runs parallel with the present stream but several tens of yards south of it. This channel has been filled with loose sand and gravel. The terrace surface slopes gently but unmistakably toward the channel both from the north side and from the south. The slope toward the old channel makes it very probable that the channel was cut into the surface of the terrace and then refilled before the third terrace was finally dissected. It has been shown that the third terrace in the North Platte Valley in Scotts Bluff County was trenched by channels that were later refilled in a similar manner, and the third terrace in the two valleys are thus correlated.

Second terrace.—The second terrace is well preserved in certain localities in both the Niobrara and the Snake Creek Valley. Along State Highway 2 it stands 47 feet above the flood plain of the Niobrara River. It is composed of gray silt with stringers and beds of gravel made up of Tertiary sandstone pebbles. At other points along the river the elevation of the terrace above the flood plain is less where it extends farther out toward the axis of the valley.

In Snake Creek Valley the second terrace is well preserved and variously developed. Near Kilpatrick Lake and west of it, it is a bench cut upon the Harrison sandstone and covered with gravel. This gravel is composed largely of Tertiary sandstone of local origin. On the north side of the Lake the Kilpatrick ranch buildings are seated upon the broad second terrace. Where the North and South Branches of Snake Creek join, the valley is wide, and the terrace is broadly developed. In the divide between the two branches a small creek was cut during the second-terrace cycle but has not been active since, so that the bottom of its valley merges with the second-terrace surface in the main valley.

East of Kilpatrick Lake the second terrace has been broadly developed on the outcrop area of the easily eroded sands of the Ogallala formation. (See pl. 1.) As nearly as can be ascertained, in the area south of Snake Creek in T. 24 N., Rs. 49 and 50 W., the second terrace extends back southward almost to the sand hills. North of Snake Creek in the vicinity of Alliance it broadens out and extends northward along the margin of the eastern lowland of the county. Alliance itself is situated on the second terrace. The sands of the Ogallala formation have been covered with a few feet of silt and gravel. The gravel is composed of local sandstone pebbles from the Marsland formation and the Harrison sandstone. Thus in the southern and eastern parts of the county the second terrace is many square miles in extent where the streams flowed over sands of the Ogallala, whereas farther west it is a bench only a few yards wide in most places, cut on the more resistant Harrison sandstone and Marsland formation.

The second terrace contains ancient flint implements of the Yuma type in some places in western Nebraska. This fact was discussed and certain speculations as to the age of the terrace were made in the Scotts Bluff County report.[7]

First terrace.—The first terrace in Box Butte County is a minor land form. It is a deposit of dark silt that stands 20 feet or slightly more above the flood plain of the Niobrara River and Snake Creek. It can also be detected in some of the smaller valleys on the central upland. Along State Highway 2 near the Niobrara River it is typically developed, standing 20 feet above the flood plain and containing dark-brown silt. Along Snake Creek it contains more gravel, but gray or dark silt makes up most of the sediment. Near Kilpatrick Lake and westward the first terrace is obscure. Eastward from the lake it seemingly becomes less high above the flood plain, and it disappears southeast of Alliance.

This terrace is not very ancient. It contains relics of Indian culture of no great antiquity and was probably deposited during a period of aridity 2,000 to 4,000 years ago.[8]

Snake Creek at present flows toward the sand hills at the east end of Box Butte County, where its further progress is obstructed. The fact that a full complement of stream terraces was developed on it must therefore have some bearing on the time when sand was moving in the sand-hills region. During the latter part of the Pleistocene, Snake Creek must have been capable of keeping its valley free of drifting sand. In fact its flood plain may have been an important source of loose sand for the winds to transport.

LAND FORMS RESULTING FROM WIND ACTION

Running water has been the chief agent in producing the topography of Box Butte County, but the wind has modified the stream-wrought scene. Like water, the wind has created both erosional and depositional forms, and the scale of operation has been local enough for these forms to be in a visibly complementary relation. For instance, sand dunes border terrains that are vulnerable to wind erosion. The exposed rock surfaces in the county were once protected from wind erosion by limy

[7] Wenzel, L. K., Cady, R. C., and Waite, H. A., op. cit.

[8] Idem.

cap-rock zones of the nature of caliche. Such a zone once capped the sediments of the Marsland and Ogallala formations. Wind erosion, therefore, operated along lines determined by stream erosion, which breached the protective caps. Wind erosion has created significant land forms in two areas. One area contains the outcrop of the Ogallala in the east-central, southeastern, and southern parts of the county; the other contains the outcrop of the Harrison sandstone in the western part of the county, chiefly north of Snake Creek.

Wind erosion.—The eastern lowland of Box Butte County, near Alliance, is separated from the upland plain to the west by an escarpment. Streams approach the lowland from the northwest and west and have cut small valleys, well graded but only a few yards wide, into the upland plain. These valleys merge in the eastern lowland. The lowland is a fairly open, level, poorly drained area containing lakes and marshes.

The eastward limit of the lowland is defined by the sand hills of the central Nebraska sand-hills region resting upon a platform of Tertiary sands. No sharper boundary of a physiographic province could be imagined. Much sand must have been carried from the eastern lowland by westerly winds, and deposited as dunes in the adjacent sand-hills region.

The terrace that extends southward from Snake Creek to the sand hills along the Morrill County line, underlain by sand of the Ogallala formation, was once an important source of wind-blown sand. Undrained depressions, a thicker and thicker cover of eolian sand, and an increasing tendency for dune formation characterize a gradational boundary zone with the sand hills to the south. Probably the principal dune building took place during or before the second-terrace stage while Snake Creek had a broad flood plain, from whence much sand was swept and piled into dunes.

In the region north of Kilpatrick Lake winds from the northwest have modified some of the valleys that are alined in the same direction. In the northwest corner of T. 25 N., R. 51 W., the floor of a valley has been deepened about 20 feet by wind deflation. (See pl. 2, *A*.) Remnants in the form of hillocks mark the level of the former stream grade, and incoherent sand of the upper part of the Harrison sandstone has been removed down to a zone of giant pipy concretions. The valley is not now drained. Another undrained depression is in sec. 34, T. 27 N., R. 52 W. It, like the first depression mentioned, has a small local centripetal drainage system that is independent of the direction of the former stream flow. A mantle of wind-blown sand on nearby upland slopes is probably the resting place of much of the sand scooped from these depressions. Stream valleys, or parts of valleys that do not trend northwestward do not show any marked effect of wind erosion.

In the northwest corner of sec. 8, T. 25 N., R. 51 W., the wind has undermined a small house by removing the earth upon which it rested. Plate 3 is a photograph of the house. It is near a stock well, and the sod was killed by the cattle that gather there. The house is situated on an outcrop of the Harrison sandstone.

Deposits of wind-blown material.—The constructional forms created by the winds have already been mentioned. The dark-brown eolian sand that mantles most of the older lands in the county is the most prevalent but not the most conspicuous. This sand is impure, with much silt and organic matter mixed in it. It is thickest near the source of loose sand, such as the Harrison or the Ogallala outcrop, where it shows a hummocky surface, as dunes have begun to form. Part of it at least is of recent origin, because it may be found on the lower terraces and perhaps even on the flood plain of the larger streams. It is not found, however, in the rough country along the valleys of Dry Creek and the Niobrara River.

In the broad sand-hills region, which extends into Box Butte County, dunes are locally common. Plate 1 shows them in the southern and southeastern parts of the county. Isolated dunes are not common. The sand hills are a great jumble of dunes from a few feet to more than 100 feet high and all are more or less modified from the typical forms they may once have had. Their history is not well known, but it has certainly been complex. Buried soil zones show that there have been periods of quiescence followed by renewed movement of sand. The last considerable movement—which blocked Snake Creek and other streams at the east—was probably more recent than the first terrace. Before the last movement, the dunes probably moved whenever the sod that covered them was weakened or removed. This could happen when the climate became dry or cold. During intervals of nonglacial climate—the present is a glacial climate—the sod might have been weak, but so would have been the winds. Thus, the most likely time for greatest movements of sand must have been during the early stages of glacial accumulation and the late periods of glacial wastage. Dry, cold northwest winds seem to have been responsible for most of the wind erosion in Box Butte County, and probably also for the wind deposition that must have accompanied the erosion. Northwest winds are anticyclonic and are characteristic of glacial climatic regimes. It is concluded, therefore, that in response to early Pleistocene glacial climate the Ogallala sands were eroded by active streams on the plain east of Box Butte County and that from the flood plains the sand of the sand hills moved up and over the divides aerially and by dune migration. Since then, renewed stream and wind activity accompanying strongly glacial climate has caused recurrent major dune movements, and any other climatic change toward aridity has caused minor movements. In this latter class would fall movements taking place during warm dry interglacial periods.

GEOLOGY

CRETACEOUS SYSTEM

The Tertiary sediments in Box Butte County, which have an aggregate thickness of nearly 1,000 feet, rest upon a floor of Cretaceous sediments, probably the Pierre shale. At Agate, Sioux County, the Pierre shale was encountered between depths of about 800 and 3,700 feet in the Cook well.[9] The Pierre shale is dark to black, plastic, and in some places sandy. It does not bear water in any useful quantities except in certain localities, and what water is found is likely to be of poor quality. The Lance formation, which overlies the Pierre shale in parts of Scotts Bluff County, may have pinched out along a line southwest of Box Butte County. So far as is known, no wells in Box Butte County have been drilled to the Cretaceous formations. This is not surprising, because, although the Lance is water bearing in Scotts Bluff County, some of the overlying Tertiary beds in Box Butte County yield water in great abundance, and there has been no need for deeper wells.

TERTIARY SYSTEM

OLIGOCENE SERIES

The White River sediments, of Oligocene age, rest unconformably upon the Cretaceous surface. These sediments are chiefly clay and silt, with some sand, ash, and miscellaneous clastic and chemically precipitated material belonging to the Chadron and Brule formations. As these formations are generally low in permeability, the top of the Brule formation might be considered the lower limit of profitable drilling for water. The Chadron and Brule formations are discussed at some length in the Scotts Bluff County report and in other publications dealing with the geology of western Nebraska.[10] These publications also deal with the Miocene and Pliocene formations described in the present report.

It is believed that test hole 4, drilled a half mile east of Alliance, encountered the Brule formation at a depth of 478 feet below land surface.

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[9] Condra, G. E., Schramm, E. F., and Lugn, A. L., Deep wells of Nebraska: Nebraska Geol. Survey Bull. 4, 2d series, pp. 265–267, 1931.

[10] Wenzel, L. K., Cady, R. C., and Waite, H. A., Geology and ground-water resources of Scotts Bluff County, Nebr.: U. S. Geol. Survey Water-Supply Paper 943 (in press). Darton, N. H., Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian: U. S. Geol. Survey Prof. Paper 17, 69 pp., 1903; U. S. Geol. Survey Geol. Atlas, Scotts Bluff folio (No. 88), 1903; U. S. Geol. Survey Geol. Atlas, Camp Clarke folio (No. 87), 1903. Lugn, A. L., Classification of the Tertiary system in Nebraska: Geol. Soc. America Bull., vol. 50, pp. 1245–1276, 1939.

MIOCENE SERIES

ARIKAREE GROUP

According to the usage of the Nebraska Geological Survey the Arikaree group contains the Gering sandstone (the basal formation), the Monroe Creek sandstone, and the Harrison sandstone.[11] These three formations have evolved from the subdivision of Darton's Gering and Arikaree formations. The Nebraska Survey places the Marsland and Sheep Creek formations in a "Hemingford group," at the top of the Miocene series. Darton mapped the areas underlain by the Marsland formation as Arikaree; but, as Schultz points out, he refers to the Daimonelix zone as being in the upper beds of the Arikaree. The Daimonelix occurs in the upper part of what is now called the Harrison sandstone. Hence, it seems that Darton did not recognize the Marsland formation as being a considerable rock unit overlying the Harrison. It is also true that the Marsland formation resembles the Sheep Creek lithologically more than it does the Harrison, although the contrast between analogous facies of the Harrison sandstone and the Marsland formation is not so great as one might suppose. In this report the Arikaree group is taken to include those beds that Darton seems originally to have named the Gering and Arikaree formations, and it includes the Gering, Monroe Creek, and Harrison sandstones but not the Marsland formation.

GERING SANDSTONE

The Gering sandstone, where exposed, can be seen to occupy broad channels cut into the upper surface of the Brule formation. It consists of gray sand, mainly of fine to medium grain, which is laminated. It is thin- and regular-bedded in most places, but locally it is cross-bedded. It contains a few pipy concretions. It is difficult to distinguish the Gering from overlying sandstones in well cuttings, and, so far as known, no wells or test holes in Box Butte County have encountered it. The nearest outcrops of Gering are in the North Platte Valley in Morrill and Scotts Bluff counties to the south, and along Pine Ridge, in the White River Valley to the north. The Gering sandstone in most places contains beds of greenish-white bentonitic diatomaceous earth. This material weathers into hard white layers with a fine-grained calcareous matrix and with opaline silica radiating out from centers which usually are siliceous shells. These layers are not restricted to the Gering, but would be useful in identifying it in drill holes.

MONROE CREEK SANDSTONE

The Monroe Creek sandstone crops out on the lower slopes of the Niobrara Valley in the northwestern part of Box Butte County, in the

[11] Schultz, C. B., The Miocene of western Nebraska: Am. Jour. Sci., vol. 35, pp. 441–444, June 1938. Lugn, A. L., Classification of the Tertiary System in Nebraska: Geol. Soc. America Bull., vol. 50, pp. 1245–1276, 1939.

northern part of T. 28 N., Rs. 51 and 52 W. (See pl. 1.) It is not extensively exposed, but along State Highway 2 the top of the sandstone is 123 feet above the surface of the Niobrara River at the highway bridge. In T. 28 N., R. 52 W., the top is about 80 feet above the river. As it is very improbable that the base of the Monroe Creek sandstone is above the river level in Box Butte County, this sandstone is probably more than 123 feet thick—possibly about 175 feet. According to Hatcher, who defined the formation,[12] it is about 300 feet thick at Monroe Canyon, Sioux County. As the top of the Monroe Creek was eroded prior to the deposition of the channel fill of the Harrison sandstone, the total thickness could be determined only by test drilling, and it would probably vary somewhat.

Primarily the Monroe Creek is composed of very fine grained homogeneous sandstone, loosely cemented with lime and containing concretions. The sandstone is light tan, but abundant dark minerals tend to give it a grayish tint; lime or ash may also locally impart a whitish tint. So homogeneous is the formation as a whole that only in the concretions can local peculiarities be detected. These concretions, which were discussed at some length in the report on Scotts Bluff County, were formed during the accumulation of the formation. The orientation of the pipy type of concretion seems to be related to ground-water movement from the ancient boundaries of the Miocene basin. From the available information it seems that pipy concretions are confined to the northern and southern parts of the present outcrop areas of the Monroe Creek sandstone. Between these two areas, as in Box Butte County, it seems that the concretions are either roundish or elongated in the vertical direction. (See pl. 2, *B*.) At an exposure along a creek 1 mile west of the town of Marsland, about a mile north of the Box Butte County line, the Monroe Creek consists of typical brown or tan sandstone. The small pitted and convoluted concretions coalesce into solid ledges about 2 feet thick, among which they are scattered and not numerous. Where weathered they tend to fracture horizontally, but where fresh they are not fractured and seem almost to blend into the matrix. In one part of the outcrop the concretions are absent. Three breaks that resemble bedding cross the outcrop horizontally, and laterally it can be seen that concretions are associated with the breaks, coming in immediately below them. Above this outcrop is a poor exposure of brown fine sandstone containing small, round concretions scattered with great regularity throughout it. At a road cut on State Highway 2, 2½ miles south of the Niobrara River, the same development of numerous evenly spaced small "potato" concretions can be seen immediately below the Monroe Creek-Harrison contact, as well

[12] Hatcher, J. B., Origin of the Oligocene and Miocene deposits of the Great Plains: Am. Philos. Soc. Proc., vol. 41, No. 169, pp. 115–119, 1902.

as zones containing pebbles or balls of ruddy sandstone. These zones resemble those in the massive silts and silty sandstones in the Marsland formation.

The uppermost 45 feet of the Monroe Creek sandstone can be seen in an unnamed gully in secs. 16–17 and 20–21, T. 28 N., R. 52 W. Here the convoluted, somewhat irregular potato concretions are irregularly distributed in the massive tan-gray fine-grained sandstone. Their tendency to fracture horizontally gives them an angular or blocky appearance. They coalesce into solid ledges 2 to 3 feet thick, which are about 15 feet apart in the vertical direction. These concretionary ledges have smooth upper surfaces but very irregular lower surfaces that suggest dripstone on the roofs of caverns. Perhaps they were deposited by descending waters. Here again the Monroe Creek contains the regular, evenly distributed potato concretions immediately below the Harrison contact.

These detailed descriptions of the concretions in the Monroe Creek are important because of their close resemblance to the flood-plain phase of the Marsland formation, which has been mistaken for the Monroe Creek sandstone. The repetition of sediments will be discussed later under the description of the Marsland formation.

As the Monroe Creek sandstone is well-sorted, wells penetrating a considerable thickness of this fine-grained sandstone obtain copious supplies of water. For instance, it is believed that some of the water yielded by the Dyer irrigation well (No. 132) in sec. 10, T. 26 N., R. 52 W., comes from the Monroe Creek sandstone. Its total yield is 722 gallons a minute, with a 32-foot draw-down. Many stock and domestic wells in the northwestern part of the county obtain much smaller supplies from this formation. Drilling through the concretionary sandstone is somewhat difficult, not only because the concretions, which are hard and irregular in shape, deflect and jam the bit, but because the associated softer sandstone under impact has an elastic or a cushioning effect.

HARRISON SANDSTONE

This sandstone crops out on the middle slopes of the Niobrara Valley in the northwestern part of the county and in a large area in the southwest corner of the county. (See pl. 1.) It rests unconformably upon the Monroe Creek sandstone, although the amount of erosion outside the stream channels was probably not great. Its thickness in most parts of Box Butte County is about 130 feet, but along the Niobrara Valley it is 85 feet thick or less. The Harrison sandstone shows a gradual change from a purely channel phase in the Niobrara Valley to a flood-plain deposit toward the south, in which primary depositional features are rare or absent. The Monroe Creek-Harrison contact is visible in Box Butte County only on the slopes of the Niobrara Valley. In sec.

5, T. 28 N., R. 52 W., the channel deposits of the Harrison sandstone rest upon Monroe Creek. A small limy band and a system of blocky fractures in the Monroe Creek near its upper surface dip under the Harrison channel fill in a direction parallel with the sides and bottom of the channel. In the northwest corner of sec. 21, T. 28 N., R. 52 W., the contact is different. Here the smooth massive more indurated Monroe Creek sandstone, containing evenly spaced small potato concretions, is separated from the Harrison sandstone by a weathered surface. At the top of the Monroe Creek is a 1½-inch zone of cemented sandstone containing dislocated potato concretions, which therefore must antedate the erosion of the Monroe Creek sandstone, and on which rest a few scattered pebbles; above this are 3 to 4 inches of lime-white slabby sandstone; a white bed of "agate," which is a limy altered bentonitic, diatomaceous earth, more or less impregnated with opaline silica; 3 or 4 inches more of the limy slabby sandstone; a hard concretionary sandstone layer 8 inches thick; and then a gray loose sandstone of the Harrison. (See pl. 4, *A*.) This contact descends northward toward the Harrison channel at a rate of about 1°. The same sort of contact can be seen in secs. 17 and 18, T. 28 N., R. 51 W., in a gully and road cut along State Highway 2.

The channel deposit in the Niobrara Valley, sec. 5, T. 28 N., R. 52 W., rests in a steep-sided channel that is cut about 85 feet into the Monroe Creek sandstone. The deposit varies in composition, but it is chiefly coarse sand and gravel, heavily impregnated with lime. Some layers are fairly loose, but others are firmly indurated. The color is gray. A curious development of concretions has resulted in the formation of zones of small knobs of coarse sandstone 1 to 2 inches in diameter. After the loose sand between them has been weathered away, they resemble an orderly heap of balls. The lime cement shows crystal faces. The bedding of the deposit dips toward the center of the channel. Above the coarser sandstone and gravel is a finer-grained brown sand capped by a zone of iron oxide, and above the iron zone is a fine-grained white silty laminated slabby slack-water deposit of sandstone containing abundant shells of gastropods.

A half mile southeast of this exposure is a 6-foot bed of limy sandstone containing volcanic ash. It is white but contains a 1-foot layer of green opaline silica. The ash bed dips 22° toward the west. West of the channel deposit the Harrison is very coarse-grained and contains large concretions, but it shows loss of the cross bedding and more uniformity than the channel deposit.

At Agate Springs the Harrison channel and associated Monroe Creek have been described by Schramm and Cook.[13] The channel deposit of

[13] Schramm, E. F., and Cook, H. J., The Agate anticline: Kanoka Petroleum Co., Bull. A, 38 pp., 1921.

the Harrison includes both coarse sand and gravel and finer-grained limy sandstone, volcanic ash, and the channel cut into the Monroe Creek sandstone. Whereas in Box Butte County these features are obviously a result of erosion and sedimentation, they are attributed in the Agate district to structural deformation of the Tertiary formations. The structural interpretation was probably based largely upon a dip in the Monroe Creek of about 8° toward the Harrison channel at the Agate fossil deposits. This seeming dip may be analogous to the weathering fractures observed following the bottom surface of the channel in Box Butte County but involving a greater thickness of sediments.

The Harrison that crops out along the south wall of the Niobrara Valley consists mostly of fine-grained to medium coarse gray limy sandstone, with numerous concretions of several varieties. The outcrops are not numerous, for the loosely cemented matrix is easily eroded by both running water and wind. In secs. 21 and 28, T. 28 N., R. 52 W., the lowest part of the Harrison can be seen resting on the Monroe Creek sandstone. The Harrison is a fine-grained loosely cemented gray limy sand with flat, elongated concretions 3 to 5 inches thick. From 20 to 40 feet above the base the concretions are irregular in size and range from 6 inches to 3 feet thick. (See pl. 4, *B*.) They are tabular in form, but pitted, and full of root impressions. Near the top of the sandstone a 15-foot zone of gray fine-grained well-sorted sand teems with a great variety of concretionary forms. These include large white vertical root impressions one-half inch in diameter and 3 to 4 inches long, small irregular potato concretions, thin long horizontal root impressions, small pitted and convoluted tabular concretions with many limy stems or roots attached, pipy concretions 8 inches in diameter and 3 to 4 feet long and ornamented by tubercules, knobs, and a few regular tabular concretions. Above this is an 8-foot zone containing pipy and irregular potato and vertical concretions. This is overlain by 4 feet of massive concretions formed by the aggregation of a multitude of root impressions filled with lime, and numerous tabular forms ¼-inch thick and 4 inches wide. One foot of massive sand with numerous root impressions is overlain by another concretion 1 to 3 feet thick composed of coalesced lime-filled root impressions. This zone can be traced laterally a few hundred feet, and the concretions become pipy, although they are coalesced into a continuous layer. Ten to twelve feet of these tabular and root concretions are overlain by a zone of giant pipy concretions, irregular in form, and 4 feet thick by 10 feet wide by 12 feet long. They are alined in a southwest-northeast direction. Over all the western part of the tableland of Box Butte County the giant concretions mark the upper part of the Harrison. These concretions occupy a 20-foot zone in which they are scattered discontinuously. The sand is otherwise massive and featureless except for a few root impressions. The topmost 10 feet of the Harrison is a gray massive sand with a few small coalesced pipy concretions. The basal beds of the Marsland formation succeed the Harrison with no visible break in sedimentation.

The character of the Harrison sandstone along the north wall of the Niobrara Valley in Dawes County is much like that described above. In the western part of Box Butte County between the Niobrara and Snake Creek Valleys the giant concretions may be overlain by 10 to 20 feet of gray to grayish-brown sand with irregular roundish concretions and root impressions. The brown tinge becomes stronger toward the south.

Along Snake Creek Valley and its headwater tributaries the Harrison sandstone is widely exposed. At the south side of Kilpatrick Lake a 40-foot section exhibits material that is typical of the Harrison in this part of the county. The lower 20 feet is made up of gray massive sandstone with smooth pipy concretions, but in the next 20 feet the concretions become tabular but irregular in form and contain many coalesced lime-filled root impressions, and the matrix becomes more and more filled with limy root impressions and small plates of limy sandstone. Near the top the concretions are tabular, with a smooth upper surface and a convoluted "dripstone" lower surface. In most other exposures in the Snake Creek lowland the Harrison is composed either of pipy concretions associated with a finer-grained massive somewhat browner matrix, or of the tabular type of concretion with coarser more limy and grayer sandstone matrix. Higher in the section the giant pipy concretions can be found in numerous localities, overlain by 10 to 20 feet of gray sand containing somewhat round concretions about 6 inches in cross section, grading upward into smaller potato concretions in a browner matrix near the contact with the Marsland formation.

The upper surface of the Harrison seems to have been originally uneven or to have been eroded before the deposition of the overlying Marsland formation. On plate 1 the Harrison is shown exposed along the unnamed creek that enters Snake Creek Valley in sec. 34, T. 25 N., R. 50 W., from the northwest. In sec. 20, same township and range, the altitude of the Harrison-Marsland contact is about 4,171 feet above sea level; in secs. 27 and 34 the altitude of the contact is about 4,140 feet above sea level. Marsland sediments crop out south of this locality at an altitude more than 20 feet lower. Moreover, the giant pipy concretions that are associated with the top of the Harrison sandstone over so wide an area in the county follow this surface and are found along the creek just referred to at lower and lower altitudes downstream. As good evidence indicates that the concretions were formed while the sandstones were being deposited, the conformance of the giant pipy concretions with the uneven upper surface of the Harrison sandstone seems to indicate either an originally uneven upper surface of the Harrison sandstone, or, more likely, a brief period of dissection at the end of the Harrison depositional cycle. Such a period of dissection, if it took place, must have been followed promptly by the formation of the giant pipy concretions.

Ground water in the Harrison sandstone exists under much the same conditions as in the Monroe Creek sandstone. Essentially a well-sorted but medium to fine-grained sandstone, the Harrison is capable of yielding generous amounts of water if the wells penetrate a great thickness of saturated material. On the average, the Harrison is coarser than the Monroe Creek sandstone. However, stock, domestic, and even irrigation wells in the central and western parts of Box Butte County obtain supplies of ground water from the Harrison sandstone that are satisfactory in quality and quantity for local needs. Seemingly small supplies can be developed at any desired point in the outcrop area of the Harrison, and the Johnson irrigation well (No. 113) obtains about 750 gallons a minute chiefly from a large saturated section that contains Harrison sandstone. Drilling wells into the formation, however, is difficult because of the numerous thick and hard concretions. As in the Monroe Creek, concretions are difficult to break by impact owing to the elastic yielding of the matrix.

MARSLAND FORMATION

The Marsland formation crops out in four areas. The largest area extends from near Alliance toward the northwest in the form of a parallelogram whose base extends westward from Alliance almost to Kilpatrick Lake; the north edge of the area practically coincides with State Highway 87. The next most extensive area is along the Niobrara Valley and along Dry Creek. The other two areas are small, the first following an unnamed creek in the northeast corner of the county and the second being at the county line south of Kilpatrick Lake. (See pl. 1.)

The Marsland formation contains an abundance of two types of material that are not found in the formations previously described. One such material is an impure sandstone that is bound with clay and not cemented with lime. It presents a blocky appearance on some outcrops owing to the vertical fractures and regular horizontal bedding planes. On other outcrops it tends to break up into roundish lumps generally 2 to 3 inches in diameter. This sandstone is very characteristic of the Marsland. Lime impregnations have formed coatings and intermeshing seams throughout these blocky and lumpy sandstones, which, in weathered outcrops, tend to disintegrate and leave hard ledges of the fine mesh of lime in the form of a honeycomb. These layers are called honeycomb ledges in the descriptions of the formation. Much of the lumpy sandstone may have been blocky originally and then redeposited as pebbles, for zones of

A. UNDRAINED DEPRESSION PRODUCED BY WIND EROSION IN WESTERN PART OF BOX BUTTE COUNTY.

B. MONROE CREEK SANDSTONE IN NORTHWESTERN PART OF BOX BUTTE COUNTY.

HOUSE IN THE WESTERN PART OF BOX BUTTE COUNTY THAT HAS BEEN UNDERMINED BY WIND EROSION.

scattered discrete lumps can be found in outcrops of other types of material in the Marsland formation. The other characteristic material is a featureless massive sandy silt, generally light-colored and very limy. Much of the Marsland formation consists of alternating zones of beds of massive silt, generally 4 to 10 feet thick, and blocky or lumpy sandstone 1 to 4 feet thick, which may have weathered to a honeycomb ledge. (See pl. 4, *C*.)

Without doubt the Marsland formation rests upon an uneven surface developed on the Harrison; but examination of the contact between them does not reveal any evidence of weathering or of the accumulation of weathering products. Along the Niobrara Valley, where the lower beds of the Marsland formation are channel or near-channel deposits, the gray or brownish-gray sands of the Harrison are succeeded by blocky sandstone and limy gray or tan silt and impure sand. On the upland south of the Niobrara, the actual contact is difficult to recognize, for instead of an abrupt change in the nature of the sediments, there is merely a gradational change from a concretionary coarser grayish-brown sand of the Harrison to a finer fluffy silty sandstone of the Marsland. The concretions at the top of the Harrison sandstone are somewhat more massive and are rounder than those of the basal Harrison but the change to the smaller vertically elongated concretions of the southern facies of the Marsland formation is also gradational. The actual contact must be chosen arbitrarily within a section of 10 feet or more.

The Marsland formation is rather complex. Systematic changes in the nature of the sediments can be recognized in the vertical section, so that the formation can be roughly divided into two parts; and a progressive change can be recognized in the lower division from a channel or near-channel phase along the Niobrara Valley to a quite different flood-plain phase in the upland south of the valley. The upper part of the Marsland formation, which is comparatively uniform in its entire outcrop area is composed of a succession of blocky and lumpy sandstone layers and beds of limy sandy silt or silty sand of light color. The lower and upper parts of the formation are in many places separated by a thick and rather massive concretionary zone that is likely to be the thickest of the zones in the Marsland section. In most exposures where this concretionary zone crops out, its upper surface is 25 to 50 feet from the top of the Marsland formation. Along the Niobrara Valley the part of the formation that lies below the thick concretionary zone contains channel deposits of coarse sand and gravel. But in the central tableland the lower part of the formation represents the flood-plain phase of the Marsland formation and consists of buff to tan fine-grained silty sand with round or vertically elongated potato concretions. Several tens of feet above the base of the formation these concretions tend to coalesce

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into continuous zones and become thicker and closer together and finally form the thick concretionary zone above which the type of sediment changes into the widespread succession of silt and blocky sandstone.

The sediments of the Marsland formation exhibit a gradual change in color from west to east. At Agate Springs, in Sioux County, the formation is mostly red or reddish brown; in the northwest corner of Box Butte County all the sandstones in the Marsland are gray, green, or gray-brown except those in the upper 15 feet or so that are red. Along State Highway 2, on the south wall of the Niobrara Valley, most of the red color has disappeared from the upper beds of the Marsland. East of Hemingford the predominant colors of the sandstone are gray, green, and brown. The color of the flood-plain phase on the tableland to the south is uniformly light buff to tan.

The thickness of the Marsland is variable. Along State Highway 2 near the Niobrara, the thickness measured with a surveying aneroid from a channel deposit of the Marsland to the top of the formation was 160 feet. Four and one-half miles west of the highway the thickness is about 185 feet. In test hole 8, in the northeast corner of sec. 19, T. 26 N., R. 40. W., apparently about 180 feet of Marsland formation was encountered. On the average, it is believed that the formation is thickest near the Niobrara Valley, where Marsland sediments fill channels that were cut deep into the underlying Harrison sandstone. The nature of the sediments indicates that channel deposits occur only in the vicinity of the Niobrara Valley; hence the Marsland formation should be expected to be thicker there than under the upland plain in the central part of the county.

In the following section the outcrops along the walls of the gully entering the inner valley of the Niobrara River from the south-southeast are described. The total thickness measured in the section by hand level is about 10 feet greater than the thickness of the formation indicated by a surveying aneroid. As the outcrops extend along the gully walls for a mile and a quarter, it is probable that the hand-leveled thicknesses are in error.

Section along walls of a gully entering the inner valley of the Niobrara River from the south-southeast in sec. 8, T. 28 N., R. 52 W.

	Feet
"Cap rock," limy, slabby, with honeycomb structure; inclusions of red sandstone near base, and near top of red clay........	4
Silt, rich, red-brown, massive; zone of lumpy sandstone near middle; upper 4 feet composed of blocky sandstone intermeshed with coatings and mazes of lime..................	10
Silt, green, massive, sandy, with irregular zone of green lumpy sandstone near middle; capped by 2-foot bed of green blocky sandstone	8

Silt, light-green, sandy, with local clusters of concretionary material; irregular concretionary zone at top up to 2 feet thick.	8
Silt, light grayish-green, massive, sandy; large limy root impressions and scattered lumps of gray-brown sandstone; concretionary zone about 6 feet below top, and one at the top that is massive in structure but stemmy locally; it is as much as 4 feet thick and dips toward the south	12
Silt, light grayish-green, massive, sandy, with limy root impressions	3
Mostly covered slope; isolated outcrops of massive sandy silt	35
Sand, loose, coarse, bright yellow-green, with numerous large pitted and irregularly shaped concretions that are composed of the same material as the matrix	18
Covered slope; some poor exposures of green blocky sandstone	30
Sandstone, green, blocky	2
Silt, light-tan, sandy, with large irregular concretions scattered through it	6
Channel sand, brown, coarse, well-sorted, containing abundant dark minerals and some beds of green sandy clay	10-12
Sandstone, bright-green, blocky	1
Silt, light sandy, with zones of lumpy brown sandstone	4
Silt, light-green, limy, with lumps and blocks of light-green sandstone that weather into honeycomb ledges	3
Sandstone, blocky, contorted, light-green	1
Sand, light-brown, green, fine, with a few stems; it pinches out and is replaced laterally by a concretionary mass of limy root impressions	1
Sandstone, blocky, green	3
Silt, sandy	1-2
Sandstone, lumpy, light-green, partly weathered to honeycomb ledge	2
Silt, light-greenish, sandy, small lumps of sandstone scattered sparsely through it	2
Covered slope	10
Sandstone, blocky, brown	3
Stems or roots, limy, vertical, impressions coalesced or discrete, but connected by horizontal slabs of lime. Individual stems several inches long; matrix weathered out. Pinches out laterally in clean brown cross-bedded medium-grained sand	3-4
Sand, soft, silty, tan-colored	1-2
Sandstone, contorted, blocky, brown	2
Silt, massive, light-tan, sandy, containing a few light-colored limy root impressions and other small limy fragments	8

The foregoing section is perhaps the best in the county for revealing the most typical materials that make up the channel and near-channel phases of the Marsland formation. Another good section can be seen on the north wall of the Niobrara Valley near Marsland, Dawes County, and also on the south wall at the Box Butte-Sioux County line. Similar materials are exposed in scattered exposures along State Highway 2 in T. 28 N., R. 51 W. Here, however, the color of the sediments in the upper part of the Marsland formation is less red. The following exposure is on the upper slopes of the Niobrara Valley.

Section on the upper slopes of the Niobrara Valley north of Hemingford, in sec. 5, T. 28 N., R. 49 W.

	Feet
Sandstone, fine, light-green, containing numerous limy root impressions overlain by "cap rock" of the Marsland formation..	10±
Sandstone, lumpy, containing fractures filled with red sandstone.	9
Sandstone, lumpy, weathering to honeycomb ledge, growing platy near top	8-12
Sandstone, green, coarse, blocky	8
Sandstone, gray, with numerous limy root impressions	4
Sandstone, light-buff, containing potato concretions, some coalesced into tabular form	10
Sandstone, light-buff, very limy, containing thin tabular but irregular concretions	8-10
Sandstone, light-brown, massive, containing some concretions and lumpy sandstone. Blocky green sandstone in beds that are contorted into whorls and waves 3 feet high and which thicken and coalesce upward until a 2-foot bed is formed. Above this is a honeycomb ledge	15

About 7 miles farther east the following section can be observed:

Section in sec. 8, T. 28 N., R. 48 W.

	Feet
Cap rock of slabby white limy sandstone; weathered and rubbly near top, grading downward into blocky zone; concretions in material below coalesce upward into same blocky cap rock....	4
Silt, light-gray, massive, sandy, limy, with limy root impressions and abundant poorly defined flannel buff concretionary zones	35
Sandstone, blocky, coarse, buff-gray	15
Concretionary zone; honeycomb form, pitted, but massive near base	10+
Silt, uniform, limy, sandy, of gray color showing buff cast, with layers of gray-green blocky and lumpy sandstone	60

Fossil-bearing channel deposits in the vicinity of the section just described lie at a lower elevation than the massive concretionary zone. They are composed chiefly of gray sands, more or less cemented, containing very numerous limy root impressions.

The foregoing descriptions show the nature of the Marsland formation as it appears in the channel and near-channel phase along the Niobrara Valley. The gradual disappearance of the red sandstones toward the east is indicated but not so well as if sections occurring farther west in Sioux County were described. The following section is typical of the Marsland formation as it is seen in the southwestern part of the large central outcrop area. Here the channel deposits are not present in the lower part of the formation; their position is occupied by the flood-plain phase. The upper part of the formation, however, is essentially uniform over the entire county. The following section was observed and measured in sec. 18, T. 25 N., R. 49 W. The lowest exposure in the section is not at the base of the Marsland formation.

Section in sec. 18, T. 25 N., R. 49 W.

	Feet
"Cap rock," white, limy, slabby; top of the formation	5
Sandstone, slabby, brown	3
Sandstone, blocky, brown, associated with layers of limy gray silt	12-15
Silt, gray-brown, here and there containing blocky sandstone	5
Layer of pipy concretions, not everywhere continuous	0-2
Sandstone, blocky, brown	4
Concretion, large, massive, featureless where fresh, honeycomb in form where weathered. Concretionary masses become smaller, isolated farther down, and near bottom the material consists of brown fluffy sandy silt containing small "potato" concretions	25

The lower beds of the Marsland formation that are exposed in the central upland are fluffy brown silt with long, upright concretions. The change from the channel and near-channel phase to flood-plain phase occurs by lensing out of the channel deposit, and thickening of the flood-plain deposit.

The existence of a brown silt or locally fine sand containing "potato," or vertically elongated, concretions in the Marsland formation duplicates the Monroe Creek sandstone exposed in the Niobrara Valley. The concretions in both formations are much the same, except that possibly those in the Marsland formation tend to be somewhat more elongate in the vertical direction. Also, the sandy matrix of the Monroe Creek seems to be slightly less silty than that in comparable beds of the Marsland formation. The field relations and vertical changes in lithology of the Marsland flood-plain sediments are the best criteria for distinguishing these similar materials.

On the average the Marsland formation is finer-grained than the formations of the Arikaree group, which it covers. The silts and blocky sands undoubtedly are of low permeability, and the channel deposits of coarse sand, although permeable to a high degree, are of limited extent if not wholly absent from the greater part of the county south of the Niobrara Valley. The relatively low permeability of the formation as a whole doubtless facilitates the fluctuation of the water level in some of the deeper wells in response to variations in barometric pressure. However, wells entering it encounter and obtain supplies of water, as in the district northwest of Alliance. Here some of the wells are only of moderate depth, but evidently they are satisfactory as sources of farm or stock supplies. Wells in this district that obtain large supplies of water must pass through the Marsland formation into more permeable sands of the Harrison and Monroe Creek. In much of the north-central and west-central parts of the county the bulk of the Marsland strata lies above the water table.

SHEEP CREEK FORMATION

After the Marsland had been deposited the land surface evidently remained for a time undisturbed, subject neither to much erosion nor to further deposition. It was then that the cap rock at the top of the Marsland formation was developed, probably as a result of the precipitation of lime at the land surface by shallow-lying ground water. Following this interval of quiescence the streams in the region including Box Butte County eroded channels. So far as is known, the channels cut in Box Butte County at this time were narrow and shallow, but larger channels have been found in Sioux and Dawes Counties. After this necessarily brief stage of down cutting, the streams filled the channels with sand and silt. These deposits contain numerous vertebrate fossils. One channel fill of this kind is situated in sec. 11, T. 28 N., R. 49 W. It consists of brick-red massive silt and is strictly limited to the single small channel. This fill is the valley-fill phase of the Sheep Creek formation and is rather complex in Sioux and Dawes Counties. Except for this one outcrop no Sheep Creek valley fill has been definitely identified in Box Butte County. The upland phase of the Sheep Creek, which is widely distributed in Box Butte County, is newly recognized and will be referred to as the Box Butte member of the Sheep Creek formation.[14]

During the early Sheep Creek channel-cutting cycle a deep valley was eroded across the southern part of Box Butte County. In the east half of its course it coincides closely with the present valley of Snake Creek but swings toward the northeast beneath Bronco Lake and Alliance. It lies south of the modern stream in the western part of the county and passes a short distance south of Kilpatrick Lake. The channel cuts through the whole thickness of the Marsland formation. This ancient valley, so far as is known, does not contain sediments belonging to the valley phase of the Sheep Creek formation; however, the Box Butte member has been found in patches on the slopes of the channel, and it probably was deposited on the floor of the channel.

The Box Butte member of the Sheep Creek formation occupies the northern part of the central upland. Its outcrop area widens considerably in the vicinity of Hemingford and eastward, so that it covers much of the eastern part of the county north of Alliance. At the east margin of its outcrop it is covered by the younger Ogallala sediments. (See pl. 1.)

The Box Butte member consists of three parts. The lowest zone is a red clay, friable when dry, with a mottling of green. White limy concre-

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[14] Cady, R. C., The Box Butte member of the Sheep Creek formation: Am. Jour. Sci., vol. 238, pp. 663–667, 1940.

tions are scattered through it, often in horizontal zones. (See pl. 5, *A*.) The concretions have a vertical axis that is as much as 6 inches in length, whereas they are only 3 to 4 inches in diameter. They are cleanly separated from the matrix. They are so numerous as to give the whole material a white color from a distance. In most exposures this subdivision is from 30 to 40 feet thick. The middle 15 feet of this basal zone in some localities is more silty and less plastic than the upper and lower portions. The basal clay zone is well exposed near the top of the south slope of the Niobrara Valley in the northwestern part of Box Butte County. On the upland plain small exposures of it are common in the valleys of the smaller streams.

The middle zone of the Box Butte member consists chiefly of successive layers of brown and green blocky and lumpy impure sandstone. Most layers are from 6 inches to 2 feet thick. These sandstones weather into honeycomb ledges. In all respects they are similar to the sandstones in the Marsland formation.

The top zone, which is a clay containing a white limy concretion, is similar to the lowest, but its color is predominantly green with minor mottlings of red. It also seems slightly more silty. Its thickness is not definitely known but is probably about 15 feet.

The following is the type section of the Box Butte member of the Sheep Creek formation:

Section in sec. 27, T. 28 N., R. 49 W.

	Feet
Covered slope, at the top of which the top zone of the Box Butte member can be found by digging through the turf.....	40
Sandstone, lumpy and blocky, brown, in beds less than 2 feet thick. At two levels, about 20 and 30 feet above the base of the sandstone, there are two honeycomb limy ledges..........	25
Sandstone, lumpy, brown, that weathers into a honeycomb ledge.	2
Silt, limy, sandy, containing thin beds of brown blocky sandstone	8
Clay, red, with white concretions of the lowest subdivision of the Box Butte member....................................	30

At an exposure in sec. 26, T. 28 N., R. 52 W., the following section may be seen:

Section in sec. 26, T. 28 N., R. 52 W.

	Feet
Covered slope..	4
Ash, volcanic, fresh, gray-white, parts of which are consolidated. It is very similar to the lower, lighter-colored ash in the gully west of Aphelops draw in the Sheep Creek section of Sioux County....................................	2
Silt, salmon-colored, limy..................................	3
Sandstone, green and gray, lumpy, impure, grading toward bright olive green near the top; weathers into honeycomb ledges....	23
Clay, red, with white concretions of the lower zone of the Box Butte member.	

The lateral extent of the volcanic ash is not known. It may be absent from the first section, or it may be present but covered.

The exposures of the Box Butte member that show the three zones, or, more specifically, the exposures showing the middle sandstone zone, are limited to the northern part of Box Butte County, near the Niobrara Valley. Hence, it is believed that the middle zone is local and does not extend very far south of the Niobrara Valley. Elsewhere the Box Butte member seems to consist wholly of clay with the conspicuous concretions.

The Box Butte member, composed chiefly of clay and silt and blanketing as it does the rolling pre-Ogallala topography, is probably a loess. The concretions are of the kind that might form in a loess. Evidently late in the Miocene the climate turned more arid. The deposition of loess appears to have been the culmination of the arid cycle and the last recorded event in the Miocene of Nebraska. The lower Ogallala deposits probably indicate a return to a somewhat wetter climate.

Three points of stratigraphic evidence justify the separation of the Box Butte member from the Marsland formation, on which it generally rests. (1) The 4-foot limy cap rock at the top of the Marsland implies an extended interval of subaerial weathering and calcification of a calichelike nature. (2) In sec. 33, T. 25 N., R. 50 W., on the lower slope of Snake Creek Valley, a remnant of the Box Butte concretion-bearing clay rests upon sediments of the lower part of the Marsland formation, showing the unconformable relation between the Marsland formation and the Box Butte member of the Sheep Creek. (3) In Dawes County northeast of the hamlet of Dunlap, in sec. 33, T. 30 N., R. 47 W., the Box Butte member overlies a channel fill of Sheep Creek sediments. The Sheep Creek channel was cut into the Marsland formation and later filled with brick-red silt and sand from which Sheep Creek vertebrate fossils have been taken.[15] At the top of the channel fill the silt has been cemented with lime, indicating a halt in deposition. The red clay of the lower zone of the Box Butte member rests upon this cemented zone.

There seems no reason to doubt that the Box Butte is definitely younger than the Marsland formation, and, indeed, younger than the channel fill of the Sheep Creek. It is not so easy to determine whether it belongs to the Sheep Creek formation or to the Ogallala, or whether it is a separate formational unit. The final answer must await a careful appraisal of the faunal and floral relations. Stratigraphically there are two opposing lines of evidence. On the one hand, the Box Butte was deposited near the bottom of the ancestral valley of the present Snake Creek. This old valley was cut through the Marsland formation before

[15] One of the writers was taken to this outcrop by Grayson Meade, a paleontologist then collecting for the Nebraska State Museum, and by Albert Potter, then a collector for the American Museum of Natural History. Both were familiar with fauna taken from this channel and are the authority for its age.

Ogallala time. Through it the Ogallala sands were later transported, and some were deposited in it. But nowhere does the field evidence indicate that the Box Butte was eroded greatly before it was covered by the Ogallala. This suggests, but does not prove, a close geographic and chronologic relation between the Box Butte and Ogallala units. On the other hand, the type of sediment of the Box Butte, particularly the blocky and lumpy sandstone of the middle zone, is very much like that of the Sheep Creek and Marsland formations. The volcanic ash in the Box Butte is similar to an ash in the Sheep Creek of Sioux County. This line of evidence suggests that the Box Butte was deposited under physical conditions approximating those of Marsland and Sheep Creek times. But it does not offer any sure guidance as to whether the Box Butte should be regarded as a member of the Sheep Creek formation or as a formation in its own right.

C. B. Schultz, of the Nebraska State Museum, has informed the writers that vertebrate fossils of Sheep Creek age were taken from the Box Butte sediments during the summer of 1939. M. K. Elias, of the Nebraska Geological Survey, is preparing a memoir on fossil grass seeds of the Tertiary, in which he shows that grass seeds taken from the Box Butte sediments are of Sheep Creek age. It appears, therefore, that these sediments should be regarded as a member of the Sheep Creek formation.

Although the tentative classification of this rock unit as a member in the Sheep Creek formation is plausible, it is necessary to reserve the possibility that the Box Butte unit is a member of the Ogallala formation.

The Box Butte member is made up of materials that have low permeability. Even the middle sandstone zone contains much fine-grained material mixed with the coarser. The two clay layers are so fine-grained that water could move through them very slowly under ordinary head. However, the clay fractures and shrinks when it is dry and thus might allow passage of water until it becomes wet. In the south-central part of T. 28 N., R. 47 W., and in the southwestern part of T. 28 N., R. 48 W., the clay layers support a perched zone of saturation in the thin Ogallala sands that lie above them. No wells are known to obtain their supply from the Box Butte member, not only because of its tightness, but also because it lies above the water table in much of the county.

PLIOCENE SERIES

OGALLALA FORMATION

The Ogallala formation was originally defined by Darton[16] to include the well-known "mortar beds." The Ogallala was believed to occupy the stratigraphic column of the Great Plains between the Arikaree forma-

[16] Darton, N. H., Preliminary report on the geology and water resources of Nebraska west of the one hundred and third meridian: U. S. Geol. Survey 19th Ann. Rept., pp. 732–742, 1898.

tion, which with the Gering sandstone was then thought to represent all the Miocene sediments and the Pleistocene glacial and alluvial sediments. The Ogallala formation is a complex sedimentary unit. In the first place, its lithologic diversity has long been a challenge to stratigraphers, who, if the diversity proved to be consistent and systematic, would subdivide the formation. In the second place, the Ogallala sediments in the Niobrara Valley region are very different from the Ogallala sediments in the North Platte Valley and regions south in Nebraska and Kansas. Furthermore, some paleontologists regard the lower faunas of the Ogallala to be Miocene in age, rather than Pliocene, which is the age of the upper faunas. The whole problem of subdividing the Ogallala formation is intricate and is based on evidence collected far afield from Box Butte County.

Since Darton's work, three studies of as many vertebrate faunas have been made of the Ogallala formation. The oldest of these faunas was collected from the Niobrara Valley region and was called the Valentine fauna, and the sands from which the vertebrates were taken were named Valentine by Barbour and Cook.[17] Two later faunas were collected and studied, one of which was called the Republican River fauna[18] and the other the Snake Creek.[19] Simpson[20] considers them both to be about equivalent in age, but Lugn believes that the Republican River fauna is composite. All in all, geologists of Nebraska have not found that the vertebrate fossils have been very helpful in their studies of the Ogallala formation, partly because correlations based upon them are perforce general, and partly because some of the zones of the Ogallala are nearly or entirely barren of vertebrates. It was not until the work of Elias[21] on fossil grass seeds in the Tertiary sediments of the Great Plains became generally known that some of the finer correlations in the Ogallala formation became possible. Using fossil seeds, Lugn[22] proposed the following subdivision of the Ogallala formation:

Ogallala group:

Kimball formation: [23]25-50 feet thick; contains *Echinochloa, Panicum,* and *Biorbia* seeds, and algal limestone (after Elias).

[17] Barbour, E. H., and Cook, H. J., Skull of *Aelurodon platyrhinus* sp. nov.: Nebraska Geol. Survey, 1st ser., vol. 7, pt. 19, pp. 173–180, 1917.

[18] Osborn, H. F., and Matthew, W. D., Cenozoic mammal horizons of western North America, with faunal lists of the Tertiary Mammalia of the West: U. S. Geol. Survey Bull. 361, 138 pp., 1909.

[19] Matthew, W. D., and Cook, H. J., A Pliocene fauna from western Nebraska: Am. Mus. Nat History Bull., vol. 26, pp. 361–414, 1909.

[20] Simpson, G. G., Glossary and correlation charts of North American Tertiary mammal-bearing formations: Am. Mus. Nat. History Bull., vol. 67, art. 3, pp. 79–121, 1933.

[21] Elias, M. K., Tertiary grass seeds and other prairie vegetation: Am. Jour. Sci., 5th ser., vol. 29, pp. 24–33, 1935. Also earlier publications referred to therein.

[22] Lugn, A. L., Classification of the Tertiary system in Nebraska: Geol. Soc. America Bull., vol. 50, pp. 1245–1276, 1939.

[23] Snake Creek channel deposits of Sioux County up to 75 feet thick are considered to be equivalent to the Sidney gravel and Kimball formation.

Sidney gravel: [23]15-50 feet thick; includes the upper part of the *Biorbia* seed zone.
Ash Hollow formation: 100-250 feet thick; includes main part of the *Biorbia* seed zone and several faunal horizons; *Krynitzkia* seed zone in lower part.
Valentine formation: 175-225 feet thick; contains *Stipidium* seeds.

A series of controversial papers by Stirton, McGrew, and Meade relating to faunal and lithologic subdivisions of the "Valentine beds" of the Niobrara Valley region has been summarized by Johnson.[24] He presents stratigraphic tables showing not only that the Valentine of the foregoing classification possesses distinct subdivisions that can be shown on a map, but also that the Valentine beds are overlain by younger sands of the Ogallala, which are lithologically different from the mortar beds south of the sand-hills region and which are designated the Ash Hollow division of the Ogallala. Lugn has found that *Krynitzkia coroniformis*, which is limited to the lower zone of the Ash Hollow in the North Platte Valley and regions to the south, is present in the cap-rock zone above the channels bearing the Burge fauna in the Valentine beds of the Niobrara Valley region. Moreover, he states that the sands above the cap-rock zone contain *Biorbia* seeds, which are characteristic of the Ash Hollow beds farther south. These correlations have led Lugn to consider that part of the Ogallala of the Niobrara Valley region which lies below the cap-rock zone to belong to the "Valentine formation", and the cap rock, together with the sands lying above it in the Niobrara Valley region, to be the correlative of the "Ash Hollow formation" of the regions to the south. It is important to note that the Ogallala sediments of the Niobrara Valley facies are different lithologically from the Ogallala of central and southern Nebraska, although parts of them may be contemporaneous. No doubt they were deposited by different streams that obtained their loads of detritus from widely separated areas.

The Ogallala sediments in Box Butte County are fairly widely distributed. In the southwestern and southern parts of Box Butte County they occupy a deep narrow channel, already referred to in the discussion of the Box Butte member of the Sheep Creek formation, which crosses the county in the vicinity of the present valley of Snake Creek. In the middle course of the channel between the east and west boundaries of Box Butte County, the Ogallala channel fill seems to have been originally about 250 feet thick, although some of the upper part has been eroded away. The channel passes beneath Alliance and debouches into a larger erosional basin, now filled with Ogallala sediments, that underlies much

[23] Snake Creek channel deposits of Sioux County up to 75 feet thick are considered to be equivalent to the Sidney gravel and Kimball formation.

[24] Johnson, F. W., Further comments on the usage of "Valentine": Am. Jour. Sci., 5th ser., vol. 36, No. 213, pp. 215–219, 1938.

of the eastern part of the county northeast from Alliance toward Box Butte Creek. (See pl. 1.) In the vicinity of test hole 4, a half mile east of Alliance, the Ogallala once was probably more than 400 feet thick, but a few feet have been removed by erosion. Northeast of Alliance the eastward thickening of the Ogallala sediments is very abrupt, but nowhere is the thickness of the Ogallala known to exceed that at test hole 4. Thin outliers of Ogallala have been mapped from the area south of Nonpareil toward the east, where they become thicker and more numerous and widely distributed. Outcrops are not numerous, and a few expose a great thickness or variety of sediments.

Very few fossils are known to have been collected from the Ogallala in Box Butte County. A sand in sec. 36, T. 24 N., R. 48 W., that is exposed at a higher altitude than the Ogallala sediments in nearby test holes, yielded vertebrate fossils. They were deposited in the municipal museum of Alliance, and later they were identified by H. J. Cook. The age of these fossils was pronounced by him to be "upper Snake Creek." This means that the upper sands near Alliance are the equivalents of either the Ash Hollow, or post-Ash Hollow divisions of the Ogallala as recognized by the Nebraskan geologists. Other Snake Creek fossils are said to have been collected from gravels west of Kilpatrick Lake, and along the present Snake Creek Valley east of Kilpatrick Lake. A Valentine fauna is also said to have been collected in Box Butte County, but the information was never made directly available to the present workers in the area by the officials of the Nebraska State Museum. Probably the most useful biotic evidence of the age of parts of the Ogallala sediments in the county were the fossil seeds found in test hole 4 and identified by M. K. Elias, of the Nebraska Geological Survey. These fossils, with their place in the Ogallala section of the Nebraskan geologists and their range of depth in the test hole, are shown below:

Stipidium commune, belonging to the "Ash Hollow", 20–367 feet.
Krynitzkia coroniformis, of the lower zone of the "Ash Hollow", 110–367 feet.
A primitive *Krynitzkia,* thought to belong in the "Valentine" beds, 170–367 feet.
A *Stipidium,* thought to be a "Valentine" form, with about the same range as the primitive *Krynitzkia.*

The fossil seeds seem to indicate that much of the Ogallala is present in Box Butte County.

Lithologically distinctive zones are found in the Ogallala that conform fairly well to the following general stratigraphic sequence: A lower zone of fine-grained massive sand, primarily brown to green in color, is associated with greenish-white clay beds; above this is a middle zone of coarser unconsolidated brown, yellowish-gray, or gray sand, often mixed or associated closely with gravel and containing clay beds and concretionary zones; an upper zone of fine soft sands and beds of clay, green or yellow in color, is widely distributed at the top of thick sections of Ogallala, and beyond the limits of the channels as well.

Outcrops of the material believed to belong to the lower zone of fine-grained Ogallala sands are found in secs. 18 and 19, T. 26 N., R. 47 W. The material is fine-grained loose brown sand. In the valley of Box Butte Creek just east of the county line is a grayish-green and green massive stemmy fairly compact sand of medium grain. The sand is associated with thin beds of blocky bright yellow-green sandstone and with zones of irregularly shaped concretions. Farther up in the section it becomes looser and more brownish. The sand overlies a grayish-green clayey sandstone, massive and featureless, which is capped with a 4-foot white limy cap rock. This same association can be seen near the bridge where the Alliance-Hay Springs highway crosses the Niobrara River. The age of the lower material is not definitely known; it may be Marsland, Sheep Creek, or Ogallala. In sec. 24, T. 27 N., R. 47 W., a limited exposure of bright yellowish-green blocky sandstone can be seen to overlie the Box Butte member of the Sheep Creek formation. In test holes 1, 2, 4, 5, and 6 the lowest material in the Ogallala is described as fine brown and green sandstones associated with clay layers. This lower fine green compact sand is thickest in test hole 4, where it is about 165 feet. In other test holes it is not only thinner absolutely but also relatively with respect to the other two zones. At test hole 1, near Kilpatrick Lake, it is about 25 feet thick, but this test hole may be near the edge of the channel.

The middle, coarser-grained zone overlies the lower fine-grained sand in secs. 18 and 19, T. 26 N., R. 47 W. The change of lithology is abrupt and distinct. The coarser sand is gray with a bright yellowish cast. Much of it is uncemented and little compacted, but concretionary zones are common. In certain localities it is firmly cemented. At the outcrop in T. 26 N., R. 47 W., it consists of loose, coarse yellow-green stemmy sand with zones of blocky green sandstone. Across the county line, east of sec. 25, T. 26 N., R. 47 W., it is well exposed. Here the sand is bright yellowish-gray coarse compact full of stems, half of which are vertical, half horizontal. Massive concretions in it resemble somewhat the "giant concretions" at the top of the Harrison sandstone, and other smaller ones have a honeycomb structure. On Wild Horse Butte pale yellow-green coarse sand is exposed. (See pl. 5, *B*.) Similar loose yellow-gray sand crops out in the western part of sec. 5, T. 25 N., R. 47 W. In test holes 2, 4, 5, 6, and in well 147, coarse sand of a considerable thickness, clay beds, and finer compact sandstone are encountered, but the chief constituents of these zones are coarse gray, green, or brown sand with gravel. The zone of coarse sand is thickest in test hole 4, where 110 feet of it was encountered, but in test hole 5 it is about 80 feet thick. In test hole 1 the material is fine sand associated with gravel. Test hole 7 did not reach this zone.

The upper zone of fine-grained sand is characterized by green impure sand associated with green clay beds, yellow silty sand, and soft gray laminated sands. This material, if it all can be properly classified with the upper zone, has a wider distribution than any of the other Ogallala sediments. It is found at the top of the channel fill in the southern part of the county, near the west edge of the Ogallala outcrop in the eastern part of the county, and in the outliers in the northern part of the county. South of the present valley of Snake Creek and in the northern outliers the Ogallala sediments are very thin compared to the full section in the channel fill beneath Snake Creek and in the eastern part of the county. At well 199, in sec. 24, T. 24 N., R. 50 W., about 35 feet of fine sand and clay and 4 feet of gravel at the base (reported by the driller) constitutes the Ogallala. At the large outlier south of Nonpareil the Ogallala is about 40 to 50 feet thick. But at test hole 4 the upper zone, including the nearest outcrop of sand and clay south of Snake Creek, is about 130 feet thick. In sec. 4, T. 24 N., R. 50 W., the following is exposed:

Section in sec. 4, T. 24 N., R. 50 W.

	Feet
Sand, fine-grained, loose, light yellow-green, with a 2-foot layer of green clay	10
Sandstone, brownish- and grayish-green, massive, stemmy; pipy and honeycomb concretions having delicate tubercules; medium-grained well-sorted sandstone. (See pl. 6, *A*.)	20
Sand, coarse, light-yellow, with pea-sized gravel, limy stems, and bone fragments	10+
Rubble of white limy concretionary fragments, possibly remnants of Box Butte clay; a few inches.	
Harrison sandstone, gray.	

This outcrop seems to be on the south side of the channel. To the south in sec. 23, T. 24 N., R. 50 W., light-yellow loose, coarse sand is exposed in a road ditch; in sec. 25, same township and range, is a similar outcrop of light olive-green silty clay. In sec. 17, T. 24 N., R. 49 W., yellow-green sand has been brought to the surface at gopher burrows near an outcrop of lime-white cemented pale-buff to gray sandstone. This sandstone is difficult to classify, but it is probably Ogallala, as it is associated with the yellowish-green sand. In sec. 36, same township and range, fine light-green and light grayish-brown sand and green silty clay crop out along State Highway 19. To the northeast along the same highway, in sec. 17, T. 24 N., R. 48 W., light-green silty clay and light-green fine silty sand crop out. In sec. 36, T. 24 N., R. 48 W., fine and coarse yellowish-green sand associated with greenish-white clay, capped by a limy caliche zone, yielded a fossil vertebrate skull of Snake Creek age and also punky fossil wood. North of Snake Creek, in sec. 29, T. 25 N., R. 49 W., a kind of material is exposed on the bank of a small creek that is difficult to classify. It consists of massive brownish-yellow silty sand associated with a thin bed of green clay and a bed of gray-green blocky sandstone. It looks somewhat like the lower fine sand in some respects but also resembles the upper fine sands. It is described with the upper material because it is likely that it is underlain by the channel that crosses the county from west to east. Northeast of this outcrop in sec. 22, T. 25 N., R. 49 W., some light-green sandy silt and silty fine sand are exposed in a road cut. Fine sands of the Ogallala are fairly well exposed in a pit at the northeast end of Bronco Lake, where there is 10 to 12 feet of gray fine loose sand that is thinly laminated. The beds are contorted and are otherwise disturbed by large concentric concretionary masses; vertical limy stems are rather abundant and also lumps and pockets of yellowish sand and green-white clay fragments. About 3 miles north of this locality, in sec. 14, T. 25 N., R. 48 W., a thin outcrop of yellow-green loose silty stemmy sand containing reworked green clay lies only a few feet above the Marsland formation. Loose yellow sand is exposed along the same road 2 miles to the north.

In sec. 25, T. 26 N., R. 48 W., yellowish-gray loose stemmy sand overlies the Marsland formation. Similar limy yellow-gray sand crops out in sec. 4, T. 25 N., R. 47 W., at a higher altitude than a nearby outcrop of coarse sand supposedly of the middle coarse sand zone. Green and yellow-green sands crop out in the outliers in the northern part of the county. Green sand crops out in sec. 19, T. 27 N., R. 47 W., in sec. 7, T. 27 N., R. 47 W., and in sec. 31, T. 28 N., R. 47 W. Blocky green sandstone is exposed in sec. 14, T. 27 N., R. 48 W. Gray-green lumpy stemmy sandstone can be seen along the Chadron Highway in sec. 15, T. 28 N., R. 48 W. On a hill 2 miles south of Hemingford, in sec. 30, T. 27 N., R. 49 W., bright-green sand and a glossy hard green cemented sandstone form the cap rock of the butte. The sandstone resembles hard vitreous sandstone of the Ogallala south of the Republican River in Franklin County. A mile west of Nonpareil, in sec. 30, T. 28 N., R. 50 W., yellow fine sand is exposed below the limy cap rock of the Ogallala. In sec. 18, T. 27 N., R. 50 W., yellow fine sand containing irregular vertical concretions is exposed.

Soft, fine-grained sandstones, green and brown in color, associated with beds of green clay, are found in the shallow zones penetrated by test holes 2, 4, 5, 6, and 7. Where most of the section is represented, this zone seems to be about 100 feet thick.

On page 38 reference was made to the classification of the Ogallala here recognized—the lower fine sand zone, the middle coarse sand zone, and the upper fine sand zone. There seems to be no reason to doubt that the lower sands in the base of the channel and in exposures described above are early Ogallala and early Valentine of the Nebraska classification, and that the upper fine sand zone represents late Ogallala, Ash Hollow, and Snake Creek formations of the Nebraska classification.

Beds belonging to different parts of the Ogallala formation are capped by a white, limy rubble that can best be called a cap rock. The cap rock is present on some of the outliers north of Alliance, south of Nonpareil, and on some of the buttes northeast of Alliance. It is not very hard but has served to protect the soft sands from erosion by rain wash and especially by the wind. It is believed that the formation of dunes in the region south and east of Box Butte County was inhibited by the cap rock until it was removed by stream erosion. This cap rock was probably formed in late Pliocene and early Pleistocene time.

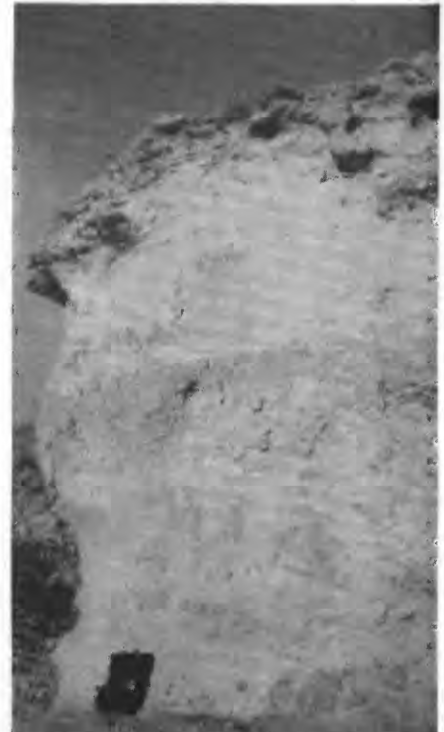
The zone of coarse sands of the Ogallala is an excellent water bearer. Even where it is thin, as at well 199, large supplies of water can be withdrawn from it by wells. For instance, it is reported that well 199, which passes through 4 feet of Ogallala gravel overlying fine sands of Harrison age, yields about 500 gallons a minute. Where the coarse zone is thicker the wells yield much more water. The Koester well (No. 144) yields 1,897 gallons a minute, day and night, during the pumping season, and the new municipal wells at Alliance have high rates of production. The area where the coarse sand is sufficiently thick for successful development of large ground-water supplies is bounded by a line running about due east from a point a mile south of Alliance and by another line running due northeast from Bronco Lake. The channel that trends across the county toward the west is not very wide. It probably passes beneath Bronco Lake and thence west-northwestward to the north of the inlier of Marsland (see pl. 1) in the northwest corner of T. 24 N., R. 50 W., after which it swerves toward the southwest, and then once again trends westward about parallel to Snake Creek but centered to the south of it. It passes a short distance south of Kilpatrick Lake. However, somewhere between test holes 1 and 2 the coarse zone becomes thinner, according to the available information—a circumstance that probably makes the Ogallala in western Box Butte County accordingly less favorable for the production of large water supplies than in the eastern part of the county.

QUATERNARY SYSTEM

Alluvium along the Niobrara River and Snake Creek is the only deposit of post-Tertiary age that would be expected to bear usable quantities of water. So far as is known, the alluvium in both valleys is fine-grained sand with only small amounts of coarser material associated with it. This alluvium doubtless yields water sparingly to wells, but

A. CONTACT OF MONROE CREEK AND HARRISON SANDSTONES IN NORTHWESTERN PART OF BOX BUTTE COUNTY.

B. HARRISON SANDSTONE IN NORTHWESTERN PART OF BOX BUTTE COUNTY.



C. CHARACTERISTIC SEDIMENTS OF THE UPPER PART OF THE MARSLAND FORMATION IN NORTHWESTERN PART OF BOX BUTTE COUNTY.

A. BOX BUTTE MEMBER OF THE SHEEP CREEK FORMATION IN NORTHWESTERN PART OF BOX BUTTE COUNTY.

B. WILD HORSE BUTTE, AN OUTLIER OF THE OGALLALA FORMATION IN EASTERN PART OF BOX BUTTE COUNTY.

A. SANDSTONE OF THE OGALLALA FORMATION IN SOUTHERN PART OF BOX BUTTE COUNTY.

B. DYER IRRIGATION WELL (NO. 132), IN WESTERN PART OF BOX BUTTE COUNTY.

possibly larger quantities of water could be obtained from it if wells were properly developed. In some places the sand acts in the manner of quicksand and flows into wells. The alluvium is cased off in many wells, and the Tertiary sands beneath are the source of the water. Dune sand is generally so fine-grained that only small amounts of water can be extracted from it by means of wells.

CHARACTER AND THICKNESS OF THE WATER-BEARING FORMATIONS

The water-bearing formations that underlie Box Butte County are calcareous sands and silts that belong to the Monroe Creek and Harrison sandstones and the Marsland and Ogallala formations. The Sheep Creek formation is fine-grained and hence is not a good water bearer. The Gering sandstone, which is fairly permeable, is absent from Box Butte County or is unrecognized.

The Monroe Creek and Harrison sandstones and the Marsland formation dip toward the east at an average rate of about 19.5 feet to the mile in the northern part of the county and of about 23 feet to the mile in the central part of the county. The dip as it was determined from logs of test holes in the central part of the county is probably representative of the greater area, for the formations are more nearly conformable, whereas the determination of the dip in the northern part of the area is based upon outcrops in an area where the principal channels passed through the county, and hence the formations are less conformable. The general eastward slope of the land surface is slightly less than that of the formations. Along the upland, in a line passing east-west through Hemingford the slope of the land surface is about 21 feet to the mile; along the lowlands of Snake Creek it is as little as 11.5 feet to the mile. Thus the land surface diverges slightly in the eastward direction from the dipping formations, and within the width of Box Butte County the water-bearing sands of the Miocene thicken eastward. The Ogallala formation, being unconformable on the Miocene formations, does not fit into this orderly arrangement. Along Snake Creek and in the southeastern part of the county the channel occupied by Ogallala sediments has been cut as much as 380 feet below the top of the Miocene at its nearest outcrop, and at test hole 4 the Ogallala rests upon the Monroe Creek at the bottom of the channel. Thus the Ogallala thickens toward the east, as do the Miocene formations, but at an abrupt and inordinate rate. As will be shown later, this circumstance is fortunate hydrologically, for the Ogallala is more permeable than the Monroe Creek and Harrison sandstones and the Marsland formation. North and east of Alliance, near Box Butte Creek, the Ogallala becomes thinner because the channel in which it rests becomes shallower. But as the Ogallala thins, the underlying Miocene formations are restored to their normal thickness, and

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the aggregate thickness of water-bearing formations is not changed to any great degree.

The thickness of the Miocene and Pliocene water-bearing formations in any given locality can be determined from test holes or the records of wells and measured from surface outcrops. In areas far from any such source of information the thickness must be estimated from cross sections drawn between outcrops, test holes, and wells and extended by extrapolation beyond these sources of information. Plate 7 shows four cross sections drawn across the county. For the location of the cross sections see plate 1. The base of the Tertiary water-bearing formations, which is the upper surface of the Brule formation, was reached in only one test hole—No. 4. Consequently, the thickness of the Monroe Creek sandstone is uncertain. But as the total thickness of the Miocene and Pliocene formations is an important item in the consideration of the ground-water supplies in Box Butte County, the top of the Brule is plotted on the cross sections with a confidence that is apparent but not actual in the minds of the investigators. Nevertheless, it is probable that the available information indicates reliably the general magnitude of the thickness of the Miocene and Pliocene section. For example, the cross sections indicate that at Alliance the water-bearing sands are about 475 feet thick; of this total thickness as much as 380 feet is Ogallala, which contains more coarse sand and even gravel than the Marsland formation or the Harrison or Monroe Creek sandstone. About 440 feet of this water-bearing material is saturated. Farther north, in the southeast corner of T. 27 N., R. 47 W., in the lowlands about Box Butte Creek, the water-bearing material is about 430 feet thick, of which nearly all is saturated. Farther west the water-bearing material becomes less thick, and a smaller portion of it is saturated. Five miles west of Berea, in sec. 19, T. 26 N., R. 49 W., it is believed that test hole 8 would have passed through about 500 feet of Miocene water-bearing sediments, of which about 375 feet is saturated. Still farther west, near well 132, in sec. 10, T. 26 N., R. 52 W., the water-bearing material is about 330 feet thick, of which about 235 feet is saturated. In the valley of Snake Creek, 4 miles southeast of Kilpatrick Lake, the water-bearing material is about 230 feet thick, and nearly all of it is saturated. In the Niobrara Valley bottom lands, in the northwest corner of the county, the saturated water-bearing material is thought to be less than 100 feet thick, and hence large supplies of ground water cannot feasibly be obtained there.

POROSITY AND PERMEABILITY OF THE WATER-BEARING MATERIAL

The thickness of the water-bearing material is not strictly analogous to the depth of a surface-water reservoir. Two other characteristics or properties of the material combine with the thickness to complete the analogy—porosity and permeability. Porosity is that percentage by volume of the material that is interstitial space. Ground water can be stored in the interstices, completely filling them, but owing to capillary attraction not all of the interstitial water will drain out through gravitational attraction. Thus, porosity is not the critical property of the water-bearing material in a discussion of the movement and effective storage of ground water in the aquifers. Some clays have a greater porosity than some gravels, but the gravels are likely to yield water copiously and the clays scarcely at all. Porosity of materials of the kind found in the Miocene and Pliocene formations in Box Butte County—chiefly uniformly grained medium to fine sands—should be about 35 to 40 percent. The porosity of four samples of these formations was found by test to average 40 percent.

Permeability is a property of water-bearing material that expresses the capacity of the material to transmit water through it under specified conditions. The capacity of an aquifer to transmit the ground water in it is precisely expressed as the field coefficient of permeability and is defined as the quantity of water, in gallons a day, that will percolate under prevailing conditions through each mile of water-bearing bed under investigation (measured at right angles to the direction of flow) for each foot of thickness of the bed and for each foot per mile of hydraulic gradient.[25] The field coefficient of permeability, which is a unit quantity, is multiplied by the appropriate thickness of saturated water-bearing material and by the hydraulic gradient at the locality in question to derive the amount of water that will pass through the section of the aquifer 1 mile long, oriented normal to the hydraulic gradient.

Coefficients of permeability are easy to use but difficult to determine. In general, two broad lines of attack for determining them have been devised. One is the laboratory method of testing samples of water-bearing material for their capacity to transmit water under controlled conditions. Coefficients of permeability determined by laboratory methods can be applied in the field only by converting them into field coefficients. The conversion involves a correction for water temperature, and sometimes corrections for other factors, such as gravity and the density of water. The field method is applied where ground water is being discharged either naturally or by pumping or by artificially induced flow. The principle is that if the rate of discharge is known, together with the changes in gradient that are produced by the discharge (the time necessary to produce the changes in gradient is required in some methods) and the volume of water-bearing material through which the water must move

[25] Wenzel, L. K., Methods for determining permeability of water-bearing materials, with special reference to field discharge methods: U. S. Geol. Survey Water-Supply Paper 887, 192 pp., 1942.

to reach the point of discharge, then the field coefficient of permeability can be computed. Two of the most widely used of the field methods is Wenzel's modification of the Thiem pumping test[26] and Theis' analysis of the recovery of the depressed water level in a well after pumping has ceased.[27] The various field and laboratory techniques have been described by Wenzel.[28]

In the present study only the recovery method of Theis was found practicable. The Thiem pumping test requires a line of observation wells that intersects the pumping well, an arrangement that could not be set up during the investigation in Box Butte County. The recovery of the water level in three irrigation wells (Nos. 132, 147, and 199) was measured after a period of pumping that lasted from 1 to 17 hours. From these measurements the coefficient of transmissibility, which is the product of the field coefficient of permeability multiplied by the thickness of the saturated water-bearing material, was determined for the material entered by these three wells. At well 132, the transmissibility of a probable thickness of 240 feet of Harrison and Monroe Creek sands was found to be 54,000,[29] giving an average field coefficient of permeability of 225. At well 147 a transmissibility of 105,800 was computed. This well penetrates a part of a section that probably consists of about 130 feet or more of comparatively coarse Ogallala sand and gravel, with clay, fine sand, and silt associated, as well as about 75 feet of Marsland fine sand and silt, and about 245 feet of Harrison and Monroe Creek fine clean sand and sandstone. The average field permeability indicated is 235. At well 199 the transmissibility is calculated to be 144,000. This well penetrates a complex section consisting of clay, a bed of gravel that is about 10 feet thick on the outcrop but that was reported to be about 4 feet in the well, and about 300 feet of Marsland, Harrison and Monroe Creek sediments. The field permeability, calculated from a thickness of saturated water-bearing material of about 365 feet, is about 394, a value considerably larger than that found at the other wells. If the field permeability of the Harrison and Monroe Creek is about the same at well 199 as it was found to be at well 132, then the field permeability of the gravel is about 14,000 if it is 4 feet thick, as re-

[26] Wenzel, L. K., The Thiem method for determining permeability of water-bearing materials and its application to the determination of specific yield—results of investigations in the Platte River Valley, Nebr.: U. S. Geol. Survey Water-Supply Paper 679–A, 57 pp., 1936.

[27] Theis, C. V., The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., 16th Ann. Meeting, pp. 519–524, 1935.

[28] Wenzel, L. K., Methods for determining permeability of water-bearing materials, with special reference to field discharge methods: U. S. Geol. Survey Water-Supply Paper 887, 192 pp., 1942.

[29] A second recovery test was run on this well during the period from November 6 to November 8, 1940. The well was pumped continuously for 8 hours. The transmissibility was calculated to be 51,500, but the value 54,000 is considered satisfactory and will be used in this report.

ported by the driller, or 5,000, if it is 10 feet thick, as it is on the outcrop nearest the well. These values for the field coefficient of permeability are not excessive for gravel, although they are higher than for that of much of the Pleistocene gravel in the Platte Valley computed by Wenzel.

A considerable measure of uncertainty becomes involved in changing the computed value of transmissibility into the field coefficient of permeability. It is only partly due to the lack of exact data on the thickness of the water-bearing sediments of the Miocene and Pliocene series. For throughout the section numerous concretionary beds of dense, hard limy sandstone have been observed, both on the outcrop and in the drilling of wells and test holes. As none of the wells from which the transmissibility of the sediments was determined pass through the whole section of saturated water-bearing material, the effective thickness of water-bearing material may in some way be diminished by the concretionary zones. This is certainly true to the extent that the concretionary beds hamper the upward movement of ground water toward the bottom of the pumping (or recovering) well. As expressing the transmitting properties of the water-bearing materials in terms of the field coefficient of permeability introduces one additional element of uncertainty, it is probable that wherever possible the same property should be considered in terms of transmissibility in the specific sense, rather than of field permeability.

In conclusion, it may be pointed out that the values of field permeability and of transmissibility seem appropriate to account for the specific capacity of the wells that are pumped at a high rate in Box Butte County. These wells compare favorably with other irrigation wells in Nebraska that tap more permeable but thinner water-bearing materials. It must be said, however, that in other areas where the field coefficient of permeability has been determined by several methods the values yielded by the recovery method, which is the method used in Box Butte County, were 5, 10, or rarely 25 percent larger than the values yielded by other methods. Thus, all factors computed from field permeability may be excessive to a like degree and by the same percentage.

DEPTH TO THE WATER TABLE

The depth to water table in Box Butte County is determined by the configuration of the land surface and the configuration of the water table. In general, the water table is high where the land surface stands high, and low where the land surface is low. But aside from possible local exceptions, the water table shows a more subdued and generalized topography than does the land surface. Hence, as a rule, the depth to the water table is greatest where the land is highest. In the bottom lands along Snake Creek and the Niobrara River and in the lowlands in the eastern part of the county the water table lies at a depth of less than 25 feet. Within these areas wells can obtain water and deliver it to the land surface with very little pumping lift. But most of these areas are also places of ground-water discharge, where vegetation can reach the water table or the capillary fringe and thus draw its vital supplies from an ever renewing source. Direct evaporation from the land surface occurs in parts of these areas. This natural subirrigation is beneficial for harvesting fodder crops and for cultivating other types of crop but not so favorable for applying ground water for artificial irrigation. In such areas of shallow water table there is great risk of the accumulation of alkali after irrigation has been carried on for some time.

In the lower reaches of Snake Creek and in the eastern part of the county are broad tracts of land beneath which the water table lies at depths of 25 to 50 feet below the land surface. Topographically these tracts are mainly terraces, and some of the most promising irrigable lands are situated on them. In the southern parts of the county, where the water table lies at depths of 25 to 50 feet, the soil is very sandy. In the upper reaches of Snake Creek, where the depth to the water table is small and along the Niobrara Valley the land is rough and dissected and hence not economically valuable.

A large area beneath which the water table lies at depths of 50 to 100 feet extends along the south and east sides of the central upland and south of Snake Creek. This area is smooth in the east and southeast, and its slightly rolling aspect does not restrict the irrigable land seriously, but in the south it is rougher and more sandy. The areas where the water table lies at similar depths along the Niobrara Valley and the valley of Dry Creek are deeply eroded.

In the central and north-central parts of the county, referred to as the central upland, the water table lies at depths that range from 100 to as much as 275 feet below the land surface. The depth is greatest in the northwestern part of the county, and in the northern part, where the water table slopes off steeply toward the Niobrara Valley. It is within this area that the depth to the water table becomes so great that successful irrigation becomes problematic, owing to the high pumping lift. The yield of stock wells is also generally small because the wind-driven force pumps are taxed by the great pumping lift. The land, however, is mainly very desirable for agriculture.

Land use in Box Butte County is to a great extent controlled by the type of soil, which in turn depends considerably on the nature of the underlying geologic formation. But depth to water is also an important control, which will assert itself more and more as water from underground sources is integrated into the agricultural system in the county. Those lands where the water table is at extremely small depths or where it is at extremely great depths will probably be changed little. Areas of shallow water table are now used as hay flats—a very apt use—and in areas of deep water table the pumping lift becomes an effective limiting factor. But in areas where the water table lies roughly from 25 to 100 feet below the land surface the possibilities of marked increase in the use of ground water are excellent.

In the Monroe Creek and Harrison sandstones and the Marsland formation the numerous dense concretionary sandstones tend to inhibit the downward seepage of the water that soaks into the ground and passes below the reach of plant roots. It is reported that occasionally a little water is detected in the drilling of wells lying on some of these concretionary zones above the water table. This water, to the extent that it can flow into a well, belongs to a perched zone of saturation and is called perched water. The perched water is believed to flow laterally along the dense zones of impermeable beds and so to bypass them and to reach the water table ultimately. Two localities were discovered where the perched zone of saturation yields enough water to be of practical significance. One area is in the northwestern part of T. 27 N., R. 48 W., and the other is in the southeastern part of T. 28 N., R. 47 W. This perched water exists in a rather thin film of Ogallala sand that overlies the clays of the Box Butte member of the Sheep Creek formation. The depth of the perched water is about 30 feet or less, depending on the topography at the land surface. A few wells end at this zone and draw the water for small domestic and stock supplies.

MOVEMENT OF GROUND WATER

The topic on movement of ground water includes discussion of the direction of movement and the rate of movement in the order named. The direction of horizontal movement of ground water can best be visualized on a comprehensive scale by means of a contour map on the upper surface of the zone of saturation—the water table. Such a map (see pl. 8) is constructed by relating the measured depths to water level in numerous wells to some fixed datum, as sea level. In this study the approximate altitude above sea level of the water level in the wells was determined by means of two surveying aneroids. The levels were run from United States Coast and Geodetic Survey bench marks, one instrument being carried to the wells in which the water level had been measured and the other being stationed at the bench mark to detect the changes in barometric pressure that might render the readings at wells in error.

In massive uniform sands, such as the water-bearing formations in Box Butte County, the ground water may be presumed essentially to move uniformly at right angles to the contour lines from higher to lower contours. Thus as the eye scans the contours, crossing from higher to lower at right angles, it closely duplicates the flow lines along which the ground water is moving. The contour interval is 10 feet. The contours indicate that ground water is entering Box Butte County chiefly from two areas—from the tablelands to the west, in Sioux County, and from the sand-hills area to the south, in Morrill County. A subsidiary underflow from the west is also indicated along the valley of the Niobrara River and along Snake Creek. In the south the ground water is moving obliquely toward Snake Creek, and all of it enters the lowlands of Snake Creek Valley. In the west the water that enters the county begins to spread out, as it were, some going southeastward into Snake Creek Valley, some going eastward beneath the central upland, and some going northward and northeastward to the Niobrara Valley. The destination of the water in the eastern part of the county is one of three places: Lower Snake Creek Valley, the undrained lowlands northeast of Alliance, or the drainage basin of Box Butte Creek. In Box Butte Creek the ground water is ultimately discharged mainly as underflow toward the Niobrara Valley, or by phreatic runoff into Box Butte Creek. But in the lowlands in the southeastern and eastern parts of the county the ground water is disposed of by evaporation and transpiration.

If the transmissibility of the aquifer remains constant from place to place then any change in the hydraulic gradient, as expressed by the spacing of the water-table contours, means a change in the rate of horizontal movement of the ground water. But in a body of ground water, such as exists in Box Butte County, changes in the hydraulic gradient may be caused by a variety of circumstances some of which can be identified and some of which are too local, insignificant, or obscure to be identified. For instance, in the southern part of the county, in T. 24 N., Rs. 49 W. and 50 W., the gradient is unusually steep. The steepening is thought to be due to the high rate of recharge that prevails in the sand hills of northern Morrill County; hence, the discharge through the sediments at this locality is unusually high, and so is the velocity of the horizontal movement of ground water. No change in transmissibility is indicated by the existing information. Along the edge of the Niobrara Valley there is another steepening of the gradient of the water table, but for a different reason. Here the saturated material becomes restricted in thickness and hence is less transmissible. A greater rate of movement is required to hold the discharge to an appropriate level in this area. In the eastern and southeastern parts of the county, near the Sheridan County line, the gradient of the water table diminishes markedly. In this area the ground water from the deeper parts of the aquifer is rising toward the surficial points of discharge, such as seepage areas and lakes. As the vertical component of the movement increases, the horizontal component decreases in measure, and the contours are farther apart. One other important area where the gradient of the water table changes is in the northeastern part of the county; it is the large bodies of perched water here that were previously described. The gradient steepens, and the reason is thought to be the decrease in the amount of recharge added to the zone of saturation. Thus, an increase in rate of horizontal movement is required to maintain a commensurate discharge through the saturated section of water-bearing material. The relation of the contours to recharge to the zone of saturation is discussed at length on pp. 51–57. In addition, some local changes in gradient are difficult to explain and probably do not indicate any important variation in conditions. It can be stated that the gradient of the water table is rather uniform eastward across the axis of the central upland and averages about 14.5 feet to the mile. The relative rate of horizontal movement of ground water has been mentioned in the foregoing discussion. The average rate of this movement can be computed in absolute terms. By the average rate of horizontal movement is meant that rate which is required to maintain the indicated discharge through a given cross section of the aquifer. On the central upland a coefficient of permeability of 245 was computed for the sediments penetrated by the Dyer irrigation well (No. 132). Using this figure for permeability, and the average hydraulic gradient of 14.5 feet to the mile, which prevails on the upland, and a porosity of 40 percent, which is the average porosity of samples taken from the outcrops of the Monroe Creek and Harrison sandstones and the Marsland formation, the average rate of movement of ground water is computed to be 90 feet a year. The porosity of the Monroe Creek, as indicated by the available sample, is higher than the porosity of the Harrison sandstone and the Marsland and Ogallala formations, which are 36 to 38.8 percent. If the porosity of 37 percent is used, the average horizontal velocity of the ground water is 100 feet a year. The range in these calculated values is not great, and it is the magnitude that is of interest. As compared with the rate of ground-water movement computed in some other parts of the country, the rate in Box Butte County is rather low. Thus, in the Platte Valley near the Grand Island, Wenzel[30] computed an average velocity of about 230 feet a year; near Kearney, 1,423 feet a year; and near Lexington, 985 feet a year. In these localities the water-bearing material is much more permeable than in Box Butte County.

REPLENISHMENT OF GROUND WATER

The ground water that is slowly migrating eastward across Box Butte County through the Tertiary aquifers has its origin in one of two sources.

[30] Lugn, A. L., and Wenzel, L. K., Ground-water resources of south-central Nebraska, with special reference to the Platte River Valley between Chapman and Gothenburg: U. S. Geol. Survey Water-Supply Paper 779, pp. 132–137, 1938.

A part of it enters the county by lateral percolation from lands to the west and south, and a part of it finds its way to the zone of saturation by downward seepage of rain water and snow water within the boundaries of the county. Perhaps a small amount of water enters the county as stream flow and contributes water to the zone of saturation by influent seepage. The water that enters the county by lateral percolation will be discussed first.

Detailed inspection of the water-table contours on plate 8 shows rather conclusively that the water that enters the county by lateral percolation from the areas to the west and south contributes relatively little to the immense reservoir beneath the eastern part of the county. Using the best estimates available for the transmissibility of the water-bearing materials, together with the hydraulic gradient by which the water is urged into movement, it is computed that about 14 million gallons a day, or 15,680 acre-feet a year, crosses the 4,350-foot water-table contour from the west. Of this amount, about 80 percent enters the natural ground-water discharge area in the lowlands of Snake Creek Valley. All the water crossing the same contour south of Snake Creek enters Snake Creek Valley rather directly; north of Snake Creek the water is deflected toward the valley more obliquely. At the north end of the contour an estimated 12 percent of the total amount moves northward and northeastward to the Niobrara Valley; and about 8 percent moves to the eastern part of the county. This 8 per cent represents a little more than one million gallons a day, or about 1,120 acre-feet a year.

The implication of the foregoing estimates is important to an understanding of the ground water in Box Butte County, for it means that recharge from the land surface must account for a great part of the water in the Tertiary water-bearing sediments. If it should be assumed that all ground water in the county between Snake Creek and the north boundary is derived from subsurface percolation from areas beyond the boundary, then there should be certain necessary and recognizable criteria. If the criteria are shown not to exist, then the assumption can be considered to be wrong. For the purpose of the discussion figure 2 was constructed. It shows fifty-foot contours, somewhat generalized to fit the reduced scale, across which the flow lines have been drawn at right angles to the contours. Areas in which the water table lies at a depth of 100 feet or more are enclosed in the broken line. In the central upland these flow lines diverge from the western area. This spreading out of the flow lines shows that if all the ground water in the county originated as underflow from the west, then one of two alternative results should obtain: (1) A decrease in the velocity of ground-water movement, or (2) a decrease in the thickness of the saturated material above the impermeable platform of the Brule surface. It can

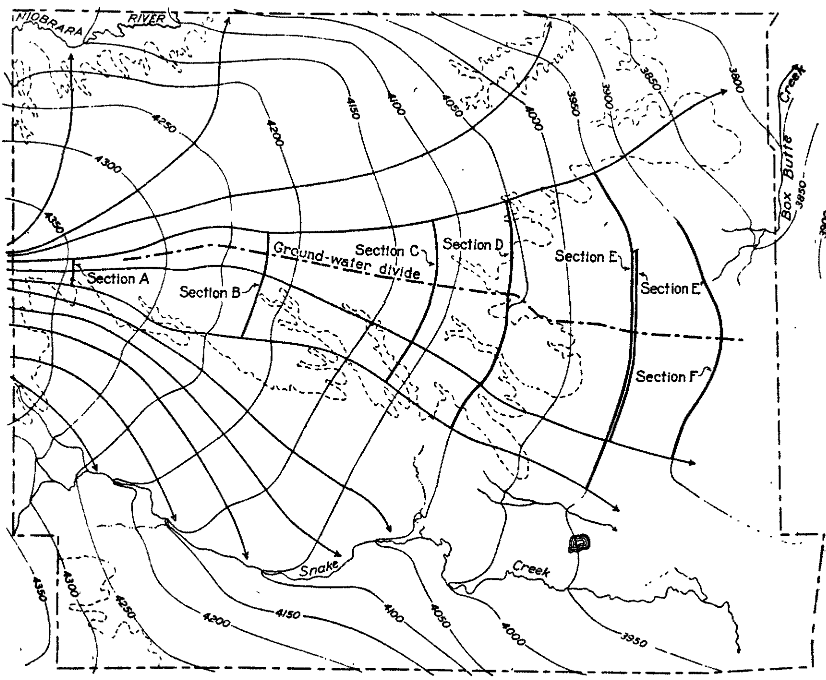

Figure 2.—Map of Box Butte County showing contours of the water table. Dashed line encloses area in which water table lies at a depth of 100 feet or more. *A-F*, sections used for computing recharge.

be stated definitely that neither of these results has been observed. In fact, the contrary condition exists. The thickness of the saturated material increases from west to east, and the slope of the water table remains about constant across the central upland, at about 14 or 15 feet to the mile. This being so, then one of two circumstances must account for it: (1) The average permeability of the water-bearing material must undergo a systematic and gradual decline across the county from west to east, or (2) much of the ground water beneath the central and eastern parts of the central upland must have as its origin recharge from the land surface. As for this pair of alternatives, it can be said that such a decline in permeability as would be required has not been detected. It is true that certain changes in the average permeability of the saturated part of the Tertiary aquifers do take place. In the western part of the county the zone of saturation involves all the Monroe Creek and a part of the Harrison sandstone. In the central part of the county all the Monroe Creek and Harrison sandstones and the lower part of the Marsland formation are saturated. In the eastern part of the county all the Monroe Creek and Harrison sandstones and all the Marsland formation are saturated, and an ever increasing proportion of the Ogallala is also water-filled. Thus, up to the point where all the Harrison is saturated, the average permeability is gradually increasing; as more and more of the Marsland formation is saturated the average permeability declines somewhat; and still farther east, as more of the Ogallala is saturated, the average permeability again increases. These changes in the average permeability of the saturated parts of the aquifers must be considered in conjunction with the thickness of the saturated material if it is to bear on the present problem. It can be shown by computation that the increase in the saturated thickness eastward more than compensates for the decline in average permeability that accompanies the intrusion of the silty Marsland formation into the zone of saturation. This means that more water crosses each contour successively toward the east. Thus, it may be said without qualification that the logically necessary corollaries of the assumption that the ground-water beneath the central upland in the central and eastern parts of the county is all derived from percolation from regions to the west are false. This may be regarded as proof that much of the ground water in these parts of the county is derived from recharge on the upland plain that has seeped down through many feet of unsaturated material to the water table.

The amount of water contributed by recharge from the land surface on the central upland can be computed. The procedure used is as follows: Sections *A* through *F* were selected in such a way that they will all lie between one and the same pair of flow lines. (See fig. 2.) As the flow lines diverge from west to east, the sections farther east become longer than those in the west. Section *A*, the section farthest west, is the shortest, and section *E*, which is in the eastern part of the county, is the longest. Because of spatial limitations, section *F* is compared with only a part of section *E*, that part being referred to as *E'*. The values for average field permeability of the saturated water-bearing material found at wells 132 and 147 were broken down in terms of the formations penetrated by these wells in order to fit the materials found at each cross section. Thus, the average field permeability of the Ogallala found by this method is 423; of the Marsland formation, 67; of the Harrison sandstone, 333; and of the Monroe Creek sandstone, 200. By assigning the average field permeability of the four formations to their appropriate thickness represented at each section, the transmissibility was computed for each section. The average gradient at each section was measured from the water-table contour map. The transmissibility multiplied by the average gradient, multiplied by the length of the section, equals the quantity of water crossing each section within a given time. When the discharge is determined it is found that more water is crossing each section farther east than the one immediately to the west. This difference is an increment that necessarily has its origin as recharge from the land surface between the sections. Thus, more water crosses section *C* than section *B*. The difference in these quantities is considered to be recharge. This recharge can be expressed either as an absolute amount or as inches over the area between the two sections and bounded laterally by the pair of diverging flow lines. The computed recharge between pairs of adjacent cross sections is set forth in the following table:

TABLE 6.—*Computed recharge between sections A through F, in acre-feet a year, and in inches a year over a tributary area*

Section	Daily discharge (gallons)	Daily recharge between pairs of adjacent sections (gallons)	Annual recharge (acre-feet)	Annual recharge over tributary area (inches)
A	712,800			
		6,265,300	7,011	4.24
B	6,978,100			
		4,124,000	4,614	1.86
C	11,102,100			
		3,065,900	3,438	1.82
D	14,168,000			
		3,985,500	4,469	1.15
E	18,153,500			
E'	9,750,200			
		3,853,600	4,312	2.24
F	13,603,800			

The computed recharge in table 6 exhibits some interesting variations. The greatest amount—4.24 inches a year—takes place between sections *A* and *B*. Much of this land is underlain by Harrison sands. As has been pointd out, the wind has excavated large hollows that are not only undrained, but that gather to themselves small centripetal drainage systems that bring storm runoff during rains of high intensity. The water thus brought in stands in these hollows until it is disposed of by evaporation and by seepage into the ground. The mechanism for heavy recharge is certainly present and coincides with the high computed value. Elsewhere in the tributary area between these two sections the lower beds of the Marsland formation are exposed at the surface; this part of the formation is lacking in continuous limy zones and is fine-grained by fairly well sorted fine silty sand. The eastward bulging of the contours is very well marked, which is a criterion of recharge. Although section *A* is very short, and the possibility of error is considerably greater than in the longer sections, the central fact of the great amount of recharge is probably correct. Between sections *D* and *E* the recharge is smallest. Between these sections the greatest proportion of area is covered by the Box Butte clay. It was pointed out that in the northeastern part of the county this clay upholds a perched zone of saturation, and in this area the contours do not bulge eastward. This observation also seems to indicate that the Box Butte inhibits recharge in areas where it has not been dissected greatly by the upland gullies. The recharge between sections *E′* and *F* is greater than that between all other sections except *A* and *B*. Here is a combination of two favorable factors that operate toward large recharge—the outcrop of the coarser Ogallala sands at the land surface, and the diminished depth to the water table. The 3,900-foot contour bulges eastward much more than the 3,950-foot contour, thus indicating the increased recharge. It is thought that these variations in the computed recharge, by coinciding with conditions that should produce them, tend to confirm their value as indicators of an actual process.

The area between sections *B* and *D* may be considered typical of much of the central upland, and hence the recharge computed for this area is probably typical of much of the central upland. The depth to the water table is nearly everywhere more than 100 feet, and the Marsland formation is exposed over nearly all of it, although a certain amount is covered by the Box Butte clay. It seems, therefore, that an annual recharge of about 1.75 inches may approximate the average recharge on the central upland of Box Butte County. In this part of the county the recharge would be expected to be the least, whereas in the lowlands, where the water table lies at a lesser distance below the land surface and where sandstone or dune sand covers the land, the recharge would be considerably greater.

Insofar as the depth to the water table affects the amount of recharge, a certain indefinite generalization can be made. Where the water table lies at greatest depth the recharge is supposed to be least, most delayed, and steadiest. In the areas of moderately deep and deep water table the increase in recharge is not offset by an increase in loss from the zone of saturation into the atmosphere; but in the areas of shallow water table, where recharge is greatest and most immediately responsive to changes in precipitation, the losses from the zone of saturation through evaporation and transpiration more than offset the increased recharge. Thus, areas into which ground water percolates and from which it is discharged by evaporation and transpiration also receive the greatest temporary contribution from recharge at the land surface.

Recharge can be detected qualitatively by changes in the water level in observation wells. Plate 9 reveals that water levels in wells 2, 16, 17, and 378 rose after heavy precipitation in the early summer of 1938. The water level in all these wells is less than 30 feet below the land surface. Well 16 showed two rises—one, amounting to about a half foot, occurred early in the summer and was followed by a decline to about its previous level; another, later in the summer, carried the water level to a stage about three-quarters of a foot higher. Wells 16 and 17 are both within the outcrop area of the Ogallala formation. It is significant that well 15, which is not far from 16 and 17 but is in an area where the Box Butte clay is exposed at the surface, showed no rise during the summer of 1938. Well 2 showed a slow rise of water level that gradually flattened out during the later part of the summer. Well 378, in which the water level lies very near the land surface, showed rapid rises and equally rapid declines as the precipitation waxed and waned.

The observation wells in areas of deep water table have shown only a slight irregular downward trend during the observation period of 6 years. As the ground water in those areas is slowly draining out into the lowlands, it is evident that the recharge which has been shown to take place there must be slow and steady. All the pulses characteristic of recharge in areas of shallow water table have been smoothed out, and an almost perfect state of equilibrium between outgo and income has been attained there.

In conclusion, it has been computed that about 15,680 acre-feet a year of ground water crosses the 4,350-foot contour and enters Box Butte County from the region to the west. Let it be recalled that all but about 1,000 acre-feet a year is ultimately diverted into the lowlands of the Snake Creek and Niobrara Valleys. Then this amount of percolation may be compared with the 20,160 acre-feet a year that crosses section *E* in the east-central part of the county (fig. 2), and some idea of the importance of recharge from the land surface to the ground-water supplies of Box Butte County may be obtained.

NATURAL GROUND-WATER DISCHARGE

It has been pointed out in a previous paragraph that the ground water in Box Butte County is migrating slowly from areas of high water table into areas of natural ground-water discharge. Ground water in the northern third of the county drains into the lowlands of the Niobrara, either directly or through Box Butte Creek. Once in these lowlands, the ground water is dissipated either by evaporation and transpiration or by runoff and subsurface underflow down the Niobrara Valley. But the ground water in the southern two-thirds of the county can be discharged only by evaporation and transpiration. There is neither runoff nor subsurface underflow out of this area, although during rare floods Snake Creek sometimes pours into the sand hills to the east of Box Butte County. The ground water, moving into the areas of shallow water table, comes within reach of the plant roots directly, or the capillary fringe intercepts the root zone, and transpiration takes place during the growing season. Where the water table and capillary fringe intercept the land surface, ground water is also evaporated directly into the atmosphere; but evaporation probably accounts for much less water in a year than transpiration. As the water near the land surface is removed, it is replaced by more water moving in from the margins of the discharge areas and also by water that moves vertically upward from deeper parts of the zone of saturation. During the nongrowing season it must be supposed that evaporation becomes the dominant process of ground-water discharge, and hence the total amount of ground water discharged is rather small.

The amount of ground water that moves into the natural discharge area and that is thence discharged into the atmosphere in the south two-thirds of the county can be approximately determined. A point was selected on the 3,900-foot contour in the eastern part of the county, north of which it appeared that ground water was deflected into the drainage system of Box Butte Creek and south of which the ground water discharged into the undrained lowlands northeast of Alliance. Then from this point westward a gradient line was constructed at right angles to the water-table contours. This flow line is the north boundary of the area in which the ground-water discharge is to be specifically studied. It is labeled the ground-water divide in figure 2. It should be noted that it has no relation to the surface-water divide between the Niobrara River and Snake Creek drainage basins that lies farther north. It follows that all ground water that enters the area south of the ground-water divide from outside and all that originates on it from infiltration must be discharged into the seepage areas. The underflow from the west has already been computed; and 12,545 acre-feet a year is calculated to enter the part of the county under consideration. The amount of underflow from the sand-hills region to the south of the county is less accessible for computation because the geologic conditions are not so well known. However, by applying the known transmissibilities found in comparable parts of the county and averaging them, a usable value was obtained. The transmissibility at the west end of the south boundary of the county is taken to be 56,000, based on fairly reliable values of permeability and thickness of saturated material. In the center of the south boundary of the county, the value of transmissibility found at well 199 was used—144,000. For the east end of the boundary line the value of transmissibility found at section *E* (see fig. 2) and used in the study of recharge was applied, for conditions there are thought to be applicable. This value is 82,000. The average transmissibility used to compute underflow from the areas south of the county becomes 94,000. The gradient of the water table was weighted and averaged from direct measurement and was 25.5 feet to the mile. The length of the section across which the water is moving was determined from measurement of the sections of water-table contours arranged en echelon. It is 27.5 miles. The product of these values gives an underflow of 73,700 acre-feet a year from the south. As for the ground water originating within this southern two-thirds of the county as recharge, two separate categories must be recognized. The first is the recharge on the upland areas, and the second is the rain that falls on the seepage areas themselves, all of which must be discharged from them. Recharge on the upland is believed to average about 2.5 inches a year over the area outside the points of natural discharge. This recharge accounts for 60,130 acre-feet a year. In those lowlands where the water table lies at a depth of less than 25 feet below the land surface, it is assumed that all the rainfall on them must be removed by the same agencies as those that remove the ground water that percolates into them. A part of this precipitation enters the zone of saturation or capillary fringe before it is discharged; the rest of it is discharged immediately or stored at the land surface temporarily. For the seepage areas as a whole this is not a very wrong assumption, because, except for about 12 square miles south of Snake Creek in the south-central part of the county, the ground water in these seepage areas lies 10 feet or less below the land surface. A yearly precipitation of 16.73 inches falling on the 195 square miles of discharge area is equivalent to about 173,970 acre-feet a year. The total computed amount of water discharged by transpiration and evaporation is the sum of all the quantities determined, from which is subtracted an estimated 1,900 acre-feet a year that is pumped from the wells in the southern two-thirds of the county. The net computed discharge from these discharge areas is 318,450 acre-feet a year, or 2.55 acre-feet an acre a year, of which 144,480 acre-feet a year, or 1.16 acre-feet a year for each acre, entered the discharge areas from outside by ground-water percolation. The rest fell on the discharge areas as rain and snow. An unknown but a probably unimportant amount of water enters the county as underflow from the east; a small amount may leave the southeast corner of the county by underflow; and an indeterminate amount of surface runoff finds its way into the discharge areas from the higher lands during rains of high intensity. These items are not accounted for. They tend somewhat to compensate and probably are not quantitatively great in relation to the quantities that have been accounted for.

The loss of water in the undrained lowlands represents about one-half of the amount of water that normally falls in 1 year on the southern two-thirds of the county. The total precipitation is computed to be 606,335 acre-feet a year; the total discharge from the discharge areas, 318,450 acre-feet a year. Of the total amount of water dropped as rain and snow on the area in question, 173,970 acre-feet a year fell on the seepage areas themselves, and 432,365 acre-feet a year fell on what are considered the uplands, outside the seepage areas. Of this 432,365 acre-feet, 60,130 acre-feet a year, or about 14 percent, is computed to have reached the zone of saturation as recharge. The remaining 372,235 acre-feet a year, or about 14.23 inches (86 percent of the total precipitation), is annually lost to the atmosphere or, to a small degree, runs off as ephemeral stream flow into the discharge areas. The water that does not run off is evaporated from standing water on the flat uplands or in undrained wind-scoured depressions and from plants and other objects on the land surface; some is readily transpired by the upland prairie vegetation; and the rest is temporarily stored in the soil of the root zone, to be extracted by plant roots and transpired at a later time. A small amount of this water may possibly pass below the root zone but later may be delivered to the root zone or land surface by capillary force or removed from the soil by evaporation. It seems, therefore, that much of the computed 86 percent of the rainfall on the upland is lost and that about 14 percent reaches the water table and is ultimately discharged as ground water from undrained discharge areas. It may be of interest to note that the total discharge of the Niobrara River at Dunlap, Dawes County, in the water year 1936–37 was equal to about 0.36 inches of water over the whole drainage area of 1,550 square miles. Thus, of about 12 inches of precipitation that fell during 1936–37, only 3 percent appeared in the river as runoff.

The discovery through field and experimental investigations of the great amount of water that plants can dispose of through transpiration has been well-nigh revolutionary in the study of hydrology. If the computed amount of water discharged from areas of shallow water table in Box Butte County are of the correct magnitude then about 30 inches of water are evaporated and transpired during a normal year, and about 14 inches of water are evaporated and transpired each year from the upland areas. According to information furnished by W. L. Tolstead, of the Conservation and Survey Division of the University of Nebraska, 4 feet of water was consumed by arrowhead, wildrice, bulrush, and cattail in Cherry County, Nebr., between July 9 and September 20, 1937. A like amount was consumed by swamp grasses and tall meadow grasses during the same period in areas where the water table lay about 3 feet below the land surface. The true prairie grasses in areas where the water table lies at depths of 3 to 6 feet below the surface were estimated by Tolstead to have transpired about one-half as much water in the same period as the other types of vegetation cited. As the water table declines, the grasses obtain and consume less water. These figures cannot be quantitatively applied to Box Butte County, but they illustrate that the lowlands of western Nebraska are tenanted with potent agents for getting rid of water. In addition, the evaporation from water surfaces, as measured at the Box Butte Experiment Farm of the University of Nebraska near Alliance, in May, June, July, August, and September, 1938, was 39.18 inches. It seems, therefore, that the computed losses of water from the areas of shallow water table are not excessive in the light of the above-mentioned information.

GROUND-WATER STORAGE AND SPECIFIC YIELD

Ground-water storage within an aquifer may be construed to be one of two quantities—the total amount of fixed water within the pore spaces of the aquifer, or the amount of the stored water that will move out of the pore spaces under the force of gravity. Obviously, the second kind of storage—that which is available to wells, springs, and perennial or intermittent streams—is the significant one in a study of water resources. But ground-water storage, thus qualified in terms of availability, becomes a rather elusive quantity, as will be shown.

The relation between mobile water and fixed water in an aquifer is expressed by the term "specific yield" of the aquifer. The specific yield of an aquifer is defined by Meinzer[31] as the "ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume." This means that if 1 cubic foot of saturated water-bearing material will yield by draining under the force of gravity a volume of water of 0.15 cubic foot, the specific yield of that water-bearing material is 15 percent. Under natural conditions in an aquifer that is exposed at the land surface and that has a specific yield of 15 percent, a recharge amounting to 0.15 foot over the area of the aquifer will produce a rise of the water table of 1 foot. Conversely, a

[31] Meinzer, O. E., Outline of ground-water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, p. 28, 1923.

decline of the water table in this aquifer of 1 foot indicates the loss of water equivalent to 0.15 foot distributed over the area of the aquifer. In detail, where minute quantities of water are being considered, specific yield is a difficult quantity to determine; the length of time for all available water to be removed by percolation under gravity is uncertain; the nature of the forces that hold or impede the movement of water in a permeable material is still being explored; the accuracy of the known methods of determining the value of specific yield in a given aquifer is not fully known; and other aspects of it are likewise unclarified. But on a regional scale, specific yield is an adequate and necessary factor and marks the effective reclamable storage of water in an aquifer.

In his discussions of the fluctuations of water levels in the observation wells in Nebraska, Wenzel[32] has assumed that the average specific yield of the water-bearing material in the State is 15 percent. For the purpose of certain illustrations concerning the ground water stored in the aquifers of Box Butte County, a specific yield of 15 percent will be assigned to these aquifers. It is believed that this assumed yield is so near enough true average specific yield of these sediments that the conclusions arrived at will be essentially correct.

With a specific yield of 15 percent, an area of 1,076 square miles, and an average thickness of saturated material of 300 feet, the stored available water in Box Butte County is 31,000,000 acre-feet. This storage may be compared with the amount of rain that normally falls on Box Butte County (assuming that the normal precipitation that falls at Alliance prevails uniformly over the county). Thus, 16.73 inches of precipitation over the 1,076 square miles amounts to 989,965 acre-feet of water a year, which means that more than 31 years' supply of rainfall is stored in available form beneath the surface of Box Butte County. This enormous storage, which is in a stable but dynamic state, can be depleted by natural and artificial discharge or can be replenished in the long run at essentially the same rate by underflow from areas outside the county and by recharge from precipitation on the land surface within the county.

Another application of specific yield can be made for the purpose of illustration. If pumping were carried on in a section of land at such a rate and for such a duration that the average draw-down of the water table would be 1 foot for the whole square mile of area, then, with a specific yield of 15 percent, 96 acre-feet would necessarily have been withdrawn. Or, stated in the reverse order, the withdrawal of 96 acre-feet would produce a draw-down, which, if it were evenly distributed over 1 square mile, would be equal to 1 foot. The draw-down

[32] See U. S. Geol. Survey Water-Supply Papers 777, 817, 840, 845, 886, and 908.

produced by pumping a well is not evenly distributed over a large area but is greatest at the pumped well. More will be said of draw-downs in the next section of this report.

The recharge in the eastern part of the county has been computed to be 2.24 inches a year under normal conditions. This recharge would, in an aquifer having a specific yield of 15 percent, produce a rise of the water table of 1.24 feet. On the upland the recharge was computed to be 1.15 inches a year. This recharge would produce an annual rise of the water table of 0.64 foot. It must be understood that this rise, if it were plotted, would not be superimposed on a horizontal base; it might, and in the recharge on the uplands it probably does, appear simply as a nullification of the decline of the water table that would take place if recharge were halted. Thus no positive rise of the water table would be expected.

EFFECTS OF PUMPING WELLS ON WATER LEVELS CONSIDERED THEORETICALLY

Having computed the transmissibility and permeability of the Tertiary aquifers, and having assumed an apparently reasonable value for the specific yield of these aquifers, we can compute the draw-downs that a well pumping under certain given conditions would produce at any distance from it, and after any desired interval of pumping. For instance, let it be supposed that a well is pumping at a rate of 1,000 gallons a minute without interruption during an irrigation period of 4 months. The draw-down of the water level at the pumped well can be determined theoretically after the first few hours of pumping, or after the first day, or week, or month, or at the end of the entire 4 months. Moreover, the effects of the pumping can be predicted on the water level in a neighboring well at a distance of 10 feet, or a quarter of a mile, a half mile, or any other reasonable distance from the pumped well at any desired time after pumping begins. If the neighboring well happens to be also a pumped well, the mutual interference of draw-downs can also be predicted at each well, or the combined draw-down of both wells at any point between them can be computed theoretically. This process cannot be said absolutely to represent reality in the present study for several reasons but is presented as an illustration that approximates reality. In the first place no outstanding group of wells collectively present a major ground-water problem to which the method under discussion could be applied, and in the second place the theory of this procedure imposes certain limitations that arise from the mathematical assumptions inherent in the basic formula. However, the computations about to be presented are a kind of summation of the quantitative hydrological factors that have been searched out in the preceding discussions.

The theoretical appraisal of the effects of pumping of wells on the surrounding water table is based on the nonequilibrium formula of Theis,[33] which states that

$$s = \frac{114.6q}{T} \int_{\frac{1.87r^2S}{Tt}}^{\infty} \frac{e^{-u}}{u}\, du,$$

in which

s is the draw-down at any point, in feet,
q is the rate of discharge of the well, in gallons a minute,
T is the coefficient of transmissibility,
r is the distance from the discharging well to the point where draw-down is to be determined, in feet,
S is the specific yield (or, under artesian conditions, the coefficient of storage), and
t is the time the well has been discharging, in days.

The calculation of s involves determining the value of $\frac{1.87r^2S}{Tt}$, the reading of the corresponding value of the integral in a table presented in Theis' paper, and the multiplication of this value by $\frac{114.6q}{T}$.

The formula will be applied in this discussion as an illustration of what may be expected under certain circumstances, arbitrarily chosen, and subject to limitations that will be brought out in due course in the discussion. In the first case it is assumed that two wells are to be pumped continuously for 4 months. One well is assumed to be situated in T. 25 N., R. 47 W., near well 147; the other in T. 26 N., R. 52 W., near well 132. A line of observation wells runs out from each well in such a way that one well is one-quarter mile from the pumped well, another is one-half mile, another is three-quarter mile, and another is 1 mile from the pumped well. The theoretical draw-down is to be computed at each pumped well at the end of the first day of pumping; then the draw-down will be computed at each pumped well and at the observation wells at the end of 4 months of pumping. Then a second case will be set up, using the same wells and observation wells, but assuming that the observation well 1 mile from the pumped well is to be pumped at the same time, for the same duration, and at the same rate as the first pumped well. Figure 3 shows the arrangement of wells and observation wells at one of the two localities. The combined draw-down at each pair of pumped wells at the end of the first day of pumping is computed, and the draw-down at each pair of pumped wells and the observation wells between them at the end of 4 months of pumping will also be computed.

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[33] Theis, C. V., The significance and nature of the cone of depression in ground-water bodies: Econ. Geology, vol. 33, No. 8, pp. 889–902, December 1938.

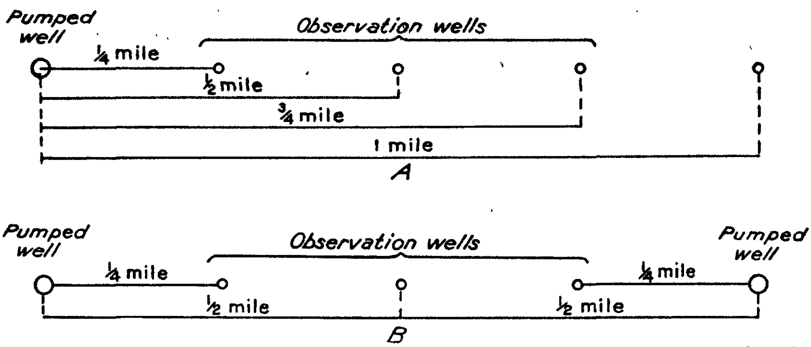

FIGURE 3.—Assumed arrangement of pumped wells and observation wells in which draw-down is theoretically computed.

In this second case the mutual interference will be shown in the combined draw-down at all points of theoretical observation.

It is assumed that the transmissibility in the vicinity of the wells and observation wells in the eastern part of the county is 100,000 and that the discharge rate of the pumped wells is 1,000 gallons a minute. The transmissibility in the vicinity of the western group of wells and observation wells is assumed to be 50,000; the wells there are to be pumped at a rate of 750 gallons a minute. The diameter of the pumped wells is assumed to be 36 inches. In both localities the specific yield is assumed to be 15 percent. It is also assumed that the aquifers are homogeneous in all respects at both localities, that all water pumped has been removed from storage, and that all pumped wells pass through the entire thickness of the water-bearing material. The computed draw-downs at chosen points and at chosen times, resulting (1) when one well is pumped, and (2) when two wells are pumped under postulated conditions in each locality, are presented in tabular form:

TABLE 7.—*Computed draw-down in pumped well in eastern part of Box Butte County and in observation wells situated in a line at stated distances from it*

Distance from center of pumped well (feet)	Interval since pumping began (days)	Draw-down (feet)
1.5	1	13.1
1.5	120	18.6
1,320	120	3.0
2,640	120	1.6
3,960	120	.9
5,280	120	.75

TABLE 8.—*Computed draw-down in pumped well in western part of Box Butte County and in observation wells situated in a line at stated distances from it*

Distance from center of pumped well (feet)	Interval since pumping began (days)	Draw-down (feet)
1.5	1	18.4
1.5	120	26.6
1,320	120	3.4
2,640	120	1.5
3,960	120	.6
5,280	120	.22

TABLE 9.—*Computed draw-down after 120 days of pumping in a pair of pumped wells 1 mile apart in eastern part of Box Butte County and in observation wells situated in a line between them*

Distance from center of pumped well (feet)	Draw-down (feet)
1.5	19.35
1,320	3.9
2,640	3.2

TABLE 10.—*Computed draw-down after 120 days of pumping in a pair of pumped wells 1 mile apart in western part of Box Butte County and in observation wells situated in a line between them*

Distance from center of pumped well (feet)	Draw-down (feet)
1.5	26.82
1,320	4.0
2,640	3.0

It has been said that the values of draw-down given above do not wholly represent reality. In the first place, none of the existing wells of which records have been obtained conform to the theoretical demands of the Theis formula. The aquifers are not homogeneous; the cemented and concretionary zones and the differences in texture of the Miocene and Pliocene sediments introduce heterogeneity. Not all of the water discharged from the pumped wells is derived from storage, for recharge is thought to be going on much of the time in parts of the area. However, these violations of the theoretical necessities are believed to result in only minor deviations from actuality. Probably the chief differences between the theoretical values given in tables 7–10 and the draw-downs that might be observed are the following: (1) The wells in Box Butte County of which records have been obtained do not pass through the entire thickness of the aquifers. Thus, water in the lower parts of the aquifers must rise during pumping from its natural depth toward the bottom of the well. This vertical component of the path of motion reduces the head of the water about the pumped well and increases the actual draw-down in and near it. (2) Most wells have not been developed to a high degree of efficiency nor properly screened, and the water may lose energy through friction in getting into the pumped well. Thus, the water level observed during pumping is not the same inside the well casing as it is outside the casing. The entrance loss of head may amount to several feet.

In spite of these discrepancies, the values of draw-down have some value in practical interpretation of the ground-water conditions in Box Butte County. For instance, in the western part of the county, near well 132, the minimum lift that must be contended with while pumping at a rate of 750 gallons a minute at the end of one day of pumping would be 18.4 feet plus about 90 feet, which is the depth to the undisturbed water table, or about 108 feet. At the end of a 4-month pumping season the minimum pumping lift would be about 117 feet. In the eastern part of the county, where the depth to water under nonpumping conditions may be 25 feet, the minimum pumping lift while pumping at the rate of 1,000 gallons a minute would be about 38 feet at the end of one day and about 44 feet at the end of 4 months. The better the well is developed and the greater the number of aquifers that the well penetrates, the nearer would the actual pumping lift approximate the theoretical value. Also, recharge might be considerable during a period of 4 months and would tend to reduce the pumping lift.

The computed values of draw-down shown in tables 6 and 7 become smaller at points more distant from the pumped well. It also takes a longer time after pumping begins for the more distant parts of the water table to begin their decline. When the cone of depression reaches some distant point the water level begins to decline rather rapidly but gradually slows down until the rate of decline there equals the rate of decline at all other points between it and the pumped well. Thus, after an initial period of adjustment the cone of depression attains a stable form and maintains it, but it gradually sinks deeper, as it were, into the zone of saturation, and in so doing spreads farther out from the pumping well. Its rate of spreading grows ever slower. Barring the effect of recharge, which changes nothing but the average rate of decline of the water level within the cone of depression, the cone of depression continues to enlarge and deepen itself indefinitely until it intercepts and brings to the pumped well enough water that had been previously escaping from the ground-water body to balance the rate of pumping. This capture of wasted ground water by the cone of depression is accomplished in two ways—either by increasing recharge or by decreasing the preexisting discharge from the aquifer. Recharge can sometimes be increased by lowering the water table in an intake area where transpiration and evaporation are taking heavy toll of the incoming water. The water table might be lowered below the root zone of the plants and thus diminish their draft, or if the cone of depression caused a lowering of the water table in an intake area, springs and streams that had been discharging ground water that could not be absorbed by the aquifer would surrender part or all of this wastage of recharge. Natural discharge can be diminished by the cone of depression if the water level is lowered in a discharge area until springs, perennial streams, and swamp plants are deprived of their wonted share of the escaping ground water. Lakes, from whose surface water is evaporated, might shrink in size or even disappear. Artificial ground-water discharge can be diminished by interference, or robbery, of neighboring wells. When enough water that once escaped from the aquifer has been captured within the cone of depression to balance the amount being pumped from the center of the cone, then and only then the cone of depression ceases to expand.

In Box Butte County the behavior of the cone of depression just described has a practical application. The removal of ground water from storage by pumping cannot increase the recharge to any great degree. But natural discharge can and will be diminished in parts of the county by large-scale pumping, and in those localities the cone or cones of depression may become stable. In the eastern part of the county and in Snake Creek Valley the lowering of the water levels by pumping will certainly result in an important salvaging of water that now is lost by evaporation and transpiration. It is even possible that the area of some of the lakes will be diminished to the point where losses by evaporation will be materially cut down. These savings of water should mean that as pumping is carried on from year to year the decline of the water table will tend to diminish or even to cease at some point. On the other hand, wells drilled on the upland far from the areas of natural ground-water discharge will create cones of depression that will grow deeper year by year for a long time to come. Thus large-scale users of ground water will be confronted with an ever increasing pumping lift. Eventually the cones of depression would impinge on the distant discharge areas and thus bring about a stabilization of the pumping levels, if pumping remains feasible for a long enough time. This fact need not be construed as an unfavorable appraisal of the chances of successful pumping on the upland areas, however, for the water in storage beneath these areas is very great, and its rate of depletion is certain to be very slow under any reasonable program of water utilization. The increase in pumping lifts from one irrigation season to the next would probably be slight.

Another aspect of the discussion of the behavior of cones of depression is implicit in the foregoing tables. That is the mutual interference between nearby pumped wells. Tables 8 and 9 show the draw-down at two pumped wells 1 mile apart and in observation wells between them. According to these tables, the effect of one pumped well on the water-level in another well 1 mile away is slight. The draw-down to be superimposed on the proper draw-down of the second pumping well is only 0.75 foot in one area postulated and 0.22 foot in the other area. A pumped well halfway between them, however, would have imposed upon it an additional lowering of the water level of 3.2 feet in the eastern part of the county, or 3.0 feet in the western part of the county. At the end of a 4-months' pumping season the two pumped wells in the eastern part of the county that are 1 mile apart would have draw-downs of nearly 21 feet, and the well between them would have a draw-down of 21.6 feet. The observation wells between each of these pumped wells at a distance of one-quarter mile would have draw-downs of 6.9 feet. The pumped wells in the western part of the county that are 1 mile apart would show draw-downs of 28.32 feet at the end of 4 months, and the pumped well midway between them, one-half mile distant from each, would show a draw-down of 29.6 feet. Observation wells halfway between the outside wells and the middle well would show draw-downs of 7.4 feet. Under ordinary circumstances the interference would not lead immediately to serious results. Two wells one-quarter mile apart would each draw the water level in the other well down an additional 3.0 feet in the eastern part of the county and 3.4 feet in the western part of the county. This spacing might be regarded as the closest that could be safely undertaken, for the mutual effects at lesser distance would increase at more than a simple arithmetic rate.

FLUCTUATIONS OF THE WATER TABLE

The upper surface of the zone of saturation is the water table. When its position can be seen at any one time, as in the contour map on plate 8, the nature and direction of the movement of the ground water can be inferred from it. When its changes of position are seen through the course of time, the state of replenishment and depletion of the zone of saturation can be inferred. But before important conclusions are reached regarding the fluctuations of the water table, the nature and cause of the fluctuations must be examined, for a rise of the water table, as reflected in the records of the water level in wells, is not in itself proof that water has been added to the ground-water reservoir. Similarly, a decline of the water level in wells can be produced at a time when water is actually being added to the reservoir at a greater rate than it is being withdrawn. Thus, some attention must be given to those forces that have been found to be capable of producing fluctuations of the water table.

The actual measurements of observation wells in Box Butte County in 1938 have been published.[34]

FLUCTUATIONS CAUSED BY CHANGES IN ATMOSPHERIC PRESSURE

An inspection of the hydrographs of the observation wells in Box Butte County in plate 9 will reveal that the successive measurements of the water level in any one well are not likely to fall into a smooth line. This is particularly true of the wells in which the water level lies at great depths, as in observation wells 129 and 338. In the hydrographs of these wells, successive measurements of the depth to water level made within a comparatively brief period show ranges of a half foot, more or less. All that has been said in this report on the recharge, discharge, and

[34] See U. S. Geol. Survey Water-Supply Paper 845, pp. 169–172.

movement of ground water beneath the upland areas of Box Butte County would lead one to believe that the variations of the water level in these wells are not caused by sudden changes in recharge or discharge, or by movement of the ground water. On the contrary, it would be expected that the hydrographs of such wells as these would be smooth lines, in which changes in trend would occur seldom and gradually. These sudden changes of the water level are quite certainly due to changes in the atmospheric pressure at the time the measurements of water level were made.

The exact manner in which the water level in a well fluctuates in response to changes in atmospheric pressure is probably complex. In part, the concretionary zones and tightly cemented layers of sandstone in the Miocene sandstone formations probably aid in segregating the air trapped in interstices at the top of the water table from the free atmosphere, including the air in the well above the water level. The same effect is obtained if a thick zone of aeration is so damp that changes in air pressure are transmitted through interstices imperfectly. Many wells show a barometric fluctuation where this condition prevails. It is believed that if recharge is occurring on the uplands of Box Butte County, as the evidence indicates, the chief reason for the barometric fluctuations of water level is the moisture in the zone of aeration.

Figure 4 shows a portion of the hydrograph of observation well 129 for the period August 18 through August 21, 1938, together with the barograph at Chadron, Nebr., for the same period. The barograph has been converted from inches of mercury to feet of water and inverted for the comparison. The automatic water-level recorder that was installed on the well was not operating very satisfactorily, but the chief features of the hydrograph are correct. The shapes of the two graphs are similar. According to the curves, the range in feet of the water-level fluctuations is about one-third of the range of the barometric curve. Thus, the barometric efficiency of the well is rather low compared with many artesian wells but is decidedly high for water-table conditions.

The water levels in some of the wells in areas of shallower water table seem not to exhibit any barometric fluctuations. The hydrographs of these wells are smooth. Other wells in these areas have irregularities that cannot certainly be attributed to changes in atmospheric pressure. It may be noted that during the summer of 1938 the wells in which the water-level is deepest show the greatest response to changes in barometric pressure. Where the water level is less than 100 feet, the barometric fluctuations almost disappear.

FLUCTUATIONS DUE TO TRANSPIRATION

In areas where ground water is being discharged by swamp-loving plants the water level in a shallow well shows a diurnal fluctuation that

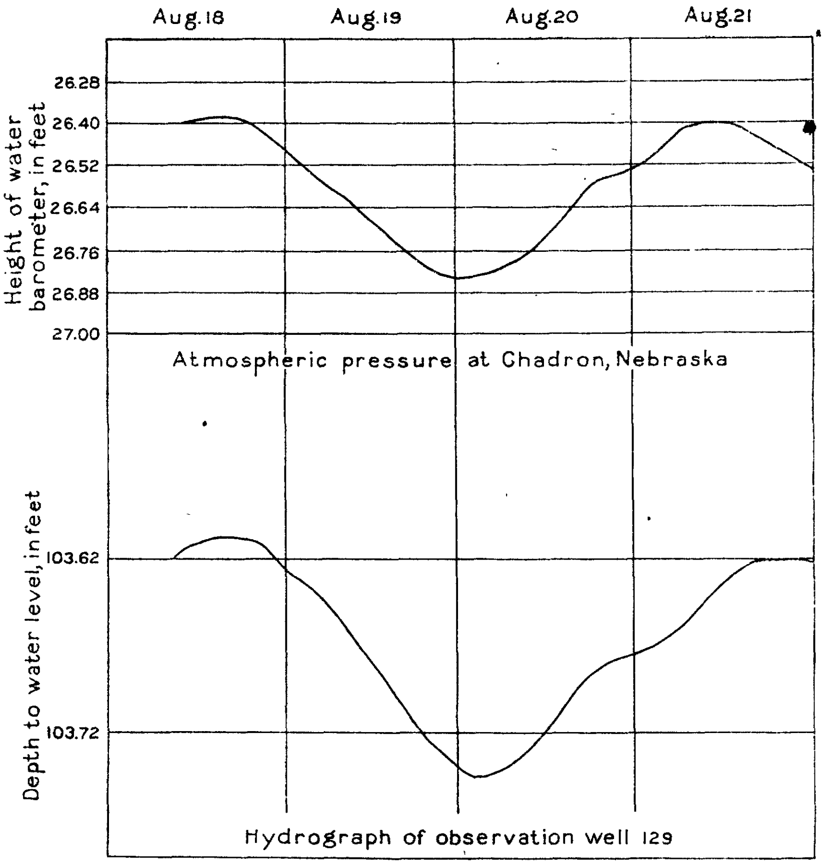

FIGURE 4.—Graph showing effect of changes of barometric pressure on water level.

is characteristic. The hydrograph on such a well[35] shows a decline beginning in midmorning and continuing to late afternoon or early evening. Then, after the curve rounds off, the recovery begins, and it continues until the decline of the next morning is about to begin. The magnitude of the fluctuation may be as much as several tenths of a foot. This type of fluctuation prevails only during the growing season. Where it prevails, two conditions may be inferred: (1) That the ground water that feeds the plants is being brought to the area of ground-water discharge from outside, and (2) that the ground water reaches the central parts of the swampy area by vertical movement from below. The ground water moves upward toward the ground surface at a nearly constant rate, the plants use water faster than it can be supplied from

[35] White, W. N., A method of estimating ground-water supplies based on discharge by plants and evaporation from soil—results of investigations in Escalante Valley, Utah: U. S. Geol. Survey Water-Supply Paper 659–A, 105 pp., 1932.

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below, and the daily decline takes place. During the night the consumption is reduced to a minimum, and the feeding in brings the water level up above the afternoon low point. In many places the hydrograph will show a gradual downward trend during dry periods, but even slight rains are likely to result in decided rises of the water level. A cloudy day will diminish the rate of transpiration, and a slight rise may occur during the day.

In Box Butte County an automatic water-stage recorder was installed on a shallow well in the bottom lands of Snake Creek Valley. The casing was of so small a diameter that the small float did not impart enough sensitivity to the recorder to allow it to detect any fluctuations in transpiration if they took place. However, as the type of grass in the lowlands of the county indicates ground-water transpiration, it is believed that the plants in the vicinity of this well use much water. Part of the irregularity of the hydrograph of observation well 378 is due to transpiration by plants. This well is situated along State Highway 2 at the bottom of the Niobrara Valley.

FLUCTUATIONS DUE TO PRECIPITATION

In a general study of the ground-water resources of an area the fluctuations of the water level in wells in response to precipitation reveals the most important information. Studies of fluctuations caused by other agencies are made chiefly to segregate them from the effects of precipitation on the water level, although they may yield certain special information. Water levels in observation wells in Box Butte County exhibit nearly all degrees of responsiveness to changes in precipitation, from immediate rises after heavy rains and sharp declines during intervening dry periods to slow changes of trend (only partly realized) in response to variations of precipitation taking place over a period of several years. The difference in the magnitude and promptness of the response among these observation wells is largely a function of the depth to the water level in them. For example, the water level in observation well 78, which lies at a depth of 10 to 12 feet, showed a rise of about 2 feet following the heavy precipitation in April and May 1935. The water level in observation well 378, which lies at a still shallower depth, also showed a rise of water level at that time, although the measurements do not cover the period perfectly. On the other hand, observation well 129 showed no effect of the rains at that time. Instead, the water level remained rather constant, with barometric fluctuations superimposed on it, up through 1937, and then the trend seems to be slightly downward. Other wells showed a response of the water level to the rather copious rains of the summer of 1938. Observation wells 2, 16, 17, and 378, in which the water level is less than 30 feet below the land surface, showed a rise in water level of as much as 0.75 foot in July and again in August and September, whereas the observation wells in which the water level lies at a depth greater than 30 feet did not show rises of water level at that time. Observation well 15, in which the water level lies about 30 feet or a little less below the ground surface, is an exception. It is situated in an area where clay of the Box Butte member crops out at the surface, which seems to have prevented recharge. The hydrographs of the other wells that show no notable rise during the summer of 1938 either maintain nearly a constant level or show a slight downward trend during the summer. One imperfection of the record shown on plate 9 is that the precipitation at Alliance is not always the same as at some of the observation wells. Many of the storms during the summer of 1938 were local.

The net rise of the water level was not large during the summer of 1938. Observation wells 2 and 17 had a rise for the summer of about 0.25 foot; observation well 16 had a rise of about 0.75 foot, but the rise amounted to about 1.75 feet by the end of 1938; and observation well 378 showed momentary rises but no net rise for the season. No great rise should be expected at observation well 378, as the upward limit is the land surface and the lower limit is probably determined by the inflow of ground-water from the highlands to the south, which tends to be rather constant. The rise of water level in the other wells represents an actual gain in the ground-water reservoir.

The shape of the hydrograph of observation well 316 was determined in part by pumping from one of the city wells of Alliance a few hundred yards away. The well was destroyed, and thus a valuable record was lost.

UTILIZATION OF GROUND WATER

Ground water is chiefly used in Box Butte County for obtaining domestic and stock, municipal, industrial, and irrigation supplies. Wells put down for the purpose of obtaining domestic and stock supplies are by far the most numerous.

DOMESTIC AND STOCK SUPPLIES

It is estimated that of the 800 to 1,000 wells in Box Butte County, probably 800 are in use. All but a few tens of these wells are being used for obtaining domestic and stock supplies. The older wells in the county were hand-dug, many of them to depths of 100 feet or more, but the later wells, which by far outnumber the older, are drilled or driven. Domestic and stock wells are generally put down to only a few feet below the water table. Thus, their potential yield is limited by the small possible draw-down. But as a high rate of yield is not sought and as the wells are not equipped for producing water at a high rate, this situation is not necessarily unfavorable. Nearly all of the wells of this class are provided with either a hand pump or a windmill, and the rate of pumping is small. In depth, these wells range from a very few feet in the lowlands of the Niobrara Valley, the valleys of Dry Creek, Box Butte Creek, and Snake Creek, and the eastern part of the county, to as much as 240 feet deep on the tableland, where the depth to water is greater. In the sand hills of the southern and eastern parts of the county the depth to water is also small, and wells are of small to moderate depth. The dug wells are 3 to 4 feet in diameter, the drilled wells mainly from 4 to 6 inches in diameter, the tubular wells mainly 4 inches in diameter, and the driven wells mostly 2 inches in diameter. So far as is known, there exists no locality in Box Butte County where it is impossible to obtain enough water to provide for a household or numerous head of stock. In the western part of the county near the rim of the Niobrara Valley, where the depth to water is greatest, drilling for water is most difficult and expensive. Exceptionally powerful windmills and stout pumps are needed in this area. In Snake Creek Valley the alluvium that underlies the land surface for as much as 50 feet is likely to be so fine-grained that it will flow into wells. But this material can be cased off where necessary, and the drilling can be carried down to a more satisfactory water-bearing material at greater depth. Drilling in the sand hills requires a rather special technique, which has been mastered by most of the drillers in the region about Box Butte County. The water obtained is satisfactory for all ordinary uses, so far as the records show.

MUNICIPAL SUPPLIES

Two municipalities in Box Butte County possess public water supplies—Alliance and Hemingford. Alliance has six wells, of which three were in use in 1938 and three were not yet in service. The older wells range in depth from about 140 to about 160 feet. They penetrate only a very small part of the water-bearing material that underlies the city. Logs of four wells are presented in the section containing the logs of wells and test holes. Well 1, which is at Seventh Street and Yellowstone Avenue, is 150 feet deep, yields 500 gallons a minute, and has a depth to static water level that is said to be 22 feet. Well 2, situated at Seventh Street and Hack Avenue, is 140 feet deep, yields less water than well 1, and has a static water level said to be 38 feet below the land surface. Well 3, situated at the rear of the City Hall, is 158 feet deep, and depth to static level is said to be 41 feet. Well 4, situated east of the municipal light plant, is 143 feet deep, yields 390 gallons a minute, and the depth to static level is said to be 44 feet. A sample of water from this well was analyzed chemically, and the analysis is presented in this report.

Well 4 is gravel-packed. Very little technical detail is known about the municipal wells of Alliance. The consumption of water at Alliance varies greatly from day to day and from month to month. In August 1938 the total consumption was 42,633,900 gallons; during that month the maximum daily consumption was 1,745,700 gallons, and the minimum daily consumption was 746,000 gallons. In March 1938 the total consumption was 14,080,000 gallons; the maximum daily consumption during that month was 760,000 gallons, and the minimum daily consumption was 427,000 gallons. The water is pumped to an elevated tank in the northwestern part of town, and from there it is released into the mains by gravity or is pumped directly into the mains. The available ground water in the vicinity for possible development is great. The pumping at the rate that prevailed in 1938 has created a slight cone of depression around the town, sufficient to have moved the 3,920-foot water-table contour some distance west of its probable original position, and has made its effect perceptible in the water level of observation well 316. But if any wells that are drilled in the future are spaced widely about the town there is no reason to believe that the ground-water reservoir will be depleted as a result of any reasonable expansion of water consumption.

The public water supply at Hemingford is obtained from two wells. Both wells are 300 feet deep, are gravel-packed, and the depth to their static water level is reported to be about 175 feet. The diameter of the well in the upper 100 feet is 14 inches; that in the lower 200 feet is 12 inches. One well is equipped with a 30-horsepower automatic electric motor and a Fairbanks turbine pump with a capacity of 220 to 300 gallons a minute. It was drilled in 1913 by E. C. Archibald, of Council Bluffs, Iowa. The other well is equipped with a Downing Keystone double-stroke pump, powered with a 15-horsepower Fairbanks-Morse 220-volt cage-type motor. The pump delivers 75 gallons a minute at 31 revolutions a minute. The wells are three blocks apart. They operate automatically on a pressure-regulating device set at 45 pounds. The water can be pumped directly into the mains or into the stand pipe. The stand pipe has a capacity of 41,125 gallons.

INDUSTRIAL SUPPLIES

The Burlington Railroad operates the only wells in the county whose output is specifically obtained for industrial purposes. At Alliance four of such wells have been in use for about 40 years. They range in depth from 156 to 163 feet; one is 10 inches in diameter, and the rest are 12 inches. In the year ending August 31, 1938, they yielded 205,276,186 gallons of water.

The Burlington Railroad also has a well at Hemingford. It is equipped with a 15-horsepower Fairbanks-Morse engine and yields from 150,000 to 160,000 gallons a month.

IRRIGATION SUPPLIES

Irrigation in Box Butte County is at present in either a pioneering or an abortive stage, depending on its future development. Within the county and immediately beyond its boundaries 13 wells were either being used for irrigation in 1938 or had been used for that purpose previously and are consequently referred to as irrigation wells. Technical descriptions of all these wells are presented in the well records at the end of this report. Additional information regarding them is set forth here.

The first irrigation well drilled in Box Butte County, so far as is known, was put down in 1936 on the property of the Koester Bros., in the NW¼NW¼ sec. 29, T. 25 N., R. 47 W., northeast of Alliance. It is numbered 144 on the map and in the well tables. The well was cased with sheet iron, which, with the drilling, cost $5 a foot. The yield of the well was measured by H. H. Odell of the Water Resources Branch of the Federal Geological Survey with a current meter. On September 14, 1938, it was discharging 1,897 gallons a minute. A Worthington turbine pump having a capacity of 2,300 gallons a minute is operated by a 100-horsepower McCormick-Deering Diesel engine, connected by a belt. The well was pumped day and night during the summer and early autumn of 1938 and was stopped only for repairs. The well seems to penetrate only about two-thirds of the total thickness of saturated material in that area.

Well 146, situated in the NW¼NW¼ sec. 7, T. 25 N., R. 47 W., on the property of E. W. Purington, derives most of its supply from the Marsland formation, which is not the most permeable part of the water-bearing section in that locality. The well has 190 feet of perforated casing. As the original depth is reported to be 230 feet and the measured depth is 200 feet, it is concluded that the sand has caved and filled much of the open hole. The well was pumped much of the time during the growing season of 1938. Considering the reported yield and the pumping lift of about 100 feet, it may be suggested that this well does not penetrate enough of the total saturated water-bearing material to attain a relatively high degree of efficiency.

Well 147, situated in the SW¼NW¼ sec. 9, T. 25 N., R. 47 W., on the property of Nels Peterson, was pumped intermittently during the summer of 1938. Recovery tests for the determination of field permeability of the aquifers at this point were carried out. This well, 130 feet deep, passed through 41 feet of sand, 20 feet of gravel, 25 feet of coarse sand with thin beds of greenish clay, and 44 feet of coarse sand. Seemingly it did not even pass through the entire thickness of Ogallala formation and, of course, none of the underlying formations. The Case tractor that furnished the power to the pump is reported to consume from 2 to 2.5 gallons of tractor fuel an hour while the pump is operating. It is said that irrigated corn in 1938 yielded 43 to 53 bushels an acre, whereas unirrigated corn yielded 7 to 14 bushels an acre.

Well 149, situated on the property of George Smith, in the SW¼NW¼ sec. 31, T. 24 N., R. 48 W., is said to yield about 500 gallons a minute.

Well 186, situated in the SW¼NW¼ sec. 31, T. 24 N., R. 48 W., on the property of O. A. Odel, was drilled by Mr. Odel. The well, 128 feet deep, seems to pass through the Ogallala sediments and into the Marsland formation. It is said to yield about 500 gallons a minute, based on the owner's estimate, and the draw-down is reported by him to be only 5 feet. The configuration of the water-table contours about the well, however, indicates that a residual draw-down of much greater magnitude than that existed at the time the water level was measured, and it is believed that the draw-down while pumping is much greater than the owner reported.

The well on the property of Ferdinand Trenkle, in the SW¼SW¼ sec. 24, T. 24 N., R. 50 W., was used intensively for irrigation during the summer of 1938. Recovery measurements carried on after a day of pumping were used to determine the field permeability of the water-bearing material at that locality. It is believed that much of the water yielded by the well comes from a bed of gravel belonging to the Ogallala formation. The yield of the well as measured with a current meter by H. H. Odell on September 12, 1938, was 438 gallons a minute in the first measurement but 506 gallons a minute in second and third measurements. The second and third measurements are believed to be the most accurate. The well is equipped with a Western turbine pump which has a capacity of 800 gallons a minute, powered by a 22-horsepower International Harvester stationary engine. The soil irrigated is sandy and is classified in the soil report as Valentine loamy fine sand. In 1938, irrigated corn yielded 40 bushels an acre; irrigated watermelons, 30 tons an acre; and irrigated potatoes, 100 bushels an acre. Twenty acres were irrigated at a cost in fuel of $70.

The well on the property of Herman Bauer, in the NE¼SE¼ sec. 34, T. 26 N., R. 47 W., was not used in 1938. It is designated as observation well 16.

The irrigation well of Louis Bauer is situated in the center of sec. 36, T. 26 N., R. 48 W. Its capacity and draw-down seem to be favorable for irrigation.

Well 113 is on the property of P. L. Johnson, in the NE¼NE¼ sec. 19, T. 26 N., R. 49 W., and was completed in the summer of 1938. This well, which was tested after drilling had gone to a depth of 200 feet, had an unsatisfactory yield and was completed at a depth of 250 feet. It now passes through the Marsland formation. Its performance would be more efficient if it penetrated a greater part of the whole water-bearing section below. A farm well with 2 feet of water in the bottom, situated about a quarter of a mile from well 113, goes dry when the latter is pumped. The well is equipped with a four-stage Pomona turbine pump that has a capacity of 1,400 gallons a minute and that is powered by a 48-horsepower Diesel stationary engine connected directly with the pump by a drive shaft. The yield of the well, as measured with a current meter by H. H. Odell on September 12, 1938, was 733 and 765 gallons a minute. Although he had a late start in irrigating, the owner of the well reported the following results with seed potatoes for the irrigating season of 1938, based partly on actual yield and partly on estimated yield: 40 acres irrigated three times yielded about 200 bushels an acre; 30 acres irrigated twice yielded about 200 bushels an acre; 35 acres, part of which was irrigated once, yielded 80 bushels an acre. The operating cost for the season was $3 an acre. According to an article in the Omaha World-Herald of March 25, 1940, Mr. Johnson irrigated 130 acres of potatoes in 1939 and obtained an average yield of 240 bushels an acre. His cost, reported in the article, was slightly more than 2 cents an acre-foot of water for each foot of lift. The average operating cost of irrigating in 1939 was $6.60 an acre.

Well 132, on the property of G. E. Dyer, in the SW¼NW¼ sec. 10, T. 26 N., R. 52 W., was completed in 1938. The owner and his sons operated the drill rig. The yield of the well was measured by H. H. Odell on September 12, 1938, and the draw-down was measured by means of an air gage during a period of pumping. The recovery of the well after a brief pumping test was measured, and from it the field permeability of the aquifer was determined. The well is equipped with a turbine pump that is powered with an old Buick automobile motor. (See pl. 6, *B*.) Irrigation was carried on in 1938.

Well 37, on the property of L. R. Hughes, in the NE¼NE¼ sec. 6, T. 28 N., R. 51 W., in the bottom lands of the Niobrara Valley, is classified as an irrigation well. It has a small yield, however, and seems not to have been used for irrigation in 1938. The water is thought to come chiefly from the Monroe Creek sandstone. The alluvium of the Niobrara Valley was reported to be neither coarse-grained nor thick.

Well 8, in Sheridan County, in sec. 32, T. 28 N., R. 46 W., was used in 1938 only to water trees.

Another well in Sheridan County, in the NW¼NW¼ sec. 30, T. 29 N., R. 47 W., is reported to be 227 feet deep, 24 inches in diameter, and to yield 1,800 gallons a minute with a draw-down of 21 feet. The static water level in it is reported to have been 26 feet. The well was not used in 1938.

Desirable as it would be, it is not possible to end this discussion of irrigation in Box Butte County and adjacent areas with a direct statement regarding the areal and other limits within which irrigation is economically possible. There are too many variable factors. The capacity of the soil to absorb and hold water, the value of crops, the efficiency of various types of pump and power plant, and the ingenuity, industry, and skill of the operator would make a joke of any generalization. There remains the inexorable fact of yield, pumping lift, and specific capacity of wells that must exert their influence in any irrigation project, but even these may vary with the strengthening or weakening of wells with use, the rise of water levels, or the depletion of the reservoir through the years. Certainly irrigation is feasible from the hydrologic point of view in much of the eastern, southern, and central parts of the county. West and north of a line or zone circumscribing the central upland, irrigation is probably impracticable. This line or zone cannot be defined here. The area where irrigation is feasible will be larger for some men than for others; it is less restricted for those who install and operate highly efficient pumps and power plants, for those whose wells pass far down into the aquifers, and for those whose wells have been efficiently screened and developed. So far as the hydrological requirements of irrigation are concerned, it is believed that much helpful information can be found in this report that will enter into the problem. Other factors must be evaluated by means of information obtained from proper and qualified sources.

TYPES OF WELLS AND WELL-DRILLING METHODS

During the settling of the High Plains most wells were dug by hand. For those men who had settled on the divide areas where the depth to the water table was great, there was no alternative to the laborious and hazardous task of digging a hole 3 feet or so in diameter and tens of feet or even more than a hundred feet deep. But more recently, wells have been put down either by drilling or by driving sand points.

Drilling is accomplished in one of three ways in Box Butte County—by the percussion or cable-tool method, by the hydraulic rotary method, or by the driving of sand points. The cable-tool rig consists essentially of a derrick for elevating the bit, a heavy steel bit, and a bailer. The earth material is broken and dislodged by raising the bit and letting it fall. The loosened material is then brought to the ground surface in the bailer. The casing, where casing is needed, is fed into the hole as it is deepened. In Box Butte County the cable-tool method is very well adapted for breaking through the numerous hard layers in the sandstone but not so well adapted for drilling the fine soft sandstone.

The rotary method of drilling involves a bit that is rotated in order to dislodge the earth material. The cuttings are removed from the hole by means of mud that is pumped down the drill pipe, that squirts out of the bit, and that returns to the ground surface outside the drill pipe. This drill rig is well adapted for penetrating the soft sands of Box Butte County but not so well adapted for drilling through the concretionary beds and zones. For cutting the harder layers in the Tertiary formations, a rock bit is needed. This is a sharp rolling bit affixed to the end of the drill pipe, and it macerates the rock rather than scrapes or pries it, as the ordinary fishtail bit does to soft sand and sandstone.

In finishing some drilled wells a casing is lowered into the hole. If the well is drilled by the cable-tool method the casing is generally lowered as the well is deepened. If the well is drilled by the rotary method the casing is generally put down after the hole is completed. After the casing is set the pump is installed, and the pump line is lowered inside the casing to a point below the static water level. Cased wells in Box Butte County are mostly 4 or 6 inches in diameter, but some are 8, 10, 12, or even 18 inches. If a large supply of water is needed the diameter should be from 12 to 36 inches. In most wells the casing is either iron or galvanized iron, but in some of them wood or tile is used. Most wells used for domestic or stock supplies in the county are left with only the bottom of the casing open to admit the water during pumping. But public, industrial, or irrigation wells should be, and are, screened, perforated, or equipped with some sort of slotted casing. Development of a drilled well involves opening the aquifer near the well by pumping and surging to shake loose and carry out the fine particles in the aquifer near the well. Gravel packing is also a special method of increasing the permeability of the aquifer near the well.

Some wells put down by the rotary or jetting method and some driven wells are not fitted with a casing, but rather with a single pipe that is both casing and pump line. These wells are called tubular wells. They have a check valve at the bottom and are nearly always equipped with a piston pump. The pipe cannot be perforated, and thus their yield cannot be large. This type of well is widely used in the sand hills. Water-level measurements should not be made in them.

Jetted wells are put down through unconsolidated material by means of a nozzle through which a strong jet of water is forced from above. The water loosens the earth material and brings it up to the ground surface. Jetted wells are usually fitted up to be tubular wells. This method of well drilling is used mainly in the sand hills.

Driven wells are found in the valley bottoms, where the water level is near the land surface, and in the sand hills. A perforated well point is affixed to a 1- or 2-inch pipe and hammered into the ground. The well point is pointed and forces the earth material aside, and the perforations in it admit the water when the well is pumped.

CHEMICAL QUALITY OF THE WATER

Most of the waters analyzed from surface and subsurface sources are moderately hard calcium-magnesium bicarbonate waters, with minor amounts of sulfate, chloride, and other constituents. The single samples taken from the Niobrara River and Snake Creek show that at the time of their collection the waters were similar in general chemical character to the samples taken from wells. A few wells have moderately large quantities of sulfate.

Fluoride is present rather spottily in samples of ground water from Box Butte County. Two samples contain 1.8 parts per million of fluoride, one sample contains 1.4 parts per million, and one sample contains 1.1 parts per million. Several samples contain no measurable amount of fluoride. As much as 1 part per million of fluoride is believed to be sufficient to cause detectable mottling of the tooth enamel[36] of children who habitually drink water containing it.

The sample of water from a lake in the eastern part of the county contains several thousand parts of sodium carbonate, bicarbonate, and sulfate, and is very soft. The high concentration of certain constituents is believed to be a result of evaporation of ground water and surface water that have accumulated there. The softening of a water that probably was once hard was perhaps accomplished by precipitation of calcium by sodium carbonate. It is a type of water that was not met with in any of the wells and streams in the county.

So far as is known, the ordinary uses of ground water—domestic, stock, industrial, municipal, and irrigation—are not prohibited by limitations arising from the chemical quality. It is possible that most of the water is rather hard for laundering.

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[36] Dean, H. T., Chronic endemic dental fluorosis: Am. Medical Assoc. Jour., vol. 107, pp. 1269–1272, 1936.

WATER ANALYSES

TABLE 11.—*Analyses of water from sources in Box Butte County and adjacent areas*

[Well numbers, where given, correspond to numbers in table of well records, pp.——. Analyzed by Margaret D. Foster. Parts per million.]

Well No.	Owner or source of collection	Depth (feet)	Date of collection	Total dissolved solids	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Total hardness as $CaCO_3$
11	Chris H. Knag	92	Oct. 3, 1938	290	53	10	21		216	26	4.2	0.0	11	174
25	H. H. Goesling	148	Oct. 2, 1938						192	15	3		6.7	153
41	M. J. Shimek	168	do						164	20	9		8.3	141
45	Albert Havorka	26	do	293	52	9.8	26		239	15	3.5	1.8	7.5	170
51	do	84	do						83	10	8		0	42
54	Charley Mracek	72	Oct. 3, 1938	234	42	9	9.8		174	7.4	2.8	0	11	142
65	School section	168	Oct. 2, 1938	428	72	10	44		247	67	24	0	14	221
82	Ollie Ray	230	do						199	[1]35	12		14	196
105	Carl Kohrman	103	Oct. 3, 1938						238	23	5		9.3	186
113	Pete Johnson	250		[2]265	42	14	13	6.9	192	24	2.1	1.8	8.2	162
128	John Caha	108	Oct. 3, 1938	276	59	11	4.7		218	6.4	3.9	1.1	11	193
132	G. E. Dyer	198	Oct. 2, 1938	243	44	11	8		178	8.6	6.8	0	10	155
163	——Rosenfelt	51±	Oct. 3, 1938						362	[1]150	74		22	432
164	Platte Valley Land Co.	130	do						162	8	2		6.7	142
209	Clarence Kilpatrick	45	do	296	64	12	16		234	19	11	.4	19	209
167	Martin Jacobsen (tenant)	109.6	Nov. 23, 1936	[4]304	55	11	18		186	25	18	.7	20	183
[3]316	William Davidson	70.96	Nov. 24, 1936	[4]401	61	17	50		326	12	31	1.4	3.5	222
	City of Alliance	143							331	[1]220	39		9.3	207
	Burlington Railroad	165	Oct. 3, 1938	950	107	32	152		370	309	68	0	11	399
	City of Hemingford	300	Oct. 2, 1938	[5]338	55	14	24	6.6	246	37	3.4	.4	9.6	195
	Lake sample of water table		Oct. 3, 1938						([6])	[1]2,500	300		0	12
	Niobrara River		Oct. 2, 1938						246	15	6		1	171
	Snake Creek		Oct. 3, 1938						225	15	6		.5	138

[1] Approximate.
[2] Silica (SiO_2) 58 parts per million.
[3] State observation well number.
[4] Calculated.
[5] Silica (SiO_2) 63 parts per million.
[6] Carbonate (CO_3) 1,692 parts per million; bicarbonate (HCO_3) 2,265 parts per million.

RECORDS OF TEST HOLES AND WELLS

TABLE 12.—*Logs of test holes in Box Butte County*

Test hole 1

[Drilled in June 1938. Location, SW¼SE¼ sec. 6. T. 24 N., R. 51 W., approximately ½ mile below Elmore Dam on Kilpatrick ranch.]

	Thickness (feet)	Depth (feet)
Topsoil and silty sand	6	6
Sand, black, clayey	2	8
Sand, fine, silty	2	10
Sand, gray, clayey	6	16
Sand, gray to black, silty (sticky)	8½	24½
Gravel, fine, water-worn sandstone in fine sand	10½	35
Sand, fine, with some gravel and water-worn sandstone	15	50
Sand, fine, compact	23	73
Sand, medium-fine (from 80 to 92 feet some gravel and fine sandstone in the sand)	19	92
Clay, sandy, greenish, turns white upon drying	11	103
Sandstone, soft, loosely cemented, brown	12	115
Sandstone, soft, brown; with concretionary hard gray sandstone at 116½ feet, 118 feet, 121 to 122 feet, 124½ feet; two thick zones of hard gray concretionary sandstone from 127½ to 136 feet and from 138 to 147 feet	32	147
Sandstone, slightly less cemented, brown; with gray concretionary zone from 160 to 163 feet	18	165
Sandstone, brownish, silty, consolidated; on drying assumes a reddish color	10	175
Sandstone, gray, hard, with concretions	1	176
Sandstone, reddish, silty, consolidated	14	190
Sandstone, consolidated, silty, slightly grayish; less reddish than above	10	200
Sandstone, silty, reddish to pinkish, with thin pink clay layers	40	240

Test hole 2

[Drilling begun July 1, 1938. Location, NW¼SW¼ sec. 31, T. 25 N., R. 50 W., 0.7 mile south of section corner, approximately 50 feet east of road on Alex Underwood ranch.]

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Sand, clayey, yellowish	3	5
Gravel	3	8
Sand, medium-fine; thin layers of greenish clay at 21, 47, 51, and 56 feet	55	63
Sand, coarser, compact, cemented; seam of greenish and flesh-colored clay; seam of greenish clay at 69 feet	33	96
Clay, greenish	2	98
Sand, coarse; seam of clay at 102 feet, and a little volcanic ash	11	109
Clay, greenish, with some soft greenish-brown sandstone	10	119
Sand, fine to medium; greenish clay and greenish-brown sandstone at 137 feet	30	149
Clay, greenish gray	5	154
Sand, fine, compact; greenish-white clay at 171-173 feet; layer of clay at 182 feet; also thin layer of clay at 200 feet and 221 feet	70	224
Sandstone, with hard concretions	14	238

TABLE 12.—*Logs of test holes in Box Butte County*—Continued

Test hole 3

[Location, SW¼SW¼ sec. 10, T. 24 N., R. 48 W., 2½ miles south of Alliance, about 100 yards southwest of house on J. J. Schill farm.]

	Thickness (feet)	Depth (feet)
Topsoil	2	2
Sandstone, platy, calcareous	8	10
Sandstone, more massive, calcareous, white to gray	4	14
Sandstone, olive-green	22	36
Sandstone, buff or light-brown, some olive-green; more greenish last 2 feet	8	44
Sandstone, greenish and buff, becoming more reddish and green from 53 feet; scattered concretions of hard limy sandstone; harder concretions at 50, 53, 62-65, 76, 80, 81-82, 89-90, 93-95, 97-98, and 100 feet	59	103
Sandstone, similar to that above, with many concretions	27	130
Sandstone, mostly reddish, with fewer concretions; hard gray sandstone concretions at 138-140, 143, 146, 148, 149, and 152-155 feet	22	152
Sandstone, very hard, gray, calcareous	3	155
Sand, fine, compact, with much mica; many concretions at 161, 163, 165, 166, 171, 172½, 174, 175-178, 180-182, and 185-186½ feet	31½	186½
Sandstone, very hard, gray; concretions from 187½ to 189 feet	2½	189
Sandstone, soft, gray	6	195
Sandstone, hard, gray, with concretions	1	196
Sand, gray, compact, with hard concretions at 200-203, 205, and 207-211 feet	26	222
Sandstone, very hard	2	224

Test hole 4

[Location, SE¼SW¼ sec. 31, T. 25 N., R. 47 W., just east of overpass about 50 yards south of railroad.]

	Thickness (feet)	Depth (feet)
Sand, light-colored, fine	43	43
Sand, compact, with some soft sandstone	50	93
Sand, brownish-gray, with some green clay	17	110
Sand, brownish-gray; clayey sandstone; green clay; small pieces of bone; carbonaceous material; some small gravel	50	160
Sand, loose, coarse, brown; slightly compact from 180 feet	38	198
Sandstone or very compact sand, brown; whitish clay	2	200
Sand, coarse, brownish, only slightly cemented	18	218
Sandstone, light-brownish, cemented	54	272
Sand, brownish, only slightly cemented	8	280
Sand, fine, brown, only slightly cemented	45	325
Sand, brown; with concretions at 325-328 and 330-335 feet	13	338
Sandstone, hard, gray	1	339
Sand, fine, rounded grains, loosely cemented; concretions from 344½ to 345½ feet; compact, hard at 348 feet	12	351
Sand, brown, compact; some gray sand; concretionary, 354½-355 feet	3½	354½
Sand, light-brown, finer and more grayish than above	12½	367
Sand, concretionary, calcareous rootlets, hard and gray	15	382
Sandstone, very hard, with concretions	1½	383½
Sandstone, very hard	2½	386
Sand, soft, brownish, uniform texture	42	428
Sandstone, hard, with concretions	1	429
Sand, soft, brownish	19	448
Sand, hard, with concretions	7	455
Sand, hard	23	478
Silt, sandy, buff	32	510

TABLE 12.—*Logs of test holes in Box Butte County*—Continued

Test hole 5

[Location, NW. corner NE¼ sec. 31, T. 25 N., R. 48 W.]

	Thickness (feet)	Depth (feet)
Clay, sandy	18	18
Clay, medium-hard, greenish	7	25
Clay and sand	8	33
Sand, brownish	9	42
Sand, gray, soft, coarse	13	55
Sand, grayish-brown, soft	11	66
Sandstone, hard	8	74
Sandstone, with fine gravel	4	78
Clay, green to olive	4	82
Sandstone, hard	4	86
Sandstone, soft, clean, coarse	6	92
Sandy clay, hard; greenish gray	6	98
Sandstone, hard, brownish	26	124
Sandstone, soft, perhaps with thin beds of clay	4	128
Sandstone, hard, coarse, clean; some fine gravel	12	140
Gravel	5	145
Sandstone, hard, greenish	7	152
Sandstone, fine, soft	4	156
Clay, sticky, greenish	3	159
Clay and sandstone, greenish to gray	5	164
Sand, well-sorted; some fine gravel	5	169
Sandstone and clay, hard, greenish	3	172
Sandstone, soft	4	176
Clay and sand, greenish gray	4	180
Sandstone, fine; varies in hardness; some gravel	15	195
Clay, sandy; grades to greenish sand	7	202
Sandstone, soft, fine	10	212
Clay, sandy and greenish	4	216
Sandstone, soft, fine	7	223
Clay, sandy	2	225
Sandstone, fairly hard, gray; coarser with depth	6	231
Sandstone, soft, brownish-gray	6	237
Sandstone, fairly hard, greenish	15	252
Sandstone, soft, grayish-brown	7	259
Sandstone, fairly hard, clean, gray, somewhat cemented	6	265
Sandstone, soft, fine, brownish	8	273
Sandstone, hard, fine	8	281
Sandstone, hard, coarse	5	286
Sandstone, hard	1	287
Sandstone, very hard zone	3	290
Sandstone, hard, white, and concretionary	7	297
Sandstone, soft, very fine, brownish	8	305
Sandstone, hard, with a few concretions	7	312

TABLE 12.—*Logs of test holes in Box Butte County*—Continued

Test hole 6

[Location, SW¼NW¼ sec. 18, T. 25 N., R. 48 W.]

	Thickness (feet)	Depth (feet)
Topsoil and sand	8	8
Sandstone and thin clay zones	18	26
Sandstone, greenish, soft; fossil seeds at 35 feet	15	41
Sandstone, soft, clean, coarse	12	53
Clay, sticky	4	57
Sand, soft, fine- to medium-grained	6	63
Sandstone, hard, greenish	5	68
Sandstone, hard, green	1	69
Sand, clean, coarse; grades to a fine gravel at the base	19	88
Clay, compact, greenish	6	94
Sandstone, hard, light-greenish	4	98
Sand and silt, not cemented	13	111
Sandstone, dirty green, fossil roots	4	115
Sand, soft, becoming coarser	9	124
Sandstone, very hard, brownish	3	127
Sandstone, brownish; uneven in hardness; concretionary	16	143
Sandstone, soft	19	162
Sandstone, hard, concretionary	6	168
Sandstone, soft, brownish-gray	14	182
Sandstone, white to gray, with a very hard zone	5	187
Sandstone, soft	1	188
Sandstone, very hard	1	189
Sandstone, soft to hard, concretionary	9	198
Sandstone, very hard, concretionary	1	199
Sandstone, soft, concretionary	5	204
Sandstone, very hard, concretionary	1	205
Sandstone, soft to hard, concretionary	16	221
Sandstone, very hard	2	223
Sandstone, soft to hard; small concretions	10	233
Sandstone, very hard	1	234
Sandstone, soft	4	238
Sandstone, very hard	1	239
Sandstone, dirty brown, hard	9	248
Sandstone, very hard	1	249
Sandstone, hard; a few small concretions	8	257
Sandstone, very hard	½	257½
Sandstone, light-colored, very hard	½	258
"Agate," very hard	½	258½

Test hole 7

[Location, NW. corner SW¼ sec. 34, T. 25 N., R. 48 W., on SE side of road intersection.]

	Thickness (feet)	Depth (feet)
Topsoil	7	7
Sand and clay, greenish	16	23
Sand, coarse, clean	11	34
Sand, fine, clean, soft; a few thin clay zones	26	60
Sand, soft	7	67
Sand and clay	3	70
Clay, greenish	11	81
Sand, soft, medium-grained	11	92
Clay, soft, green	3	95
Sandstone, hard	1	96
Sand, coarse, clean	4	100
Clay, green	2	102
Sandstone, gray, hard	9	111
Sandstone, hard	4	115
Sand and clay, green	2	117
Sand, soft	8	125
Sand, brownish-gray, fine	8	133
Sandstone, fine, concretionary	2	135
Sandstone, hard	12	147
Sandstone, very hard	2	149
Sandstone, hard, brown, fine-grained	4	153
Sandstone, light-colored, very hard	2	155
Sandstone, brown, soft, fine	8	163
Sandstone, brown, hard, with many small hard concretions	29	192

TABLE 12.—*Logs of test holes in Box Butte County*—Continued

Test hole 8

[Location, NE. corner sec. 19, T. 26 N., R. 49 W., on property of P. E. Johnson.]

	Thickness (feet)	Depth (feet)
Topsoil, sandy	4	4
Sandstone and debris, hard and weathered	5	9
Clay, soft	2	11
Sandstone, brownish with light spots, hard	45	56
Sandstone, hard	1	57
Sandstone, less hard	11	68
Sandstone, hard	1	69
Sandstone, less hard	2	71
Sandstone, light-colored, hard	2	73
Sandstone, hard	1	74
Do	2	76
Do	2	78
Sandstone, hard, uneven, small concretions, brown	70	148
Sandstone, very hard	2	150
Sandstone, brownish, hard, many concretions	23	173
Sandstone, very hard	1	174
Sandstone, brownish, soft to hard, with hard concretions	9	183
Sandstone, very hard	2	185
Sandstone, hard with many concretions	14	199
Sandstone, very hard with thin, soft, gray to white layers	9	208
Sandstone, dirty gray and black, soft, with small concretions	13	221
Sandstone, hard	1	222
Sandstone, soft	4	226
Sandstone, hard	1	227
Sandstone, soft	2	229
Sandstone, light-colored, very hard	4	233
Sandstone, soft	2	235
Sandstone, hard	3	238
Sandstone, soft, with a few hard concretions	12	250
Sandstone, white, very hard	3	253
Sandstone, soft gray	5	258
Sandstone, very hard	1	259
Sandstone, hard to soft	4	263
Sandstone, very hard, with two thin soft layers	5	268
Sandstone, soft	5	273
Sandstone, very hard	2	275
Sandstone, light-colored, soft, fine	4	279
Sandstone, very hard	½	279½
Sandstone, white, soft	4½	284
Sandstone, very hard	1	285
Sandstone, hard	5	290
Sandstone, hard, uneven, with thin soft spots	7	297
Sandstone, very hard	2	299
Sandstone, white, soft	3	302
Sandstone, very hard	1	303
Sandstone, soft	4	307
Sandstone, very hard	1	308
Sandstone, coarse, hard	7	315
Clay, white, hard	8	323
Sandstone, brownish-gray to greenish, soft, fine	7	330
Sandstone, hard	3	333
Sandstone, soft	6	339
Sandstone, greenish-brown, hard	2	341
Sandstone, very hard	2	343
Sandstone, brown, hard	9	352
Sandstone, very hard	½	352½
Sandstone, soft to hard, coarse	32½	385
Sandstone, hard	½	385½
Sandstone, soft to hard, coarse	4½	390
Silt, sandy, light-buff	20	410

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TABLE 12.—*Logs of test holes in Box Butte County*—Continued

Test hole 9

[Location, NW¼NW¼ sec. 17, T. 26 N., R. 51 W.]

	Thickness (feet)	Depth (feet)
Topsoil, sandy	6	6
Sandstone, reddish-brown, soft to hard, concretionary, brittle	32	38
Sandstone, hard	3	41
Sandstone, dirty-brown, soft	24	65
"Agate," pink, hard	1	66
Sandstone, dirty-brown, soft	13	79
Sandstone, white to gray, very hard	3	82
Sandstone, soft	13	95
Sandstone, very hard	2	97
Sandstone, dirty-brown, soft	15	112
Sandstone, very hard	1	113
Sandstone, hard, with many small hard concretions	4	117
Sandstone, very hard	1	118
Sandstone, hard; small concretions	3	121
Sandstone, soft	3	124
Do	5	129
Sandstone, white, very hard, fine	1	130
Sandstone, hard	2	132
Sandstone, very hard	1	133
Sandstone, brown, hard, fine	11	144
Sandstone, medium-hard	2	146
Sandstone, white, very hard, fine	1	147
Sandstone, white, hard, concretionary	4	151
Sandstone, brown, hard, fine, silty	22	173
Sandstone, hard	½	173½
Sandstone, brown, hard, fine, silty	29½	203
Sandstone, gray, very hard	1½	204½
Sandstone, brown, soft, well-sorted	12½	217
Sandstone, very hard	1½	218½
Sandstone, brownish, hard; a few very small concretions	11½	230
Sandstone, very hard	¼	230¼
Sandstone, hard	5¾	236
Sandstone, very hard	½	236½
Sandstone, brownish, soft	16½	253
Sandstone, hard, with some gray clay	4	257
Sandstone, soft, coarse	17	274
Clay, irregular or concretionary	12	286
Sandstone, greenish-brown, medium-hard, with clay	19	305

Test hole 10

[Location, NE¼ sec. 25, T. 27 N., R. 47 W., on property of A. S. Gerdes.]

	Thickness (feet)	Depth (feet)
Topsoil, sandy	6	6
Sand, clean	8	14
Sandstone, yellowish-brown, soft	10	24
Sandstone with clay zones, light-colored	14	38
Sandstone, greenish-brown, soft	10	48
Limestone, white, very hard	4	52
Sandstone, light-brown, hard, fine	20	72
Clay, reddish and green, sticky	12	84
Sandstone, greenish, hard; a few thin clay zones	18	102
Clay, white, sticky	2	104
Sandstone, greenish	5	109
Clay, white	2	111
Sandstone and thin clay beds	17	128
Sand, medium-grained, soft, clean	25	153
Sandstone, greenish, medium-grained	12	165
Sandstone, brownish, soft	37	202
Sandstone, brownish, hard, concretionary	6	208

TABLE 13.—*Logs of municipal wells at Alliance, Nebr.*

City well No. 1

[Location, Seventh Street and Yellowstone Avenue.]

	Thickness (feet)	Depth (feet)
Sand, hard, dry	22	22
Sand, fine	43	65
Clay, blue, and sandstone	35	100
Sand, fine	33	133
Shale, blue	5	138
Sand, fine	12	150

City well No. 2

[Location, Seventh Street and Hack Avenue.]

	Thickness (feet)	Depth (feet)
Sand, hard, dry	22	22
Sand, fine	21	43
Clay, blue	12	55
Sand, fine	14	69
Sandstone	13	82
Clay, blue	11	93
Sand	4	97
Shale, blue	9	106
Sand, fine	31	137
Shale, blue	3	140

City well No. 3

[Location, near City Hall.]

	Thickness (feet)	Depth (feet)
Soil and clay	7	7
Sand, fine	15	22
Sand, fine, hard	19	41
Sand, fine	19	60
Sandstone	10	70
Clay, blue	9	79
Sand, fine	12	91
Shale, blue	7	98
Sand, fine	5	103
Shale	4	107
Sand, fine	6	113
Sand, hard, and clay	23	136
Quicksand	10	146
Shale, blue	12	158

City well No. 4

[Location, east of city light plant.]

	Thickness (feet)	Depth (feet)
Soil and clay	6	6
Sand and clay	6	12
Sand, fine	12	24
Sand, hard	16	40
Sand, fine	22	62
Clay and sandstone	13	75
Sand, fine	20	95
Sandstone	4	99
Sandstone and clay, hard	16	115
Sand and gravel	7	122
Sand, fine	13	135
Do	8	143

TABLE 14.—*Records of wells in Box Butte County and adjacent areas*

Well No.	Location	Owner or name	Driller	Year completed	Type [1]	Depth (feet) [2]	Diameter (inches)	Type of pump [3]	Size of pump (inches)	Kind of power [4]	Use of water [5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
Sheridan County																
1	T. 29 N., R. 46 W. NW¼SW¼ sec. 30.	T. L. Hughes	Harry Minnick	....	Dr	36.0	6	None	......	None	A	Top of casing	0.0	27.42	July 28, 1938	In a broad valley.
Dawes County																
2	T. 29 N., R. 47 W. SE¼SW¼ sec. 32.	John Potmesil	....	....	Dr	79.5	6	..do..	......	..do..	A	....do......	−1.0	71.50	July 29, 1938	Valley tributary to Niobrara Valley.
3	T. 29 N., R. 50 W. SW¼ sec. 35.	——Taylor	....	....	Dr	140.0	6	Pl	......	..do..	A	....do......	+.7	126.27	Aug. 4, 1938	On a high flat terrace.
4	T. 29 N., R. 52 W. SW¼NE¼ sec. 31.	....	....	....	Dr	145.0	......	Pl	......	W	S	On steel pump base.	+.9	124.41	Aug. 12, 1938	Windmill in pasture.
5	SW¼SW¼ sec. 34.	....	....	....	Dr	90.0	......	Pl	......	W	S	On 2 by 4 in. beam.	+1.2	64.27	....do......	Do.
6	T. 29 N., R. 51 W. SE¼NE¼ sec. 31.	August Rohde, Sr.	....	....	Dr	136.0	......	Pl	......	W	D, S	On 3 by 5 in. beam.	+.3	118.82	....do......	On slope of Niobrara Valley.
Sheridan County																
7	T. 28 N., R. 46 W. NW¼SE¼ sec. 30.	R. H. Lockman	Mat Cullen	1893	Dr	29.0	6	Pl	......	W	S	Top of casing	+0.5	8.3	July 28, 1938	Easternmost of two nearby wells.
8	Center of sec. 32.	Hans Jaggers	Harry Minnick	....	Dr	276.0	16 in. to 50 ft., 10 in. to bottom.	T	8	T	I	....	....	....	....do......	Covered and could not be measured.
9	SE¼NE¼ sec. 33.	....do........	....	....	Dr	52.0	4	Pl	......	W	S	Top of casing	+2.5	22.54	Aug. 15, 1938	Well is in pasture in edge of sand hills.
10	SW¼NW¼ sec. 32.	....do........	....	....	Dr	55.0	6	Pl	......	W	S	On platform.	+1.45	11.61	....do......	½-mile west of irrigation well.

Box Butte County

	T. 28 N., R. 47 W.															
11	SW¼NW¼ sec. 14	Chris G. Knag			Dr	92.0	6	Pl		W	D, S	Top of casing	+0.25	79.58	July 28, 1938	
12	NE¼NE¼ sec. 17	John Potmesil			Dr	54.0	6	Pl		W	S	Pump base	+1.0	26.46	....do......	
13	NW¼NW¼ sec. 18	Cecil Potmesil			Dr	118.0	6	Pl		None	A	Top of casing	+1.5	106.19	July 29, 1938	On a hill.
14	NE¼NE¼ sec. 24	Fred Gilbert			Dr	15.0	6	Pl		W	S	....do......	+1.0	6.88	July 28, 1938	Well is in a valley.
15	SE¼NE¼ sec. 27	Chester Ross			Dr	115.0	6	None		None	A	Pump base	+1.0	88.56	July 27, 1938	
16	SE¼SE¼ sec. 32	James McClean			Dr	108.5	6	..do..		..do..	A	Top of casing	+.85	107.95	July 29, 1938	On knoll on a rolling upland.
	T. 28 N., R. 48 W.															
17	SW¼SE¼ sec. 3	Joe Schramek			Dr	212.0	6	Pl		W	D	....do......	+.75	179.64	July 30, 1938	
18	NE¼SW¼ sec. 4	Tom Prochazka			Dr	78.0	6	Pl		W	S	....do......	+.5	59.75	....do......	
19	SW¼NE¼ sec. 8	Joseph Prochazka			Dr	56.0	6	Pl		W	D, S	On pump base	+.5	29.50	....do......	
20	SW¼SE¼ sec. 10	Joseph Schramek			Dr	195.0	6	Pl		W	S	....do......	+1.0	163.63	....do......	
21	NE¼NE¼ sec. 11	P. G. Dobson			Dr	128.0	6	Pl		W	S	On concrete base.	+1.2	98.91	July 29, 1938	
22	NW¼SW¼ sec. 25	Sam D. Graham			Dug	89.0	48	Pl		W	S	On platform.	+1.5	81.62	July 28, 1938	Well is in a valley.
23	SW¼NW¼ sec. 34	W. J. Roes			Dr	164.0	6	Pl		W	D, S	Top of casing	+1.0	110.38	July 30, 1938	On gently undulating tableland.
	T. 28 N., R. 49 W.															
24	NE¼NE¼ sec. 4	Phillips Pitts			Dr	103.0	6	Pl		W	S	On pump base	+2.0	87.02	....do......	On terrace in Niobrara River Valley.
25	NW¼NW¼ sec. 5	H. H. Goesling			Dr	148.0	6	Pl		W	S	Top of casing	+2.0	122.28	Aug. 4, 1938	On slope of the Niobrara Valley.
26	SE¼NE¼ sec. 7	Leo Fronaple	——Donam		Dr	222.0		Pl		W	D, S	....do......	.0	215.72	....do......	On a hill.
	T. 28 N., R. 49 W.															
27	NW¼SE¼ sec. 13	Charley Duffels			Dr	74.0	6	Pl		W	S	Top of platform.	+1.10	60.01	July 30, 1938	On side of valley.
28	SW¼SW¼ sec. 15	H. P. Foley			Dr	158.0	6	Pl		W	D, S	On 2 by 4 in. beam.	+.5	141.98	....do......	Flat upland.
29	SW¼SW¼ sec. 17	Durland Trust Co.			Dr	158.0		Pl		W	D, S	On pump base	+1.15	145.47	Aug. 4, 1938	
30	NW¼SW¼ sec. 27	August Drews			Dr		6	Pl		W	S	....do......	+.5	120.28	Aug. 2, 1938	In valley.
31	SE¼SW¼ sec. 31	August C. Deitcher			Dr		6	Pl		W	A	....do......	+1.0	141.86	Aug. 4, 1938	Gently rolling tableland.
32	SE¼SE¼ sec. 34	Indiana State Life Insurance Co.	——Reeves		Dr	152.0	6	Pl		W	D, S	....do......	+1.4	144.88	Aug. 8, 1938	Do.
	T. 28 N., R. 50 W.															
33	SE¼NW¼ sec. 15	John Foltyn			Dr	187.0		Pl		W	D, S	On platform.	.0	168.28	Aug. 4, 1938	
34	SE¼SE¼ sec. 26	Ignatius E. Kriz			Dr	170.0		Pl			A	....do......	+1.4	147.74	....do......	
35	NW¼NW¼ sec. 29	Winnie Keane			Dr	204.0		Pl			A	On steel clamp.	+1.5	170.42	Aug. 5, 1938	
36	SW¼SW¼ sec. 34	Louis Heinz			Dr	206.0		Pl		W	D, S	Top of casing	+.9	190.72	....do......	
	T. 28 N., R. 51 W.															
37	NE¼NE¼ sec. 6	J. R. Hughes	J. R. Hughes		Dr	300.0		C		T	I	On 3 by 12 in. beam.	+.2	19.11	Aug. 3, 1938	
38	SE¼SE¼ sec. 6	University of Nebraska.		1935	Dug	11.2	1				O	Top of pipe	+1.55	5.24	June 18, 1938	Observation well 378.
39	SW¼NW¼ sec. 8	W. T. Gregg	Luther Clark		Dr	102.0	6	Pl			A	On pump base	+1.5±	87.07	....do......	Observation well 39.
40	NE¼NE¼ sec. 11	Bertha Hitchcock			Dr	185.0	6	Pl		W	D, S	Top of casing	+1.0	172.24	Aug. 5, 1938	
41	NW¼NW¼ sec. 20	M. J. Schimek			Dr	168.0		Pl		W	D, S	On platform.	+.6	139.33	Aug. 3, 1938	
42	NW¼NW¼ sec. 23	Mrs. E. C. Evans			Dr	228.0		Pl		W	D, S	On pump base	+1.0	225.24	Aug. 5, 1938	
43	SE¼NW¼ sec. 29	John Schimek			Dr	218.0	6	Pl		W	D, S	On 2 by 4 in. beam.	+2.3	205.78	....do......	

See footnotes at end of table.

TABLE 14.—*Records of wells in Box Butte County and adjacent areas*—Continued

Box Butte County—Continued

Well No.	Location	Owner or name	Driller	Year completed	Type [1]	Depth (feet) [2]	Diameter (inches)	Type of pump [3]	Size of pump (inches)	Kind of power [4]	Use of water [5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
	T. 28 N., R. 52 W.															
44	NW¼SW¼ sec. 3	Robert Orr	......	....	Dr	90.0	6	Pl	......	W	A	Top of casing	+0.8	60.34	Aug. 3, 1938	Rolling terrace.
45	NW¼SW¼ sec. 9	Albert Hovorka	......	....	Dr	26.0	6	Pl	......	W	S	....do......	+1.6	19.21	....do......	
46	NE¼SW¼ sec. 26	Archie Schimek	......	....	Dr	303.0	......	Pl	......	W	D, S	On steel clamp.	+.4	277.98	Aug. 5, 1938	
47	SE¼NW¼ sec. 28	L. E. Ford	——Skribs	....	Dr	152.0	6	None	......	......	A	Top of casing	+1.0	132.50	Aug. 3, 1938	
48	NE¼NW¼ sec. 31	Albert Hovorka	......	....	Dr	151.0	6	None	......	......	A	....do......	+.5	123.50	....do......	
49	SW¼SW¼ sec. 34	L. E. Ford	Buck Lyman	....	Dr	340.0	6	Pl	......	W	D, S	On 3 by 4 in. clamp.	+.2	277.06	....do......	On high edge of slope of Niobrara Valley.

Sioux County

Well No.	Location	Owner or name	Driller	Year completed	Type [1]	Depth (feet) [2]	Diameter (inches)	Type of pump [3]	Size of pump (inches)	Kind of power [4]	Use of water [5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
	T. 28 N., R. 53 W.															
50	SE¼ sec. 23	Albert Hovorka	Buck Lyman	....	Dr	136.0	6	Pl	......	W	S	Top of casing	+0.5	118.68	Aug. 3, 1938	In tributary valley on slope of Niobrara Valley.
51	SE¼NE¼ sec. 24	....do......	......	....	Dr	84.0	6	Pl	......	W	S	On steel clamp.	+.2	64.86	....do......	
52	NW¼ sec. 24	....do......	Buck Lyman	....	Dr	106.0	6	Pl	......	W	S	On board....	+1.0	86.90	....do......	

Sheridan County

Well No.	Location	Owner or name	Driller	Year completed	Type [1]	Depth (feet) [2]	Diameter (inches)	Type of pump [3]	Size of pump (inches)	Kind of power [4]	Use of water [5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
	T. 27 N., R. 46 W.															
53	NW¼SW¼ sec. 16	G. A. Dilling	G. A. Dilling	....	Dr	22.0	6	Pl	......	W	S	Top of casing	+0.5	7.97	July 28, 1938	In valley among sand hills.
54	NE¼NW¼ sec. 18	Charley Mracek	Charley Mracek	....	Dr	72.0	6	Pl	......	W	S	On platform.	+1.0	11.36	....do......	In broad low valley of Box Butte Creek.
55	SW¼NE¼ sec. 21	G. A. Dilling	G. A. Dilling	....	Dr	60.0	6	Pl	......	W	S	On pump base	+.2	42.72	....do......	In valley in sand hills.
57	NW¼NE¼ sec. 30	Paul R. Taylor	......	....	Dr	......	6	Pl	......	......	A	Top of casing	+1.1	11.13	Aug. 9, 1938	In lowland among sand hills.

Box Butte County

Well No.	Location	Owner or name	Driller	Year completed	Type [1]	Depth (feet) [2]	Diameter (inches)	Type of pump [3]	Size of pump (inches)	Kind of power [4]	Use of water [5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
	T. 27 N., R. 47 W.															
58	SE¼SE¼ sec. 10	J. A. Sheldon	Buck Lyman	....	Dr	95.0	4	Pl	......	......	A	Top of casing	+0.10	63.42	July 28, 1938	
59	SW¼SW¼ sec. 8	First Trust Co., Lincoln.	......	....	Dr	132.0	6	Pl	......	W	D, S	....do......	+.80	34.19	July 29, 1938	Gently undulating upland.

60	SE¼SW¼ sec. 19	L. P. Kosmicki	....	....	Dr	111.0	6	Pl	....	W	D, S	....do......	+1.60	45.56	Aug. 9, 1938	
61	NE¼NW¼ sec. 23	——Shremik	....	....	Dr	64.0	6	Pl	......	......	A	....do......	+1.00	29.92	June 20, 1938	Flat to gently rolling land. Observation well 15.
62	SW¼SE¼ sec. 25	R. A. Kittelman	R. A. Kittelman	....	Dr	......	24	......	......	......	I	....do......	+.50	30.47	July 29, 1938	Incompleted irrigation well, 69 feet deep.
63	SE¼NE¼ sec. 28	——Reilly	....	....	Dr	74.0	4	Pl	......	W	D, S	....do......	+1.00	33.78	....do......	
64	SE¼SE¼ sec. 31	D. H. Fishburn	Tom Tucheck	....	Dr	95.0	......	Pl	......	W	D, S	On concrete platform.	+.50	34.51	July 27, 1938	
	T. 27 N., R. 48 W.															
65	NE¼NE¼ sec. 16	School section	....	....	Dr	168.0	......	Pl	......	......	A	Top of casing	+.80	111.48	July 30, 1938	
66	NE¼NW¼ sec. 11	Charlotte Worley	....	....	Dr	118.0	......	Pl	......	......	A	On pump base	+2.50	83.18	Aug. 8, 1938	In valley on tableland.
67	NE¼NE¼ sec. 26	Miss Hood	....	....	Dr	114.0	......	Pl	......	W	D, S	Top of casing	+.50	67.25	Aug. 9, 1938	
68	NW¼SW¼ sec. 27	T. C. Dowell	....	....	Dr	139.0	......	Pl	......	W	D, S	On platform.	+1.65	86.61	....do......	On knoll on tableland.
69	SE¼SW¼ sec. 29	Clifford Bergfield	....	....	Dr	126.0	......	Pl	......	......	A	....do......	+1.00	82.98	....do......	In valley on tableland.
	T. 27 N., R. 49 W.															
70	SW¼NW¼ sec. 9	Joe Howry	....	....	Dr	164.0	......	Pl	......	W	D, S	On 2 by 6 in. beam.	+1.80	134.26	Aug. 2, 1938	
71	NE¼NW¼ sec. 13	Wm. Newman	....	....	Dr	144.0	......	Pl	......	W	A	On pump base	+.95	118.85	....do......	
72	NE¼NW¼ sec. 19	M. Nielson	....	....	Dr	......	......	Pl	......	W	D, S	....do......	+.30	121.66	....do......	
73	NW¼SW¼ sec. 21	E. S. Wildy	Buck Lyman	....	Dr	156.0	......	Pl	......	......	A	Hole in casing	+.63	119.29	June 18, 1938	Observation well 338.
74	SW¼SE¼ sec. 23	Gottlief Wurst	....	....	Dr	139.0	......	Pl	......	W	A	Hole in pump	+2.20	109.61	Aug. 8, 1938	Gently rolling tableland.
	T. 27 N., R. 50 W.															
75	NE¼NE¼ sec. 6	Thos. R. Enyeart	....	....	Dr	220.0	......	Pl	......	......	A	On platform.	.0	183.18	Aug. 6, 1938	On knoll on rolling tableland.
76	NE¼NE¼ sec. 15	Derlin Trust	....	....	Dr	198.0	......	Pl	......	W	D, S	On pump base	+1.00	159.82	Aug. 2, 1938	
77	NE¼NE¼ sec. 20	Charles Baldwin	....	....	Dr	210.0	......	Pl	......	W	A	On platform.	+2.00	176.50	June 23, 1938	Flat tableland. Observation well 12.
78	NE¼NE¼ sec. 27	C. E. Carrell	....	....	Dr	192.0	......	Pl	......	W	D, S	....do......	+.80	165.87	Aug. 8, 1938	Knoll on tableland.
79	SE¼SW¼ sec. 30	O. E. Phillips	....	....	Dr	155.0	......	Pl	......	W	D, S	....do......	+1.00	136.32	....do......	
80	NW¼NE¼ sec. 33	G. E. Peterson	....	....	Dr	164.0	......	Pl	......	W	D, S	....do......	+.50	146 60	Aug. 6, 1938	
81	SE¼SE¼ sec. 35	O. D. Rouse	O. D. Rouse	....	Dug	140.0	......	Pl	......	W	D, S	....do......	+.90	133.03	July 26, 1938	
	T. 27 N., R. 51 W.															
82	NE¼NE¼ sec. 3	Ollie Ray	Buck Lyman	....	Dr	230.0	6	Pl	......	W	D, S	Top of casing	+.30	218.42	Aug. 5, 1938	
83	NW¼NW¼ sec. 6	L. Homrighausen	....	....	Dr	240.0	6	Pl	......	W	D, S	On concrete platform.	+.90	220.96	Aug. 2, 1938	
84	SW¼SW¼ sec. 8	Frank Turek	....	....	Dr	233.0	4	Pl	......	W	D, S	Top of casing	+1.20	212.29	Aug. 6, 1938	
85	SW¼SE¼ sec. 12	——Leonard	....	....	Dr	227.0	6	Pl	......	W	D, S	On concrete platform.	+.50	209.36	Aug. 2, 1938	On tableland.
86	NE¼SW¼ sec. 15	J. M. Wanek	Buck Lyman	....	Dr	187.0	......	Pl	......	W	D, S	Top of casing	+.30	148.27	....do......	
87	SW¼SW¼ sec. 21	C. Klemke	....	....	Dr	223.0	6	Pl	......	......	A	On platform.	+.80	206.21	Aug. 6, 1938	
88	NE¼SE¼ sec. 31	A. J. Kresl	Buck Lyman	....	Dr	256.0	6	Pl	......	W	D, S	Top of casing	+.20	215.12	July 25, 1938	
89	NW¼SE¼ sec. 35	Mrs. Lorenze	....	....	Dug	163.5	40	......	......	......	A	On platform.	+.60	152.67	....do......	
	T. 27 N., R. 52 W.															
90	NE¼SW¼ sec. 6	Albert Hovorka	....	....	Dr	158.0	6	Pl	......	W	S	On pump base	+.70	140.62	Aug. 2, 1938	
	T. 27 N., R. 52 W.															
91	SE¼SE¼ sec. 10	Joe M. Kresl	Buck Lyman	....	Dr	275.0	6	Pl	......	W	D, S	On 3 by 6 in. beam.	+.70	250.96	....do......	On upland.
92	NE¼SE¼ sec. 19	W. W. Dyer	....	....	Dr	216.0	......	Pl	......	W	A	On pump base	+.30	215.25	Aug. 6, 1938	
93	SE¼SE¼ sec. 24	Karl Spacht	....	....	Dug	154.0	48	Pl	......	W	D, S	On platform.	+.60	152.70	....do......	In valley about 50 feet below tableland.
93a	NW¼NE¼ sec. 32	——Talemka	....	....	Dr	215.0	6	Pl	......	W	......	....do......	+.50	198.53	July 22, 1938	Rolling.

See footnotes at end of table.

TABLE 14.—*Records of wells in Box Butte County and adjacent areas*—Continued

Well No.	Location	Owner or name	Driller	Year completed	Type [1]	Depth (feet) [2]	Diameter (inches)	Type of pump [3]	Size of pump (inches)	Kind of power [4]	Use of water [5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
	Sioux County															
	T. 27 N., R. 53 W.															
94	SE¼SE¼ sec. 25	Nick Lehe			Dr			None			A	On steel clamp.	+0.70	139.03	Aug. 6, 1938	
	Sheridan County															
	T. 26 N., R. 46 W.															
95	NW¼NE¼ sec. 6				Dr	43.0	6	Pl		W	S	Top of casing	+1.00	17.38	Aug. 9, 1938	Sandhill valley.
96	NE¼NE¼ sec. 8				Dr	35.0	6	Pl		W	S	....do......	+1.00	23.16	....do......	Edge of sand hills.
97	SE¼NE¼ sec. 29				Dr	25.0	12	Pl		W	S	....do......	+1.70	23.39	Sept. 9, 1938	
98	SW¼NE¼ sec. 30				Dr	31.0	8	Pl		W	S	....do......	+2.50	27.55	....do......	
	Box Butte County															
	T. 26 N., R. 47 W.															
99	NE¼NE¼ sec. 11	Mrs. William Nye			Dr	50.0	6	Pl		W	S	On 6 by 6 in. beam.	+1.30	29.33	July 27, 1938	Gently undulating lowland.
100	NW¼NW¼ sec. 22	Samuel O'Brien			Dr		6	Pl			A	On 2 by 4 in. beam.	+2.20	38.67	....do......	Broad flat to undulating valley.
101	SE¼SE¼ sec. 23	Christy Brost			Dr	50.0	6	Pl		W	D, S	On 2 by 8 in. beam.	+.50	30.10	....do......	
102	NW¼NW¼ sec. 29	D. L. Lawrence			Dr	79.0	6	Pl		W	D, S	Top of casing	+1.30	47.20	July 22, 1938	On side of hill.
103	NE¼SE¼ sec. 34	Herman Bauer	Herman Bauer		Dr	116.0	24	T	8	T	I	....do......	+1.00	26.42	June 20, 1938	Was not used in 1938. Observation well 16.
	T. 26 N., R. 48 W.															
104	NW¼NE¼ sec. 4	O. A. Davig			Dr	75.5	6	None			A	....do......	+.95	74.59	July 26, 1938	
105	SW¼SE¼ sec. 12	Carl Kohrman	Mill Holnerick		Dr	103.0	6	Pl		W	D, S	On platform	+.50	57.97	July 27, 1938	
106	NW¼SW¼ sec. 22	Peter Kicken			Dr	152.0	6	Pl		W	S	On pump base	+1.80	93.86	July 26, 1938	On knoll on upland.
107	SW¼SW¼ sec. 31	E. Panawitz			Dug	94.0	48	Pl			A	On platform	+1.00	83.95	July 21, 1938	
108	NW¼SW¼ sec. 34	——Nielson			Dr	112.0	6	Pl		W	D, S	....do......	+.90	90.92	....do......	
	T. 26 N., R. 49 W.															
109	SE¼NE¼ sec. 1	H. Von Bargan	H. Von Bargan		Dr	130.0	6	Pl		G	S	Top of casing	+.30	91.87	July 26, 1938	
110	NW¼NW¼ sec. 3	W. H. White			Dr		6	Pl		W	D, S	On 2 by 8 in. beam.	+1.20	112.01	....do......	

111	[illegible]¼NE¼ sec. 6	Orville Kidwell	.....	....	Dr	160.0	6	Pl	......	W	D, S	On platform.	+1.00	137.42	Aug. 8, 1938	
112	NE¼SE¼ sec. 11	Mrs. Ruth Rasmussen.	.....	....	Dr	120.0	6	Pl	......	W	A	....do......	+.40	96.43	July 27, 1938	
113	NE¼NE¼ sec. 19.	P. L. Johnson	Tom Tucheck	1938	Dr	250.0	30 in. to 200 ft. 18 in. to 250 ft.	T	8	Diesel	I	....do......	.0	118.42	July 26, 1938	52 feet draw-down reported; measured yield 744 gallons a minute.
114	SW¼SW¼ sec. 23.	Albert Munk	.....	....	Dr	150.0	6	Pl	......	......	A	On pump base	+1.00	105.17	....do......	
115	SE¼SE¼ sec. 30	Lincoln Land Bank.	.....	....	Dr	163.0	6	Pl	......	W	D, S	On disk wheel	+.55	125.70	....do......	
	T. 26 N., R. 50 W.															
116	SE¼SW¼ sec. 4	J. P. Jensen	.....	....	Dr	150.0	6	Pl	......	W	D, S	On 2 by 4 in. beam.	+.90	112.62	July 25, 1938	
117	SE¼SW¼ sec. 6	Theodore Keigh	.....	....	Dug	120.0	42	Pl	......	W	D, S	On platform.	+1.40	115.83	....do......	
118	SW¼SE¼ sec. 12	Mrs. L. A. Rosenberg	.....	....	Dug	105.0	48	Pl	......	W	A	....do......	+1.00	102.17	June 18, 1938	Observation well 10.
119	NW¼NW¼ sec. 19	H. C. Hansen	H. C. Hansen and ——Larsen.	....	Dug	144.0	48	Pl	......	W	S	....do......	+1.30	138.38	July 25, 1938	
120	NW¼NW¼ sec. 22	G. M. Jenkins	Buck Lyman	....	Dr	112.0	6	Pl	......	W	D, S	On pump base	+1.80	71.33	....do......	
121	NE¼SE¼ sec. 31	Bill Kiester	.....	....	Dug	46.0	48	Pl	......	W	S	On platform.	+.50	41.15	....do......	In a valley.
122	SE¼NE¼ sec. 34	——O'Connor	.....	....	Dug	103.0	48	Pl	......	W	S	....do......	+1.00	93.40	July 20, 1938	
	T. 26 N., R. 51 W.															
123	SW¼SW¼ sec. 8	W. M. Roth	.....	....	Dr	115.0	6	Pl	......	W	D, S	On pump base	+.50	109.09	July 25, 1938	
124	NW¼NW¼ sec. 13	An unknown land company.	.....	....	Dug	144.0	48	Pl	......	G	S	On platform.	+1.40	139.88	....do......	
125	SE¼SE¼ sec. 20	Joe Caha	.....	....	Dr	75.0	6	Pl	......	W	S	Top of casing	+.55	66.24	July 23, 1938	In broad flat upland valley.
126	NW¼NE¼ sec. 22.	James Fowler	.....	....	Dug	126.0	40	None	......	......	A	On platform.	+1.50	120.96	....do......	On colluvial slope at base of upland.
127	NW¼SW¼ sec. 25.	O. T. Wilkins	.....	....	Dr	108.0	4	Pl	......	Hand	......	Base of pump	+1.00	96.69	June 17, 1938	On hillside. Observation well 8.
128	NW¼NW¼ sec. 32	John Caha	.....	....	Dr	108.0	6	Pl	......	W	D, S	On pump base	+.65	86.82	July 23, 1938	On knoll on tableland.
129	NW¼NW¼ sec. 35	Royal Highlanders.	Tom Tucheck	....	Dr	124.0	......	Pl	......	W	S	Top of casing	+.60	115.89	....do......	
	T. 26 N., R. 52 W.															
130	SW¼SW¼ sec. 1	Edna Randal	.....	....	Dug	110.0	36	Pl	......	W	D, S	On platform.	+.50	108.03	....do......	In a broad valley.
131	NE¼NE¼ sec. 7	P. A. Dyer	.....	....	Dr	105.0	6	Pl	......	W	D, S	Top of casing	+.30	89.01	Aug. 6, 1938	Gently rolling valley.
132	SW¼NW¼ sec. 10.	G. E. Dyer	G. E. Dyer	1938	Dr	198.0	24	T	8	G	I	....do......	+1.50	94.87	July 22, 1938	32 feet draw-down; pumping 721 gallons a minute.
133	NW¼NE¼ sec. 17.	Lew Barr	.....	....	Dr	103.0	......	Pl	......	W	A	On pump base	+1.00	74.60	June 23, 1938	Observation well 9.
134	SW¼NW¼ sec. 18.	V. J. Vesley	.....	....	Dug	115.5	48	Pl	......	W	D, S	On platform.	+1.70	108.42	Aug. 12, 1938	
135	NW¼NW¼ sec. 21	L. E. Hood	L. E. Hood	....	Dug	90.0	72	Pl	......	W	S	....do......	+2.80	78.64	July 20, 1938	
136	NE¼NW¼ sec. 24.	.....	.....	....	Dug	66.0	42	Pl	......	W	A	....do......	+1.85	61.93	July 23, 1938	About 30 feet above valley bottom.
137	NW¼NW¼ sec. 33	L. E. Hood	L. E. Hood	....	Dug	56.0	48	Pl	......	W	D, S	On platform.	+.50	47.63	July 20, 1938	
138	SW¼NE¼ sec. 35.	W. J. Roes	.....	....	Dug	71.5	40	None	......	......	A	....do......	+1.50	70.49	July 23, 1938	

Sioux County

	T. 26 N., R. 53 W.															
139	NW¼SE¼ sec. 36.	Clayton Henderson	.....	....	Dr	138.0	......	Pl	......	W	S	On platform.	+0.50	125.18	Aug. 12, 1938	

See footnotes at end of table.

TABLE 14.—*Records of wells in Box Butte County and adjacent areas*—Continued

Sheridan County

Well No.	Location	Owner or name	Driller	Year completed	Type [1]	Depth (feet) [2]	Diameter (inches)	Type of pump [3]	Size of pump (inches)	Kind of power [4]	Use of water [5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
	T. 25 N., R. 46 W.															
140	NW¼NW¼ sec. 5.	....	....	....	Dr	29.0	4	Pl	......	W	S	On platform.	+1.00±	22.20	Sept. 9, 1938	
141	NW¼NW¼ sec. 6.	....	....	....	Dr	23.0	6	None	......	......	A	Top of casing	+1.50±	13.90	....do......	

Box Butte County

Well No.	Location	Owner or name	Driller	Year completed	Type [1]	Depth (feet) [2]	Diameter (inches)	Type of pump [3]	Size of pump (inches)	Kind of power [4]	Use of water [5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
	T. 25 N., R. 47 W.															
142	NE¼NE¼ sec. 19.	John Lawlor.......	John Lawlor.......	....	Dr	35.50	6	Pl	......	W	S	Top of casing	+0.50±	21.56	June 20, 1938	Observation well 17.
143	SE¼SE¼ sec. 28...	Mary Ackerman....	....	....	Dr	57.0	6	Pl	......	W	D, S	On pump base	+1.50	52.98	July 22, 1938	
144	NW¼NW¼ sec. 29	Koester Bros.......	Harry Minnick.....	1936	Dr	340.0	18	T	......	Diesel	I	Could not measure.	....	63.0	....	45 feet draw-down reported; measured yield, 1897 gallons a minute.
145	SE¼SW¼ sec. 1...	Frankie Bauer.....	....	....	Dr	47.0	6	Pl	......	W	S	On platform.	+1.50	30.85	July 22, 1938	At edge of sand hills.
146	NW¼NW¼ sec. 7.	E. W. Purington...	L. E. Frye.........	1938	Dr	200.0	16	C	......	T	I	On pump base	+.60	57.30	Sept. 9, 1938	47 feet draw-down reported; pumping about 200 gallons a minute.
147	SW¼NW¼ sec. 9..	Nels Peterson......	Harry Minnick.....	....	Dr	......	......	......	......	T	I	....do......	+.65	23.84	Aug. 14, 1938	52 feet draw-down reported; pumping 700 gallons a minute.
148	NE¼NW¼ sec. 8..	....do...........	....	....	Dr	35.0	6	Pl	......	W	S	On platform.	+1.00	10.62	July 22, 1938	
149	NW¼NW¼ sec. 21	George Smith......	Harry Minnick.....	....	Dr	150.0	28	C	......	T	I	Reported....	....	27.00±	....	24 feet draw-down reported; pumping 500 gallons a minute.
150	SW¼SW¼ sec. 11.	Charley Bauer.....	Joe Carry.........	....	Dr	54.0	6	Pl	......	W	D, S	Top of casing	+.50	19.14	July 22, 1938	About 10 feet above valley bottom.
151	NE¼NE¼ sec. 35.	Mr. Jennings......	....	....	Dr	71.0	8	Pl	......	W	D, S	On platform.	+1.50	46.28	....do......	On terrace.
	T. 25 N., R. 48 W.															
152	SW¼NW¼ sec. 1..	Mrs. Purington....	....	....	Dug	61.0	42	Pl	......	W	D, S	....do......	+1.60	55.14	July 21, 1938	
153	SE¼SW¼ sec. 7...	Mrs. Knapp.......	....	....	Dug	94.0	36	Pl	......	W	A	....do......	+3.20	89.43	....do......	
154	SE¼SW¼ sec. 15..	L. T. Burros.......	....	....	Dr	61.0	4	Pl	......	W	D, S	....do......	+1.50	49.84	....do......	
155	SE¼NE¼ sec. 30..	Mrs. E. A. Wells...	....	....	Dr	21.0	6	None	......	......	A	Top of casing	+.50	15.50	June 20, 1938	Observation well 2.
156	SW¼NE¼ sec. 35.	Mrs. C. H. Devee..	....	....	Dr	56.0	4	Pl	......	W	A	On pump base	+.50	43.18	July 18, 1938	Observation well 1.

	T. 26 N., R. 48 W.															
157	Center sec. 36	Louis Bauer	L. E. Frye	....	Dr	260.0	......	C	......	T	I	....do....	.0	Rept. 60.00±	Aug. 13, 1938	48 feet draw-down reported; pumping about 700 gallons a minute.
	T. 25 N., R. 49 W.															
158	NE¼SE¼ sec. 3	Barnes Estate	....	....	Dr	155.0	6	None	......	......	A	Top of casing	+.40	114.11	July 21, 1938	
159	SE¼SE¼ sec. 5	Mary Norton	....	....	Dug	84.5	42	..do..	......	......	A	On platform.	+1.00	80.39	....do......	About 15 feet above creek.
160	SW¼SE¼ sec. 15	C. L. Hoshman	C. L. Hoshman	....	Dug	45.5	42	Pl	......	W	D	....do......	+.80	32.72	....do......	On high point in valley.
161	SW¼SW¼ sec. 27	Alliance Bank	....	....	Dr	46.0	6	Pl	......	W	D, S	....do......	+1.70	43.97	....do......	
162	NW¼SE¼ sec. 30	L. W. Lore	L. W. Lore	....	Dr	23.5	6	Pl	......	W	D, S	....do......	+.90	19.97	July 20, 1938	
163	SW¼SW¼ sec. 33	——Rosenfelt	....	....	Dr	51.0	6	Pl	......	W	D, S	On 2 by 4 in. beam.	+1.50	26.28	July 19, 1938	
	T. 25 N., R. 50 W.															
164	SE¼SE¼ sec. 11	Platte Valley Land Co.	....	....	Dr	130.0	6	Pl	......	W	D, S	....do......	+.30	96.90	July 20, 1938	Flat upland.
165	SE¼SW¼ sec. 17	Kloke Invest. Co.	....	....	Dug	33.0	40	Pl	......	W	S	On platform.	+1.50	25.47	....do......	In valley.
166	NE¼SE¼ sec. 27	Jacob B. Rohrbauck	Jacob B. Rohrbauck	1909	Dug	56.0	60	Pl	......	W	D	....do......	+1.50	52.13	....do......	
167	NW¼NE¼ sec. 31	Mutual Trust Life Insurance Co.	....	....	Dr	109.5	6	None	......	......	A	On iron plate	+.61	103.68	June 18, 1938	Observation well 129.
	T. 25 N., R. 51 W.															
168	SW¼SW¼ sec. 3	——Gernstead	....	....	Dr	78.0	6	Pl	......	Hand	D	On platform.	+1.30	76.34	July 23, 1938	
169	NE¼NE¼ sec. 7	Amda Elsea	....	....	Dr	68.0	6	Pl	......	W	S	Top of casing	+3.80	47.97	July 19, 1938	
170	SE¼NE¼ sec. 14	C. A. Allen	....	....	Dr	112.0	6	Pl	......	W	A	....do......	+.50	88.83	June 23, 1938	Observation well 7.
171	NE¼SW¼ sec. 17	Jacob Elsea	....	....	Dr	51.0	6	Pl	......	W	S	....do......	.0	32.33	July 19, 1938	
172	NW¼SE¼ sec. 29	Kilpatrick Bros.	Kilpatrick Bros.	....	Dr	101.0	6	Pl	......	W	S	On platform.	+.80	67.03	....do......	
173	NW¼SE¼ sec. 31	....do........	....do........	....	Dr	43.5	6	Pl	......	W	D, S	Top of casing	+.20	34.17	July 16, 1938	
174	SE¼SE¼ sec. 35	....	....	....	Dr	112.0	6	Pl	......	W	S	On concrete platform.	.0	74.01	July 18, 1938	
	T. 25 N., R. 52 W.															
175	SW¼SW¼ sec. 12	J. W. Kennedy	J. W. Kennedy	....	Dug	51.0	40	Pl	......	W	S	On curb.....	+1.90	44.70	July 19, 1938	
176	NW¼NW¼ sec. 17	Henry Clayton	....	....	Dr	38.0	6	Pl	......	W	S	On platform.	.0	23.77	July 20, 1938	Well is about 15 feet above creek.
177	Center sec. 21	J. W. Kennedy	J. W. Kennedy	....	Dr	27.0	6	Pl	......	W	S	Top of casing	+1.50	6.63	July 19, 1938	In Snake Creek Valley.
178	NE¼NE¼ sec. 30	Dick Henderson	Dick Henderson	....	Dr	37.0	8	Pl	......	W	D, S	On platform.	+1.30	11.93	....do......	

Sioux County

	T. 25 N., R. 53 W.															
179	NW¼NE¼ sec. 24	Mrs. Earl Henderson	Earl Henderson	....	Dug	......	42	Pl	......	W	D, S	On platform.	+0.30	12.83	Aug. 12, 1938	

Box Butte County

	T. 24 N., R. 47 W.															
180	SE¼SE¼ sec. 5	——Lechtenberg	....	....	Dr	69.0	6	Pl	......	W	D, S	Top of casing	+1.40	31.88	July 21, 1938	
181	NW¼NW¼ sec. 6	Enoch Buyer	....	....	Dr	76.0	8	Pl	......	W	D	....do......	+1.30	35.15	....do......	
182	SE¼SE¼ sec. 23	....	....	....	Dr	14.0	6	Pl	......	W	A	....do......	+3.00	8.28	Aug. 19, 1938	

See footnotes at end of table.

TABLE 14.—*Records of wells in Box Butte County and adjacent areas*—Continued

Box Butte County—Continued

Well No.	Location	Owner or name	Driller	Year completed	Type [1]	Depth (feet) [2]	Diameter (inches)	Type of pump [3]	Size of pump (inches)	Kind of power [4]	Use of water [5]	Measuring point	Distance of measuring point above or below land surface (feet)	Depth to water level below measuring point (feet)	Date of measurement	Remarks
	T. 24 N., R. 48 W.															
183	SW¼SW¼ sec. 8	——Schultz			Dr	29.0	6	Pl		G	D	Top of casing	+1.40	20.14	July 20, 1938	
184	NW¼NE¼ sec. 14	M. Wright			Dr	24.0	8	Pl		W	D, S	On platform.	+1.20	8.66	July 21, 1938	
185	NW¼NE¼ sec. 28	S. Smith			Dr	35.0	6	Pl		W	D, S	On 8 by 8 in. beam.	+3.00	30.92	....do.....	
186	SW¼NW¼ sec. 31	O. A. Odel	O. A. Odel		Dr	137.0	40	C		T	I	On 12 by 12 in. beam.	+1.00	37.37	July 20, 1938	Well has no casing below 35 feet.
187	NW¼NE¼ sec. 31	....do	....do		Dr	100.0	14	None		None	None	Top of casing	+1.00±	38.92	Aug. 15, 1938	To be irrigation well.
	T. 24 N., R. 49 W.															
188	SW¼SW¼ sec. 5	H. J. Worley			Dr	86.0	6	Pl		W	D	On platform.	+.50	51.78	July 20, 1938	
189	SE¼NW¼ sec. 10	Elmer Engelhorn			Dr	22.0	6	None			A	Top of casing	+.20	10.56	....do.....	
190	SW¼SW¼ sec. 11	R. R. Seda			Dr	21.0	6	Pl		W	D	....do.....	+2.20	13.69	....do.....	Valley bottom.
191	NW¼SE¼ sec. 20	Fred C. Robbins			Dr	96.0	8	Pl		W	D, S	On concrete platform.	+.50	67.87	July 19, 1938	
192	NE¼NE¼ sec. 34	Fannie Shanklin			Dr	69.0	6	Pl		W	D	....do.....	+.40	36.02	July 20, 1938	
193	SE¼NW¼ sec. 32	Lyle Morse			Dr	61.0	6	Pl		G	D	Top of casing	+1.40	35.69	....do.....	
	T. 24 N., R. 50 W.															
194	SW¼NW¼ sec. 7	Goldie McCulley			Dr	16.5	6	None			A	....do.....	+3.15	15.88	July 18, 1938	
195	NE¼NE¼ sec. 10	John Nolan			Dr	82.0	12	Pl		W	D, S	On pump base	+.70	51.98	....do.....	Observation well 3.
	T. 24 N., R. 49 W.															
196	SE¼NE¼ sec. 7	P. J. Kneep			Dr	44.0	6	Pl		W	S	Top of casing	+1.30	7.77	July 20, 1938	
	T. 24 N., R. 50 W.															
197	NE¼SE¼ sec. 20	——Robson			Dr	45.0	6	Pl		W	D, S	On plank....	+1.50	17.16	July 19, 1938	
198	NW¼NW¼ sec. 24	Frank Ramsdell			Dr	24.6	8	Pl		W	D, S	On platform.	+2.00	14.50	....do.....	
199	SW¼SW¼ sec. 24	Ferdinand Trenkle	Lynn Frye	1938	Dr	122.0	12	C		G	I	On pump base	.0	29.79	Oct. 3, 1938	12 feet draw-down reported; measured yield, 506 gallons a minute.
200	NW¼NE¼ sec. 32	R. W. Reddish	Joe Carry		Dr	55.0	8	Pl		W	S	On 2 by 6 in. beam.	+4.00	19.12	July 18, 1938	
201	NE¼NE¼ sec. 36	L. Morse			Dr	24.0	8	Pl		W	S	Top of casing	+.20	7.76	July 19, 1938	
	T. 24 N., R. 51 W.															
202	SW¼SE¼ sec. 4	Kilpatrick Bros.	Kilpatrick Bros.		Dug	15.0	48	Pl		W	D	On platform.	+2.48	8.15	July 18, 1938	
203	SE¼SE¼ sec. 10	Charley Tiernan			Dr	23.0	6	None			A	Top of casing	+.40	6.87	....do.....	
204	NW¼SW¼ sec. 15	....do			Dr	71.0	6	Pl		W	D, S	....do.....	+.80	55.69	....do.....	
205	NE¼SE¼ sec. 20	....do			Dug	50.0	48	Pl		W	S	On platform.	.0	26.74	....do.....	
206	SW¼NE¼ sec. 30	....do			Dr	70.0	6	Pl		G	S	Top of casing	+1.50±	49.67	....do.....	
207	NE¼NE¼ sec. 35	Burr Underwood			Dr	34.0	6	Pl		W	S	On platform.	+1.75	10.69	....do.....	

	T. 24 N., R. 52 W.														
208	SW¼NE¼ sec. 7	Di^k Henderson			Dug	54.0	36	Pl		W	S	do	+2.70	51.42	July 16, 1938	
209	NE¼NE¼ sec. 12	Clearance Kilpatrick			Dr	45.0	6	Pl		W	S	On 2 by 6 in. beam.	+1.20	27.69	do	
210	NW¼SW¼ sec. 13	Dr. G. D. Shepard			Dr	93.0	6	Pl		W	A	On pump base	+.30	78.19	June 17, 1938	Observation well 5.
211	SE¼SW¼ sec. 18	Lewis N. Worley			Dr	120.0		Pl		W	S	On platform.	+1.60	106.94	Aug. 11, 1938	
212	NW¼NW¼ sec. 21	——Lambdore	Joe Nerud		Dr	95.0	6	Pl		W	D	On 4 by 6 in. beam.	+.80	80.14	July 16, 1938	
213	SE¼SE¼ sec. 22	R. A. Richardson			Dr	100.0	6	None			A	Top of casing	.0	.0	Aug. 10, 1938	
214	NF¼NE¼ sec. 35	——Baily			Dr	120.0	4	Pl		W	S	On pump base	.0	99.43	June 17, 1938	Observation well 6.
	Sioux County															
	T. 24 N., R. 53 W.															
215	SE¼NW¼ sec. 15	Nels Worley			Dr	90.0	24	Pl		W	S	On platform.	+1.40	88.85	Aug. 11, 1938	
	Morrill County															
	T. 23 N., R. 51 W.															
216	NE¼NW¼ sec. 5	E. W. Becker	Morton Hatch		Dr	98.0	6	Pl		W	D, S	On platform.	+0.80	75.03	Aug. 10, 1938	
	T. 23 N., R. 52 W.															
217	NW¼NE¼ sec. 4	George Acker	Jack Fincher	1908	Dr	175.0	6	Pl		W	D, S	On concrete platform.	+.40	167.15	Aug. 11, 1938	
	Scotts Bluff County															
218	NE¼NE¼ sec. 6	——Jurgens			Dr	197.0	6	Pl		W	S	On 2 by 6 in. beam.	+1.10	142.01	July 16, 1938	
	Morrill County															
219	NW¼SW¼ sec. 11				Dr	155.0	6	Pl		Hand	A	On platform.	+0.30	143.12	Aug. 10, 1938	
	Scotts Bluff County															
	T. 23 N., R. 53 W.															
220	NW¼NE¼ sec. 2				Dr	135.0	6	None			A	Top of casing	+1.80	132.85	Aug. 11, 1938	On upper slope of Platte Valley.

[1] Dr, drilled.
[2] Where measured, given to nearest tenth of foot.
[3] Pl, plunger; T, turbine; C, centrifugal.
[4] W, wind; T, tractor; G, gasoline engine.
[5] A, abandoned; S, stock; D, domestic; I, irrigation; O, observation.

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