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GEOLOGICAL SURVEY CIRCULAR 156

RECONNAISSANCE OF THE GEOLOGY AND GROUND-WATER RESOURCES OF THE PUMPKIN CREEK AREA, MORRILL AND BANNER COUNTIES, NEBRASKA

By H. M. Babcock and F. N. Visher

WITH A SECTION ON THE CHEMICAL QUALITY OF THE WATER

By W. H. Durum

Prepared as part of a program of the
Department of the Interior for
Development of the
Missouri River Basin

UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

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RECONNAISSANCE OF THE GEOLOGY AND GROUND-WATER RESOURCES OF THE PUMPKIN CREEK AREA, MORRILL AND BANNER COUNTIES, NEBRASKA

WITH A SECTION ON THE CHEMICAL QUALITY OF THE WATER

ABSTRACT

The area described in this report includes the eastern, or lower, end of the valley of Pumpkin Creek and is in Morrill and Banner Counties, in western Nebraska. A reconnaissance of the geology and ground-water resources of the area was made to determine the possibilities of developing ground-water supplies for irrigation.

Rocks that crop out in the Pumpkin Creek area are shown on a geologic map that is included in the report. They range in age from Oligocene to Recent and consist of the Brule, Arikaree, and Ogallala formations and of the alluvium. The Chadron formation, of Oligocene age, underlies the area but is not exposed at the surface. The Lance formation, of Late Cretaceous age, underlies the Chadron formation. Sandstones, which are thought to be in the Lance formation, contain ground water under artesian pressure and might yield sufficient water for irrigation on a small scale. Several thousand feet of Pierre shale, which is not known to yield appreciable quantities of water to wells, underlies the Lance formation. In some places sufficient water for irrigation can be obtained by wells from fractures in the Brule formation. Large supplies of water can be expected in places where the fractures are extensive or where they are overlain by saturated alluvial material. A few springs that are fed by recharge from the upland area issue at the contact of the Brule and Arikaree formations. The Ogallala formation yields water to domestic and stock wells in the upland areas south of Pumpkin Creek valley. Inasmuch as this formation is high topographically and is well drained, the depth to water is considerable--generally 100 ft or more--and the thickness of the saturated material probably is not great. It is doubtful, therefore, that sufficient water for irrigation could be obtained from this material; however, it may be possible in some places to obtain water for irrigation on a small scale.

Alluvium, which underlies the floodplains of Pumpkin Creek and some of its major tributaries, is the principal aquifer in the area. The alluvium of Quaternary age consists of coarse sand and gravel and yields sufficient water for irrigation. In most places yields of 1,000 to 2,000 gpm probably could be obtained from properly constructed wells in this material.

It is estimated that about 21,000 acre-ft of ground water annually leaves the area as stream flow. This represents approximately the amount of additional ground water available for development; however, if sufficient ground water is pumped to lower the water table appreciably, the additional water salvaged from loss by evaporation and transpiration also would be available for irrigation use. The development of any additional ground water from the unconfined ground-water reservoir will cause a reduction in the flow of Pumpkin Creek.

Water from the alluvium and the Brule formation is moderately mineralized. Although most water is hard, some soft water is obtained from the Brule. The dissolved solids in water from the Brule formation and the alluvium ranged from 236 to 356 ppm. Hardness in these two water-bearing formations ranged from 6.0 to 204 ppm.

Water obtained from deep wells in the Lance formation is more mineralized and softer than water obtained from the overlying formations. The dissolved solids, which consist largely of sodium bicarbonate and sodium chloride, range from 812 to 1,170 ppm. Although the water from the Lance formation is satisfactory

for domestic needs, the high percentage of sodium restricts its use for irrigation.

INTRODUCTION

Purpose and scope of the investigation

This investigation is one of several being made by the United States Geological Survey as a part of the program undertaken by the Department of the Interior for the control, conservation, development, and use of the water resources of the Missouri River basin. The purpose of this study is to determine the character, thickness, and extent of the water-bearing formations, the source, occurrence, movement, quantity, and quality of ground water, and the possibility of developing ground-water supplies for irrigation in the Pumpkin Creek area.

This report covers the progress of the work from the beginning of the investigation in May 1949 through December 1949. The work was under the general supervision of A. N. Sayre, chief of the Ground Water Branch of the Geological Survey, and G. H. Taylor, regional engineer in charge of ground-water investigations in the Missouri River basin, and under the immediate supervision of S. W. Lohman, district geologist for Colorado and Wyoming.

The water-quality studies were under the general direction of S. K. Love, chief of the Quality of Water Branch, and under the immediate supervision of P. C. Benedict, regional engineer in charge of Missouri River basin water-quality investigations. The chemical analyses of the ground-water samples collected in the area were made by W. M. Barr, L. R. Kister, R. H. Langford, and A. S. Moehl, chemists of the Quality of Water Branch, Lincoln, Nebr.

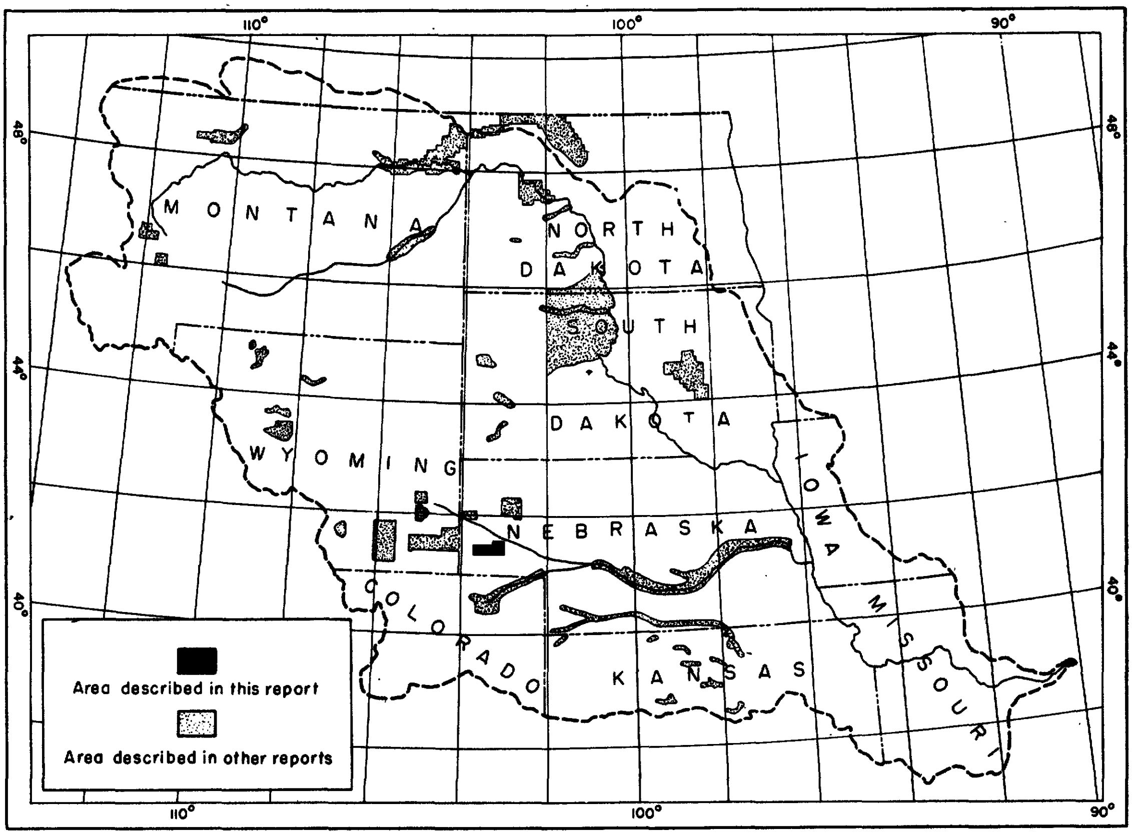

Figure 1. Map of the Missouri River basin showing areas in which ground-water studies have been made under the Missouri Basin development program.

Location and extent of the area

The Pumpkin Creek area is in Morrill and Banner Counties, in western Nebraska (see fig. 1); it lies in the northwestern part of the High Plains section of the Great Plains physiographic province. The area studied comprises the eastern part of the valley of

Pumpkin Creek. It extends westward from the junction of the creek with the North Platte River to State Highway 29, a distance of about 34 miles. The area lies within Tps. 18 and 19 N., and Rs. 50 through 55 W., and covers about 400 sq mi.

Methods of investigation

Records of 83 wells and springs in the area were obtained. Most of the information regarding the character of the water-bearing material and the yield and drawdown of the wells was obtained from well drillers or well owners. Thirty-five of the wells recorded were measured using a steel tape to determine the depth of well and depth to water below some fixed measuring point, generally the top of the casing or the bottom of the pump base. Reported data were recorded for those wells that could not be measured. Records of "shot holes" made during seismic surveys by oil companies were studied but are not listed in this report. Twenty-five samples of water for chemical analysis were collected from representative wells and springs and from creeks in the area, and five samples were collected from wells outside the area.

In May 1949, five representative wells were selected for monthly observations of water level in order to obtain information concerning the seasonal fluctuations of the water table. Water-level measurements of one other well (19-55-29acb) have been made intermittently since 1934 in cooperation with the Conservation and Survey Division of the University of Nebraska.

The geologic and hydrologic field data were recorded on large-scale aerial photographs and later transferred to a base map that was prepared by the Nebraska Department of Roads and Irrigation. The geologic mapping and hydrologic studies were restricted to the valley of Pumpkin Creek, where irrigation from wells is deemed most practicable. Logs of wells and shot holes were useful in the determination of the character, extent, and thickness of the alluvium.

Wells and springs shown on the map were located within the section by use of an odometer and by inspection of the aerial photographs; the locations are believed to be accurate to 0.1 mile.

Well-numbering system

In this report, the wells and springs are numbered according to their location within the General Land Office system of land subdivision. The well number shows the location of the well by township, range, section, and position within the section. The first numeral of a well number indicates the township, the second the range, and the third the section in which the well is located. The lowercase letters following the section number locate the well within the section. The first letter denotes the quarter section (160-acre tract), the second the quarter-quarter section (40-acre tract), and the third the quarter-quarter-quarter section (10-acre tract). These subdivisions are designated a, b, c, and d; the letters are assigned in a counterclockwise direction, beginning in the northeast quarter of the section. When more than one well is situated in a 10-acre tract, consecutive numbers beginning with 1 are added to the well number.

This method of well numbering is illustrated in figure 2.

Previous investigations

The geology of the Pumpkin Creek area has been described by Darton in the Camp Clark (1903a) and the Scotts Bluff (1903b) folios.[1] An investigation of the geology and ground-water resources of Scotts Bluff County, north of the Pumpkin Creek area, was made by Wenzel, Cady, and Waite (1946). The information in these reports proved very helpful in this investigation.

Acknowledgments

Residents of the area were very cooperative in supplying information and permitting the measurement of their wells. Seismograph companies and well drillers were very helpful in giving subsurface information.

GEOGRAPHY

Topography and drainage

The Pumpkin Creek valley, which is about 8 miles wide, is bounded on the south by bluffs that mark the edge of the High Plains. The valley is bounded on the north by the narrow Wildcat Ridge, which rises about 500 ft above Pumpkin Creek valley (fig. 3) and separates it from the valley of the North Platte River. The upper 400 ft of the north valley wall consists of nearly vertical bluffs; the lower 100 ft consists of rock-cut pediment slopes that are steep at the foot of the bluffs and gradually decrease in gradient toward Pumpkin Creek. On the south side of the valley, gravel-mantled pediments gradually rise about 350 ft from Pumpkin Creek to the foot of the nearly vertical bluffs, which rise an additional 300 ft.

1 See list of references at end of report.

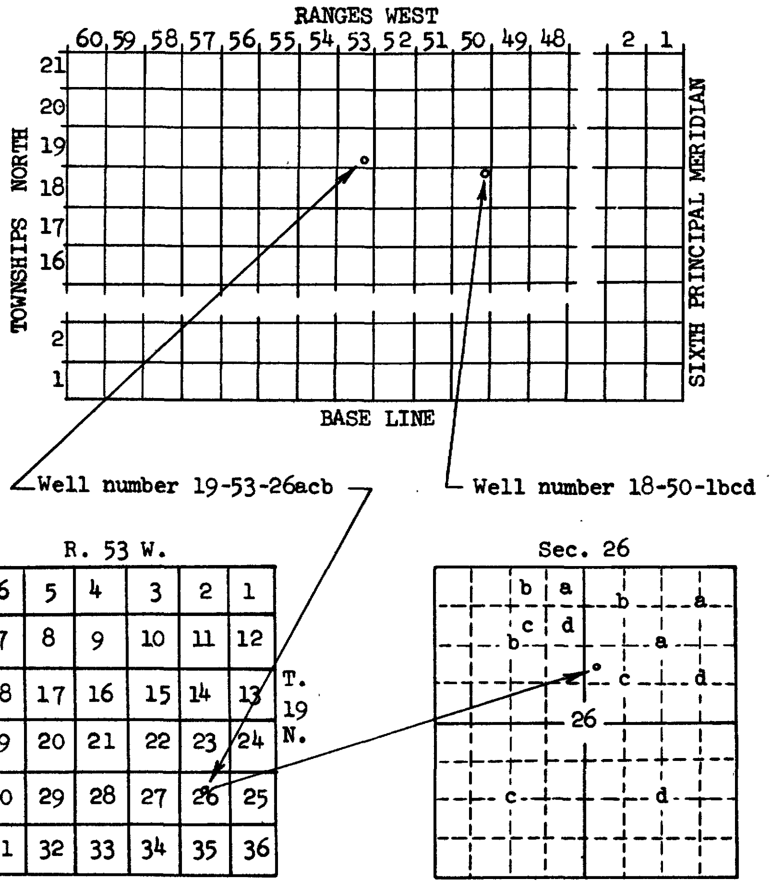

Figure 2. Sketch showing well-numbering system.

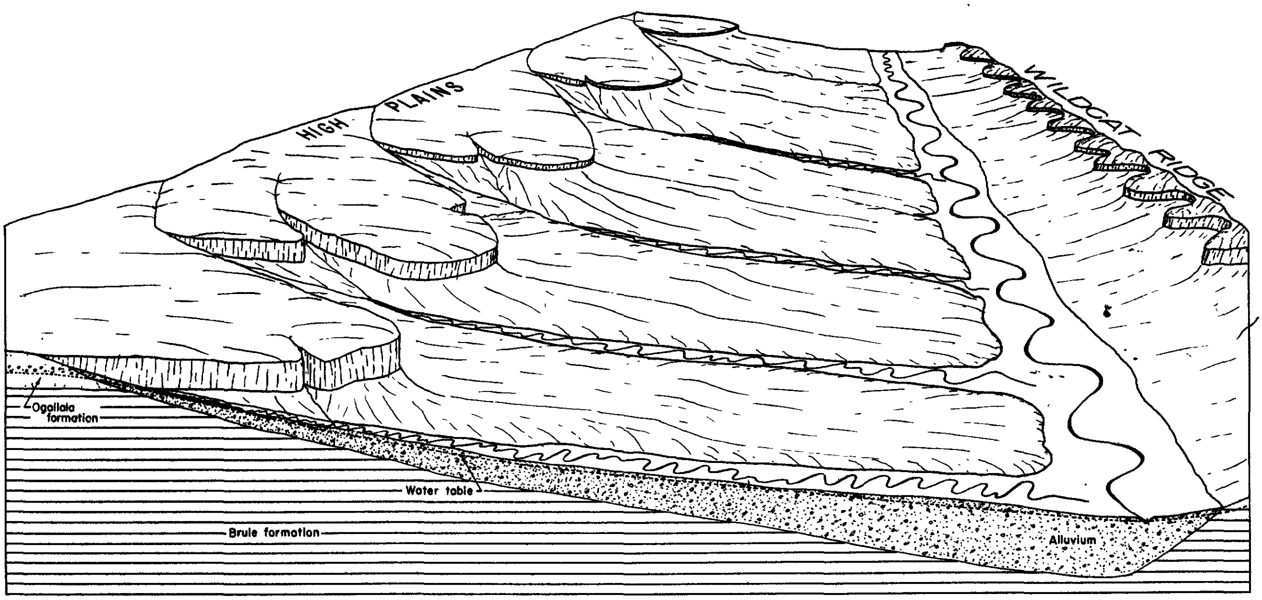

Figure 3. Block diagram, looking west in Pumpkin Creek valley, Nebr.

Pumpkin Creek rises near the Wyoming-Nebraska line at an altitude of 4,600 ft, and flows eastward about 50 miles to its confluence with the North Platte River, at an altitude of 3,600 ft. It has an average gradient, therefore, of about 20 ft to the mile. In the mapped area, however, the stream has an average gradient of only 16 ft to the mile.

The main tributaries that enter Pumpkin Creek from the south rise as springs in the canyons that are cut into the adjacent tableland. The water from most of these springs flows on the surface only a few hundred feet and disappears into a thin alluvial mantle that covers the canyon floors. Greenwood Creek and Lawrence Fork are the only tributaries that are perennial throughout most of their courses. The flow of these streams normally does not empty directly into Pumpkin Creek but sinks into the alluvium that underlies the flood plain of Pumpkin Creek. Most of the other tributaries from the south are ephemeral and many do not have recognizable channels at their confluence with Pumpkin Creek. The small tributaries that enter Pumpkin Creek from the north carry water only during periods of very heavy rainfall.

Climate

The climate of the Pumpkin Creek area is much like that of other parts of the High Plains section. It is characterized by low precipitation, rapid evaporation, and a wide range of temperature. The weather is variable from year to year, but usually the summers are dry and hot and the winters are very cold. The summer days generally are hot but, owing to the movement of wind and to the low humidity, the nights generally are cool.

There are no climatological stations in the Pumpkin Creek area; however, the U. S. Weather Bureau maintains a station at Bridgeport, 2 miles north of the eastern part of the area, and at Scottsbluff, 10 miles north of the western part. The annual precipitation during the period of record for these stations is shown graphically in figure 4. The normal annual precipitation is 16.21 in. at Bridgeport and 15.62 in. at Scottsbluff. The greatest annual precipitation recorded was 23.67 in. at Bridgeport and 27.48 in. at Scottsbluff. The least annual precipitation recorded at the two stations was 7.93 in. and 9.47 in., respectively. Extremely dry periods like those that prevailed from 1931 through 1937 caused repeated crop failures where the land was not irrigated. Monthly precipitation reaches a maximum during the spring and early summer and decreases to a minimum in the fall and winter, when it usually takes the form of light dry snow. The summer rains occur largely as thunderstorms that are usually sporadic and unevenly distributed. The amount of rainfall in a single storm varies greatly from one part of the area to another. These storms occasionally are accompanied by high winds and hail that cause considerable damage to crops.

The mean annual temperatures are 48.3 F and 48.5 F at Bridgeport and Scottsbluff, respectively. The length of the growing season is usually about 5 months.

Agriculture

Detailed descriptions of the soils in the area are contained in the reports on the soil surveys of Banner (Hayes and Bedell, 1921) and Morrill (Hayes, Hawker, and others, 1921) Counties, and no attempt is made to describe them in this report.

Most of the area is utilized for dry farming of grain crops, but the rougher parts are used for pasture. Some land along Pumpkin Creek and its tributaries is irrigated from creeks and wells. Wheat, oats, hay, and corn are the main crops raised on the irrigated lands.

GEOLOGY AND GROUND WATER

Summary of stratigraphy

The rocks that crop out in the Pumpkin Creek area are sedimentary and range in age from Oligocene to Recent. (See pl. 1.) The Tertiary formations that crop out in the area include the Brule, Arikaree, and Ogallala formations. Quaternary sediments which include alluvium, dune sand, and terrace deposits overlie the Brule formation in parts of the valley of Pumpkin Creek, but only the alluvium is shown on plate 1.

The Chadron formation of Oligocene age, which is the oldest Tertiary formation in the area, underlies the Brule formation but does not crop out. The Lance formation of Late Cretaceous age underlies the Chadron formation. In adjacent areas both the Chadron and Lance formations contain water-bearing sandstones. Beneath the Lance formation lies several thousand feet of Pierre shale, which is not known to yield appreciable quantities of water to wells in western Nebraska.

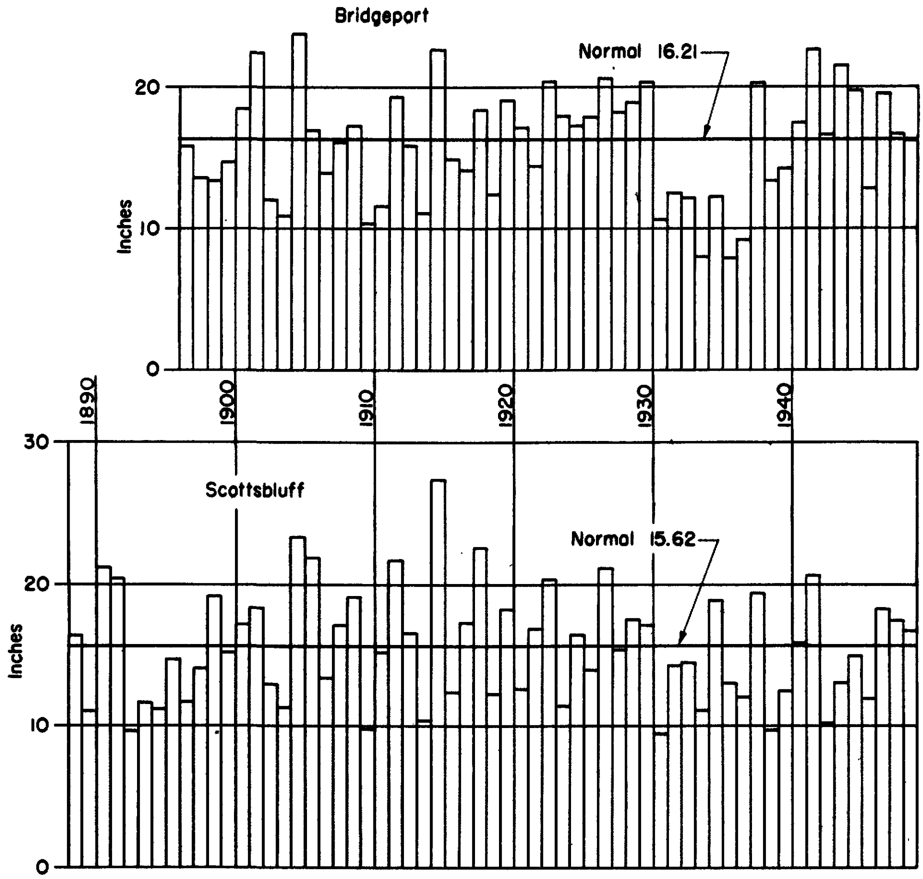

Figure 4. Graph showing annual precipitation at Bridgeport and Scottsbluff, Nebr. (From records of the U. S. Weather Bureau)

Summary of geologic and physiographic history

Cretaceous period

Toward or at the close of the Cretaceous period, the sediments that had been accumulating almost without interruption since early Carboniferous time were uplifted and folded into the vast anticlines and synclines of the Rocky Mountains, and the mountains were eroded as they were uplifted. The streams flowing eastward from the mountains began to aggrade and develop broad flood plains on which were deposited the sands and clays of the Lance formation. At times during this period, part of the area east of the mountains was occupied by an inland sea.

Tertiary period

At the beginning of the Tertiary period, further uplift ended the deposition and there followed a long period of erosion during which the Lance formation was deeply dissected and, in many places, was removed entirely. The following discussion is taken from the Camp Clark folio (Darton, 1903a, p. 4):

"Later in Tertiary time, after the outlines of the great mountain ranges to the north and west had been carved, there was a long period in which streams of moderate declivity flowed across the central Great Plains region; these, with frequently varying channels and extensive local lakes, due to damming and the sluggish flow of the waters, laid down the widespread mantle of Oligocene or White River deposits. These began with the sands of the Chadron formation, which show clearly the course of old currents by channels filled with coarse sandstone and areas of slack water and overflow in which . . . clays were laid down . . . The White River epoch was continued by the deposition of the Brule (silts) under conditions in which the currents were less strong and local lakes and slack-water overflows were more extensive.

"At the beginning of Miocene time the general conditions had not changed materially, but doubtless for a while an extensive land surface existed in the central Plains area. In . . . the stream channels extending across this surface the Gering member of the Arikaree was laid down, one channel extending across this area. Next came the deposition of a widespread sheet of sands derived from the mountains to the west . . . The streams of this time shifted their courses across the plains, spreading the debris from the mountains in a sheet which in some portions of the area attained a thickness of 1,000 feet. This is the Arikaree formation."

Following another period of erosion the streams in Pliocene time again began to aggrade and spread out over the vast expanse of material that had previously been deposited east of the mountains. This later deposit is the Ogallala formation.

Quaternary period

At the close of Ogallala time, the streams of the area flowed eastward across a broad nearly featureless alluvial plain, a large remnant of which exists today between Pumpkin Creek and Lodgepole Creek. The ancestral Pumpkin Creek extended to the Laramie Range and was one of the major tributaries to the ancestral North Platte River. Following the uplift of the area, the main streams began to deepen and enlarge their valleys. This valley cutting caused a lowering of the water table in the divide areas between the main streams and dried up minor streams and tributaries that had previously been fed by ground water. As surface water was the primary agent of erosion, this disappearance of the minor streams virtually stopped erosion in the divide areas.

The valley that Pumpkin Creek cut into the Ogallala and Arikaree formations probably was relatively narrow until the stream cut down into the Brule formation. Erosion was then greatly accelerated, and the sides of the valley began to retreat. The southern escarpment retreated until the gravel from the uplands covered the springs that issued from the top of the Brule and that previously had been undermining the overlying formations. During the same time, the upland between Pumpkin Creek and the North Platte River was eroded to a narrow ridge.

This escarpment retreat resulted in a pediment, which corresponds to the second pediment above the third terrace of the North Platte River valley. The terraces and pediments of the North Platte River valley are described by Visher in a report on the Dutch Flats area (Babcock and Visher, 1950, pp. 10-12). Subsequent erosion and down cutting deepened the valley an additional 100 ft and produced a pediment that corresponds to the first pediment above the third terrace of the North Platte River valley.

Following the development of this pediment, the North Platte River deepened its channel and thus, lowered the mouth of Pumpkin Creek about 200 ft below its present level, and the channel cutting extended up Pumpkin Creek and its major tributaries. Subsequently, the streams aggraded and their channels were filled with sand and gravel to about the level of the present flood plain, which corresponds to the third terrace of the North Platte River valley.

A protective mantle of gravel, which was derived from the Ogallala formation, has preserved the older pediments on the south side of the valley. Lacking a protective mantle, the entire pediment slope on the north side of the valley was lowered with each successive rejuvenation of erosion, hence, while the down cutting was taking place, the tributaries of Pumpkin Creek were eroding headward into the Ogallala-covered upland to the south and were intercepting the existing drainage courses. Most of the drainage areas thus intercepted were small; however, the piracy that resulted in the present drainage of Lawrence Fork embraced a large area. Lawrence Fork eroded headward and captured the trunk stream that drained most of the upland between Pumpkin Creek and Lodgepole Creek. Since the time of capture, Lawrence Fork has cut a deep canyon into the upland.

During the third terrace stage of the North Platte River valley, the retreating Goshen Hole escarpment intercepted the middle course of ancestral Pumpkin Creek near La Grange, Wyo., and the headwaters were diverted. The upper part of ancestral Pumpkin Creek and its present extension through Goshen Hole is now called Horse Creek. Deprived of its main source of water, Pumpkin Creek became a meandering, aggrading stream, and did not participate in the down cutting associated with the development of the first and second terraces of the North Platte River valley.

Geologic formations and their relation to ground water

Cretaceous system

Lance formation

The Lance formation of Late Cretaceous age underlies the area but does not crop out. The shale encountered from 530 to 835 ft in well 19-55-33aaa is referred to as Lance by Cady (Wenzel, Cady, and Waite, 1946, p. 58). Cady's interpretation of the driller's log of this well has been essentially substantiated by more recent drilling.

A coarse clean sand about 40 ft thick, which may be a part of the Lance formation, underlies the northeastern part of the area. This sand, overlain by Tertiary sediments and underlain by Cretaceous sediments, has many of the characteristics of the Chadron formation observed in Goshen County, Wyo. Although this sand is not similar to materials encountered in the Lance formation in the western part, the chemical quality of the water is similar to that of water from the Lance formation, and on this basis, the sand tentatively is classified as Lance.

The Lance formation possibly underlies all the area. It is about 300 ft thick in well 19-55-33aaa. The formation thickens to the west and thins to the east. The eastern extent of the formation is not known.

Well 18-56-2cca, which is 3 miles west of the southwest corner of the mapped area, obtains water from the Lance formation. This well penetrates the entire formation but does not produce more than a few gallons a minute.

Well 19-50-11cad, in the eastern part of the area, flows at a rate of about 200 gpm from the sand that underlies the northeastern part. The chemical quality of the water from this sand is similar to water from other wells in the Lance formation in adjacent areas.

Tertiary system

White River group

Chadron formation.--The Chadron formation of Oligocene age underlies the Pumpkin Creek area but is not exposed. Where outcrops of the formation were studied nearby, the material was found to consist chiefly of red, green, and brown clay that contains channel sandstones. The Chadron formation was deposited on an erosional surface of strong relief and, consequently, varies considerably in thickness. Well 19-55-33aaa penetrated Chadron-like material between the depths of 400 and 530 ft. (See log in table 6.)

Where channel sandstones are present in the Chadron formation, they may yield sufficient water for domestic and stock use. These channel sandstones generally are narrow and widely separated and, therefore, are difficult to locate. Water in the sandstones is confined under artesian pressure; hence, it would rise above the points at which it is encountered, and in some parts of the area, it might flow at the surface.

Brule formation.--In its typical development the Brule formation of Oligocene age is a pale-buff or flesh-colored sandy siltstone of compact texture and massive structure and locally is called "hardpan." The formation was called the Brule clay by Darton; however, a mechanical analysis that is given in the Scotts Bluff report (Wenzel, Cady, and Waite, 1946, p. 67) indicates the material is 69 percent silt and only 4 percent clay.

The Brule formation is traversed by numerous vertical to nearly vertical fractures that range in width from a few inches to several feet. The fracturing is thought to have resulted from the weight of overlying sediments and from regional warping. The Brule is a weak, brittle formation and tends to succumb to induced tension rather than to induced shear. The weight of the overlying formations was sufficient to cause failure when regional warping caused relief of the lateral support; consequently, the fracturing tends to parallel the strike of the warping.

Because fractures or groups of fractures constitute zones of weakness in the bedrock, many of the water courses occupy valleys and draws that are controlled in part by underlying fractures in the Brule.

The entire area is underlain by the Brule formation, which extends beneath the surface of western Nebraska and adjoining regions. Only the upper 300 ft of this formation is exposed in the Pumpkin Creek area; in Scotts Bluff County it is reported (Wenzel, Cady, and Waite, 1946, p. 66) to be 560 ft thick.

The Brule is the source of water supply for many wells. Fractures in the formation generally contain water and in most places yield sufficient water to wells for domestic and stock use. In some areas where the fractures are overlain by saturated alluvium, sufficient water for irrigation can be developed from the Brule formation.

Arikaree sandstone

The Arikaree sandstone of Miocene age forms Wildcat Ridge on the north and is exposed along most of the escarpment south of Pumpkin Creek valley. The sandstone has a thickness of more than 400 ft on Wildcat Ridge but lenses out to the southeast where the Ogallala formation directly overlies the Brule. The Arikaree sandstone consists mainly of silt, sand, and soft sandstone.

As the sandy soils formed from the Arikaree sandstone absorb most of the precipitation, there is little surface runoff and, hence, not much erosion. On the other hand the considerable runoff on the relatively impermeable Brule surfaces causes the Brule to erode rapidly. The contact between the rapidly eroding Brule formation and the slowly eroding Arikaree sandstone, therefore, generally is marked by an escarpment several hundred feet high. Springs that issue from the contact between the Brule and the Arikaree formations are fed by recharge from the upland areas and erode the Brule and undermine the

Arikaree. The Arikaree is high topographically and only the lower part of the formation is saturated; hence, the depth to water probably is considerable.

Ogallala formation

The Ogallala formation of Pliocene age lies unconformably on the Arikaree or Brule formations and caps the high tableland south of Pumpkin Creek valley. The formation is 200 ft thick at Langs Point and thickens toward the south.

The Ogallala formation consists of beds of sand, gravel, and poorly to moderately cemented sandstone. The Ogallala, like the Arikaree, is topographically prominent because its highly permeable soils have little surface runoff and, consequently, erode slowly. Under recent climatic conditions, the contact springs at the top of the Brule seemingly lacked sufficient flow to remove the gravels that have slumped over them from the overlying Ogallala. Most of the springs have been buried by these gravels and the water passes directly into the gravel-choked canyons without coming to the surface.

The Ogallala formation yields water to domestic and stock wells in the upland areas south of Pumpkin Creek valley. Inasmuch as this formation is high topographically and is well drained, the depth to water is considerable--generally 100 ft or more--and probably only a small part of the total thickness is saturated. It is doubtful, therefore, that sufficient water for large-scale irrigation could be obtained from this material; however, in some places it may be possible to obtain water for irrigation on a small scale.

Quaternary system

Alluvium

The flood plains of Pumpkin Creek and many of its tributaries are underlain by deep channels filled with sand and gravel. The alluvium averages about 1 mile in width along Pumpkin Creek and extends up most of the major tributaries. Although little information is available regarding the maximum thickness of this material, it is known to be 199 ft thick near the mouth of Pumpkin Creek and at least 60 ft thick at a point 26 miles above the mouth.

The alluvium consists of uncemented well-sorted stream-laid deposits of sand and gravel. Some of the material may have come directly from the mountains to the west, but most of it probably was derived locally from the Ogallala formation.

The alluvium is highly permeable and yields large quantities of water to irrigation wells.

Principles of occurrence of ground water

The fundamental principles of the occurrence of ground water are set forth in an authoritative and detailed report by Meinzer (1923). Only a brief discussion of the subject will be given here, and the reader is referred to Meinzer's report for a more detailed discussion.

Ground water is derived mainly from water that falls as rain or snow. A part of this precipitation runs off directly into streams, a part evaporates, a part is returned to the atmosphere through transpiration by plants, and a part percolates through the soil and underlying rocks to the zone of saturation. Much of the water in the zone of saturation eventually returns to the surface through seeps, springs, or wells, or is discharged by plants. The porous rocks in the zone of saturation will yield water to wells only if the rocks are sufficiently permeable.

The Pumpkin Creek valley contains three geologic units from which ground water is obtainable in sufficient quantities for irrigation use: (1) the coarse alluvium that underlies the flood plain of Pumpkin Creek and its tributaries; (2) the fractures in the Brule formation; and (3) the sandstones in the Lance formation.

The upper surface of the zone of saturation in permeable soil or rocks is the water table. The water table is not a level surface, but generally conforms somewhat to the land surface and hence has many irregularities. It does not remain stationary but fluctuates. The major irregularities are caused chiefly by local differences in the gain or loss of water, and the fluctuations are caused principally by differences in the ratio of ground-water recharge to discharge. Where the ground water occurs in a confined formation under artesian pressure, the water will rise above the level at which it is encountered in tightly-cased wells to a level referred to as the piezometric surface. Both water-table and artesian conditions exist in the Pumpkin Creek area.

The amount of water released from storage in an aquifer is proportional to the coefficient of storage, which is defined as the amount of water, in cubic feet, discharged from each vertical column of the aquifer with a base 1 ft sq, as the water level or artesian head declines 1 ft. The coefficient of storage of an unconfined aquifer commonly is called the specific yield. The rate of movement of ground water is determined by the quantity, size, shape, and degree of interconnection of the interstices in the aquifer, and by the slope or hydraulic gradient of the water table or piezometric surface. The capacity of a rock to transmit water under hydraulic head is its permeability. The field coefficient of permeability may be expressed as the rate of flow of water, in gallons a day, through a cross-section 1 ft high, 1 mile wide, under a hydraulic gradient of one foot per mile at the prevailing temperature. The coefficient of transmissibility may be defined as the number of gallons of water a day transmitted through each vertical strip 1 ft wide and extending the thickness of the aquifer, under a unit-gradient and at the prevailing temperature. The coefficient of transmissibility is the product of the coefficient of permeability and the thickness of the aquifer, in feet.

Hydrologic properties of the principal water-bearing formations

Lance formation

No tests were made to determine the water-bearing properties of the Lance formation. The formation underlies at least part of the Pumpkin Creek area and contains sandstones in which ground water is confined by relatively impermeable beds of clay. Inspection of the cuttings from well 19-50-11cad indicates that the water-bearing material is a coarse-grained loosely cemented sandstone, which has been tentatively classified as Lance. Additional information is needed to determine the water-bearing properties of the formation.

Brule formation

No attempt was made by the authors to determine the water-bearing properties of the Brule formation as a detailed study of this material in the Scotts Bluff area was made by Wenzel and others (Wenzel, Cady, and Waite, 1946, pp. 83-86). The following discussion of the Brule formation is taken from their report:

"The coefficient of permeability of a sample of typical Brule, taken from a fresh road cut on the face of Scotts Bluff monument halfway between tunnels Nos. 1 and 2, and 140 feet below the contact with the Gering formation, was determined in the hydrologic laboratory of the Geological Survey to be 4. Another sample, taken at the lower portal of tunnel No. 2 had a coefficient of permeability of 7. This means that 4 or 7 gallons a day of water at 60° F. would percolate through a cross section 1 mile wide and 1 foot thick under a hydraulic gradient of 1 foot to the mile. It is evident that where the Brule formation as a whole is no more permeable than its constituent materials, the discharge through it is slight, even where the formation is thick. The cracks and fissures, however, that occur in the Brule at most places in Scotts Bluff County greatly increase the permeability of the formation, the degree of this increase depending on the number, size, and interconnection of the openings. Because their character differs so greatly from place to place, it is difficult to determine the effect of these openings on the permeability of the formation as a whole . . . The porosities of the samples were 51 and 54, an average of 52.5. Thus the average specific yield of the samples is 29.6. This indicates that a cubic foot of Brule, if allowed to drain for a long period, will yield about 0.296 cubic foot of water and will retain about 0.229 cubic foot.

"Investigations have shown that a sample of material after being saturated will not yield its water at once but the water will drain rather slowly, the rate of draining being somewhat proportional to the permeability of the material. The Brule, because of its tight character, yields water sluggishly, and several months to a year or more are doubtless required before the specific yield calculated in the laboratory is reached. As a result the quantity of water that is removed from storage by a decline of the water table in the Brule cannot be calculated from the specific yield determined in the laboratory unless the water table remains below the material for a long period. The comparatively large seasonal fluctuation of water levels in wells that tap the Brule results in part from the incomplete draining of the material during the time allowed. This means that the water table may decline for a considerable period before much water comes out of storage, except what drains from the cracks and fissures. This decline, however, will gradually slow up as the water table reaches lower stages, and a greater thickness of the formation thereby becomes available for draining."

Alluvium

Pumping test

A pumping test was made on well 19-52-26ddc2 in order to determine the coefficients of transmissibility and storage (specific yield) of the alluvium. The well is 18 in. in diameter and 83 ft deep. The total thickness of the aquifer is not known, but it is assumed that the well penetrates most, if not all, the saturated thickness of the water-bearing material, and that the error caused by possible partial penetration of the aquifer probably is small.

The test well was pumped continuously at an average rate of 1,480 gpm for 29¼ hr. A longer period of pumping would have been desirable, but this was not possible. During the pumping test, the changes in water level were observed in two observation wells that were 100 ft and 640 ft from the test well. Measurements of the recovery of the water level in the pumped well were made after the pump was shut off. The data from the pumping test were used to compute the coefficients of transmissibility and storage by both the Theis formula (Theis, 1935, pp. 519-24), and the Thiem formula (Wenzel, 1942, pp. 81-85).

The average value of the coefficient of transmissibility obtained by these formulae was 310,000 gpd/ft, and the average value of the coefficient of storage was 0.15. The average coefficient of transmissibility determined by the test, although probably representative, is not necessarily indicative of the value throughout the entire area as it varies considerably with differences in composition and thickness of the aquifer. The average coefficient of storage computed from the test represents a minimum value. Under water-table conditions the coefficient of storage increases with time as additional water drains from that part of the aquifer within the cone of depression that is created by pumping. The values obtained from the pumping test, although subject to the errors mentioned above, are thought to be accurate enough for use in determining the approximate effects of pumping wells. To obtain more accurate values of these coefficients, it would be necessary to conduct pumping tests of longer duration at several places in the area.

Interference between wells

In areas where irrigation wells are closely spaced, pumping lifts may be greatly increased by interference between wells. Figure 5 shows the theoretical shape and extent of the cones of depression around a well (19-52-26ddc2) that has been pumped at a rate of 1,000 gpm for various periods of time. The theoretical drawdown curves were computed by the Theis formula using the data obtained from the pumping test.

Inspection of the curves shows that the theoretical drawdown decreases as the distance from the pumped well increases. For example, the theoretical drawdown after pumping for 5 years at a rate of 1,000 gpm would be 2.6 ft at a distance of 1,000 ft from the pumped well and 2.06 ft at a distance of 2,000 ft. As the drawdown is directly proportional to the rate of discharge, the theoretical drawdown for various rates of discharge also can be determined from the curves.

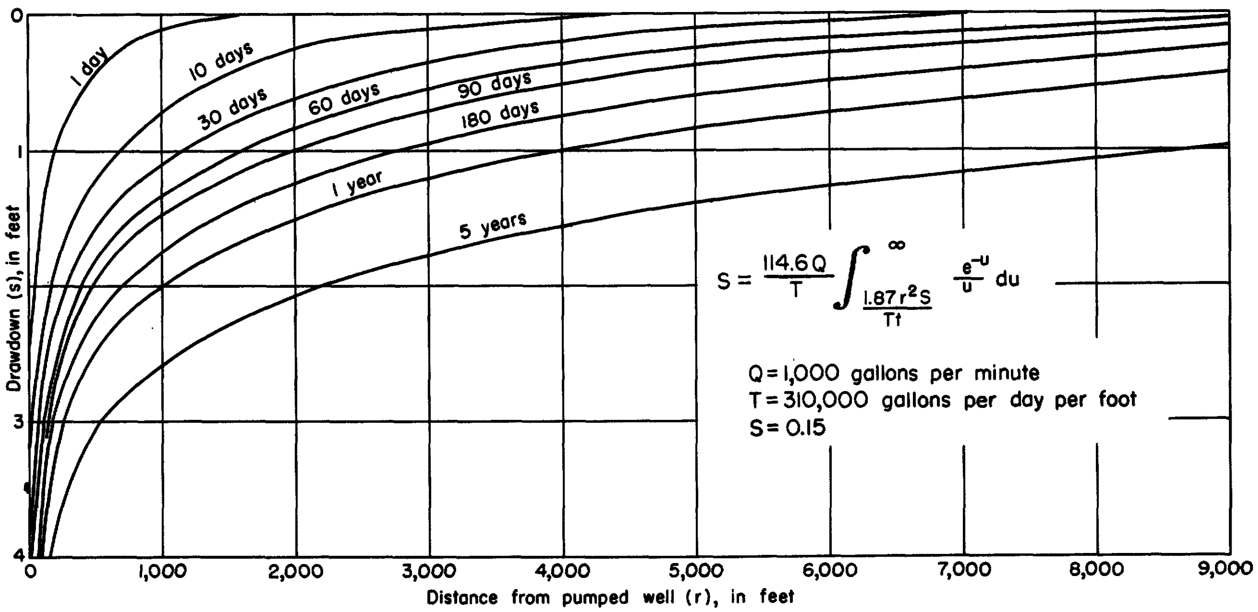

Figure 5. Graph showing theoretical drawdown, according to the Theis formula, due to pumping a well at a constant rate.

A hypothetical case with the following ideal conditions is set up to explain the effect of pumping water for irrigation. The following four assumptions are made: (1) the coefficients of transmissibility and storage are constant throughout the area of influence; (2) no recharge occurs during the pumping period from irrigation, rainfall, or surface flow; (3) the pump supplies 2 acre-ft of water per acre for a farm of 160 acres, or a total of 320 acre-ft of water; (4) all the water is pumped during a 3-month period.

The average rate of pumping would be $\frac{320 \text{ acre-ft}}{90 \text{ days}}$ or 3.55 acre-ft per day or 800 gpm. From the curve in figure 5, the theoretical drawdown is computed as $\frac{800}{1{,}000} \times 1.0$ or 0.8 ft at a distance of 2,000 ft from the pumped well at the end of 90 days pumping. Owing to recharge from adjacent areas and from Pumpkin Creek during the remaining 9 months of the year the water level would recover most, if not all, of the drawdown that occurred during the pumping period. The above values represent only the drawdowns that would result from pumping from storage; the fluctuations that would occur due to the effects of natural recharge and discharge are not taken into consideration.

Specific capacity

The specific capacity of a well is defined as the number of gallons a minute that a well yields for each foot of drawdown. Under water-table conditions, this relation is constant only when the drawdown is a small fraction of the saturated thickness of the aquifer; it also varies with the differences in the construction and development of wells. However, a comparison of the specific capacities of wells is useful in estimating the relative efficiency of wells and the relative transmissibility of formations. The specific capacities of the irrigation wells in the alluvium range from 20 to 181 gpm and average 78 gpm per foot of drawdown. The drawdown and discharge of wells in the area are given in the remarks column in table 7.

Depth to ground water

The depth to the water table in the Pumpkin Creek area, in general, increases with the distance from the creek and in some places is more than 100 ft below the land surface. In the valleys the depth to water in most places is less than 25 ft below the land surface.

Ground water under artesian pressure was encountered in what is thought to be the Lance formation in wells 19-50-11cad and 19-51-21dad. Both wells flow at the surface. Considerable test drilling would be necessary to determine the extent and thickness of this formation and the slope of the piezometric surface.

Ground water recharge

Precipitation

Recharge is the term used to denote the addition of water to the ground-water reservoir. Recharge to the unconfined ground-water reservoir is derived mainly from precipitation, which falls as rain or snow in the valley of Pumpkin Creek and on the adjacent upland areas. Of the total precipitation in the area, part is discharged as runoff, some is used by growing plants, a small part percolates to the water table, and the remainder is lost by evaporation. After the water becomes part of the ground-water reservoir, it moves in the direction of the slope of the water table and is discharged at some point down gradient. The movement of the unconfined ground water is from the areas of recharge toward Pumpkin Creek and its tributaries, where it either flows on the surface or continues as underflow in the alluvium. In places, the ground water temporarily appears at the surface as springs and is subsequently returned to the ground-water reservoir.

Recharge to the confined ground-water reservoir in the Lance formation occurs where the formation crops out west of the Pumpkin Creek area, or from the overlying Tertiary sediments.

Irrigation

Part of the water used for irrigation seeps down to the water table. No attempt was made to determine the amount of water recharged to the ground-water reservoir from irrigation, but it is possibly as much as 50 percent of the amount applied. Studies made in the Safford valley, Arizona (Turner, and others, 1941, p. 28) show that about half the water diverted from the Gila River and about one-fourth of all water pumped from wells is returned to the ground-water reservoir.

Ground-water discharge

Water is discharged from the unconfined ground-water reservoir in the Pumpkin Creek area by transpiration and evaporation, by seepage into streams, by underflow out of the area, by springs, and by wells.

Transpiration and evaporation

Water may be taken into the roots of plants directly from the zone of saturation or from the capillary fringe and may be discharged from the plants by the process known as transpiration. The depth from which plants will lift ground water ranges from a few inches for some grasses and field crops to more than 50 ft for some desert plants.

The discharge of ground water by transpiration and evaporation is limited mainly to the flood plain of Pumpkin Creek and a few of its main tributaries where the water table is shallow. The areas of greatest rate of loss by transpiration generally are indicated by an abundance of cottonwood and willow trees. Some of the water now being lost by evaporation and transpiration could be salvaged by lowering the water table to such an extent that these processes would be reduced materially, thus adding to the amount of ground water available to wells. Although this would increase the total amount of ground water available for development it would decrease the rate at which water could be developed from each individual well.

Streams

Pumpkin Creek is an effluent stream throughout its entire course in the studied area, and most of the surface flow of the creek is derived from ground water. The daily precipitation records in the area and the daily discharge measurements of the flow of Pumpkin Creek indicate that runoff occurs only after periods of exceptionally heavy rainfall. Observations made in the field during the spring and summer of 1949 verify this. The amount of ground water leaving the entire drainage basin of Pumpkin Creek as stream flow is estimated to be about 90 percent of the total runoff, or an average of about 21,000 acre-ft per year. (See table 1.)

Table 1.--Total runoff, in acre-feet, of Pumpkin Creek near the mouth

[From records of the Surface Water Branch of the U. S. Geological Survey obtained in cooperation with the Nebraska Department of Roads and Irrigation]

Year	Total runoff	Year	Total runoff
1931-32	24,300	1940-41	19,410
1932-33	22,600	1941-42	23,770
1933-34	21,380	1942-43	22,300
1934-35	26,090	1943-44	26,190
1935-36	22,280	1944-45	31,610
1936-37	14,290	1945-46	29,190
1937-38	22,140	1946-47	26,780
1938-39	23,660	1947-48	27,140
1939-40	19,090	Average	23,700

Underflow

Sufficient data were not available to determine accurately the amount of water leaving the Pumpkin Creek area as underflow. However, an approximate estimate can be made by applying the value of transmissibility obtained from the pumping test on well 19-52-26ddc2 at Redington. The total thickness of the saturated alluvium where Pumpkin Creek valley joins the North Platte River valley is greater than the thickness at Redington; consequently, the coefficient of transmissibility would be greater at the lower end of the valley. By using the value of transmissibility computed from the pumping test, it is estimated that about 2,500,000 gpd, or 2,800 acre-ft of water a year, leave the area as underflow.

Springs

Several springs on the south side of the valley discharge water from openings in the Brule formation or from gravel overlying the fractured Brule. These springs occur near the contact between the Brule and the overlying Arikaree or Ogallala formations. Seeps and moist areas were observed in some places where the contact between the Brule and the Arikaree or Ogallala formations is covered by slope wash. Records of some of the springs in the area are given in table 7. The total quantity of water discharged from springs in the area is believed to be small.

Wells

Water is pumped from wells for irrigation, stock, and domestic uses. Twenty wells in the area obtain ground water for irrigation, and their reported yields range from 200 to 2,400 gpm. Most of these wells are used only a small part of the year and the annual combined pumpage of the wells probably does not exceed 2,000 acre-ft of water. A more detailed discussion of the irrigation wells is presented in the section on the development of ground water for irrigation.

Most of the stock and domestic wells in the area yield from less than 1 gpm to several gallons a minute. Their yields are generally small because little water is available or because they are not constructed or equipped to yield large quantities of water.

Fluctuations of the water table

The water table does not remain stationary but fluctuates with the changes in the rates of recharge and discharge. If the discharge from a ground-water reservoir exceeds the recharge, the water table will decline, and vice versa. Therefore, the average level of the water table depends upon the net rate at which the reservoir is depleted or replenished. A ground-water reservoir is in equilibrium when the recharge is equal to the discharge; then the water table is more or less fixed in position within seasonal limits.

In order to observe the fluctuations of ground-water levels in the area, six wells were selected for regular observation. Periodic water-level measurements have been made in one of these wells (19-55-29acb) since 1934. Water-level measurements in these wells are given in table 2. From the available data, it appears that no significant change in ground-water storage in the area has occurred in recent years; however, the measurements indicate a seasonal rise and decline of the water levels. The water level in well 19-55-29acb was about 2 ft higher in November 1949 than it was during the same month in 1934.

If extensive development of ground water for irrigation is undertaken in the future, a considerable change in the position of the water table may take place. Discharge of ground water by wells in part is a new discharge that is superimposed on the natural balanced system. Before equilibrium under pumping conditions can be established, water levels must fall sufficiently throughout the aquifer to increase the natural recharge or to decrease the natural discharge, or both, by the net amount being discharged from the wells. In the alluvium, water levels will decline in the vicinity of the pumping wells during the irrigation season but can be expected to recover during the nonpumping season when the ground-water reservoir is replenished from stream flow and from underflow from adjacent areas. Also, the withdrawal of water from the alluvium will cause a decrease in the flow of Pumpkin Creek and, during periods of heavy withdrawal, may dry it up in places.

Table 2.--Water levels, in feet below land-surface datum, in observation wells

18-52-11ddd

Date	Water level	Date	Water level
May 18, 1949	23.66	Mar. 28, 1950	23.54
July 12	24.11	May 9	23.76
Sept.15	23.76	29	23.82
Oct. 12	23.68	June 22	23.84
Nov. 17	23.56	Aug. 20	24.13
Dec. 16	23.51	Sept.21	23.90
Jan. 27, 1950	23.57	Oct. 19	23.81
Feb. 20	23.50		

19-50-30cdd

Date	Water level	Date	Water level
May 18, 1949	23.61	Mar. 28, 1950	23.74
July 12	24.18	May 9	23.55
Aug. 19	23.91	29	23.58
Sept.15	24.03	June 22	23.67
Oct. 13	23.99	July 17	23.66
Nov. 17	23.81	Aug. 20	23.82
Dec. 16	23.88	Sept.21	23.44
Jan. 27, 1950	23.06	Oct. 19	23.35
Feb. 20	23.70	Jan. 18, 1951	23.49

19-52-26ddc2

May 18, 1949	18.99	May 9, 1950	19.14
July 6	18.53	29	19.20
Aug. 19	19.36	July 17	22.62
Oct. 17	23.50	Aug. 20	19.68
Jan. 27, 1950	19.38	Sept.21	19.89
Feb. 20	20.70	Oct. 19	19.63
Mar. 28	19.60	Jan. 18, 1951	19.51

19-53-25acc

June 27, 1949	23.94	Feb. 20, 1950	24.12
July 13	24.32	May 9	23.86
Aug. 19	24.47	29	23.94
Sept.15	24.44	June 22	24.24
Oct. 13	24.39	Sept.21	34.91
Nov. 17	24.20	Oct. 19	24.82
Dec. 16	24.16	Jan. 18, 1951	24.37
Jan. 27, 1950	24.15		

19-54-15bbb

May 16, 1949	22.72	Feb. 20, 1950	23.38
July 13	22.40	Mar. 28	23.39
Aug. 19	22.78	May 9	23.33
Sept.15	24.04	29	23.19
Oct. 13	23.19	Sept.21	24.10
Nov. 17	23.27	Oct. 19	24.39
Dec. 16	23.30	Jan. 18, 1951	23.83
Jan. 27, 1950	23.41		

19-55-29acb

Oct. 12, 1934	32.53	Aug. 7, 1936	30.47
Nov. 19	32.88	29	30.75
Jan. 10, 1935	33.27	Dec. 3	31.94
Mar. 5	33.96	Apr. 7, 1937	33.31
June 15	32.37	June 24	33.85
July 18	29.70	Aug. 12	34.22
Aug. 20	28.28	Oct. 19	34.45
Sept.19	26.99	June 27, 1938	34.52
Oct. 26	27.21	Oct. 27	26.38
Nov. 29	27.32	June 13, 1939	27.90
Jan. 2, 1936	27.60	Dec. 6	30.50
22	27.85	Apr. 6, 1940	32.17
Mar. 31	28.78	July 28	32.92
June 9	29.75	Nov. 8	31.11

Table 2.--Water levels, in feet below land-surface datum, in observation wells--Con.

19-55-29acb--Continued

Date	Water level	Date	Water level
Oct. 25, 1941	30.41	Feb. 20, 1950	32.13
Nov. 27, 1942	33.58	Mar. 28	32.70
June 21, 1949	30.24	May 9	33.39
July 13	30.21	29	33.68
Aug. 19	30.36	June 22	34.12
Sept.15	30.54	July 17	35.05
Oct. 13	30.65	Aug. 20	35.60
Nov. 17	31.05	Sept.21	35.25
Dec. 16	31.48	Oct. 19	34.74
Jan. 27, 1950	31.75	Jan. 18, 1951	35.33

Ground water for irrigation

Present development

Information was obtained on all the irrigation wells in the area, but no attempt was made to obtain data on all the domestic and stock wells. Of the 20 irrigation wells in the area, 16 obtain water from the alluvium, 2 obtain water from both the Brule formation and the alluvium, 1 obtains water from the Brule formation, and 1 obtains water from what is thought to be the Lance formation. Most of these wells have a large diameter and penetrate most of the available water-bearing material. Information on the operation of the irrigation wells is given in the remarks column in table 7.

Potential development

Unconfined ground water

Additional ground water could be developed from the alluvium underlying the flood plains of Pumpkin Creek and some of its major tributaries. If selection of the sites is preceded by adequate test drilling to determine the most favorable areas, wells that yield 1,000 to 2,000 gpm probably could be developed from this material in most places. Also, pumping tests should be run to determine the yield and the proper spacing of wells and the potential yield of the aquifer.

In some places, ground water can also be obtained in sufficient quantities for irrigation from fractures in the Brule formation. Large supplies of water may be obtainable in places where the fracturing is very extensive or where the fractures are overlain by saturated alluvial material. Under the latter conditions water from the overlying alluvium travels downward into the fractures in the Brule and moves laterally through the fractures to the wells. Because erosion follows the path of least resistance, valleys cut in the Brule tend to develop along fracture zones; therefore, the principal fracture zones of the Brule formation often underlie the alluvium of the valleys. Where a sufficient quantity of water can not be obtained from the alluvium, additional water sometimes can be obtained by drilling into the Brule formation.

The amount of water that can be withdrawn from the ground-water reservoir without causing excessive permanent lowering of the water table depends upon the capacity of, and the recharge to, the reservoir. If water is pumped continuously from the ground-water reservoir faster than it is being recharged, the water levels in wells will decline, and the supply will eventually be depleted. If the recharge during the nonpumping period replaces the water removed, water can be pumped from the reservoir in excess of the rate of recharge for short periods of time without causing serious damage. To develop the maximum amount of ground water from the alluvium, water must be pumped in excess of the rate of recharge during the growing season. The withdrawal of additional ground water in the area will cause a reduction in the flow of streams leaving the area.

It is estimated that an average of about 21,000 acre-ft of ground water leaves the valley of Pumpkin Creek annually as surface flow. (See table 1.) This represents the amount of rejected or excess ground water and is approximately the amount of additional ground water available for development. If sufficient ground water is withdrawn to cause a decline of the water table, additional water would be salvaged from loss by evaporation and transpiration and would be available for irrigation use. Also, some of the water pumped for irrigation would percolate into the ground-water reservoir. Part of this "return flow" could be re-used; however, part of this water should be allowed to leave the area in order to prevent accumulation of salts in the soil and ground water.

If an extensive program of ground-water development is undertaken in the area, records should be kept of the amount of water pumped and the changes in water level, and samples of water should be collected from selected wells for chemical analysis.

Artesian water

In parts of the area, irrigation wells of relatively small yield probably could be developed from sandstones, which are thought to be in the Lance formation. Considerable test drilling would be necessary to determine the lateral extent and thickness of the sandstones. Water in the sandstones is confined under artesian pressure; hence, it would rise appreciably above the point at which it is encountered and, in some parts of the area, would flow at the surface. Where the water is not under sufficient pressure to flow at the surface, water could be obtained by pumping.

Cost of pumping water

The cost of pumping water from wells depends upon the cost of well development, the cost of the fuel or power, the cost of drilling the well and installing the pump, and the cost of maintenance and operation. The main consideration in determining the operating cost of pumping ground water--the cost of the fuel or power--is the only one discussed in this report.

1.6 kwhr per acre-foot per foot of lift for a pumping test run in the Dutch Flats area (Babcock and Visher, 1950, p. 37). The electric motor and pump had an over-all efficiency of 64 percent. During a detailed study of the ground-water resources of Deer Valley, Ariz. (Bluhm and Walcott, 1949, p. 9), it was determined that 1.8 kwhr were required to lift 1 acre-ft of water a height of 1 ft. The over-all efficiency of the pumping plants used in these tests probably was somewhat less than the 64 percent computed during the test in the Dutch Flats area, and probably more nearly represents the average conditions that would exist in a pumping project. No attempt was made to determine the cost of electric power required to pump water owing to the very complicated sliding scale used in computing electric power costs.

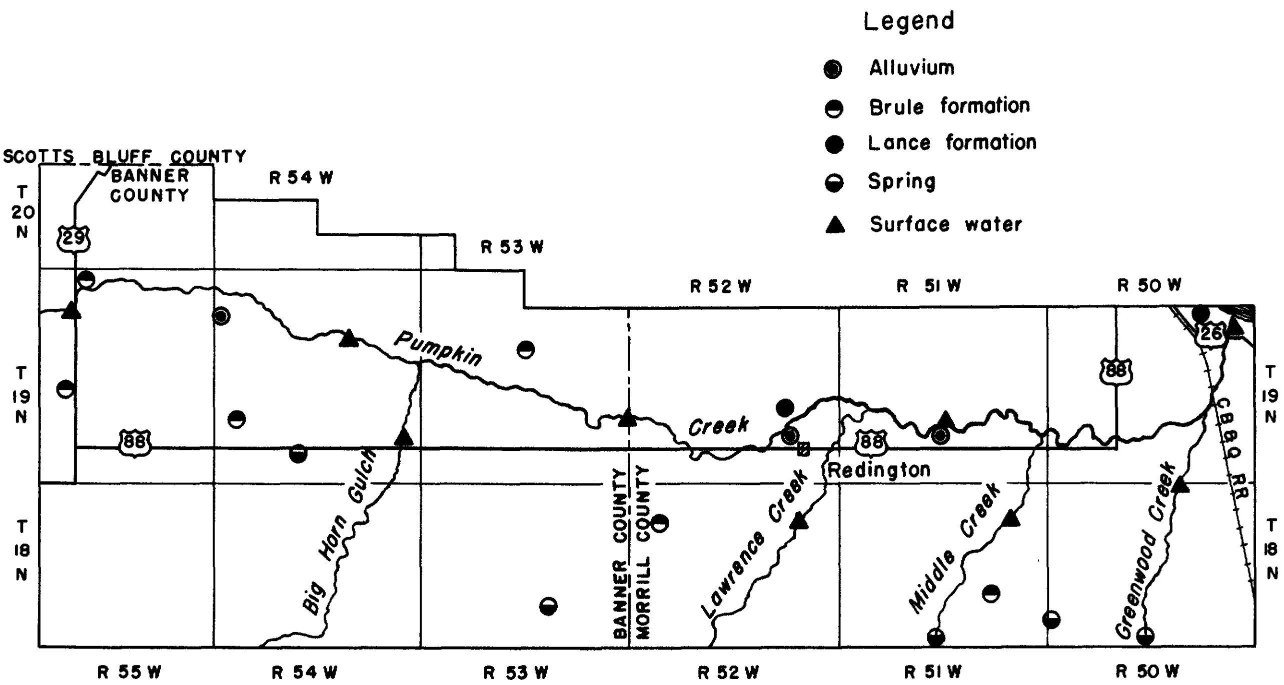

Figure 6. Map showing sampling points in the Pumpkin Creek area, Nebr.

Records were kept of the amount of fuel used during the pumping test on well 19-52-26ddc2. During the test, 97.6 gal of butane were used to pump 7.9 acre-ft of water a height of 36 ft (total pumping lift). This amounted to 12.3 gal of butane per acre-foot of water pumped, or 0.34 gal per acre-foot per foot of lift. At the present price of butane, about 12¢ per gallon, the cost of fuel would be about 4¢ per acre-foot per foot of lift.

The amount of electric power required to pump an acre-foot of water was computed as

CHEMICAL QUALITY OF THE GROUND WATER

Introduction

In this section, the chemical quality of the ground water is discussed briefly with reference to its general suitability for domestic or irrigation use. Consideration is also given to the quality of the water as related to the mineral substances in the geologic source. This discussion is based on the results of analyses of 31 samples (see fig. 6), which include 5 samples that were collected from wells outside the area.

Ground-water samples were obtained from the following: (1) relatively shallow wells, 25 to 83 ft deep, drawing water from the alluvium; (2) wells, 45 to 330 ft deep, penetrating the Brule formation; and (3) very deep wells, 454 to 925 ft deep, tapping the Chadron and Lance formations. Several of the samples collected outside the area are helpful in correlation work relating to the deep water-bearing formations. Three springs flowing from contact zones between the Arikaree and Brule formations and two springs issuing from the alluvium were sampled. In addition, surface samples were obtained from Pumpkin Creek and its main tributaries.

sources are shown diagrammatically in figure 7, in which the height of the bar is equal to the total cation or anion equivalents for the particular analysis.

Chemical character in relation to source

Water from deep wells that encounter the Lance formation is generally more highly mineralized, softer, and less siliceous than water in the overlying bedrock and alluvium. The range in concentration of principal mineral constituents in water from the several geologic sources is more easily noted in table 5.

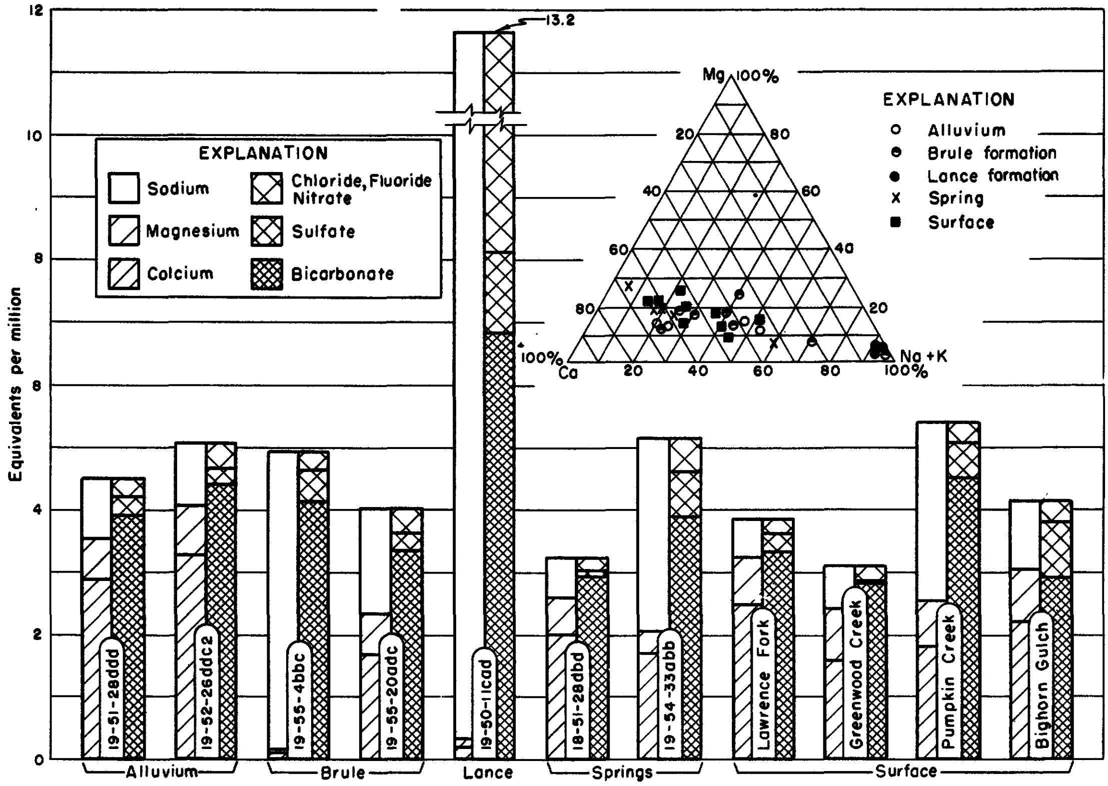

Figure 7. Mineral constituents and reacting values of basic radicals in waters, Pumpkin Creek area, Nebr.

Analytical results, in parts per million, for water samples from 4 wells drilled in the alluvium, 12 wells drilled in bedrock (Brule, Lance, and Chadron formations), and 5 springs, and 9 surface-water samples are given in table 3. The wells are listed by number and under geologic source. Springs are listed by number only, as the exact source of spring water generally is difficult to determine; the probable source of the water from various springs is discussed on page 21.

The results of analyses, in equivalents per million, are given in table 4. In addition, analyses of representative water from various

Hardness of the water tends to decrease with depth of well both in the alluvium and Brule formation; however, this relationship is not well defined. Hardness, in parts per million, ranges as follows: in the alluvium, 119 to 204; in the Brule formation, 6.0 to 140; and in the Lance formation, 17 to 43.

The quantity of dissolved solids in water shows no correlation with depth of well in either the alluvium or Brule formation. With the exception of water in very deep water-bearing horizons, most of the mineral accumulation in the water in deposits of Tertiary age has occurred in the upper strata of bedrock.

Table 3.--Chemical analyses, in parts per million, and related physical measurements of waters in the Pumpkin Creek area, Nebr.

Source	Date of collection	Depth of well (feet)	pH	Specific conductance (micromhos at 25°C)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$: Total	Hardness as $CaCO_3$: Noncarbonate	Percent sodium
Alluvium																					
19-51-28ddd..................	July 13, 1949	30	7.8	412	48	....	58	8.0	19	7.2	0	234	15	5.0	0.4	8.1	....	288	178	0	18
19-52-23cdd..................	Oct. 12	...	7.7	419	54	0.04	36	7.0	55	6.7	0	250	21	8.0	.4	9.0	0.30	338	119	0	48
19-52-26ddc2................	July 11	83	7.8	466	49	.03	66	9.5	20	5.6	0	266	12	5.0	.4	16	....	328	204	0	17
19-54-7bab....................	Oct. 13	25	7.6	394	55	.64	36	8.5	45	6.2	0	224	19	9.0	.4	18	.30	320	125	0	42
Brule formation																					
17-51-14ddb [1]	Oct. 13, 1949	225	7.7	313	50	0.07	42	5.3	13	5.2	0	172	9.0	6.0	0.4	7.4	0.20	236	127	0	18
17-52-24abc [1]	Oct. 13	330	8.2	320	41	.06	39	8.2	16	6.3	8	162	9.0	8.0	.4	8.7	.30	240	131	0	20
18-51-23baa..................	Oct. 12	172	7.9	296	59	.03	24	11	29	4.4	0	172	17	6.0	1.2	2.1	.40	248	106	0	36
18-52-7aab....................	Oct. 12	128	7.6	376	57	.17	37	10	40	5.0	0	208	28	15	.4	4.6	.30	318	134	0	38
19-53-15bba..................	Oct. 13	180	9.2	261	61	.03	13	3.1	48	5.6	12	136	11	7.0	.4	1.0	.30	254	45	0	67
19-54-30aab..................	Oct. 13	45	7.5	313	54	.04	42	8.5	24	4.7	0	188	21	9.0	.4	5.7	.30	270	140	0	26
19-55-4bbc....................	Oct. 13	160	8.4	429	66	.06	2.0	.2	106	4.2	18	218	24	7.0	1.2	4.0	.40	356	6	0	95
19-55-20adc..................	July 13	100	8.3	374	57	....	33	7.3	36	5.6	6	192	14	7.0	.4	8.6	....	276	113	0	40
Chadron formation																					
20-50-26cdd [1]	Nov. 17, 1949	870	7.8	541	64	0.04	32	7.7	74	8.8	0	242	63	13	0.4	12	0.40	412	112	0	57
Lance formation																					
18-56-2cca [1]	Oct. 12, 1949	925	8.0	1,750	14	1.7	5.0	1.9	478	4.8	0	960	5.0	190	1.2	0.7	....	1,170	21	0	98
19-48-30b [1]	Sept.15	518	8.1	1,360	15	....	12	3.2	290	4.8	0	432	106	169	.4	.2	....	834	43	0	93
19-50-11cad..................	Aug. 18	454	8.1	1,340	25	.05	4.0	1.6	292	2.4	0	418	62	182	1.0	.0	....	812	17	0	97
	Apr. 7, 1950	454	7.7	1,430	..	....	6.0	.5	293	3.2	0	412	.....	191	...	....	0.70	.....	...	..	97
Springs																					
18-50-19ccc..................	Sept.16, 1949	...	8.0	305	62	....	40	7.0	17	2.4	0	180	8.0	4.0	0.4	2.4	....	232	129	0	22
18-50-28dba..................	Sept.15	...	7.5	313	45	....	42	9.0	5.5	3.2	0	178	9.6	2.2	.4	4.5	....	228	142	0	8
18-51-28dbd..................	Sept.16	...	8.1	304	53	....	40	7.7	8.8	10	0	172	6.4	3.0	.4	6.3	....	224	132	0	12
18-53-22acd..................	Oct. 12	...	7.9	331	51	0.03	47	8.9	14	3.6	0	208	2.0	6.0	.4	2.4	0.20	258	154	0	16
19-54-33abb..................	Sept.16	...	7.9	495	53	....	34	4.5	67	8.0	0	234	34	18	.6	3.3	....	352	104	0	56
Surface waters																					
Pumpkin Creek at State Highway 29..................	Sept.15, 1949	...	8.2	508	47	0.04	44	12	51	8.0	11	278	24	7.8	0.4	1.9	....	350	160	0	40
Pumpkin Creek at main Banner County road crossing.......	Sept.15	...	7.9	568	42	.04	42	12	63	7.2	0	316	27	10	.6	2.9	....	384	155	0	46
Pumpkin Creek at Morrill-Banner County line.........	Sept.15	...	8.1	498	46	.20	36	8.5	63	4.8	0	278	27	8.5	.4	4.4	....	340	125	0	51
Pumpkin Creek at Roundhouse Rock......................	Sept.16	...	7.9	497	46	.06	43	11	50	4.8	0	280	28	9.6	.4	2.6	....	338	153	0	41
Pumpkin Creek at gaging station on U. S. Highway 26...	Sept.15	...	8.0	582	44	.04	51	13	51	7.2	0	256	78	12	...	4.6	....	402	181	0	37
Big Horn Gulch at State Highway 88....................	Sept.15	...	8.1	427	47	.04	44	10	26		0	176	42	12	...	3.6	....	300	151	7	27
Lawrence Fork, 2 miles south of Redington, Nebr.........	Sept.16	...	8.0	360	49	.04	50	9.0	8.4	8.8	0	204	13	4.2	.4	4.3	....	262	162	0	10
Middle Creek near confluence with Pumpkin Creek.........	Sept.15	...	7.8	378	54	.04	50	10	9.1	4.8	0	208	4.8	5.8	.4	5.3	....	276	166	0	10
Greenwood Creek south of Courthouse Rock Canal......	Sept.15	...	8.0	326	51	.04	32	10	9.7	8.8	0	172	3.2	4.4	.6	2.8	....	206	121	0	14

1 Outside immediate area of investigation.

Table 4.--Chemical analyses, in equivalents per million, of samples of water in the Pumpkin Creek area, Nebr.

Source	Ca	Mg	Na	K	HCO_3	SO_4	Cl,F, NO_3
Alluvium							
19-51-28ddd..................	2.85	0.65	0.81	0.18	3.88	0.32	0.29
19-52-23cdd..................	1.80	.58	2.39	.17	4.10	.44	.40
19-52-26ddc2.................	3.26	.78	.87	.14	4.38	.25	.42
19-54-7bab...................	1.80	.70	1.97	.16	3.67	.40	.56
Brule formation							
17-51-14ddb 1	2.13	.44	.58	.13	2.78	.19	.31
17-52-24abc 1	1.96	.67	.70	.16	2.91	.19	.39
18-51-23baa..................	1.19	.90	1.25	.11	2.84	.35	.26
18-52-7aab...................	1.84	.82	1.73	.13	3.43	.58	.51
19-53-15bba..................	.65	.25	2.07	.14	2.64	.23	.24
19-54-30aab..................	2.08	.69	1.03	.12	3.11	.45	.36
19-55-4bbc...................	.10	.02	4.69	.11	4.09	.50	.33
19-55-20adc..................	1.66	.60	1.58	.14	3.33	.29	.36
Chadron formation							
20-50-26cdd 1	1.62	.64	3.28	.23	3.90	1.29	.58
Lance formation							
18-56-2cca 1	.25	.16	20.76	.12	15.76	.10	5.43
19-48-30b 1	.60	.26	12.86	.12	6.94	2.18	4.72
19-50-11cad..................	.20	.13	12.82	.06	6.80	1.28	5.13
	.30	.04	12.74	.08	6.76	1.01	5.39
Springs							
18-50-19ccc..................	1.96	.58	.73	.06	2.99	.17	.17
18-50-28dba..................	2.14	.76	.24	.08	2.87	.20	.15
18-51-28dbd..................	1.97	.61	.37	.26	2.87	.13	.21
18-53-22acd..................	2.33	.71	.60	.09	3.46	.04	.23
19-54-33abb..................	1.69	.37	2.89	.21	3.86	.71	.59
Surface waters							
Pumpkin Creek at State Highway 29.....................	2.22	.99	2.24	.21	4.89	.50	.27
Pumpkin Creek at main Banner County road crossing........	2.12	1.00	2.76	.18	5.14	.56	.36
Pumpkin Creek at Morrill-Banner County line..........	1.82	.71	2.76	.12	4;52	.56	.33
Pumpkin Creek at Roundhouse Rock.......................	2.17	.92	2.21	.12	4.51	.58	.33
Pumpkin Creek at gaging station on U. S. Highway 26....	2.60	1.08	2.25	.18	4.12	1.58	.41
Big Horn Gulch at State Highway 88.....................	2.20	.82	1.13		2.88	.87	.40
Lawrence Fork, 2 miles south of Redington, Nebr..........	2.49	.74	.37	.23	3.35	.27	.21
Middle Creek near confluence with Pumpkin Creek..........	2.48	.81	.40	.12	3.44	.10	.27
Greenwood Creek south of Courthouse Rock Canal.......	1.61	.82	.42	.23	2.81	.07	.20

1 Outside immediate area of investigation.

The percentage of sodium for samples of water in the alluvium ranges from 17 to 48; in the Brule formation, from 18 to 95. The percentage of sodium for water in the Lance formation is remarkably uniform, ranging from 93 to 98.

Alluvium

Ground water in the alluvium, as represented by four samples from drilled wells adjacent to Pumpkin Creek (see fig. 6), is of moderately low mineral content and is hard. The dissolved-solids content is rather uniform, ranging from 288 to 338 ppm. The depth of wells ranges from 25 to 83 ft, with one depth not known. The water from all wells is quite siliceous, a characteristic of ground water in many western areas of the Great Plains region. In addition to silica, the dissolved solids consist largely of calcium, sodium, and bicarbonate ions.

The water sample from one of the wells (19-54-7bab) had an iron content of 0.64 ppm,

Table 5.--Range in mineral constituents, in parts per million, of samples of water from several geologic sources

Constituent	Alluvium		Brule formation		Lance formation	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Silica.............	55	48	66	41	25	14
Calcium + magnesium	76	43	50	2.2	15	5.6
Sodium + potassium.	62	26	110	18	483	294
Bicarbonate........	266	224	218	136	960	412
Chloride...........	9.0	5.0	15	6.0	191	169
Dissolved solids...	338	288	356	236	1,170	812
Total hardness.....	204	119	140	6	43	17
Percent sodium.....	48	17	95	18	98	93

which was the highest obtained in the area sampled. This quantity of iron is reportedly sufficient to give a rust color to the water prior to clearing the pump.

The percentage of sodium is not uniform in water from the alluvium and is probably influenced to some extent by the mineral character of the Brule formation.

Only two boron analyses were made, and both results for this element are low and about the same as that found in water from the Brule.

Brule formation

Eight samples were obtained from wells that are in the Brule formation and that range in depth from 45 to 330 ft. (See fig. 6.) As in water from the alluvium, the concentrations of dissolved solids are moderately low and range from 236 to 356 ppm. The percentage of sodium is more variable, with a range from 18 to 95.

Although higher in ratio of sodium (95 and 67 percent, respectively) and softer than water from other wells in the Brule formation, samples of water from wells 19-55-4bbc and 19-53-15bba are similar in respect to the other acid constituents, sulfate, chloride, fluoride, and nitrate. This suggests that encroachment by chloride-bearing waters from the Lance has not occurred, and that the changes in the character of the water were brought about through base exchange. Evidently the Brule formation differs in various areas with respect to mineral matter capable of entering into base exchange reactions.

The iron and boron contents were generally low in samples of water in which these constituents were determined.

Chadron formation

One sample (20-50-26cdd) was obtained from the Chadron formation (outside the immediate area of investigation) for the purpose of comparing the character of this water with that of the Brule and Lance formations. This water, sampled from a well 870 ft deep, is similar in most respects to the high sodium water that is encountered frequently in the Brule formation. The dissolved solids content is 412 ppm and is composed largely of sodium and calcium bicarbonate. Although the percentage of sodium is 57, total hardness as $CaCO_3$ is 112 ppm. The water has a high silica content of 64 ppm, and the sulfate concentration of 63 ppm is higher than that found in samples from the Brule formation. High sulfate water in the Brule formation in other adjacent areas in Nebraska has been reported by Wenzel (Wenzel, Cady, and Waite, 1946, pp. 128-129).

Lance formation

Water, thought to be from the Lance formation (see fig. 6), is a distinctly different type than found in other formations of this region. The differences can readily be seen in table 5. Compared to water obtained from the overlying Tertiary and Quaternary deposits, water from the Lance formation is lower in silica and total hardness and is much higher in sodium and potassium, bicarbonate, chloride, dissolved solids, and percentage of sodium. The percentage of sodium is relatively constant, ranging from 93 to 98 percent. The high content of chloride is evidence of the marine origin of some of the material through which water in the Lance formation has percolated.

The water from one well (18-56-2cca) had 960 ppm bicarbonate and only 5.0 ppm sulfate. The sulfate-bicarbonate relationship in water from the Lance formation has been previously observed in other ground-water studies in Wyoming and Montana. Riffenburg (1925, p. 47), in reviewing the work of the other investigators, has suggested that the relation of sulfate and bicarbonate in water from the Lance and Fort Union formations may be explained as due either directly or indirectly to the reducing action of lignite, carbonaceous shale, or natural gas in these formations. In this reduction, an equivalent amount of bicarbonate is formed for the sulfate reduced. Hydrogen sulfide is an end product in this reaction. In view of the wide range in the concentration of sulfate (5.0 - 106 ppm) in water from the Lance formation, it might be postulated that completeness of reduction of the sulfate is a function of time or existing quantities of carbonaceous materials. Also, the sulfate content in the water, as represented here, originally must have been substantially larger than that found in the water in overlying deposits. Otherwise, only nominal differences in the bicarbonate content of the water from the several formations would be expected. If the source of recharge to the Lance formation is derived principally from the overlying Tertiary formations, then appreciable solution of sulfate must occur in the water as it moves through the Lance formation. Renick (1929, p. 48), reports the chemical analyses of several samples of materials obtained from the Lance formation. A summary of the major water- and acid-soluble substances follows:

Analyses of water- and acid-soluble constituents, in percent of air-dried sample, of rock materials from Lance formation, Rosebud County, Mont.

Material	Ca	Mg	Na+K	HCO_3	SO_4	Cl	NO_3	Total
Sand.	0.01	0.00	0.28	0.03	0.58	T 1/	T 1/	0.91
Shale	.05	.02	.32	.05	.85	T 1/	T 1/	1.29
Shale	.03	.04	.34	.05	.87	0.03	0.01	1.36
Sandstone	.00	.00	.01	.02	.02	T 1/	T 1/	.05

1/ T = Trace

Most of the water-soluble minerals in the shales and sands consist of sodium sulfate (Na_2SO_4), though there are noticeable amounts of calcium and magnesium, largely as carbonate (reported as bicarbonate). As the materials collected would be near the ground surface, the insignificant amount of chloride is an indication that substantial leaching occurred in the Rosebud County samples. Undoubtedly, there must be considerable variation in the types and amounts of water-soluble substances in different parts of the formation.

Reference is again made to the trilinear diagram in figure 7. All the plotted points for samples of water from the Lance formation are found near the lower right vertex (Na+K) of the triangle. Similar high sodium ratios were found by Wenzel (Wenzel, Cady, and Waite, 1946, pp. 128-129) in the analyses of water from the Lance formation in Scotts Bluff County. Base exchange properties of some minerals found in the Lance formation in Montana, particularly those in the leverrierite group, have been described by Renick (1929, p. 28). He points out that the exchange of calcium and magnesium in the water for the sodium in the base exchange silicate is rapid and that the exchange may be complete after the water has percolated through a few feet of rock material that contains leverrierite.

Springs

Five springs issuing either through openings in the Brule formation or from gravels that overlie the Brule were sampled. (See fig. 6.) As shown in table 3 and illustrated in figure 7, the water from springs is similar to that from the Brule formation and the alluvium. Water from all the springs has a moderately low mineral content and is hard. Water from spring 19-54-33abb differs from the water from other springs in having a relatively high sodium ratio (56) and in containing more sulfate and chloride--an occurrence often associated with waters from the Brule formation.

Quality of water in relation to drainage

Water samples were obtained from several points on Pumpkin Creek and its principal tributaries from the south. (See fig. 6.) There is little increase in dissolved solids downstream, probably because the tributary waters are all of lower mineral content than the main stream. (See table 3.) The dissolved solids concentration of Pumpkin Creek water ranges from 206 to 402 ppm. Hardness as calcium carbonate ranges from 121 to 181 ppm.

Pumpkin Creek water has a higher concentration of sodium than the tributary streams; to some extent this is attributable to diversion in Courthouse Rock Canal and subsequent irrigation return flows. Also, there is a significant increase in the ratio of equivalents of sulfate to total equivalents of anions in the main stream at the gaging station on Highway 26, as compared to other samples taken upstream. (See fig. 6.)

To date, irrigation has had no adverse effect on the chemical quality of the ground water in the area.

Quality of water in relation to use

Except for being somewhat hard, water from the alluvium, Brule formation, and springs, as represented by samples collected during this investigation, is of satisfactory quality for most domestic needs. The mineral content of all the water, with exception of that from the Lance formation, is considerably lower than the upper limit of 500 ppm suggested by the U. S. Public Health Service (1946). An excerpt of these standards, which also include specifications for biological, sanitation, and other chemical substances, is given below.

Constituent	Maximum parts per million
Iron and manganese (together)......	0.3
Magnesium.........	125
Sulfate...........	250
Fluoride..........	1.5
Chloride..........	250
Dissolved solids..	500 (1,000 permitted)

Undesirable quantities of iron may be present in some places in water from the alluvium, but for the most part, this constituent is found only in negligible quantities.

Although in many places the water from the Lance formation is soft and therefore suitable for domestic supplies, the water in some areas may contain undesirable quantities of chloride. All the analyzed samples of water from the Lance formation are of satisfactory quality for most domestic needs.

With respect to use for irrigation, the samples of water from the alluvium and Brule formation for the most part rate "excellent to good" by the method of rating proposed by Wilcox (1948, p. 27). These ratings are contingent upon normal soil, crop growth, and drainage conditions. In Wilcox's method, the criteria of total concentration (expressed as micromhos per cm. at 25°C) and percentage of sodium (ratio of equivalents of sodium to total cation equivalents and multiplied by 100) in the water are used for classification. The expression of the results in various classes or groups is more easily seen in figure 8, in which specific conductance and percent sodium are shown on the abscissa and ordinate, respectively.

As the conductivity or mineral concentration of the water increases, the water is given a lower quality classification. Likewise, the quality classification becomes poorer when the percentage of sodium increases above 50. Thus water of low dissolved solids content but of high sodium ratio may not be satisfactory for irrigation. Because of its high percentage of sodium, one of the samples of water from the Brule formation (19-55-4bbc) falls into the unsuitable category. All of the samples of water from the Lance, by reason of high percentage of sodium and relatively high mineralization, are not satisfactory as irrigation supplies.

Flowing well 19-50-11cad supplies water for irrigation. Because of the very high percentage of sodium (97) the water is classified as unsuitable. However, the owner reports no evidence to date of damage to the farm soils, which are sandy and well-drained.

CONCLUSIONS

Unconfined ground water in sufficient quantities for irrigation supplies is contained in the Quaternary alluvium that underlies the flood plains of Pumpkin Creek and some of its major tributaries. Wells that yield 1,000 to 2,000 gpm probably could be developed from this material in most places. Ground water also can be obtained in sufficient quantities for irrigation from fractures in the Brule formation in places where the fracturing is extensive or where the fractures are overlain by saturated alluvium.

This reconnaissance was not designed to give the detailed data required for the proper location and construction of wells; hence, more detailed studies of the water-bearing properties of the alluvium should be made prior to the construction of irrigation wells. The selection of sites for irrigation wells should be preceded by adequate test drilling in order to determine the most favorable places for development in the alluvium. Also, additional pumping tests are desirable to determine the yield and proper spacing of the wells and the safe yield of the aquifer. Such pumping-test data obtained should be supplemented by laboratory tests on the hydrologic properties of the water-bearing materials.

It is estimated that about 21,000 acre-ft of additional ground water is available annually for development from the alluvium. If sufficient ground water were developed to cause a decline of the water table, additional water would be salvaged from loss by evaporation and transpiration and would be available for irrigation use. Also, some of the water pumped for irrigation would percolate into the ground-water reservoir. Part of this "return flow" could be re-used; however, part of this water should be allowed to leave the area in order to prevent the accumulation of salts in the soil. If an extensive program of ground-water development is undertaken in the area, records should be kept of the amount of water pumped and the changes in water levels, and samples of water should be collected periodically from selected wells for chemical analysis.

In parts of the area, wells of small yield probably could be developed from the sandstones that are thought to be in the Lance formation. Considerable test drilling would

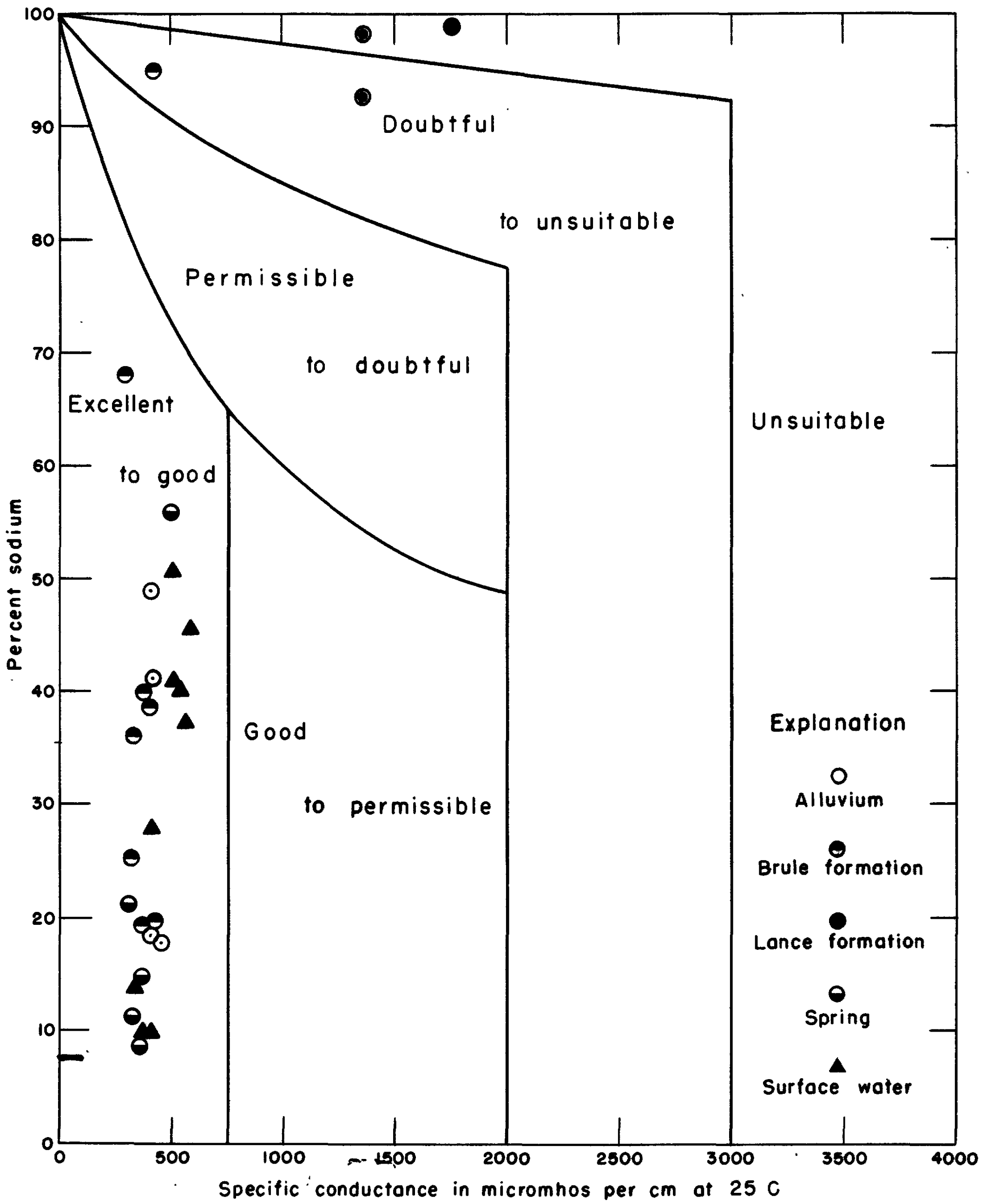

Figure 8. Classification of waters in the Pumpkin Creek area for irrigation use.

be necessary to determine the extent and thickness of the sandstones. Water in the sandstones is confined under artesian pressure; hence, it will rise appreciably above the point at which it is encountered and, in some parts of the area, will flow at the surface.

Results of analyses of 31 water samples from ground and surface locations depict water that ranges from moderately mineralized, hard water in the alluvium to more highly mineralized, soft water in the deeper Lance formation. Water in the Brule formation, though similar in mineral content, differs widely in the degree of hardness. These differences imply that base exchange materials may be present in some parts of the Brule formation. Water obtained from the water-bearing sandstones in the Lance formation is characterized by percentages of sodium exceeding 90, low degree of hardness, and high concentrations of bicarbonate and dissolved solids. The water is further identified with chloride concentrations of more than 150 ppm. The content of sulfate varies considerably, depending on the extent of reduction to bicarbonate that has occurred.

Although somewhat harder than is desirable, water from the alluvium and from the Brule formation is of satisfactory quality for most domestic needs. However, there may be a problem of high iron in some supplies from these sources. The percentage of sodium in the water from the Brule in some places is relatively high, but water from this source as well as from the alluvium is as a rule of satisfactory quality for irrigation.

The chloride content of water in the Lance formation in some places may be undesirable, particularly in the supplies from the very deep wells. Otherwise, the water is very soft and will meet the requirements for most domestic needs. Conversely, by virtue of the high sodium percentages, water from the Lance formation is not satisfactory for irrigation.

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LOGS OF WELLS

Logs of wells obtained from well drillers and well owners are presented in table 6. It was not possible to verify the logs by examination of the drill cuttings; consequently, the logs are presented with the drillers' terminology largely unchanged. It is believed that the logs are reasonably accurate and give a fairly good description of the materials penetrated.

Table 6.--Logs of wells in the Pumpkin Creek area, Nebr.

18-50-5add

	Thickness (feet)	Depth (feet)
Sand, fine, and soil......	35	35
Gravel and clay...........	2	37
Hardpan (Brule formation).	26.5	63.5

18-50-6aaa

Loam, sandy (no gravel)...	30	30
Hardpan (Brule formation).	40	70

18-51-3dcb

Sand, fine; some gravel...	40	40
Clay (Brule formation)....	50	90

18-51-23baa

Soil......................	10	10
Gravel....................	50	60
Clay (Brule formation)....	112	172

18-52-11ccc

Soil and gravel, coarse...	35	35
Clay (Brule formation)....	8	43

18-52-12bbc

Soil......................	10	10
Gravel....................	66	76
Hardpan (Brule formation).	4	80

18-52-13acc

Soil and gravel...........	24	24
Clay......................	58	82

18-54-1bbd

	Thickness (feet)	Depth (feet)
Soil......................	14	14
Quicksand.................	9	23
Hardpan (Brule formation).	10	33
Gravel....................	27	60

19-50-11cad

Sand and gravel...........	199	199
Hardpan (Brule formation).	101	300
Chalk rock and limestone..	125	425
Sandstone.................	29	454

19-50-23ddd

Soil......................	6	6
Gumbo, black..............	2	8
Sand, fine................	17	25
Sand, clean, and gravel...	12	37

19-50-30cdd

Soil and sand.............	20	20
Gravel....................	61	81

19-51-25dcc

Soil and sand.............	23	23
Gravel and sand...........	39	62
Hardpan (Brule formation).	2	64
Gravel, coarse............	31	95

19-51-35aaa1

Soil, fine, sandy.........	15	15
Clay......................	15	30
Gravel....................	10	40

19-52-25bbd

Soil......................	30	30
Gravel, coarse............	13	43

19-52-26ddc2

Soil......................	12	12
Gravel....................	71	83

19-52-34abb

Soil......................	5	5
Clay......................	10	15
Gravel, coarse............	14	29

Table 6.--Logs of wells in the Pumpkin Creek area, Nebr.--Continued

19-52-36bbd

	Thickness (feet)	Depth (feet)
Loam, sandy	28	28
Sand and gravel	22	50
Gravel, coarse	15	65

19-53-22bcb

	Thickness (feet)	Depth (feet)
Sand, fine	11	11
Quicksand	9	20
Gravel	40	60

19-53-26acb

	Thickness (feet)	Depth (feet)
Soil	11	11
Sand, fine	9	20
Gravel, coarse	38	58

19-53-26cda

	Thickness (feet)	Depth (feet)
Soil (no gravel)	28	28
Clay (Brule formation)	72	100

19-54-15bbb

	Thickness (feet)	Depth (feet)
Soil and sand, fine	19	19
Gravel and boulders	3	22
Sand and gravel	26	48
Brule formation	2	50

19-54-15bcc

	Thickness (feet)	Depth (feet)
Clay, sandy	18	18
Sand and gravel	22	40
Gravel	23	63
Brule formation	2	65

19-55-1cda

	Thickness (feet)	Depth (feet)
Soil	16	16
Gravel	8	24
Hardpan (Brule formation)	56	80

19-55-2cbd

	Thickness (feet)	Depth (feet)
Soil	14	14
Gravel	6	20
Clay (Brule formation)	80	100

19-55-20adc

	Thickness (feet)	Depth (feet)
Soil	20	20
Gravel	8	28
Brule formation	72	100

19-55-33aaa

	Thickness (feet)	Depth (feet)
Soil	8	8
Sand	22	30
Hardpan, yellow (Brule formation)	370	400
Shale, blue	65	465
Mud, yellow (clay)	10	475
Mud, blue (clay)	20	495
Shale, light blue	25	520
Shale, sandy	10	530
Mud, yellow (clay)	15	545
Shale, blue	85	630
Shale, hard, black	10	640
Shale, brown	175	815
Shale, brown	20	835
?	25	860
Clay, sticky, blue	60	920
Shale, brown	60	980
Shale, dark blue	640	1,620
Shale, gray	160	1,780
Shale, blue	70	1,850
Shale, sandy, light gray	120	1,970
Shale, dark gray	40	2,010
Shell	3	2,013
Shale, dark	177	2,190
Shale, sandy	30	2,220
Shale, dark	70	2,290
Shale, sandy, dark	180	2,470
Shell, hard	3	2,473
Shale, soft, dark	347	2,820
?	180	3,000
Shale, sandy	45	3,045
Shale, dark	416	3,461
Shell, hard	1	3,462
Shale, limy, light gray	263	3,725
Shale, light brown	100	3,825
Shale, sandy, dark gray	115	3,940
?	100	4,040
Shale, dark blue; contains hard streaks	120	4,160
Shale, light blue; contains hard streaks	415	4,575
Shale, light blue, and shale, white; contains hard streaks	25	4,600
Shale, hard	3	4,603
Shale, dark-brown	257	4,860
Slate	190	5,050
Lime	30	5,080
Lime and shale, broken	10	5,090
Lime	45	5,135
Shale, black	15	5,150
Shale, soft, blue	10	5,160
Sand, fine, hard	10	5,170
Lime, hard	30	5,200
Shale, light blue	80	5,280
Slate, contains hard streaks	70	5,350

Table 6.--Logs of wells in the Pumpkin Creek area, Nebr.--Continued

19-55-33aaa--Continued

	Thickness (feet)	Depth (feet)
Shale, limy...............	95	5,445
Shell.....................	5	5,450
Shale, brown..............	105	5,555
Shale, bentonitic, white..	5	5,560
Shale, brown..............	15	5,575
Shale, bentonitic, white..	20	5,595
Shale, soft, dark.........	67	5,662
Shell, hard...............	1	5,663
Sand, black...............	14	5,677
Shale, soft, brown........	20	5,697

RECORDS OF WELLS AND SPRINGS

Records of 83 wells and springs in the Pumpkin Creek area were obtained during the investigation and are given in table 7. The location of these wells is shown on plate 1. All information classed as reported was obtained from the owner or driller.

Table 7.--Records of wells and springs in the Pumpkin Creek area, Nebr.

Well number: See text for description of well-numbering system.
Type of well: Dr, drilled well; Du, dug well; Sp, spring.
Depth of well: Measured depths are given in feet and tenths below measuring point; reported depths are given in feet below land-surface datum.
Type of casing: P, iron or steel pipe; W, wood.
Character of water-bearing material: G, gravel; S, sand; Sl, siltstone; Ss, sandstone.
Geologic source of ground water: Kl, Lance formation; Qa, alluvium; Ta, Arikaree sandstone; Tb, Brule formation.
Method of lift (first letter): C, cylinder; Cf, centrifugal; F, natural flow; J, jet; N, none; T, turbine.
Type of power (second and third letter): B, butane; E, electric motor; G, gasoline or diesel engine; H, hand operated; W, windmill.
Use of water: D, domestic; I, irrigation; N, none; O, observation; S, stock.
Measuring point: Bpb, bottom of pump base; Ls, land surface; Tbc, top of board cover; Tc, top of casing; Tpb, top of pump base; Tpc, top of pipe clamp.
Depth to water: Measured depths to water level are given in feet, tenths, and hundredths; reported depths are given in feet.
Remarks: Ca, sample collected for chemical analysis; D, discharge in gallons a minute (E, estimated; M, measured; R, reported); DD, drawdown in feet while discharging at the preceding rate; L, log of well given in table 6; T, temperature in degrees Fahrenheit.

Well no.	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (inches)	Type of casing	Character of water-bearing material	Geologic source of ground water	Method of lift	Use of water	Measuring point: Description	Measuring point: Distance above (+) or below (-) land surface (feet)	Distance to water level below measuring point (feet)	Date of measurement	Remarks
Banner County														
18-53-15aaa	C. W. Schneider.	Dr	440	6	P	Sl	Tb	N	N	Ls	....	80	1949	
-22acd	....	Sp	....	..	.	G	Qa	F	S	...	....	......	....	Ca
18-54-1bbd	Mr. Wyatt.......	Dr	60	6	P	S,G	Qa	N	N	...	....	......	....	L
-29ada	Walter Petterson	Sp	....	..	.	S	Ta	F	S	...	....	......	....	D10E
19-53-15bba	D. Brown........	Dr	180	6	P	Sl	Tb	C,W	D,S	Ls	....	140	1949	Ca
-22bcb	P. Wyat.........	Dr	60	6	P	S,G	Qa	C,G	D,S	Ls	....	20	1949	L
-25acc	Dr. Sears.......	Dr	70	12	P	S,G	Qa	T,G	I	Tpb	0	23.94	6-27-49	D600R
-26acb	A. F. Burnett...	Dr	58	14	P	S,G	Qa	T,G	I	Ls	....	11	1949	D900R, DD37, L
-26cda	.....do.........	Dr	100	6	P	Sl	Tb	C,W	D,S	Ls	....	60	1949	T55, L
-34bcd	....	Dr	....	6	P	Sl	Tb	C,W	S	Tpc	+0.4	36.12	6-28-49	
19-54-7bab	D. Croathouse...	Dr	25	6	P	S,G	Qa	C,W	D	Ls	....	13	1949	Ca
-15bbb	Bert Rodgers....	Dr	50	18	P	S,G	Qa	T,G	I	Tc	+.4	23.12	5-16-49	D580M, DD14.5, L
-15bcc	.....do.........	Dr	65	18	P	S,G	Qa	T,G	I	Tpb	+.2	32.70	5-16-49	D420M, DD21.5, L
-15ddd	....	Dr	....	4	P	Sl	Tb	C,N	N	Tc	+2.0	52.67	5-16-49	
-22daa	M. Farrell......	Dr	....	4	P	Sl	Tb	C,H	D	Tc	+1.0	66.00	5-16-49	
-25bdd	T. Muhr.........	Dr	60	18	P	S,G	Qa	T,G	I	Ls	....	30	1949	D800R
-30aab	W. O. Brown.....	Dr	45	6	P	Sl	Tb	C,E	D	Ls	....	22	1949	Ca

19-54-33abb	....	Sp	....	..	.	Sl	Tb	F	S	...	....	......	....	D2E, Ca
-34aaa	E. J. Whipple...	Du	50+	48	W	Sl	Tb	C,G	D	Ls	....	50	1949	
19-55-1cda	F. L. Johnson...	Dr	80	24	P	G,Sl	Qa,Tb	T,G	I	Ls	....	19	1941	D2,300R, L
-2cbd	Mead Co.........	Dr	100	18	P	S,G	Qa	N	N	Tc	+.7	10.97	6-29-49	L
-4bbc	J. G. Shaul.....	Dr	160	6	P	Sl	Tb	C,W	D,S	...	....	......	....	Ca
-20adc	Mr. Stauffer....	Dr	100	18	P	G,Sl	Qa,Tb	T,G	I	Ls	....	20	1949	T53, D1,200E, DD13.5, Ca, L
-29acb	Fred Grant......	Du,Dr	80	18	P	S,G	Qa	N	O	Tpb	+1.4	31.64	6-21-49	
-33aaa	Prairie Oil Co..	Dr	5,697	..	P	....	.....	N	N	Ls	....	105	1917	L
Morrill County														
18-50-1bcd	C. B. & Q. RR...	Dr	....	6	P	Sl	Tb	C,H	D,S	Tbc	+.2	25.80	5-19-49	T55
-5add	R. Hart.........	Dr	63.5	6	P	Sl	Tb	N	N	Tc	+.3	46.18	5-19-49	L
-6aaa	D. C. Hutchinson	Dr	70	6	P	Sl	Tb	C,W,G	D	Ls	....	58	1949	L
-19ccc	B. E. Ogard.....	Sp	....	..	.	Sl	Tb	F	S	...	....	......	....	D10E, Ca
-21bbb	W. Harless......	Dr	65	4	P	Sl	Tb	C,E	D,S	Tc	-6.7	12.02	8-19-49	
-28dba	....	Sp	....	..	.	Sl	Tb	F	I	...	....	......	....	T56, D560M, Ca
18-51-1ccc	....	Sp	....	..	.	G	Qa	F	S	...	....	......	....	
-2ddd	L. Coulter......	Dr	20	6	P	S,G	Qa	C,W	S	Tpc	+1.8	8.87	5-19-49	
-3dcb	.....do.........	Dr	90	6	P	Sl	Tb	C,W	S	Bpb	+1.6	39.95	5-20-49	L
-16ccb	County School...	Dr	75	6	P	Sl	Tb	T,G	I	Ls	....	53	1949	D1,200R, DD8
-23baa	A. Albers.......	Dr	172	5	P	Sl	Tb	C,W	S	Tpc	+1.6	74.60	5-19-49	L, Ca
-24bcc	H. S. Welker....	Du	54	48	.	Sl	Tb	C,W	D,S	Ls	....	50	1949	
-28dbd	J. Miller.......	Sp	....	..	.	G	Qa	F	I	...	....	......	....	T61, D900E, Ca
18-52-1bcc	J. Niehouse.....	Dr	74	18	P	S,G	Qa	T,G	I	Bpb	0	16.18	5-18-49	D1,200R
-7aab	Walter A. Lease.	Dr	128	6	P	Sl	Tb	C,W	S	Ls	....	68	1949	Ca
-8ddb	Guy Seckles.....	Dr	140	6	P	Sl	Tb	C,W	D,S	Ls	....	85	1949	
-11cca	Fred Wright.....	Dr	23.5	6	P	Sl	Tb	N	N	Tc	+.5	22.68	5-19-49	
-11ccc	.....do.........	Dr	43	6	P	Sl	Tb	C,G	D	Ls	....	22	1949	L
-11ddd	J. Barden.......	Dr	....	18	P	S,G	Qa	T,G	I	Tpb	+.5	24.16	5-18-49	
-12bbc	R. Nelson.......	Dr	80	18	P	S,G	Qa	T,G	I	Tpb	+.5	10.20	5-18-49	D1,800R, DD24, L
-12ccc	J. Barden.......	Dr	....	18	P	S,G	Qa	T,G	I	Tpb	+.2	24.02	5-18-49	
-13acc	G. Mewkirk......	Dr	82	6	P	Sl	Tb	C,W	S	...	....	......	....	T56, L
-28bda	....	Sp	....	..	.	G	Qa	F	S,I	...	....	......	....	D900E
19-50-11cad	John Thompson...	Dr	454	5	P	Ss	Kl?	F	I	...	....	......	....	T60, D200E, Ca, L
-23ddd	P. Hutcheson....	Dr	37	6	P	S,G	Qa	C,H	D	Tc	+.5	13.32	5-19-49	L
-25bcc	N. G. Beskas....	Dr	44	6	P	S,G	Qa	C,H	D	...	....	......	....	T53
-29aad	H. C. Laux......	Dr	40+	6	P	S,G	Qa	C,W	D	Tpb	+.7	32.50	5-20-49	T56
-30cdd	P. Reuter.......	Dr	81	24	P	S,G	Qa	T,G	I	Tc	....	23.61	5-18-49	D1,500R, L
-33baa	H. Yardley......	Dr	25	6	P	S,G	Qa	C,W	D	Tc	+.5	16.08	5-18-49	
-34bcc	M. Shannon......	Dr	28	6	P	S,G	Qa	C,G	D	Ls	....	20	1949	
-36bbb	R. Hart.........	Dr	36	6	P	S,G	Qa	C,W	D,S	Ls	....	15	1949	T56
19-51-19ccc	V. E. Eckert....	Dr	68	18	P	S,G	Qa	T,G	I	Tpb	+1.0	16.76	5-23-49	D1,450R, DD8

Table 7.--Records of wells and springs in the Pumpkin Creek area, Nebr.--Continued

Well no.	Owner or tenant	Type of supply	Depth of well (feet)	Diameter of well (inches)	Type of casing	Character of water-bearing material	Geologic source of ground water	Method of lift	Use of water	Measuring point: Description	Measuring point: Distance above (+) or below (-) land surface (feet)	Distance to water level below measuring point (feet)	Date of measurement	Remarks
Morrill County--Continued														
19-51-21dad	Emeric Nerud I..	Dr	....	..	.	Ss	Kl?	F	N	...	....	......	....	D200R
-25dcc	K. Christensen..	Dr	95	18	P	S,G	Qa	T,G	I	Ls	....	23	1949	D2,400R, DD15.5,L
-26dda	L. Coulter......	Dr	30+	..	.	S,G	Qa	C,W	S	Tpc	+2.0	17.70	5-20-49	T55
-28aac	L. Trott........	Du	....	48	.	S,G	Qa	C,H	D	Ls	....	12	1949	
-28ddd	County School...	Dr	30	6	P	S,G	Qa	C,H	D	Ls	....	20	1949	T52, Ca
-30daa	Mr. Smith.......	Dr	....	6	P	S,G	Qa	C,W	S	Tc	+2.90	19.20	5-23-49	
-31aac	Mr. Holmes......	Dr	68	4	P	S	Qa	C,G	S	Ls	....	20	1949	
-31acd	.....do.........	Dr	120	6	P	Sl	Tb	N	N	Ls	....	30	1949	
-34aba	A. Schreder.....	Dr	55	18	P	S,G	Qa	T,G	I	Ls	....	20	1949	
-35aa1	L. Coulter......	Dr	40	6	P	S,G	Qa	C,W	D	Ls	....	26	1949	L
-35aa2	.....do.........	Du,Dr	50	..	.	S,G	Qa	Cf,G	I	Ls	....	26	1949	
19-52-23cdd	L. Eckert.......	Dr	....	6	P	S,G	Qa	C,W	S	Tpc	+1.5	20.52	5-23-49	Ca
-25bbd	C. W. Schneider.	Dr	43	6	P	S,G	Qa	C,H	D	Ls	....	25	1949	L
-25cbc	.....do.........	Du	25	48	W	S	Qa	C,W	D	Tpc	+.2	18.86	5-23-49	
-25dcb	.....do.........	Dr	35	6	P	S,G	Qa	C,G	S	Tpc	+1.7	29.47	5-23-49	
-26ccc	C. Rice.........	Dr	....	..	.	S,G	Qa	C,W	D,S	Ls	0	5.40	6-27-49	
-26ddc1	J. Schneider....	Dr	40+	4	P	S,G	Qa	N	O	Tc	-.5	18.72	5-18-49	
-26ddc2	.....do.........	Dr	83	18	P	S,G	Qa	T,B	I	Tpb	+.7	19.69	5-18-49	T54, D1,480M DD17, Ca, L
-28aba	B. Coulter......	Dr	100	6	P	Sl	Tb	C,W	D	...	....	......	....	
-29add	.....do.........	Dr	30	..	.	S,G	Qa	C,W	S	Ls	....	6	1949	
-30aad	V. A. Nielsen...	Dr	13	6	P	S,G	Qa	C,E	D	Ls	....	5	1949	
-31bbb	....	Dr	....	6	P	Sl	Tb	C,W	S	...	....	......	....	
-31ccb	....	Dr	....	6	P	Sl	Tb	C,W	S	Tbc	+.2	81.12	6-28-49	
-34abb	G. Williams.....	Dr	29	7	P	S,G	Qa	C,W	D,S	Ls	....	13	1949	L
-35aaa	County School...	Dr	30+	6	P	S,G	Qa	C,H	D,O	Tpb	+.7	19.67	7- 6-49	
-36bbd	R. Nelson.......	Dr	65	18	P	S,G	Qa	T,G	I	Tc	+.4	27.85	5-18-49	D900R, DD20, L

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