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COUNTY GROUND WATER STUDIES 4

GEOLOGY AND GROUND WATER RESOURCES

Barnes County, North Dakota

PART III
GROUND WATER RESOURCES

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Prepared by the United States Geological Survey in cooperation
with the North Dakota State Water Commission,
North Dakota Geological Survey
and Barnes County Board of Commissioners

GRAND FORKS, NORTH DAKOTA
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GEOLOGY AND GROUND WATER RESOURCES of Barnes County, North Dakota

Part III - Ground Water Resources

by T. E. Kelly

ABSTRACT

There are two major types of aquifers in Barnes County, those in consolidated rocks and those in unconsolidated glacial deposits.

The Dakota Sandstone is the principal aquifer in the consolidated rocks. The average artesian flow from the aquifer is less than 10 gpm (gallons per minute), but flows exceeding 700 gpm are reported. The water is highly mineralized. Small yields of water are obtained from the Pierre Shale

The Spiritwood aquifer is the most productive Barnes County aquifer composed of unconsolidated glacial deposits. Individual well yields of 1,000 gpm are available locally and the water is generally of good quality. There are numerous other glacial aquifers in the county. Only Valley City and Kathryn have adequate supplies of good-quality water. Several other communities have suitable ground-water supplies potentially available to them, but these are not yet developed.

INTRODUCTION

A study of the ground-water resources and geology of Barnes County was begun in 1961 by the United States Geological Survey, in cooperation with the North Dakota State Water Commission and the North Dakota Geological Survey. The purpose was to make a detailed study of the geology and hydrology of the region in order to determine the quantity and quality of ground water in the county. The availability of water for irrigation and for municipal use was of primary interest.

Barnes County is located in southeastern North Dakota (fig. 1). It has an area of 1,501 square miles and, according to the 1960 census, a population of 16,719. Slightly less than half the population lives in Valley City. The economy of the county is based on agriculture, with wheat, barley, and flax being the principal crops.

Records of more than 2,000 wells and springs were collected during the study and 97 test holes were drilled. Also, monthly water-level measurements were made in more than 50 observation wells during a 19-month period that ended December 1963. Seventy wells and springs were sampled for chemical analysis. These data have been published as Part II of the Barnes County ground-water study (Kelly, 1964b). Interpretations of these data are included in this report, Part III. The geology of the county was studied jointly by T. E. Kelly of the U.S. Geological Survey and D. A. Block of the North Dakota Geological Survey (unpublished thesis), and the report will be published as Part I of the Barnes County ground-water study (Kelly, manuscript in preparation).

Previous Investigations

The earliest geologic study in Barnes County was by Upham (1895) as part of his study of glacial Lake Agassiz. D. E. Willard (1909) investigated the geology and ground-water resources of southern Barnes and adjoining counties. Brief mention of the geology of Barnes County was made by Leverett (1912, 1932). The first extensive study of the county was made by Hard (1912); he prepared a soils map and discussed the availability of ground water for stock and irrigation. Simpson (1929) briefly described the geology and ground water in Barnes County as part of a statewide survey; Abbott and Voedisch (1938) listed the chemical constituents of ground-water samples from the area. Wenzel and Sand (1942) made a study of the Dakota Sandstone in the southeastern part of the State which included a portion of Barnes County. Ground-water studies have been made for three of the communities in the county: Wimbledon (Dennis, 1948), Litchville (Akin, 1952), Sanborn (Huxel, 1961a). Studies of the ground water in eastern Stutsman County and western Barnes County were made by Huxel (1961b) and Kelly (1964a).

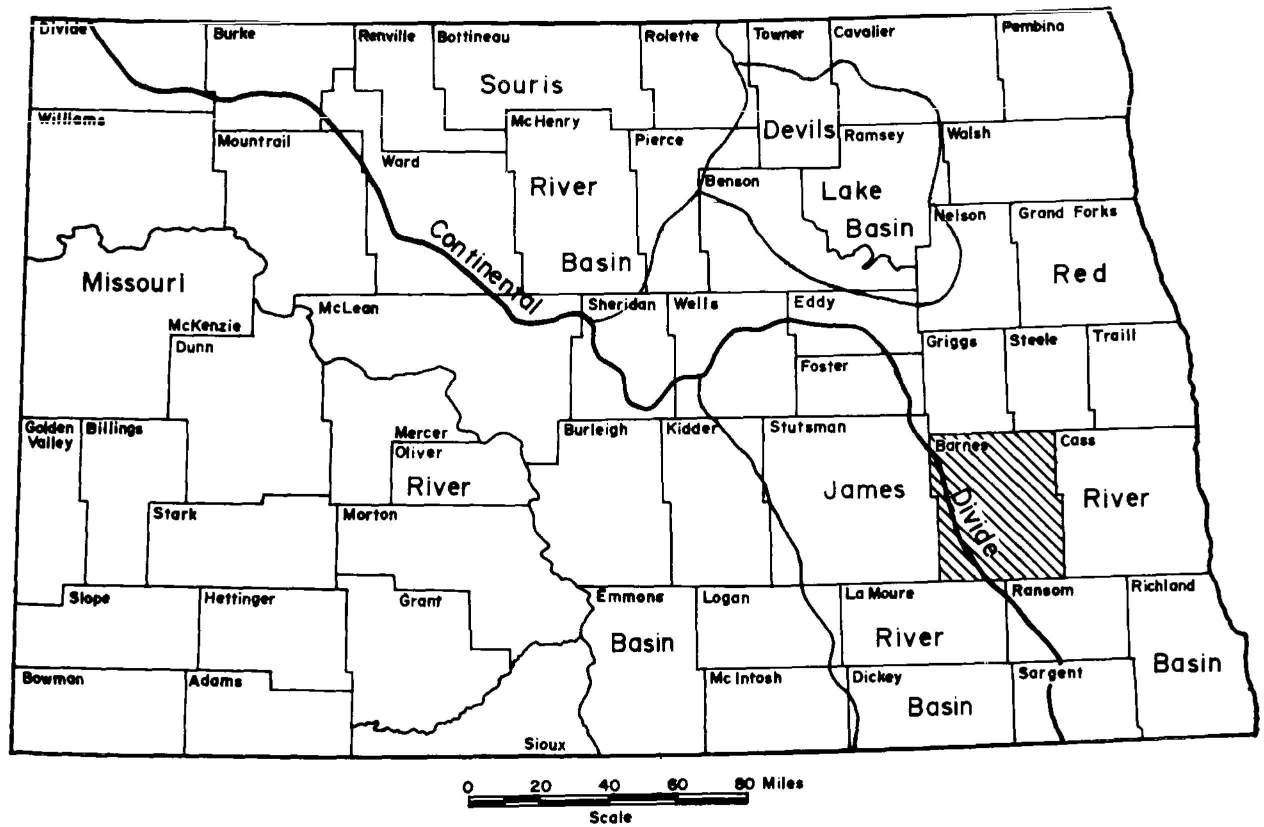


Figure 1. Location of Barnes County, North Dakota, and its relation to the drainage basins and the Continental Divide. (Modified after Inter-Agency Committee on Water Resources Subcommittee on Hydrology, 1961).

Acknowledgments

The author is grateful to many of the residents of Barnes County for contributing helpful information during the study. Mr. O. N. Bergman, Jr., formerly of the Municipal Utilities, Inc., Valley City, Mr. Eugene Klein of Eckelson, and Mr. Robert Christ, Jr., of Leal, deserve special mention for their cooperation. The writer gratefully acknowledges the sample logs furnished by Frederickson's Inc., Fargo, and Schnell, Inc., and Empire Drilling Co., Bismarck.

GENERAL FEATURES OF THE AREA

Most of Barnes County is drained by the Sheyenne and Maple Rivers, which are part of the Red River of the North drainage system. The Red River flows northward and drains into Hudson Bay. In Barnes County the Sheyenne drainage is bounded on the west by the north-south-oriented Continental Divide (fig. 1). That part of the county west of the Divide is drained by the James River, which flows southward and joins the Missouri River and ultimately empties into the Gulf of Mexico. The Sheyenne and Maple Rivers are the only perennial streams in the county. Four smaller channels occupied by chains of shallow lakes are present in the west-central part of the area.

In general the topography of the county is characterized by gently rolling plains and poorly defined drainage channels. The topography was produced by glacial erosion and deposition, but is controlled in part by the preglacial bedrock surface. Glacial deposits cover the entire area except in the Sheyenne River valley and in the Baldhill Creek valley. The major physiographic features are oriented north-south; these include large, irregular-shaped areas of ground moraine having a gently undulating surface, and linear belts of end moraine characterized by hilly topography and numerous undrained depressions. The Sheyenne River valley is the most prominent physiographic feature in the area. It is more than 200 feet deep and averages less than 1 mile in width; the valley walls are generally steep but locally include gravel-capped terraces.

The Sheyenne River extends across the county from north to south and has eroded more than 200 feet below the surrounding plain. Locally the valley width exceeds 3 miles; however, it averages less than 1 mile. The river has eroded into a bedrock high throughout most of its length in the county. South of Lake Ashtabula, however, the Sheyenne River makes an abrupt turn to the southeast, where it has exhumed a tributary of the Spiritwood drainage complex. The river follows this exhumed channel for approximately 8 miles. This is the only major part of the Sheyenne valley not eroded into bedrock. Also the valley is narrower in this reach than elsewhere in the area. In T. 140 N., R. 58 W., the river turns abruptly to the south, leaves the exhumed channel, and again flows on bedrock.

Geologic Setting

PREGLACIAL ROCKS

The geologic study of Barnes County was devoted almost entirely to the Pleistocene deposits, which contain the most important aquifers. However, small amounts of water are obtained from older, consolidated rocks, so it is necessary to give a brief summary of the geology of the consolidated rocks. The study was based on outcrops, well logs, and previous reports. The classification and nomenclature of the rock units discussed in this report conform to the usage of the North Dakota Geological Survey.

Precambrian rock, generally called "granite," underlies the area at a depth of more than 2,000 feet. This rock crops out in Minnesota approximately 70 miles east of the study area and slopes westward into the Williston Basin at 10 to 15 feet per mile. Only small amounts of water are available from the "granite" and generally it is highly mineralized. In Barnes County the Precambrian is overlain by a thin sequence of Cambrian sandstone and shale of the Deadwood Formation and by three Ordovician formations composed primarily of limestone, dolomite, and shale (Nelson, 1955). The total thickness of the Paleozoic section penetrated in the Pollard and Davis--Guscette No. 1 oil test well (142-61-20bbb) in northwestern Barnes County is 755 feet. The Paleozoic rocks contain saline water that is too highly mineralized for most uses.

An angular unconformity separates the Ordovician strata from the overlying Dakota Sandstone of Cretaceous age. The Dakota Sandstone is the oldest formation in Barnes County that yields potable water. The formation is composed primarily of gray siltstone and shale with interbedded sandstone. In the eastern part of the area, the shallowest water-bearing stratum is approximately 500 feet below land surface. However, owing to the westward dip and to the increased thickness of the overlying deposits, and first sandstone is 1,200 feet deep in western Barnes County. The community of Litchville utilized water from the Dakota Sandstone for its municipal supply. However, because of the depth to this aquifer and the poor quality of the water in it, no test holes were drilled to the Dakota as part of the county study.

A thick sequence of Upper Cretaceous shale conformably overlies the Dakota Sandstone. The shale has been divided into the following units: Belle Fourche, Greenhorn, Carlile, Niobrara, and Pierre Formations. The youngest three shale formations are truncated by an erosional surface which separates them from the overlying glacial till (fig. 2). The Carlile Shale is composed of dark-gray to black, fissile, noncalcareous shale. Three test holes entered this formation near the eastern edge of the county; there are no known outcrops of the Carlile in North Dakota. The Niobrara Formation crops out in the Sheyenne River valley south of Kathryn, and directly underlies glacial drift in most of the eastern third of the county. The

Niobrara closely resembles the overlying Pierre Shale in well cuttings and it is often difficult to distinguish the two. However, at the outcrops, the Niobrara is yellowish buff, whereas the Pierre Shale is characteristically gray. Neither the Carlile nor the Niobrara Formation is an aquifer in Barnes County.

The Pierre is conformable with the underlying Niobrara Formation and the two possibly interfinger (Gill and Cobban, 1961, p. D-185). Throughout most of the area, the Pierre Shale directly underlies glacial deposits. The thickness of the shale varies appreciably owing to the westward dip of the formation and the presence of the erosional surface. The shale thickens from a featheredge in eastern Barnes County to more than 450 feet in the western part of the county (Strassberg, 1954; Nelson, 1955). Many of the test holes that reach the Pierre Shale penetrated an oxidized zone at the top. A few wells in the county obtain water from this weathered zone or from the fissile shale, which is highly jointed. The water is characteristically high in dissolved solids.

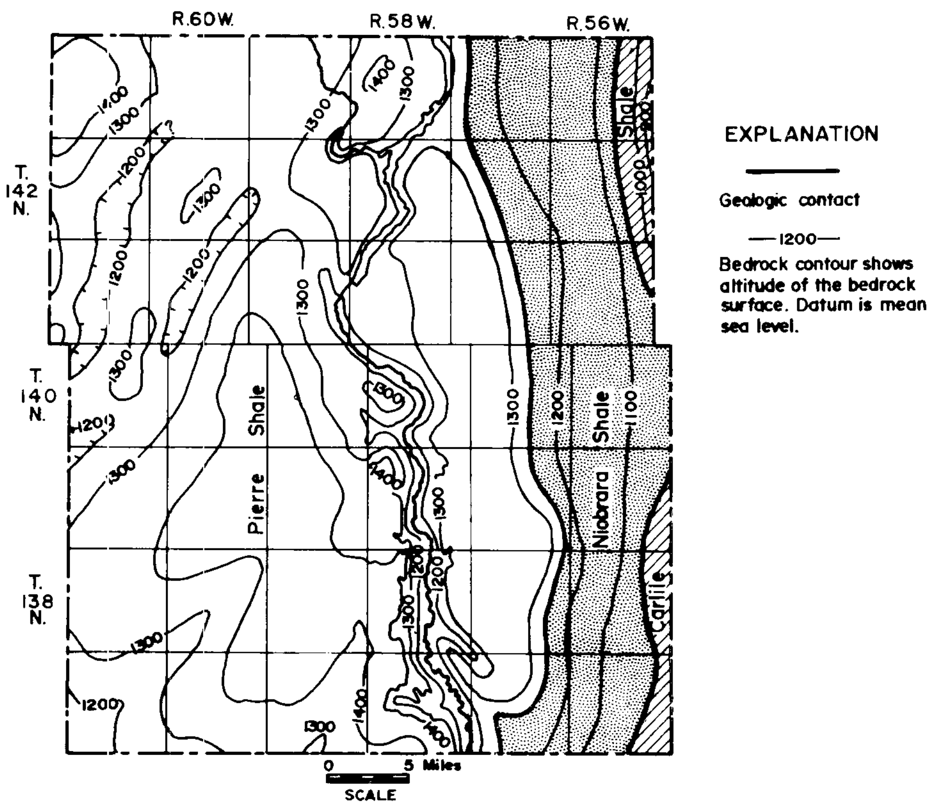


Figure 2. Configuration of the erosional surface between the bedrock and glacial till.

Bedrock Topography

Study of the bedrock topography was based on data from more than 100 test holes drilled in Barnes County and adjacent areas; sample logs from various sources were also used (Kelly, 1964b, table 3). These data indicate that the bedrock has an irregular surface which slopes from west to east at approximately 15 feet per mile; its altitude decreases from 1,450 feet above sea level in T. 143 N., R. 61 W., to less than 900 feet in T. 143 N., R. 56 W. This subdrift topography was formed by northeastward-flowing streams prior to glaciation (Flint, 1955, p. 139-143; Lemke and Colton, 1958, p. 42-43). A soil profile was developed on the surface and the upper 9 feet or more was oxidized. Southward-moving glaciers modified the bedrock surface and removed the weathered shale from most of the area. During one of the glacial advances a large channel was eroded into the bedrock, which has been called the Spiritwood buried valley by Huxel (1961b, p. D-179).

The Spiritwood channel was eroded more than 250 feet into the Pierre Shale in western Barnes and eastern Stutsman Counties, and more than 40 test holes have penetrated the channel. As defined by the 1,300-foot contour, the channel averages 6 miles in width south of T. 143 N. but widens toward the north.

Two large tributaries enter the main channel from the northwest and several smaller ones join the channel from the northeast. These tributaries have a typical dendritic pattern. A rather large tributary joins the main channel in T. 142 N., R. 59 W., and extends southeastward to the vicinity of Valley City, where it apparently terminates.

An unusual feature of the bedrock topography is the closed depression that has a long axis parallel to the main channel and east of it (fig. 2). This feature is more than 10 miles long and averages 1 1/2 miles in width. The depression bears little resemblance to a tributary and can best be explained as a glacially scoured feature.

There are three possible explanations for the origin of the Spiritwood valley complex. The channel may have been eroded by a northeastward-flowing stream that was diverted toward the south by an advancing glacier. The drainage complex can also be explained as a simple melt-water drainage system. Both these explanations are supported by the southward gradient of the main channel and major tributaries, and by the dendritic drainage pattern. A third possibility is that the Spiritwood complex is part of the preglacial ancestral Sheyenne River drainage system, which is known to have entered North Dakota directly south of the area of study (Flint, 1955, p. 148). However, the origin of the Spiritwood drainage system is still in question. Clarification of the problem will depend upon further study of the system in adjoining counties.

GLACIAL AND POSTGLACIAL DEPOSITS

The surface deposits in Barnes County are composed primarily of material of glacial origin. These deposits, which range in texture from clay to large boulders, are called glacial drift. Throughout most of the area, the drift is composed of a heterogeneous mixture of clay, silt, sand, and gravel termed glacial till. However, in places these deposits were sorted by melt water from the glacier so that distinct beds of sand or gravel are present. These stratified deposits, termed outwash, occur as individual units or are interbedded with the till. The glacial drift is absent from most of the Sheyenne River valley, but elsewhere in the county it is more than 300 feet thick (test hole 2124, T. 137 N., R. 57 W., 6bbb). East of the Sheyenne River the thickness of the drift averages approximately 125 feet, and in the Spiritwood valley, western Barnes County, it averages nearly 200 feet. However, in the remaining areas the drift is rather thin, averaging less than 50 feet. Owing to oxidation of the till, the upper 15 to 20 feet is buff in color, whereas the unweathered till below this depth is bluish gray.

Glacial drift may be subdivided into several types on the basis of lithology and (or) topographic form. The types of drift include end moraine, ground moraine, outwash, ice-contact features, and lake deposits.

A ridgelike accumulation of drift built along the front margin of a glacier is called end moraine. The ridge is typically discontinuous and irregular in width. Though most end moraines consist of till, all end moraines contain a certain amount of stratified drift. The topography of end moraines is characterized by undulating surfaces having numerous undrained depressions and poorly developed drainage systems.

Two major belts of end moraine were mapped in the county. The Kensal-Oakes end moraine extends from Wimbledon south-southeastward to Kathryn, and can be traced into adjoining counties (Hard, 1929, p. 31; Lemke and Colton, 1958, p. 50; Colton and others, 1963). The Luverne end moraine extends from Nelson County southward through Barnes and into Ransom County. This moraine was named by Block (1965, unpublished doctoral dissertation) for the town of Luverne in southern Steele County. Although locally discontinuous, the Luverne end moraine forms a high elongate belt, locally called the Alta ridge. The topographic relief of this moraine is greater than of other morainic belts in the area.

Several smaller end moraines are present in Barnes County. A segment of the Cooperstown end moraine extends northwestward across T. 143 N., Rs. 58 and 59 W., and continues into Griggs County to the north. The log of test hole 2097 (143-58-18dda) indicates that in northern Barnes County the Cooperstown moraine is very thin, and locally is less than 30 feet thick. The relief of this moraine can be attributed to the bedrock high upon which it is located. A short segment of end moraine, which extends southwestward from the Kensal-Oakes moraine in T. 137 N., R. 58 W., is part of the Waconia end moraine (Willard, 1909, p. 3). Other isolated patches of end moraine are present in the area.

Ground moraine deposits consist primarily of till and commonly exhibit a gently undulating topography of low relief. These deposits probably formed near the base of a moving glacier, although the mechanics of deposition are not clear. Ground moraine is widespread throughout the area.

Glacial drift in the form of end moraine and ground moraine is an important source of ground water in the county. Stratified sand and gravel within the till yields small quantities of water to stock and domestic wells, and the community of Wimbledon obtains its municipal supply from these deposits. Although the yields are rather low, most of the rural areas are dependent upon water from morainal deposits.

Outwash consists of stratified drift that was transported and deposited by melt water. Grain size variations are abrupt and numerous, the range being from boulders through sand sizes. The silt and clay fraction is small, and these fine sediments are found primarily in thin, discontinuous beds. Outwash is present in the subsurface as well as on the surface of Barnes County. The largest deposit of outwash in the area lies directly on bedrock in the buried Spiritwood valley. In southern Barnes County, the Stoney Slough outwash channel extends southeastward to the so-called Sand Prairie south of Kathryn. The Stoney Slough outwash is confined to a broad shallow channel and its tributaries, whereas the Sand Prairie outwash is a wide flat plain having indistinct boundaries.

The Sheyenne valley in Barnes County was formed as a proglacial outwash channel. Four terrace levels record various stages of down-cutting. Many of these terraces are capped by coarse gravel, which locally exceeds 50 feet in thickness. Valley City and Sibley are located on two of the larger gravel-capped terraces, from which they obtain their water supplies. Other terraces are devoid of sand and gravel, but were eroded into bedrock or drift by glacial melt water.

Numerous small deposits of outwash are scattered throughout the county. Most of these are confined to narrow channels oriented toward the southeast. The outwash deposits form good ground-water reservoirs in Barnes County.

Isolated deposits of sand and gravel having distinctive topographic forms are termed ice-contact features. These deposits were formed in close association with the glacial ice, and in many instances they developed within the glacier itself. These features are composed of poorly sorted gravel, sand, silt, and clay. Ice-contact deposits are named according to their origin and landform characteristics; They include kames, eskers, and crevasse-fillings (Flint, 1957, p. 146-159). Although restricted in distribution, ice-contact deposits yield moderate quantities of water. Ice-contact features are most numerous in the north half of the county.

Extensive deposits of stratified silt and clay accumulated in pro-glacial lakes which were formed by damming of the outwash channel now occupied by the Sheyenne River. The lake deposits generally are thin and relatively impermeable; therefore, they yield very little water.

Alluvium consists of postglacial sediments laid down by streams since the retreat of glaciers from the area. These are restricted to the Sheyenne valley and its larger tributaries. Silt and clay are the primary constituents of the alluvium along the Sheyenne River, although thin deposits of sand are present locally. The sands yield small quantities of water, but the alluvium is a relatively unimportant source of ground water. These sediments are the only postglacial deposits of significant quantities in the county.

GROUND-WATER RESOURCES

Principles of Occurrence of Ground Water

Rocks and surficial deposits that form the crust of the earth contain numerous small openings called pores. These are extremely small between particles of clay and silt, but may be relatively large between sand grains or pebbles. Rocks may also be jointed, or cracked. Where the pores and joints contain water that is free to move into wells in sufficient quantity to be of consequence as a source of supply, the water-bearing unit is called an "aquifer" (Meinzer, 1923b, p. 52).

PHYSICAL PROPERTIES OF AQUIFERS

A knowledge of the physical properties of an aquifer aids the understanding of water movement through an aquifer. These properties, which are best determined in the laboratory, include porosity, permeability, specific retention, and specific yield. Unfortunately, laboratory determinations have inherent errors resulting from spot sampling and disturbance of the natural state of the material.

The porosity of a rock or aquifer is its property of containing openings, or pores. The size and number of these pores depend upon the character of the material and these, in turn, control the presence of ground water in the material. In sand and gravel, the pores are connected and water moves from one void to another. However, in some material the openings are isolated or so small that there is little, or no movement of water. This is particularly true of clay and shale. Porosity is expressed as the percentage of the total volume of the rock material occupied by pores.

Permeability is defined as the capacity of a rock or rock material for transmitting a fluid. This is a function of the amount of interconnection, number, and size of the pores in the material. Permeability is measured by the rate at which a fluid of standard viscosity can move in a given distance through a given interval of time.

Specific retention is the volume of water that material will retain against the pull of gravity if it is drained after being saturated. Specific yield is defined as the ratio of the volume of water drained by gravity to the total volume of the saturated sample. Both specific retention and specific yield are expressed as percentages (Meinzer, 1923a, p. 28).

HYDROLOGIC PROPERTIES OF AQUIFERS

Determination of certain hydrologic properties of water-bearing materials is necessary where a quantitative estimate of the amount of available ground water is desired. The hydrologic properties of an aquifer can be determined by means of carefully controlled pumping tests on wells. These properties include transmissibility, storage, and specific capacity. A detailed discussion of aquifer-test analysis is given by Ferris and others (1962), Theis (1935; 1938), and Wenzel (1942).

Transmissibility, or coefficient of transmissibility, is the rate of flow of water, in gallons per day, at the formation temperature, through a vertical strip of the aquifer 1 foot wide extending the full height of the aquifer under a unit hydraulic gradient. Transmissibility is equal to the permeability, at formation temperature, multiplied by the saturated thickness of the aquifer, in feet.

Storage capacity, generally expressed as the coefficient of storage, is the volume of water released from storage in a vertical column of the aquifer 1-foot square, when the water surface declines 1 foot. Under water-table conditions, the storage capacity is approximately equal to specific yield (Theis, 1938, p. 894). Specific capacity is the amount that a well will yield per foot of drawdown (Wenzel, 1942, p. 151).

The water table may be defined as the upper surface of the zone of saturation where water is free to move in response to gravity and not confined above by an impermeable rock. The water table is an irregular surface that is controlled by topography, geology, and hydrology of the area. Inasmuch as the surface is not flat, the water moves through the strata from the area of recharge to the place of discharge (fig. 3). This movement results in fluctuations of the water table in response to additions to, or withdrawals from, the aquifer.

Water is said to occur under artesian conditions if it is confined in the aquifer by an overlying, relatively impermeable stratum. Under such conditions, water will rise above the top of the aquifer when a well passes through the confining stratum. The rise in water level is produced by hydrostatic pressure, and the imaginary surface to which the water will rise is called the piezometric surface. It may be at, above, or below the water table, depending upon local conditions (fig. 3). When water is withdrawn from an artesian well, the aquifer remains saturated because of expansion of the water and contraction of the aquifer due to lowered pressure. The movement of water in an artesian aquifer is controlled by gravity or pressure. Recharge to the artesian aquifer is moved by gravity to a lower elevation, where it is discharged under hydrostatic pressure. The Dakota Sandstone is an example of an artesian aquifer.

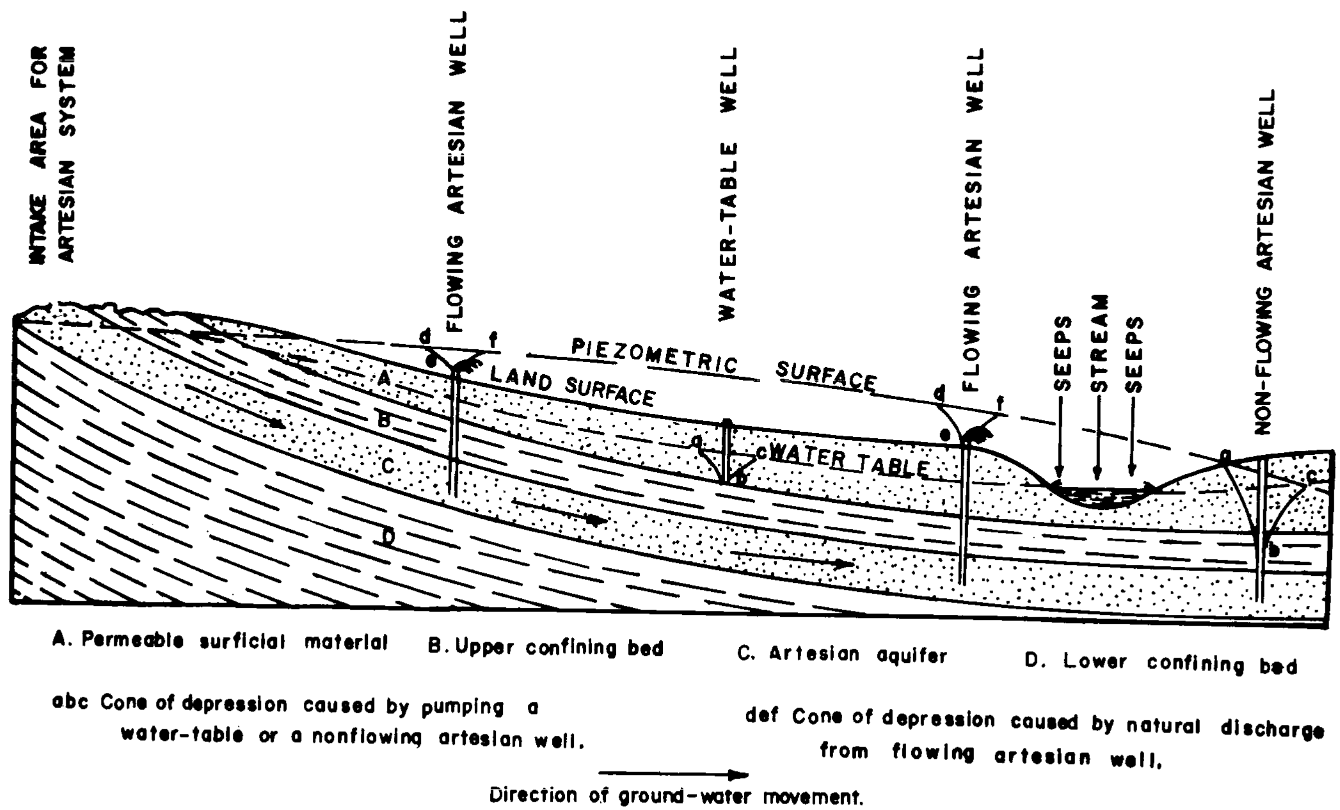


Figure 3. Schematic diagram showing artesian and water-table conditions.

Although both water-table and artesian aquifers are present in Barnes County, the most common type is the "leaky" artesian aquifer. This type is intermediate between an unconfined, or water-table aquifer and a confined, or artesian aquifer. It commonly receives water through confining deposits above and (or) below the aquifer. In such cases, the confining beds only retard the movement of ground water rather than prevent it. Glacial drift contains numerous leaky artesian aquifers in the form of semiconfined sand and gravel deposits. The glaciofluvial deposits are surrounded by glacial till through which water moves very slowly into and out of the semiconfined aquifers. The water levels in wells penetrating these leaky artesian aquifers will rise to within a few inches or a few feet of the water table in the till. Wells that penetrate the saturated till without entering a sand or gravel lens fill with water very slowly. Thus the water levels in wells newly developed in glacial drift usually represent a common peizometric surface, whether they penetrate leaky artesian aquifers or till. The configuration of the piezometric surface in Barnes County is shown on figure 4.

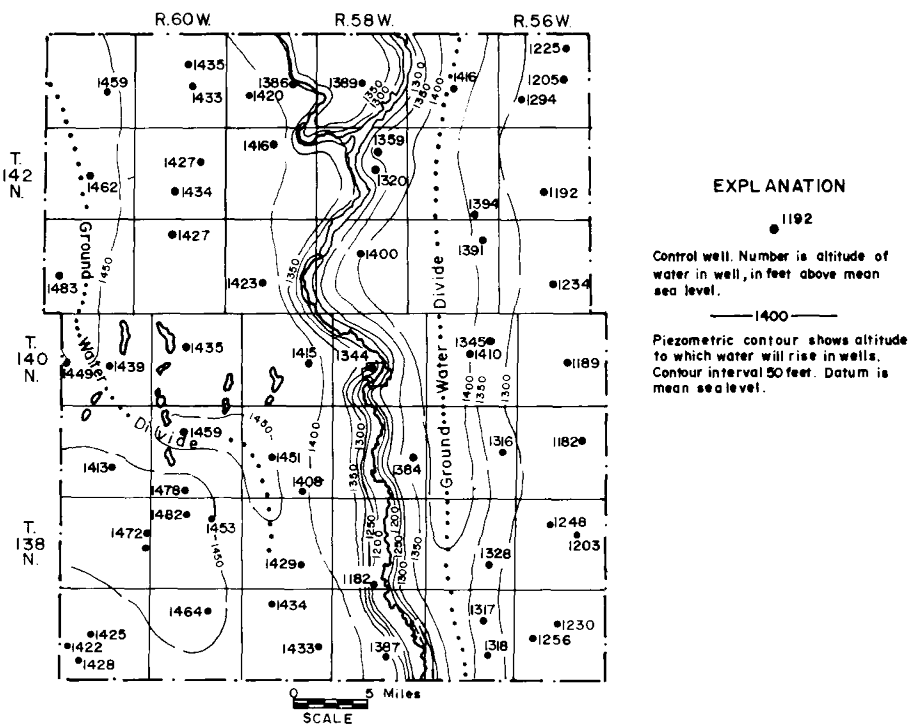


Figure 4. Configuration of the piezometric surface, October 1962. Ground water divides control the direction of subsurface flow.

RECHARGE, MOVEMENT, AND DISCHARGE OF GROUND WATER

Aquifers derive their water from precipitation. Much of the precipitation on the earth surface becomes surface runoff, much goes back to the atmosphere by direct evaporation or by transpiration from plants, and only a very small part seeps through the soil and underlying deposits to the water table as recharge.

It has been estimated that only half an inch per year of the precipitation escapes evaporation and transpiration and enters the ground-water reservoirs of the High Plains (Theis, Burleigh, and Waite, 1935, p. 2-3). This is only a small percentage of the total annual moisture, but one-half inch of precipitation is equal to more than 4 million gallons per square mile.

Although most of the annual precipitation falls during the growing season, water levels in wells decline during this period (fig. 5). This indicates that under normal conditions more water is lost to plants and by evaporation than is available in the form of precipitation. Only during periods of above-normal rainfall, as in 1962, are the aquifers recharged during the growing season.

Ground water in Barnes County is derived almost entirely from local precipitation in the form of rain and snow. The mean annual precipitation at Valley City is 18.07 inches. Approximately 50 percent falls during June, July, and August, when the climate is characterized by brisk winds, high temperatures, and low humidity. Consequently, much of the rainfall evaporates and is lost to the atmosphere. During the months of May through September 1962, total evaporation from a free water surface at the Edgeley Experimental Station was 30.39 inches. Also, a large part of the precipitation is used by plants and then returned to the atmosphere through transpiration. It is obvious that most of the precipitation on the county reverts back to the atmosphere soon after it reaches the land surface.

The effect of ground-water recharge from precipitation in the county is shown in figure 5. During a period of normal precipitation, the principal recharge to the glacial drift occurs during the spring months immediately following the spring thaw. At this time the water held in storage as snow and ice is released to the ground-water reservoirs. Rainfall is an important source of recharge during the spring also.

The Sheyenne River and Baldhill Creek in Barnes County have eroded their channels below the water table. Consequently, in the vicinity of these streams, the water table fluctuates in accordance with the water level in the stream (fig. 6). During a period of low river stage the aquifers drain into the stream, but the streams contribute water to the aquifers during high stage. It should be noted that the water level in observation well 138-58-15baa (fig. 6) rose approximately 1 foot during December 1962 and January 1963 in response to increased discharge in the Sheyenne River, but the mean water level in the county declined nearly three-fourths of a foot during the same period (fig. 5).

Alluvium in the Sheyenne and Baldhill channels is variable in lithology. Silt

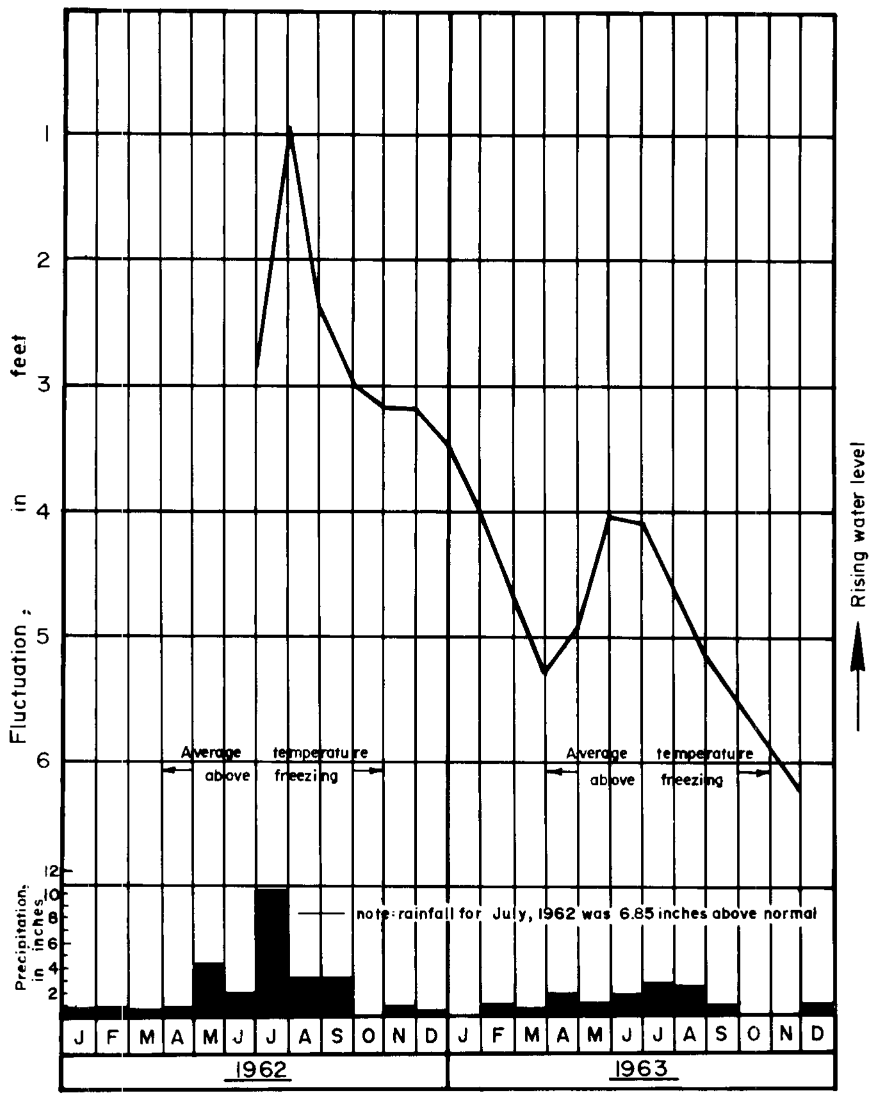


Figure 5. Relation of mean-water-level fluctuations from more than 50 wells to monthly precipitation at Valley City.

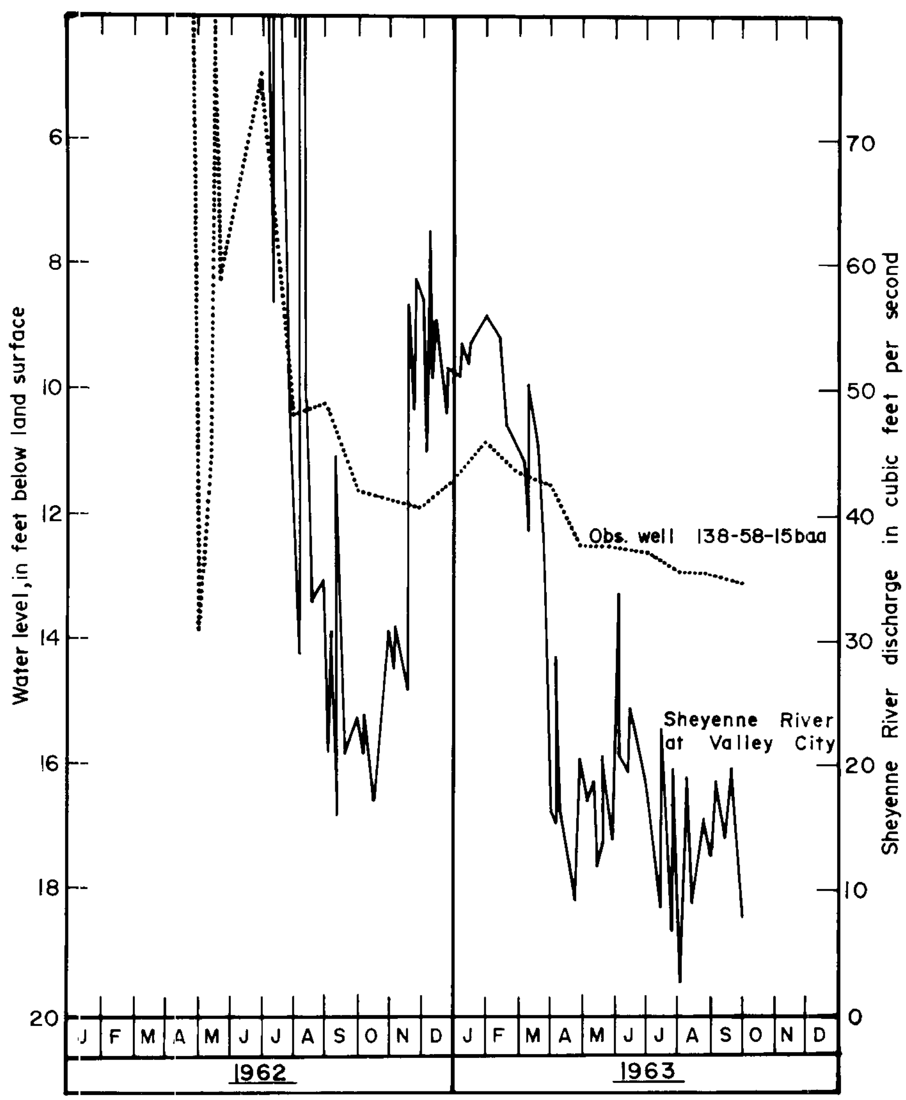


Figure 6. Relation of discharge in the Sheyenne River at Valley City to water-level fluctuations in a well approximately 50 feet from the river.

and clay are the principal sediments and the minor amounts of sand are fine grained and lenticular. Therefore, the streams recharge only those sand aquifers that are in direct contact with the streambed. The other alluvial aquifers are recharged by direct precipitation only.

Almost all ground water is in motion from areas of recharge to areas of discharge. The rate of movement is a function of hydrologic gradient of the water table or piezometric surface and the ability of the aquifer to transmit water. In general, the movement is greatest in sand and gravel aquifers and is much less in glacial till. The rate probably ranges from several feet per day to a few feet per year.

The release of ground water from storage through natural or manmade outlets is called discharge. In Barnes County ground water is discharged primarily by evaporation and transpiration and secondarily through springs and subsurface outflow.

Large quantities of ground water discharge through springs into the Sheyenne River and Baldhill Creek. The total volume of discharge has not been measured, inasmuch as many of the springs are not developed. However, most of the springs that were measured during the study have a flow of 3 to 5 gpm (gallons per minute). Many of these are used for stock and domestic purposes and for supplying the community of Kathryn. Several springs in the southwest quarter of T. 137 N., R. 58 W., yield a total of more than 1,000 gpm; this is one of the largest concentrations of springs in the county.

The amount of water lost from the county as subsurface flow is relatively small. Ground water moves eastward from the ground-water divide in eastern Barnes County and enters Cass County at the rate of approximately 25,000 gpd (gallons per day), and the subsurface outflow in the Spiritwood aquifer is approximately 2,500,000 gpd. The total outflow from the county is of minor significance, however.

Chemical Quality of the Water

Rain and snow are the purest forms of water that occur in nature, but even these contain organic and inorganic impurities. As water from precipitation enters the ground, it dissolves part of the soluble mineral constituents of the soil and rock with which it comes in contact. The amount of mineral matter dissolved depends mostly upon the amount of soluble material in the rocks, the length of time the water is in contact with the soluble material, and the amount of carbon dioxide and other constituents in the water.

The chemical character of water is often the factor determining its suitability for use. The U.S. Public Health Service has set standards for the quality of drinking water used in interstate carriers (U.S. Public Health Service, 1962, p. 7).

These drinking water standards, in part, are as follows:

Constituent		Concentration (ppm)
Chloride	(Cl)	250
Fluoride	(F)	1.7*
Iron	(Fe)	.3
Manganese	(Mn)	.05
Nitrate	(NO_3)	45
Sulfate	(SO_4)	250
Total dissolved solids		500

*Varies for different parts of the country.

Fluoride and nitrate may be physiologically harmful if consumed in quantities exceeding those recommended by the Public Health Service. Fluoride in drinking water will prevent dental decay when consumed in small amounts; however, excessive fluoride produces mottled tooth enamel and affects bone structure (Hem, 1959, p. 113). Excessive nitrate in domestic supplies can cause methemoglobinemia, or cyanosis, in infants whose feeding formulas are mixed with these waters (Comly, 1945). Nitrates are dissolved readily from soils that contain them. Animal waste is a source of organic nitrogen as well as bacteria, and a large amount of nitrate in well water may indicate bacterial pollution. This is illustrated by two wells of similar depth located in northeastern Barnes County (143-56-21add). One well located near the house had 2.0 ppm nitrate, whereas a stock well near the barn had 120.0 ppm nitrate (Kelly, 1964b, table 4).

Most of the more common constituents in drinking water are objectionable only when they are present in sufficient quantities to be noticeable to the taste. Chloride in concentrations of 200 to 300 ppm is sufficient to give a salty taste noticeable to most people. Similar concentrations of sulfate in drinking water commonly have a laxative effect.

Iron and manganese stain clothing and plumbing fixtures; generally, when present in large quantities, these constituents are undesirable in water supplies used for domestic purposes. Hardness in water is produced by dissolved calcium and magnesium. These constituents readily combine with soap and form an insoluble scum during washing processes that use soap. Thus large amounts of soap are necessary in order to produce a lather or suds in very hard water.

The residue that is left after a sample of water has evaporated consists mainly of the dissolved solids. The total dissolved solids are a measure of the overall mineral quality of water; as the amount of dissolved minerals increases, the quality decreases. Total dissolved solids can be approximated by measuring the specific electrical conductance of a water sample and using the following relationship:

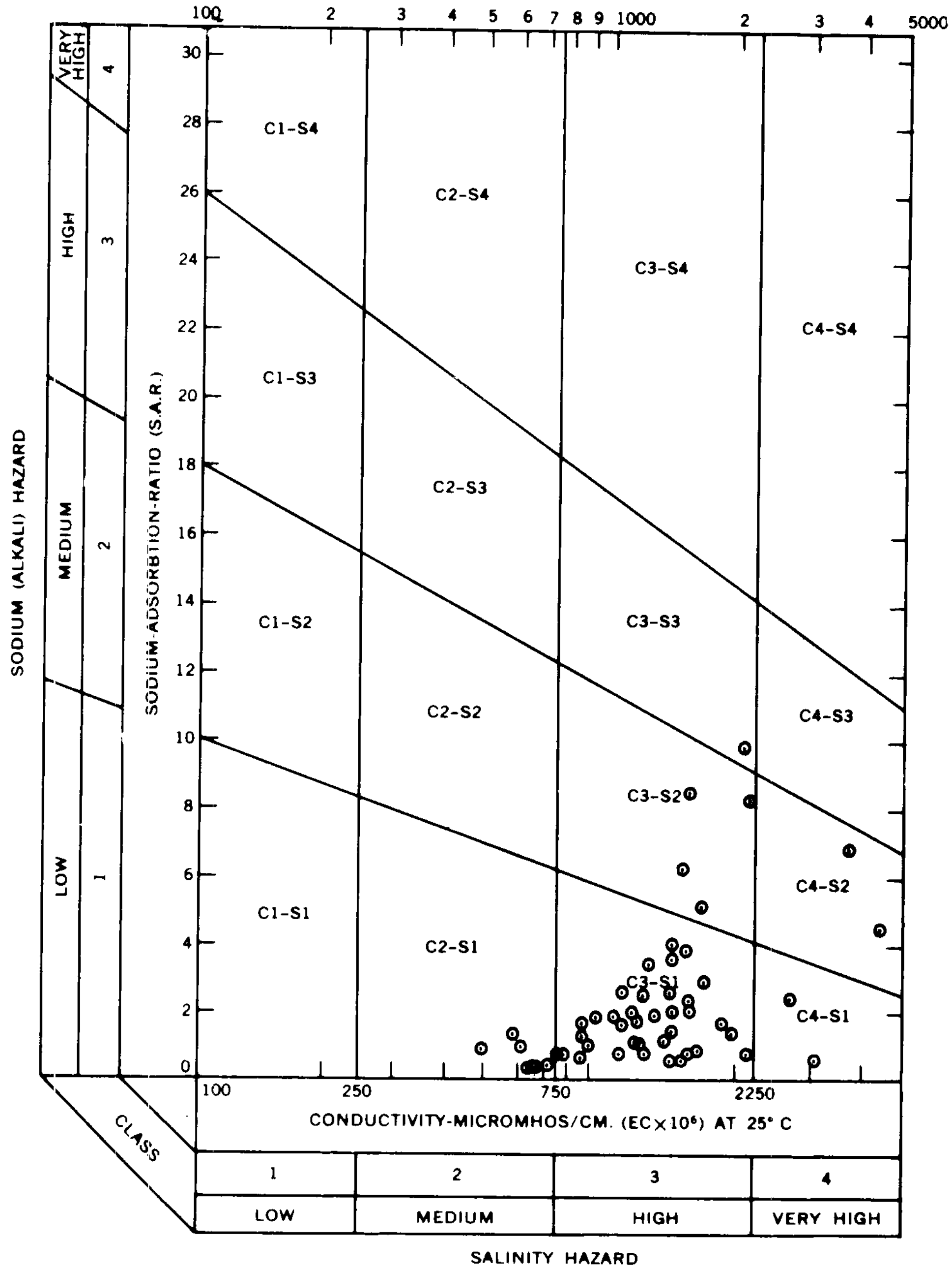


Figure 7. Classification of water samples for irrigation use from glacial drift.

specific conductance (micromhos at 25° C) (0.65 ± 0.10) = dissolved solids (ppm)

The evaporated dissolved solids and the specific conductance of 70 Barnes County water samples are given by Kelly (1964b, table 4). The specific conductance of more than 400 water samples from the county have also been published (Kelly, 1964b, table 1). Most of the samples analyzed had total dissolved-solids content exceeding that recommended by the U.S. Public Health Service for drinking water.

The most important characteristics in determining the suitability of water for irrigation are the concentration of sodium ions and the dissolved-solids content. The concentration of sodium ions is expressed as the sodium-adsorption ratio (SAR) which is the ratio of relative activity of sodium ions in the water with soil extracts (U.S. Salinity Laboratory Staff, 1954). When the SAR and specific conductance of water are known, the suitability of water for irrigation can be determined graphically (fig. 7). These data from water in glacial drift aquifers of Barnes County are plotted in figure 7, most of the samples falling within the C3-S1 range. This water can be used for irrigation of plants with good salt tolerance (corn, wheat, rye, flax) provided there is adequate drainage and the soil salinity is controlled.

The chemical character of water in Barnes County is shown by analyses of samples from wells deriving water from the principal aquifers and surface-water sources (Kelly, 1964b, table 4). Averages of the major constituents of water from the more important water-bearing units are shown in figure 8. For the purpose of illustration, the constituents were converted to equivalents per million using the conversion factors given by Hem (1959, table 4).

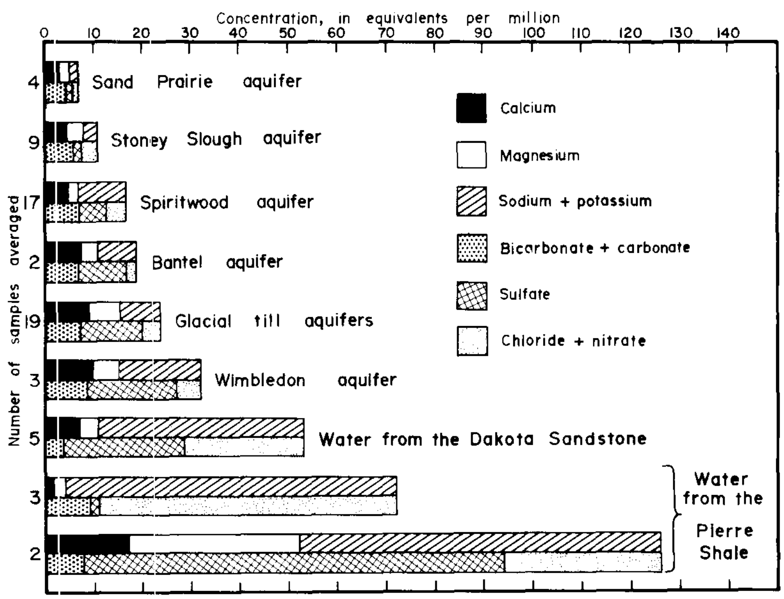


Figure 8. Chemical constituents of water.

Ground Water in the Consolidated Rocks

Although the rock strata underlying the Cretaceous Dakota Sandstone contain large quantities of water, the water is highly saline and is not used in large quantities in Barnes County at the present time. Therefore the hydrology of these rocks is not discussed in this report. More than 1,000 feet of shale separates the Dakota Sandstone from the overlying glacial deposits (Nelson, 1955, p. 2-4). Only the Pierre Shale, uppermost formation in the thick shale sequence, is known to yield water to wells in Barnes County.

DAKOTA SANDSTONE

The Dakota is one of the most widespread formations in the United States. It has been described in most of the States of the Great Plains from western Iowa to Montana and New Mexico. Lithology of the formation is quite variable and ranges from conglomerate to shale. However, the predominant rock types are fine-grained quartzose sandstone and dark-gray bentonitic shale. The sandstone and shale occur in varying proportions in different parts of the country and it is the amount of sandstone present that controls the availability of ground water.

Numerous wells have penetrated the Dakota Sandstone in Barnes County, generally ranging in depth from 600 to 1,500 feet. Dakota wells are most numerous in the eastern half of the county owing to the shallower depths at which the water-bearing sands are present. Although it is commonly believed that there are three principal aquifers ("Three Flows") in the formation beneath Barnes County, seven distinct water-bearing zones were penetrated in a well located north of Valley City (140-58-8ddb). This well penetrated a total of 110 feet of sandstone in addition to numerous thin beds of sandy shale, but it is doubtful that it penetrated the entire formation. The Pollard and Davis-Dwane Guscette No.1 oil test hole (142-61-20bbb) penetrated the entire Dakota Sandstone. The borehole passed through only four distinct sandstone strata; however, one stratum was 209 feet thick (Nelson, 1955). These wells illustrate the variable nature of the Dakota. It is difficult to distinguish the individual aquifers and it is doubtful that they are persistent for any great distance. However, it is probable that many of the aquifers interfinger and are hydrologically connected.

Very little is known of the physical properties of the Dakota Sandstone. Drill cuttings indicate that the sand is rather well sorted and free of intergranular clay and silt. However, cores of the Dakota from oil tests indicate that the sandstone is interbedded with shale laminae which are not apparent in drill cuttings. In general, samples of the sandstone are rather poor, owing to its friable character and to the soft shale, which is lost in the drilling mud. Consequently, it is often difficult to determine accurately the lithology of the formation from drill cuttings.

The Dakota Sandstone has produced more water than any other aquifer in Barnes County. The earliest wells were drilled during the 1880's, but fewer wells are now being drilled in the Dakota because of the unsuitability of the water in modern plumbing and appliances. Its primary use at the present time (1966) is for stock watering.

Most of the wells drilled to the Dakota flow at the surface when completed. Rates of flow differ appreciably within the county; a few wells do not flow, although the water level rises several hundred feet above the top of the aquifer. One of the earliest wells to tap the Dakota Sandstone in Barnes County was drilled in 1889 at Wimbledon. Initially this well flowed 400 gpm (Simpson, 1929, p. 69); however, many of the early wells flowed less than 100 gpm (Willard, 1909, p. 10). Most of the wells drilled in recent years flow only a few gallons per minute, usually less than 10 gpm. This is due to the low hydrostatic pressure in the shallow sand lenses of the Dakota. These flows are sufficient for stock watering, and consequently the wells are not deepened to obtain greater flows. Deep wells do yield relatively large quantities of water. A 1,335-foot stock well drilled in sec. 35, T. 140 N., R. 59 W., reportedly flowed 65 gpm and a 1,154-foot well north of Valley City (140-58-8dad) had an initial flow of approximately 750 gpm.

Many of the Dakota Sandstone wells have continued to flow for 40 years or more. Generally the flows decrease gradually with age of the well, and ultimately the wells cease to flow. This decrease in flow rate probably is due primarily to the decline in hydrostatic pressure, and secondarily to the incrustation of the well casing by minerals precipitated from the water. The rate at which incrustation occurs varies appreciably. A well (141-56-23bbc) drilled to a depth of 984 feet in 1950 flowed several gallons per minute; now, however, the well has ceased to flow. Conversely the D. Pederson well (139-58-9aac) was drilled to a depth of 1,020 feet in 1908. The measured flow was 3.0 gpm on July 11, 1928, 3.5 gpm on September 20, 1935, and 2.3 gpm on September 30, 1964.

Wenzel and Sand (1942, p. 79-80) measured the flow of 35 Dakota wells in 1938. At the present time, only two of these are known to be flowing; one is the Pederson well described above, and the second (139-60-32ccb) is located on the Orval Shape farm south of Sanborn. Inasmuch as the rate of flow has not decreased appreciably in either of these wells, the decline in hydrostatic head within the Dakota Sandstone seems to have been negligible during the past 40 years. A considerable decrease in hydrostatic head reportedly occurred prior to 1923 (Meinzer and Hard, 1925, p. 82).

It is extremely difficult to calculate the quantity of water available to wells penetrating one or more sandstone members of the Dakota. This is due to the lack of available data on the physical characteristics of the deposit. Thickness of the sandstone strata within the formation is not uniform. Also, very little is known of the porosity and permeability of the sandstone. Quantitative values of these properties are available from one well drilled near Glenfield in Foster County, about 17 miles northwest of Barnes County. The average porosity of four samples was 42.8 percent and the average permeability was 234 meinzer units (Wenzel and Sand, 1942, p. 41). If it is assumed that this porosity is representative of the formation, and that the average thickness of the aquifer is 60 feet (Meinzer and Hard, 1925, p. 90), more than 31 billion gallons of water would be held by each square mile of the aquifer. The average rate of flow of Barnes County wells is approximately 3 gpm. Approximately 20,000 years would be required to completely drain 1-square mile of the sandstone at the rate of 3 gpm.

Very few quantitative data are available on the hydrologic properties of the Dakota Sandstone. This is due to the fact that hydrologic data are much more difficult to obtain on a flowing well than on a well that is pumped. Akin (1952, p. 28) estimated that the transmissibility is 12,000 gpd per foot and the coefficient of storage is 0.0011 at Litchville, in southwestern Barnes County. These estimates are in agreement with those computed by Dennis and Akin (1950, p. 29) at Portland, about 25 miles northeast of Barnes County where the coefficient of transmissibility was 16,100 gpd per foot and the coefficient of storage is 0.0004. The Portland determinations were based on one pumping test. A coefficient of transmissibility of approximately 14,000 gpd per foot is obtained by multiplying the permeability of 234 meinzer units obtained in the Glenfield well by an estimated average thickness of 60 feet. The coefficient of transmissibility of the Dakota Sandstone generally ranges from 12,000 to 16,000 gpd per foot and the coefficient of storage is approximately 0.0007.

These values are based on the test mentioned above and are presented as the best estimate that can presently be made of the hydrologic properties of the formation. A great deal more information is necessary before more accurate values of transmissibility and coefficient of storage can be obtained for the aquifer.

Water from the Dakota Sandstone is highly mineralized and generally unsatisfactory for domestic use. It is a sodium sulfate type water (fig. 8). By U.S. Public Health Service standards, the water generally contains excessive amounts of chloride, fluoride, iron, and sulfate. One distinctive characteristic of Dakota water is the small amount of silica, usually less than 10 ppm. Water from most other sources in the county had more than 20 ppm silica. The water from the Dakota Sandstone is highly toxic to most domestic plants and small grain crops, but it may be suitable for some industrial uses.

PIERRE SHALE

Although the Pierre Shale is not a major aquifer in the county, a few farms are dependent solely upon the formation as a source of water (fig. 9). Most of these wells are in the central part of the county, where the Pierre is covered by relatively thin glacial deposits.

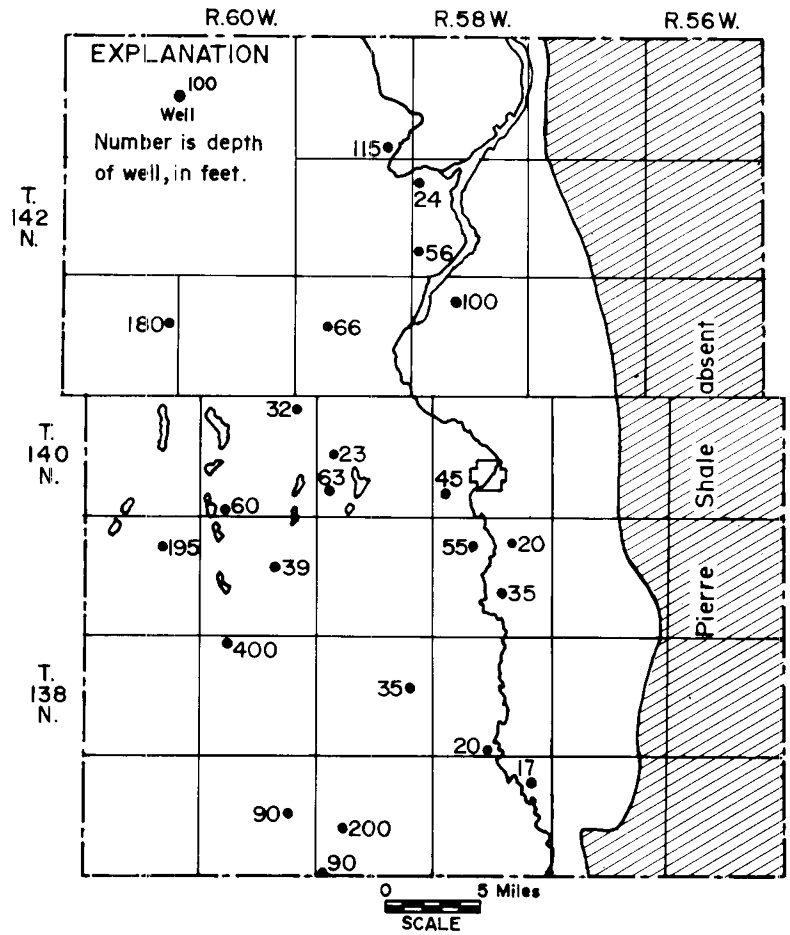


Figure 9. Location of wells obtaining water from the Pierre Shale.

In Barnes County the Pierre has a total thickness of 244 feet in test hole 2137 (140-61-19bbb), and the formation consists of light-gray blocky, calcareous marl conformably overlain by dark-gray to black fissile, noncalcareous shale. The black fissile shale is exposed in the upper slopes of the Sheyenne River valley and has also been penetrated by numerous test holes drilled west of the river. It commonly contains thin beds and laminae of bentonite. No sandstone has been observed in outcrops or well cuttings from the Pierre Shale in Barnes County.

The Pierre Shale is directly overlain by glacial drift, and the two units are hydrologically connected. Consequently, fluctuations of the water levels in the Pierre Shale are closely related to precipitation and subsurface flow. The relationship of water-table fluctuations and precipitation is shown in figure 10.

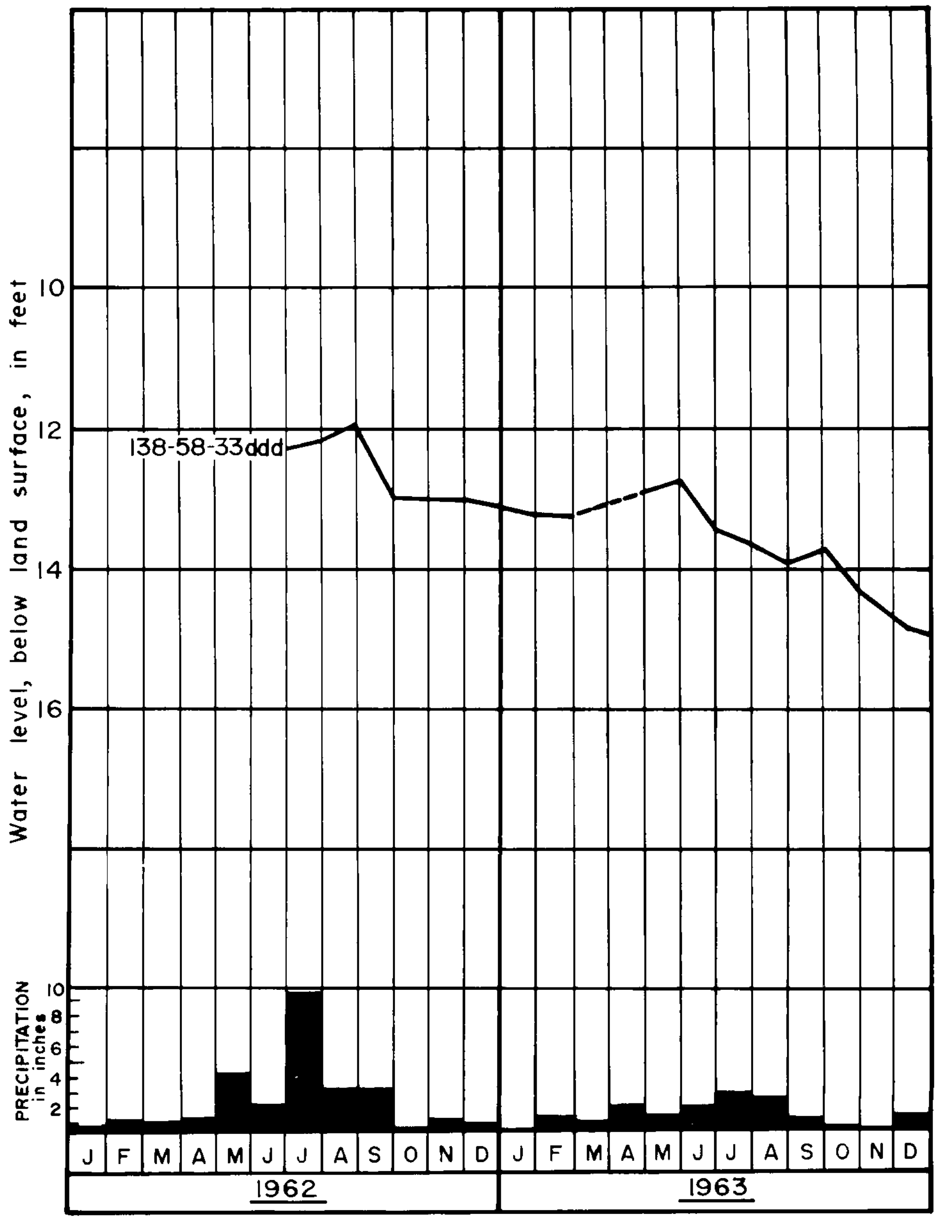


Figure 10. Relation of ground-water level fluctuations in the Pierre Shale to monthly precipitation at Valley City.

Inasmuch as shale has a very low permeability, water movement through the Pierre is restricted to the joint systems and cleavage planes. These fractures are best developed in the upper part of the shale and were produced by weathering and glacial erosion. Also, owing to the physical nature of the Pierre, the black fissile shale is more highly fractured than the blocky, calcareous marl. Therefore, wells developed in the Pierre Shale usually obtain water from the fracture systems in the upper part of the formation. It is probable that most of the water in the Pierre is derived from the overlying glacial drift, and once in the fracture systems the water moves toward areas of discharge.

Locally the Pierre Shale lacks a joint system, thus forming a nearly impermeable boundary for the vertical movement of ground water. A well bored approximately 30 feet through terrace gravel in sec. 9, T. 139 N., R. 58 W., penetrated 1 foot of water-bearing gravel lying directly on unfractured Pierre Shale. The water moved over the impermeable shale and discharged through springs at the edge of the terrace. Many of the springs in the Sheyenne valley originate in this manner, although a few of the springs originate from the fracture zones themselves.

Very little is known of the volume of water available from the Pierre Shale, owing to the variation in fracture systems. It is doubtful that the water yield from the shale would exceed 5 gpm per well except in locations where there is an exceptionally thick fractured zone in the shale. One well, 139-61-10bca, penetrated 48 feet of black fractured shale between depths of 147 and 195 feet. Upon completion of the well, water rose more than 100 feet above the top of the Pierre and reportedly was pumped at the rate of approximately 50 gpm with very little drawdown. Most domestic and stock wells that are dependent upon the Pierre for water are drilled completely through the fractured zone and into the non-water-bearing shale. The lower portion of the well then serves as a reservior that is filled slowly when the well is not in use.

A detailed study of the shale was made at Michigan City, North Dakota (Aronow, Dennis, and Akin, 1953), where more than 40 wells are known to obtain water from the Pierre Shale. Although the Michigan City study area is about 50 miles north of Barnes County, the data are probably applicable to both areas, owing to the uniform lithology of the Pierre Shale over great distances.

Three aquifer tests were conducted on wells penetrating the Pierre in the Michigan City area. "Computed values of the coefficient of transmissibility range from 490 to 900 gpd per foot and averaged 710 gpd per foot. Computed values of the coefficient of storage ranged from 2.8×10^{-4} to 5.8×10^{-4} and averaged 4.2×10^{-4}" (Aronow, Dennis, and Akin, 1953, p. 76). It is readily apparent from these low values that the Pierre does not yield large quantities of ground water to individual wells. For example, slightly more than 100,000,000 gallons of water is available in 1 square mile of the aquifer 1 foot thick. This is less than one-third the quantity that would be available from a similar section of the Dakota Sandstone.

There are two entirely different types of water in the Pierre Shale, although both types are highly mineralized (fig. 8). One is a very hard sodium sulfate water obtained from wells located near the east edge of the Pierre Shale in the south-central part of the county. It is the most highly mineralized water in Barnes County. Other Pierre wells yield relatively soft sodium chloride water. In general, both types of water from the Pierre Shale are highly toxic to plants.

Ground Water in the Glacial Drift

More than 90 percent of the wells in Barnes County obtain water from deposits of glacial origin, which include nearly all the sediments above the shale bedrock. The origin of the aquifers is diverse and the water yield from them varies appreciably (pl. 1). In general, there are two basic types of glacial aquifers: (1) Buried sand and gravel deposits closely associated with the glacial till are the most numerous. This type of aquifer is recharged primarily by subsurface underflow, and secondarily by direct precipitation and runoff. Major aquifers of this type include the Spiritwood, Wimbledon, and Bantel aquifers. (2) Surficial aquifers composed of glacial outwash are recharged primarily by precipitation and runoff, and secondarily by subsurface flow. This type of aquifer is more restricted and occurs only at the surface. The Valley City, Sand Prairie, and Stoney Slough aquifers are examples of this type.

SPIRITWOOD AQUIFER

Location and Extent

The Spiritwood aquifer is one of the largest water-bearing deposits in eastern North Dakota and it is the most important aquifer in Barnes County. It was named for the community of Spiritwood, which is near the western edge of the aquifer in eastern Stutsman County (Huxel, 1961b, p. D-179). The aquifer was investigated during the Stutsman County ground-water study (Huxel, 1965), and the aquifer was defined more fully during the Barnes County study. Subsequent drilling in Griggs County indicates that the aquifer extends northward to central Griggs County (J. B. Shell, oral communication; Kelly, unpublished data). As presently defined, the aquifer has an areal extent exceeding 400 square miles, more than half of which is in Barnes County (fig. 11). Also, it is probable that the Spiritwood aquifer is hydrologically connected with the Heimdal aquifer in Griggs County (H. Trapp, oral communication).

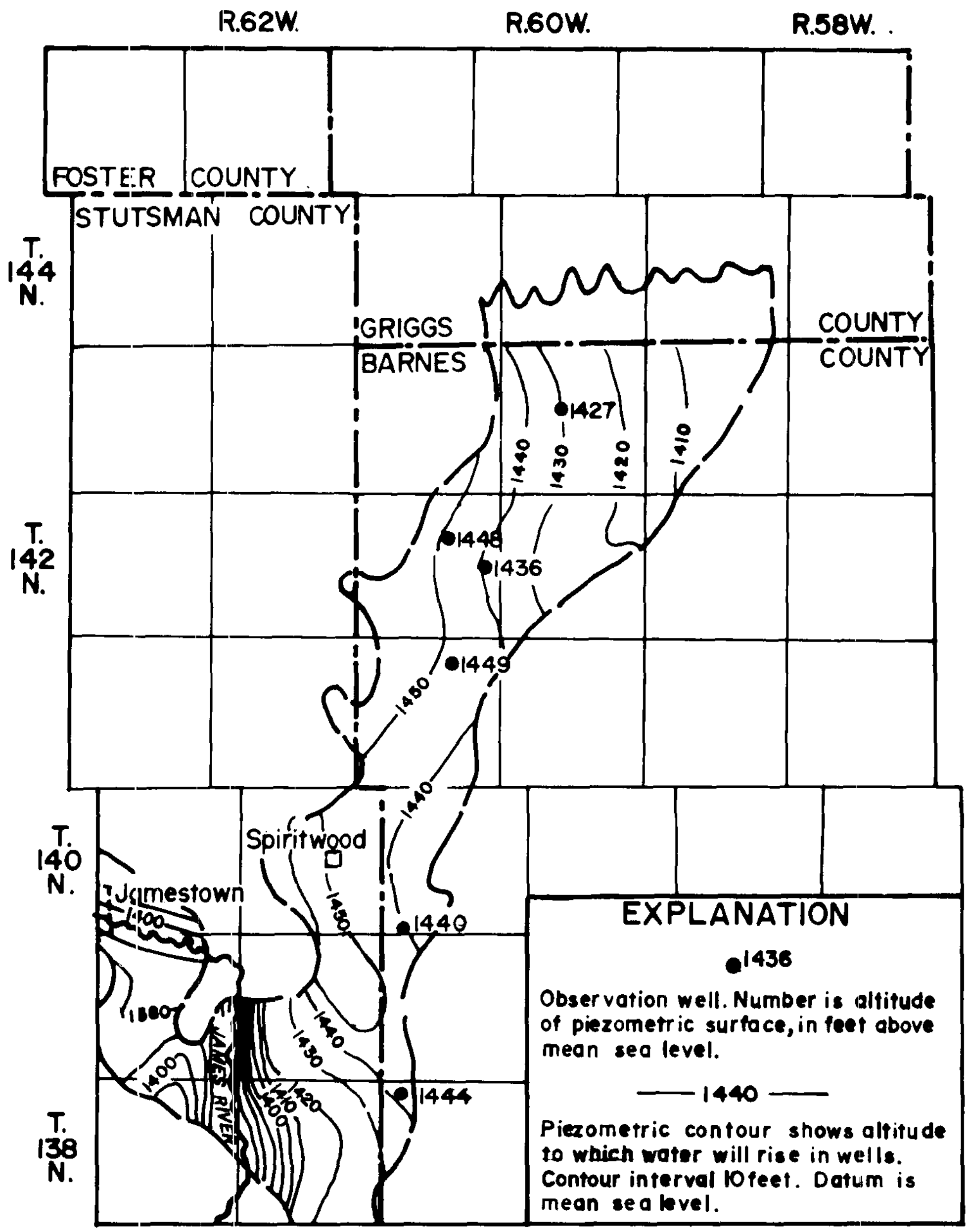


Figure 11. Configuration of the piezometric surface of the Spiritwood aquifer, eastern North Dakota. (Modified after Kelly, 1964a, fig. 3.)

Thickness and Lithology

The aquifer consists of glacial outwash deposited in the Spiritwood channel. In general the outwash is thickest near the center of the channel and thinnest at the channel margins (Kelly, 1964a, p. D-163). One test hole (140-61-31bcd) penetrated 162 feet of sand and gravel, but the average thickness of the aquifer is 50 feet. There is a general thinning of the deposits toward the south.

The outwash deposits composing the aquifer consist primarily of sand and gravel in varying proportions. The sand grains are variable in size and are angular to subangular. The gravel consists primarily of subangular to subrounded shale and limestone fragments; as much as 30 percent of the total is composed of igneous and metamorphic rock fragments. The shale fragments probably were derived locally and locally constitute more than 90 percent of the gravel. The other rocks are typical of those in the Canadian Shield and are common in glacial till throughout the county. The samples of the aquifer materials collected during this study were obtained by rotary drilling. Such samples are often contaminated by caving material and they may lack both the very fine and the very coarse sediments actually present in the aquifer. Nevertheless, the samples, together with the behavior of the drilling rig during the drilling, indicate that the aquifer is coarsest at the base. A boulder pavement several feet thick is present at the base of the aquifer in T. 143 N. Silt and clay are minor constituents of the Spiritwood deposits and they occur primarily in thin, discontinuous strata.

The Spiritwood aquifer is buried beneath drift generally ranging in thickness from 75 to 150 feet. The drift, which is composed primarily of till, is thickest in northwestern Barnes County and thins southwestward into Stutsman County. Locally the drift has been removed in the James River valley and the aquifer deposits are overlain by valley outwash and alluvium.

Reservoir Characteristics

Water-level fluctuations — Water in the Spiritwood aquifer is under artesian pressure and the water levels in wells penetrating the aquifer rise more than 100 feet above the top of the aquifer. In most wells the water rises to within 50 feet or less of the land surface, and in two wells the water reportedly flows at the surface.

During the Barnes County study observation wells were installed in the aquifer to monitor the water-level fluctuations (fig. 11). Hydrographs of three of these wells show that the annual water-level fluctuations are less than a foot (fig. 12). The figure shows that there is little relation between water-level fluctuation and precipitation for the period of record. Observation wells 141-61-2ccc and 142-61-9ddd show a relatively stable water level from the beginning of record through February 1964, and that it has declined since that time.

Two of the Spiritwood observation wells are within the area influenced by irrigation wells (fig. 13). An aquifer test was run on well 140-61-31dca1 during

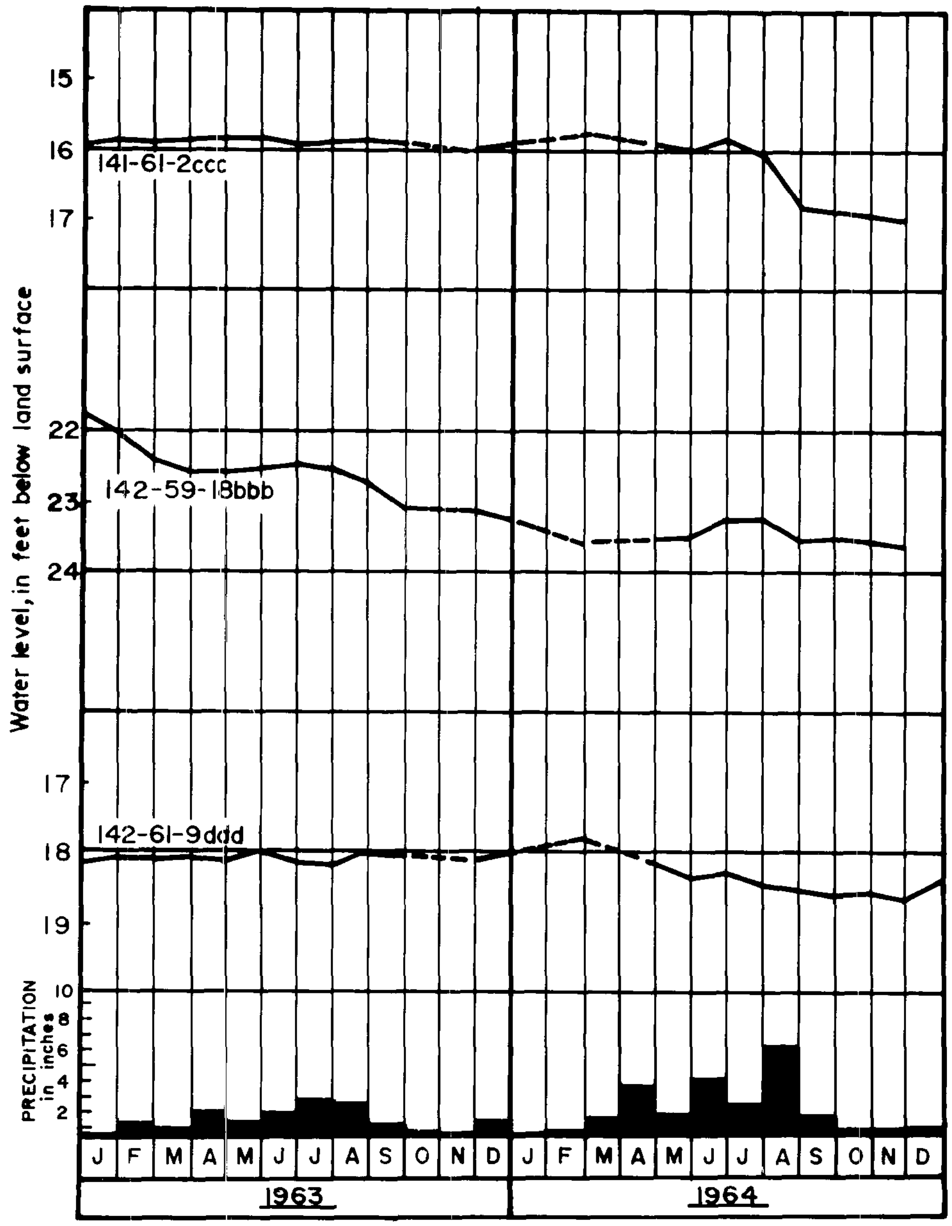


Figure 12. Relation of water-level fluctuations in the Spiritwood aquifer to precipitation at Valley City.

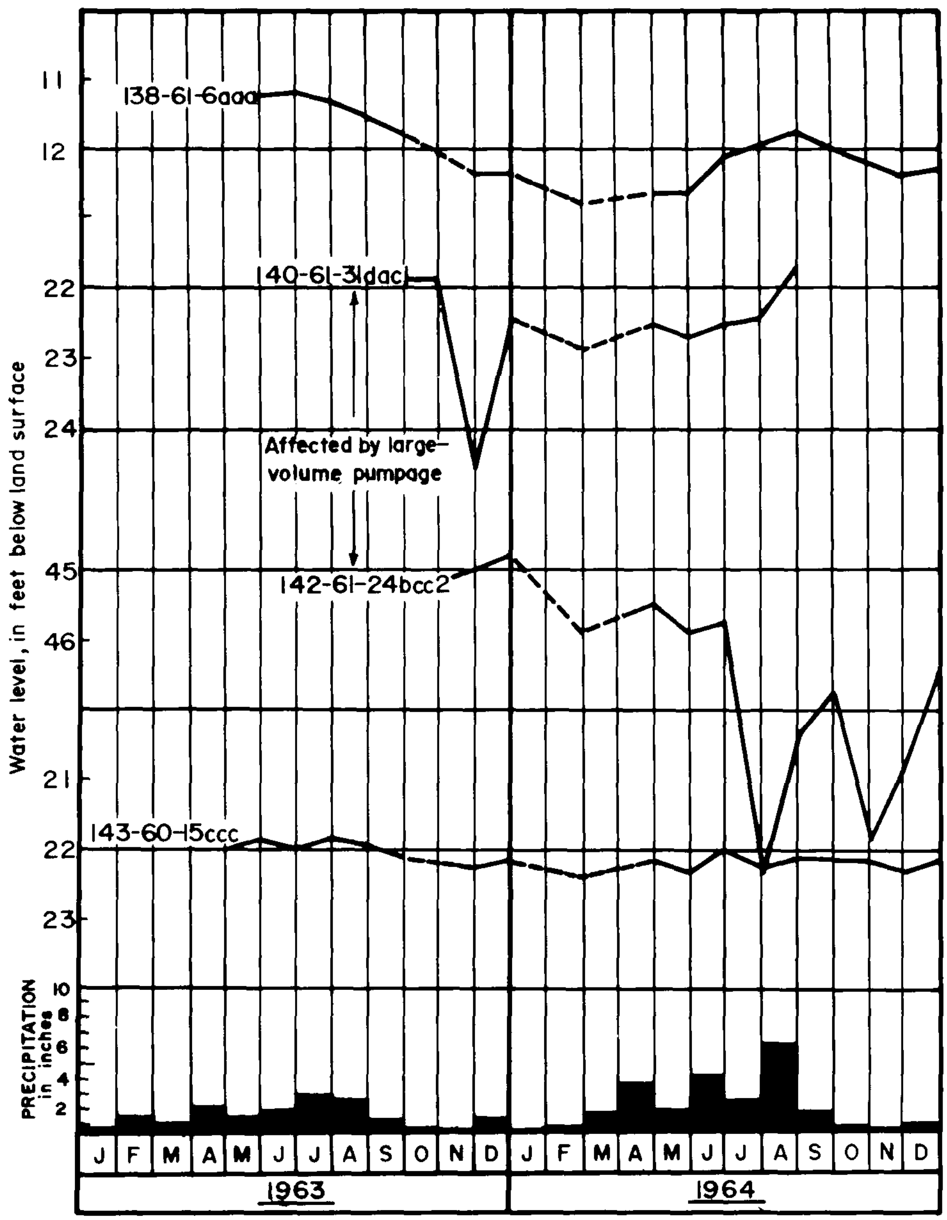


Figure 13. Relation of water-level fluctuations in the Spiritwood aquifer for 4 wells, 2 of which are affected by large-volume pumping, to precipitation at Valley City.

November 1963. Approximately one month later the static water level was 2.67 feet below the pretest level. However, during December 1963, the water level recovered 2.13 feet and followed a pattern similar to that of other wells in the aquifer during the subsequent spring and summer months. Insufficient records preclude showing total recovery of the water level in well 142-61-24bcc2, which is within the zone of influence of a nearby irrigation well.

Aquifer tests – Two aquifer tests were conducted in the Spiritwood aquifer during the Barnes County study. One test was made on the Eugene Klein farm in sec. 31, T. 140 N., R. 61 W.; the second test was made on the Robert Christ, Jr., farm in sec. 24, T. 142 N., R. 61 W.

The aquifer test at the Klein well was made in October and November 1963, using well 140-61-31dca3, which completely penetrated the aquifer. Four observation wells were drilled at distances of 100, 730, 1,360, and 2,050 feet from the pumped well. The well was pumped at a rate of 545 gpm for 5,640 minutes. Drawdown and recovery measurements were made on all five wells.

A plot of the drawdown data obtained during the aquifer test is shown in figure 14. The coefficient of transmissibility was 82,000 gpd per foot of drawdown as determined from the Klein test well. Aquifer coefficients obtained from the test well and observation wells are shown in table 1. The coefficients of transmissibility ranged from 66,000 to 96,000 gpd per foot and averaged 83,000 gpd per foot. Variation in values of the transmissibility is due to differences in aquifer characteristics and well development. The average coefficient of storage obtained from the four observation wells was 0.0009. The results of the test, combined with other hydrologic and geologic data, indicate that yields of 1,000 gpm per well can be obtained from the aquifer in the vicinity of the Klein test.

The aquifer test on the Christ farm was conducted during November 1963. Well 142-61-24bccl only partially penetrated the aquifer; however, three observation wells were used that completely penetrated the sand and gravel (table 1). These observation wells were located at distances of 100, 400, and 1,500 feet from the test well. The Christ well was pumped at the rate of 275 gpm for 2,820 minutes. All wells were measured during drawdown and recovery.

A plot of the drawdown measurements made on two of the Christ wells are shown in figure 15. Coefficient of transmissibility ranged from 22,000 to 54,000 gpd per foot and averaged 42,000 gpd per foot. This average value is probably less than the true coefficient of transmissibility. Numerous problems were encountered during installation of the pumped well and it is probable that the well was not sufficiently developed prior to beginning the test. The coefficients of transmissibility obtained from data measured in observation wells 2 and 3 are believed to be more representative of the aquifer. There is little variation in the coefficient of storage determined from data on the three observation wells. The average coefficient of storage is 0.0006. The test results, shown in table 1, indicate that several hundred gallons per minute could be produced from that portion of the Spiritwood aquifer.

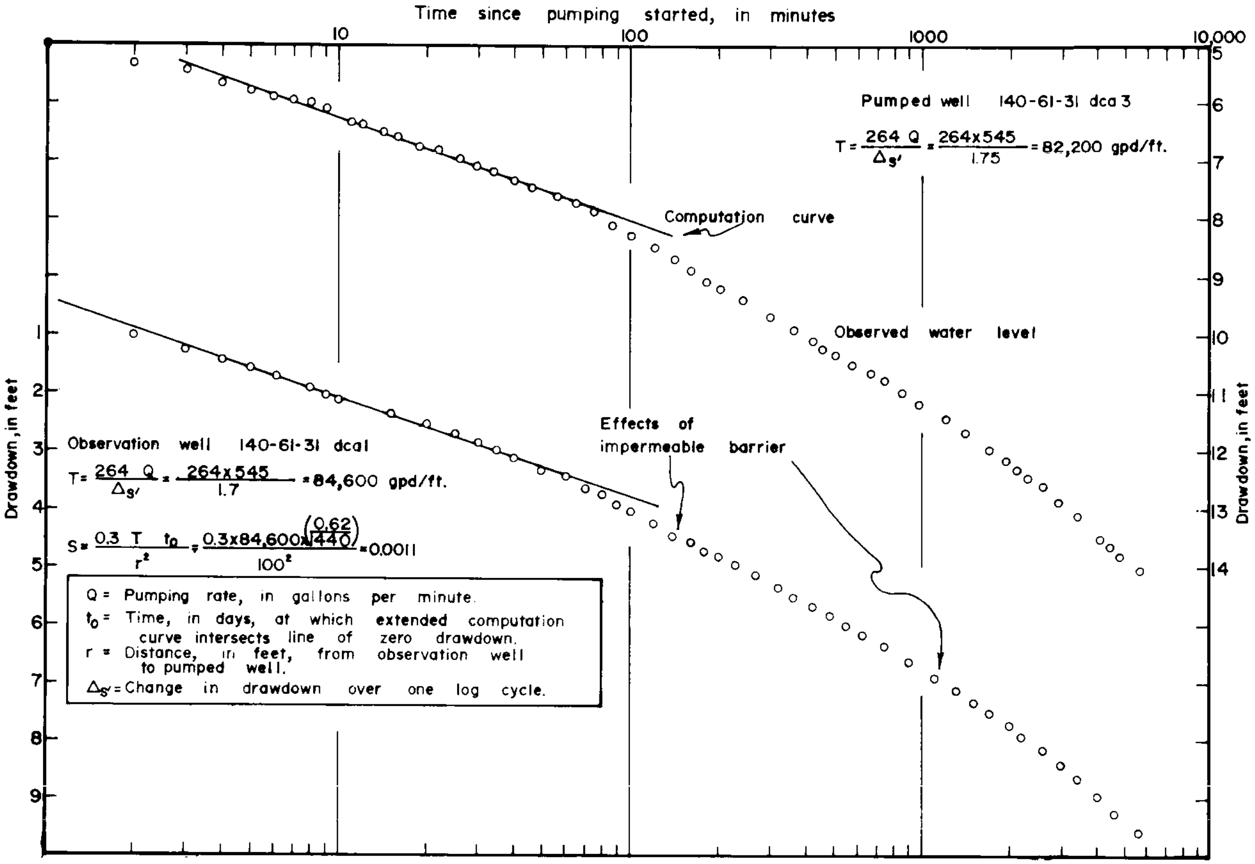


Figure 14. Drawdown data obtained during the aquifer test on well 140-61-31dca3.

Test	Well location	Aquifer Thickness	Distance from test well (ft.)	Specific Capacity (gpm per foot of drawdown)	Coefficient of Transmissibility (gpd per foot)	Coefficient of Permeability (gpd per square foot)	Coefficient of Storage	Aquifer	Well
E. Klein 5,640 minutes 10-28-63 to 11-5-63	140-61-31dca3	43	..	39	82,000	1,910	....	Coarse sand; fine gravel	Pumped well
	140-61-31cdb	25	1,360	..	66,000	2,600	0.0006	Fine gravel	Obs. well no. 1
	140-61-31cda	25	730	..	85,000	3,400	0.0001	Fine gravel	Obs. well no. 2
	140-61-31dcal	51+	100	..	85,000	1,650	0.0011	Med. gravel; coarse sand	Obs. well no. 3
	140-61-31dda	23	2,050	..	96,000	4,150	0.002	Medium sand	Obs. well no. 4
R. Christ, Jr. 2,820 minutes 11-13-63 to 11-17-63	142-61-24bccl	49+	..	±20	22,000	320	....	Medium sand; gravel	Pumped well
	142-61-24bcc2	85	100	..	38,000	450	0.0011	Fine to medium sand	Obs. well no. 1
	142-61-24bcd	78	400	..	54,000	690	0.0004	Coarse sand and gravel	Obs. well no. 2
	142-61-24bdc	79	1,500	..	54,000	680	0.0004	Medium sand; gravel	Obs. well no. 3

Table 1. Summary of test-well data and aquifer coefficients in the Spiritwood aquifer, Barnes County.

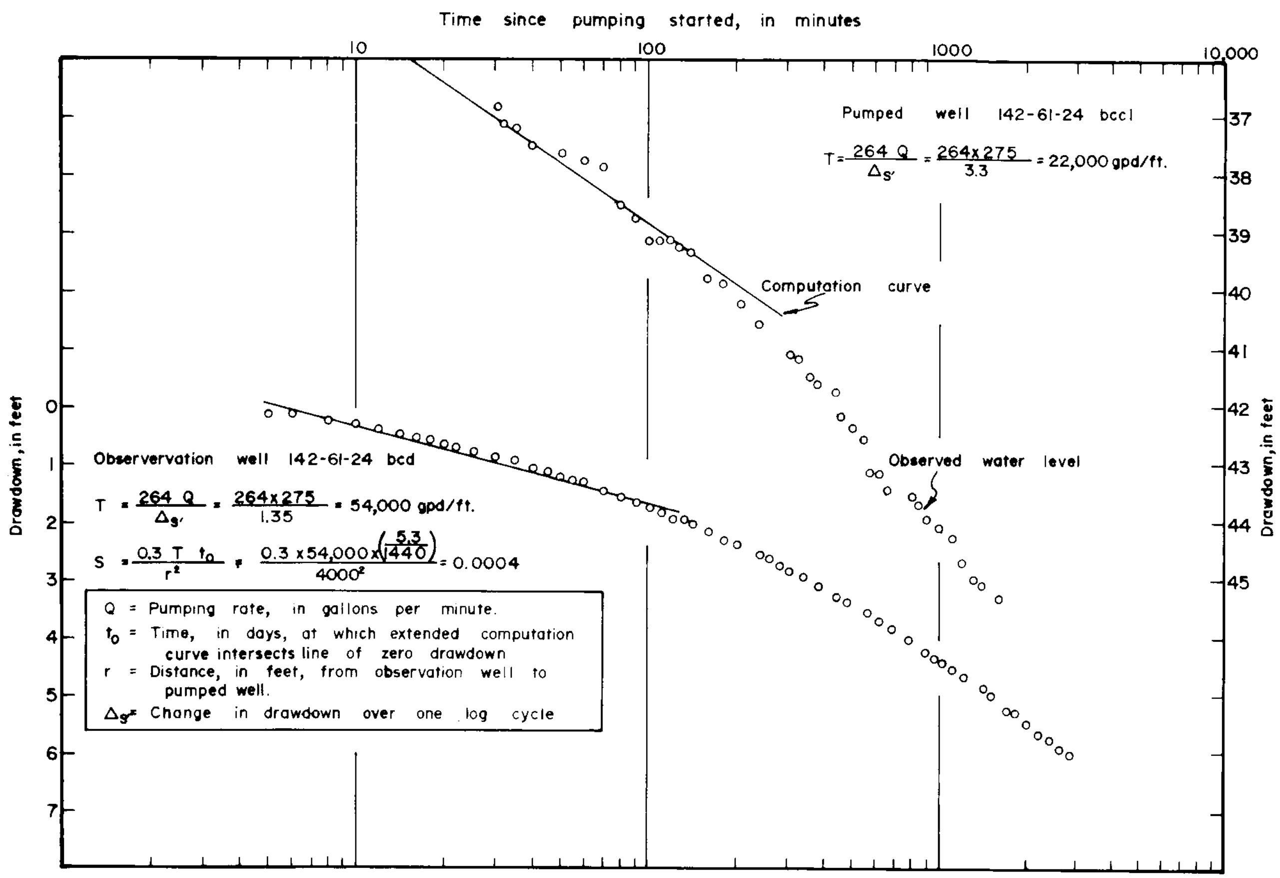


Figure 15. Drawdown data obtained during the aquifer test on well 142-61-24bccl.

Several significant differences are apparent by comparison of data from the two aquifer tests. The coefficients of transmissibility at the Klein wells are approximately one-third greater than those at the Christ wells. Also, the coefficients of permeability are significantly higher in the vicinity of the Klein wells than in the vicinity of the Christ wells. These differences are due to the lithology of the aquifer in the two areas. Most of the Klein wells penetrated well-sorted, medium to coarse sand and gravel, whereas the Christ wells were developed primarily in poorly sorted sand.

Analysis of the test data discloses evidence of two impermeable barriers in the vicinity of the Klein test. These barriers to water movement are represented by changes in the slope of the time-drawdown curve (fig. 14). These barriers are interpreted as shale walls that confine the Spiritwood aquifer on the east and northeast. The coefficient of transmissibility was appreciably reduced by these barriers. It is probable that more barriers are present within the vicinity of the well than were identified during the 4 day aquifer test. Therefore, in predicting water-level declines that would be produced by long-term pumping, it is necessary to use appreciably lower values of transmissibility.

No distinct impermeable barriers were recognized during the Christ test, although there was a gradual decrease in the apparent coefficient of transmissibility throughout the test. This gradual decrease is probably the effect of lithologic variations within the aquifer. The absence of distinct barriers is due to the low pumping rate, short test duration, and central location of the test site with respect to aquifer boundaries as defined by test drilling. Undoubtedly, aquifer barriers are present but would be apparent only after continuous pumping for more than 48 hours.

Movement and storage — The principal direction of movement of water in the Spiritwood aquifer is toward the east. As shown by figure 11, the highest water levels are in the vicinity of Spiritwood. In Tps. 140-143 N., water moves east and northeast across the aquifer. This suggests that recharge is derived from the glacial drift and the bedrock on the west side of the aquifer. South of T. 140 N., water movement is toward the south and southwest to the James River. During the period of record, the James River has had an average daily discharge of 49.3 cubic feet per second at Jamestown, north of the Spiritwood discharge area, and 57.9 cubic feet per second at LaMoure, south of the discharge area. This net gain cannot be attributed solely to water loss by the Spiritwood aquifer, inasmuch as several intermittent streams enter the James River between Jamestown and LaMoure. However, it is probable that a large part of this gain is derived from the aquifer.

As described in a previous section, the Spiritwood aquifer reaches a thickness of 162 feet. Logs of 40 test holes that completely penetrated the aquifer indicate that the average thickness of the deposit is slightly more than 50 feet, and that it underlies an area exceeding 320 square miles in Barnes and Stutsman Counties. If a porosity of 30 percent is assumed, more than 3 million acre-feet of water is

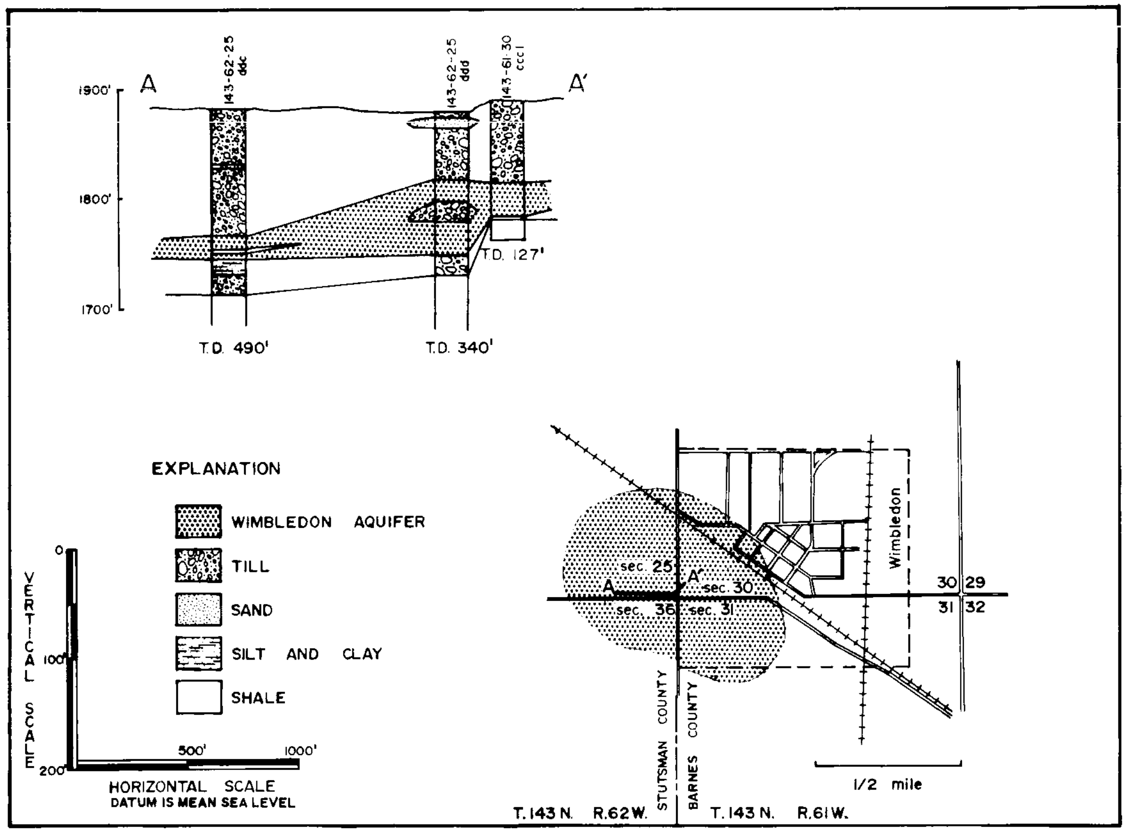


Figure 16. Vertical and approximate horizontal extent of the Wimbledon aquifer.

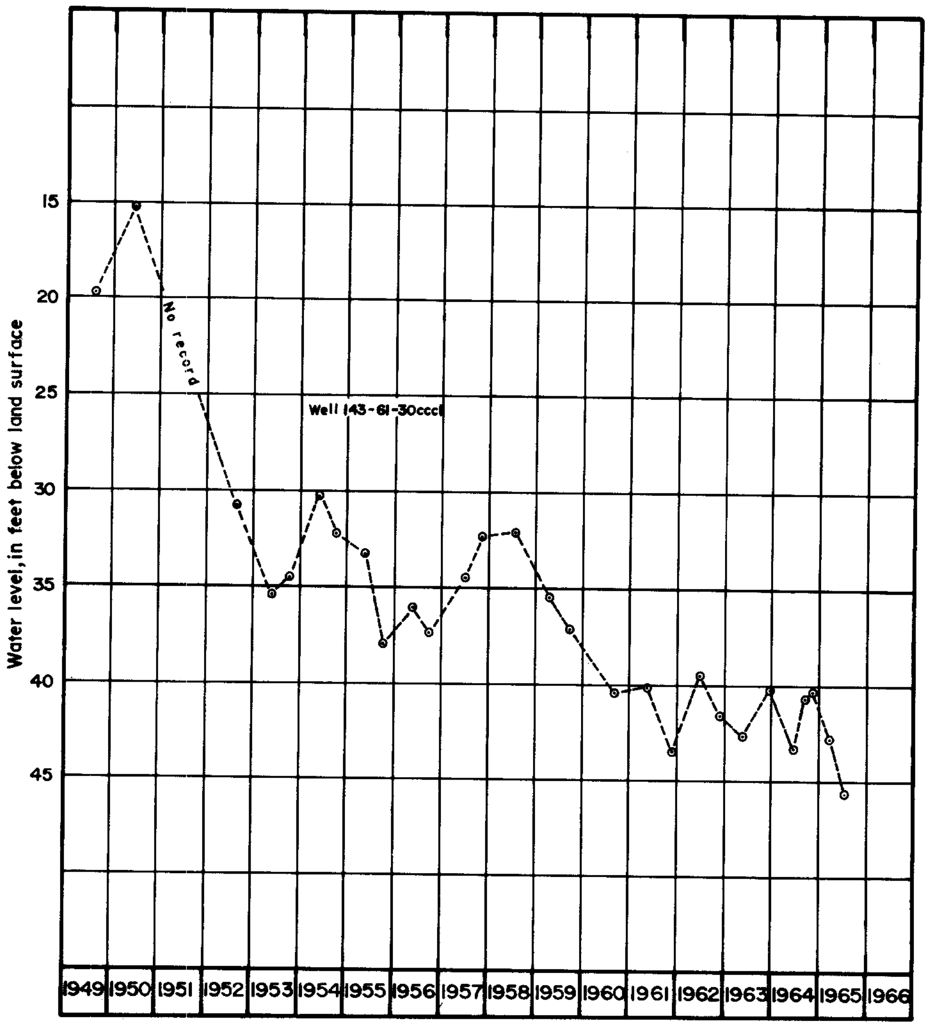


Figure 17. Effect of water withdrawal from Wimbledon aquifer after installation of municipal well in 1950.

in transient storage within the Barnes-Stutsman County segments of the Spiritwood aquifer. In comparison the Valley City municipal supply averages 900 acre-feet per year (U.S. Public Health Service, 1963, p. 125).

Water obtained from wells tapping the Spiritwood aquifer generally is of good chemical quality (fig. 8). Most of the samples analyzed were of the sodium bicarbonate type. However, several samples collected near the edge of the aquifer were of sodium sulfate water, the same type as water found in the underlying Pierre Shale. The amount of chemical constituents of the Spiritwood water generally is less than the maximum standards set by the U.S. Public Health Service. The amount of dissolved iron is present in excessive concentrations locally, and although the water is hard by national standards, it is relatively soft in comparison with water from many of the other aquifers in the county. Water from the Spiritwood usually falls within the high salinity-low sodium (C3-S1) classification and is satisfactory for irrigation of well-drained soils.

WIMBLEDON AQUIFER

Location and Thickness

The city of Wimbledon (population 492, 1960 census), in northwestern Barnes County, obtains its water supply from a buried sand and gravel deposit within the glacial till. The aquifer underlies the SW1/4 sec. 30, T. 143 N., R. 61 W., and extends into sec. 31, T. 143 N., R. 61 W., Barnes County, and secs. 25 and 36, T. 143 N., R. 62 W., Stutsman County (fig. 16). Two test holes, 143-62-25ddc and 143-62-25ddd, were drilled through the aquifer during the Wimbledon ground-water investigation (Dennis, 1948). Test hole 143-62-25ddd penetrated a total of 50 feet of sand and gravel; however, the other wells penetrated thinner sections, indicating that the aquifer thins toward both the northeast and the west (fig. 16). These data indicate that the Wimbledon aquifer is very restricted in areal extent and probably underlies an area of less than 1 square mile.

Reservoir Characteristics

Prior to the installation of the municipal well in 1950, the static water level in this artesian aquifer ranged from 15 to 20 feet below land surface (fig. 17). The water level then declined rapidly until April 1953, when the static water level was 35.56 feet below land surface. Although the water level has fluctuated since that time, there has been a gradual decline through 1965. This indicates that a large quantity of water has been mined from the Wimbledon aquifer, and the static water level probably will continue to decline.

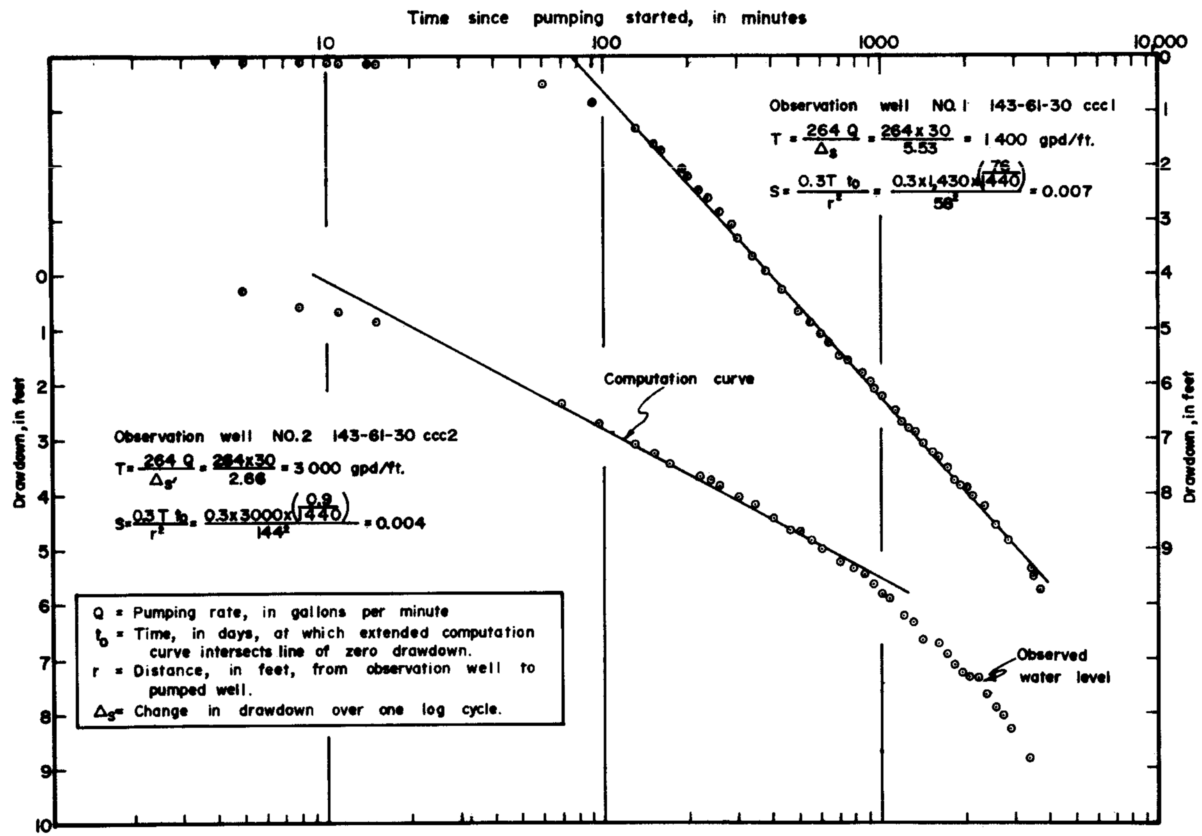


Figure 18. Drawdown data obtained during Wimbledon aquifer test on municipal well 143-61-30ccc.

A test was conducted on the Wimbledon aquifer in August 1949. The municipal well (143-61-30ccc) was pumped at the rate of 30 gpm for 3,710 minutes. Measurements were made on the test well and two observation wells during drawdown and recovery. The observation wells were located at distances of 58 feet and 144 feet from the test well.

Data obtained during the Wimbledon aquifer test are shown in figure 18. The coefficient of transmissibility at observation well 1 (143-61-30ccc) is 1,400 gpd per foot and at observation well 2 (143-61-30ccc2) 3,000 gpd per foot. The coefficient of transmissibility computed at well 1 is believed to be correct. Well 2 seemingly did not respond immediately and probably was partly plugged, at least during the early part of the test. No aquifer barriers are apparent from the data. However, owing to the rather restricted nature of the Wimbledon aquifer, the barriers were probably reached within the first few minutes of the test. The coefficient of storage of 0.007 was computed from data obtained from well 1. These data indicate that the aquifer is capable of yielding only small quantities of water without becoming depleted.

Water from the Wimbledon aquifer is of the sodium sulfate type; sulfate is present in quantities exceeding the maximum limit recommended by the U.S. Public Health Service. The water is relatively hard, but contains only minor amounts of iron and is satisfactory for domestic uses. In general this water is more highly mineralized than water from other glacial deposits in the county (fig. 8).

BANTEL AQUIFER

Location and Thickness

This aquifer was named for the W. W. Bantel farm located in the NE 1/4 sec. 26, T. 137 N., R. 56 W., southeastern Barnes County (fig. 19). The aquifer occupies an east-west-oriented buried valley more than 3 miles in length. The areal extent of the Bantel aquifer has not been accurately defined. Two test holes have penetrated the aquifer and several farm wells are known to tap it. Also, the aquifer is exposed in gravel pits in secs. 31 and 32, T. 137 N., R. 55 W., Cass County. This information indicates that the Bantel aquifer occupies a partly exhumed buried channel that extends from the NW 1/4 sec. 26, T. 137 N., R. 56 W., Barnes County to the NW 1/4 sec. 32, T. 137 N., R. 55 W., Cass County.

Only a few data are available on the thickness of the aquifer. Test hole 137-56-25ada penetrated 80 feet of sand and sandy gravel, and test hole 137-56-26aaa penetrated 88 feet of sand and gravel. In both test holes the water-bearing deposits were confined by till. However, the overlying till has been eroded from an intermittent stream channel and, locally, as much as 30 feet of the aquifer has been

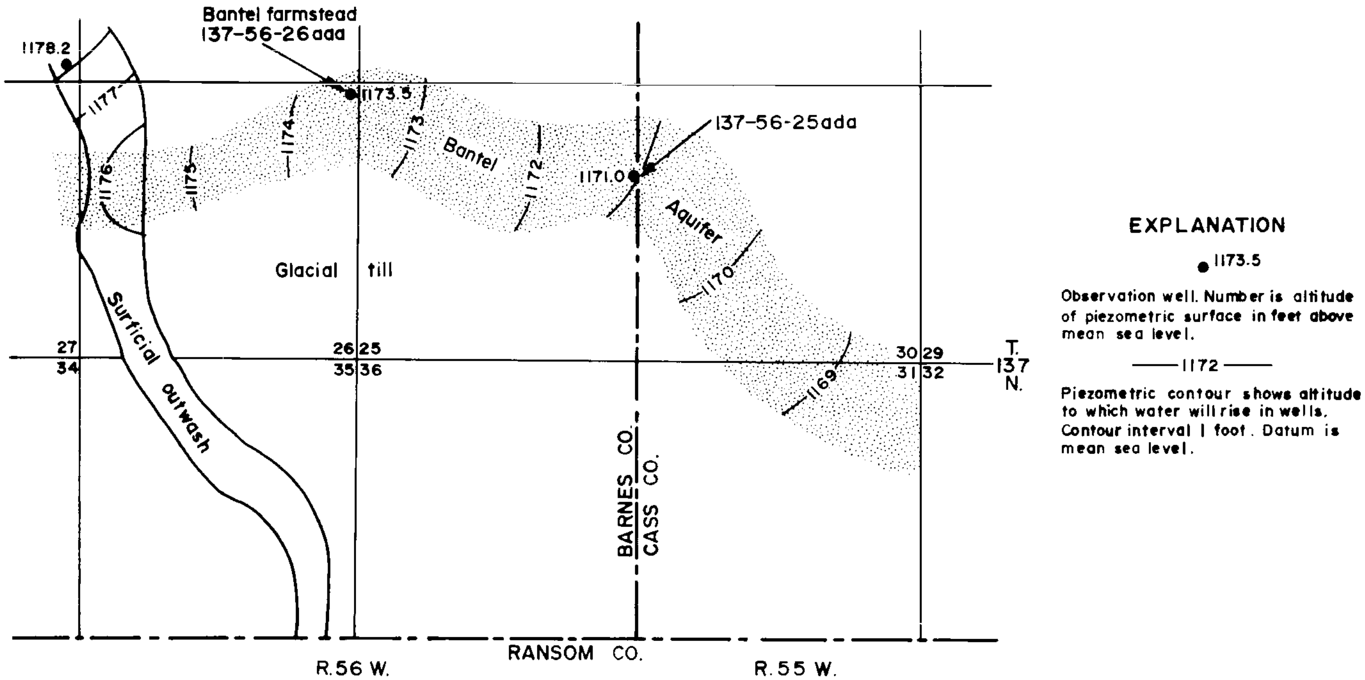


Figure 19. Configuration of the piezometric surface of Bantel aquifer in Barnes and Cass Counties.

removed. An inventory of farm wells indicates that the sand and gravel pinch out along the flanks of the former outwash channel. Seemingly the Bantel aquifer is lenticular in cross section, its thickness ranging from 0 feet at the edges to 88 feet near the center. Recent erosion has locally exposed parts of the aquifer. The profile of the aquifer probably is uniform from west to east.

Reservoir Characteristics

Water-level fluctuations within the Bantel aquifer were monitored between May and December 1963. During this time the water level in observation well 137-56-26aaa fluctuated between 23.59 feet and 24.54 feet below land surface. Although a longer period of record is desirable, these data indicate that the water level is relatively stable and probably fluctuates less than 2 feet during a year of normal precipitation.

The water levels in the Bantel aquifer are maintained by recharge from two sources. The most important source is the outwash deposit that overlies the aquifer in sec. 6, T. 137 N., R. 56 W. (fig. 19). Lesser amounts of recharge enter the aquifer from the enclosing glacial drift. The water level in observation well 137-56-25ada (Cass County) is approximately 2.5 feet lower than that in observation well 137-56-26aaa (R. L. Klausing, oral communication). This indicates that the water movement in the Bantel aquifer is from west to east. Small quantities of water are discharged through springs where recent erosion has exposed the aquifer.

Few domestic and stock wells have been developed in the aquifer, and they have little effect on the static water level of the aquifer. The fact that water is discharged through springs is evidence that additional water can be withdrawn from the Bantel aquifer without reducing the amount of water in storage. On the basis of an average porosity of 30 percent and an average thickness of 40 feet, the Bantel aquifer contains approximately 1,800 acre-feet of water in transient storage. This is a sufficient quantity to support small-scale irrigation projects; the water quality is suitable for irrigation also.

TILL AQUIFERS

Glacial till is discussed here because of its control on ground-water movement and its widespread distribution. As pointed out in a previous section, the entire county is covered by glacial till, with the exception of the Sheyenne River valley and its tributaries, and isolated localities from which the till has been removed by erosion. The greatest known thickness of till in the county is 313 feet, in test hole 2124 in the NW 1/4 sec. 6, T. 137 N., R. 57 W. Most wells that are drilled into the till penetrate sand or gravel bodies, locally called "veins," that yield water more readily than the enclosing till. The Wimbledon and Bantel aquifers are examples of this type. Wells in such sand and gravel deposits may yield several hundred gallons per minute; however, the yields are usually much less.

Wells that fail to penetrate sand or gravel within the till are not uncommon. Such wells usually yield less than 20 gpm and are recharged very slowly. In such cases the water yield is controlled by the permeability of the till. Norris (1962, p. E-150) found that the permeability of till samples from the Midwest ranged from 0.003 to 1.0 gpd per square foot and averaged 0.15 gpd per square foot. These values are extremely low as compared with the permeabilities of sand and gravel from the Spiritwood aquifer. However, wells in the till will often yield sufficient water for domestic or stock use provided that a large area of till is exposed by the well. Thus a large-diameter well of considerable depth may yield moderate quantities of water. Wells in till usually are pumped dry readily but are refilled in a matter of hours. These wells are rather common in Rs. 56 and 57 W., and are present at scattered localities throughout the county.

The permeability of glacial till is increased considerably by the presence of joints or other fractures. These joints serve as open paths through which water moves quite freely. A well that intersects a joint system usually yields greater quantities of water than a well in unjointed till. Two wells owned by Mr. Leonard Ronzheimer (142-59-13ada) reportedly penetrated a joint system through which water was observed to move. The wells contain more than 18 feet of water. They supply water for domestic use and for 35 head of cattle.

Recharge to the till is derived primarily from precipitation and secondarily from subsurface flow. Owing to the low specific yield of the till, minor changes in available water produce rather abrupt fluctuations in the water table (fig. 20). In general these fluctuations reflect the precipitation. The configuration of the water level within the glacial till is shown on figure 4.

Locally, large amounts of water are lost from the till by evaporation. This water moves upward through the till by capillary action and evaporates at the surface, where the dissolved salts are deposited as a white residue. The residue is composed primarily of sodium and calcium sulfate (fig. 21).

There is a great variation in the chemical quality of water from the glacial till aquifers. The total dissolved solids in water from these aquifers range from less than 400 ppm to nearly 4,000 ppm. Most of the water is of the calcium sulfate type, but sodium sulfate water is present locally (fig. 8). Although most of the water is rather hard, much of it can be softened satisfactorily. In places, the water is reported to be objectionable for domestic use because of high iron content. With the exception of sulfate, most of the dissolved constituents are present in quantities less than the maximum recommended by the U.S. Public Health Service. Most of the samples of water from the till aquifers are classed as high salinity-low sodium (C3-S1) water (fig. 7). This water could be used for irrigation of plants that are moderately tolerant to salt, provided there is adequate drainage.

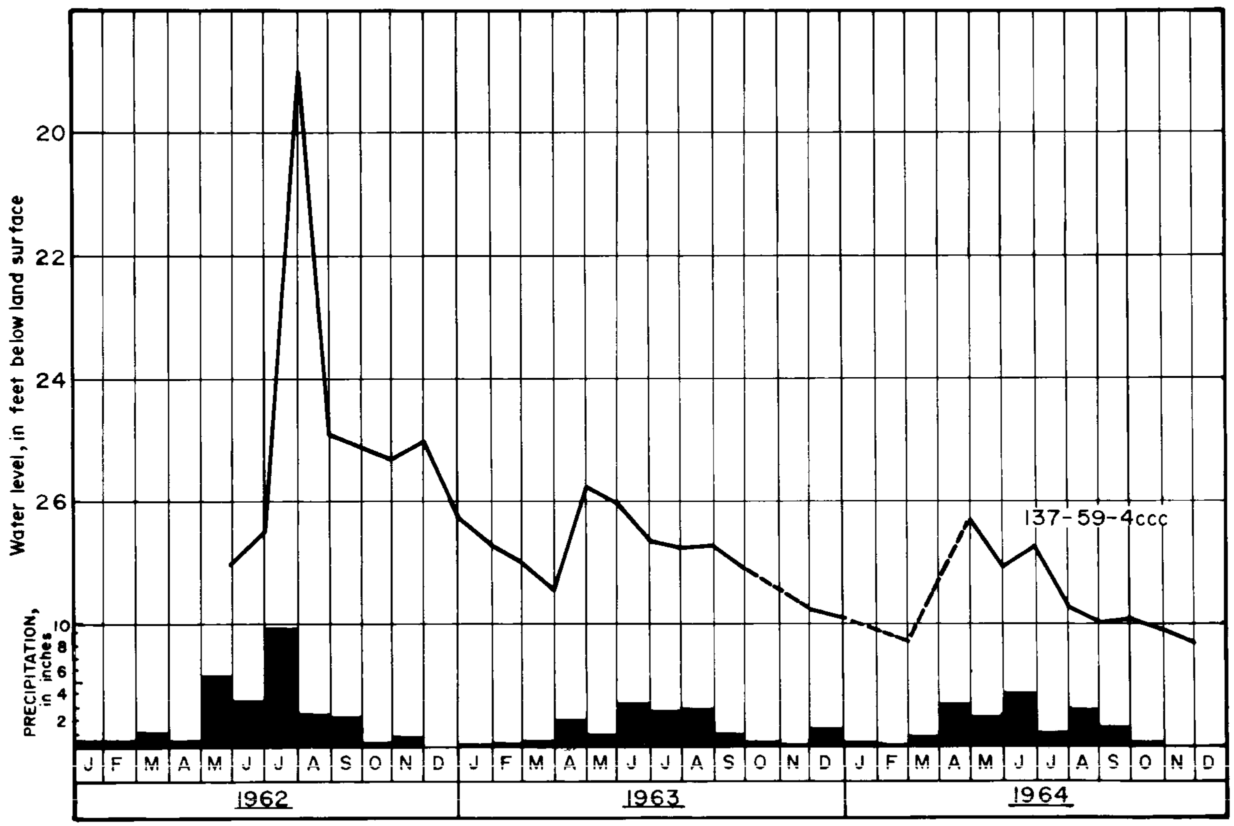


Figure 20. Relation of water-level fluctuations in a well penetrating glacial till to precipitation at Litchville.

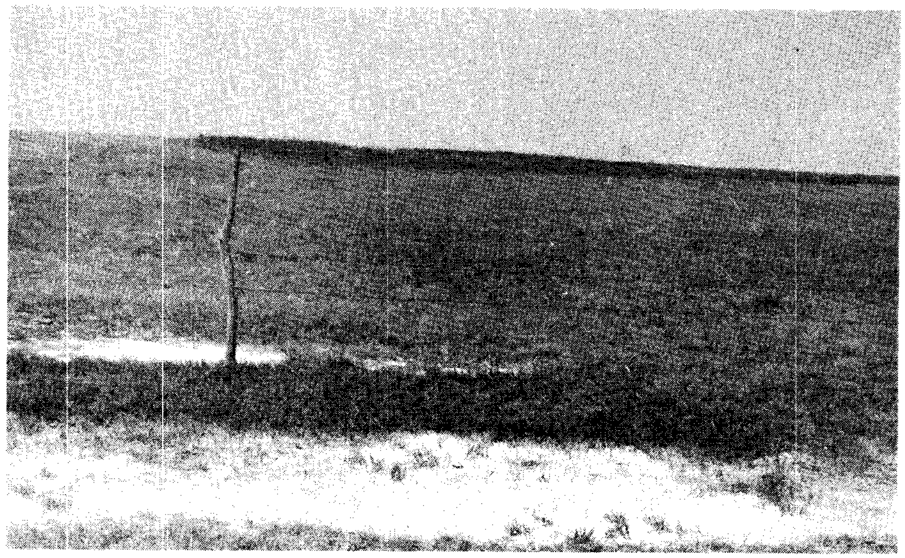


Figure 21. Sodium and calcium sulfate deposits on till, formed by evaporation of ground water, in the vicinity of Fingal.

VALLEY CITY AQUIFER

Location and Thickness

Valley City (population 7,809, 1960 census) obtains its municipal water supply from a terraced outwash deposit in the Sheyenne River valley. The aquifer, which underlies much of the city, is located primarily in secs. 21 and 22, T. 140 N., R. 58 W., but extends into the adjoining sections on the north. The areal extent of the aquifer is approximately 1 square mile.

The thickness of the outwash deposit is as much as 50 feet near its center and less toward its edges (fig. 22). Test drilling indicates that, in general, the outwash does not extend south or east of the river. The deposit is confined on the west and northwest by the valley walls of Pierre Shale and glacial till and interfingers with silt and clay on the south and east.

The outwash deposits consist primarily of fine to medium gravel with minor amounts of sand, but thick strata of clean, well-sorted sand are present also. Clay, silt, and fine sand are noticeably absent from the deposits. Much of the gravel is highly iron-stained and manganese concretions derived from the Pierre Shale are abundant.

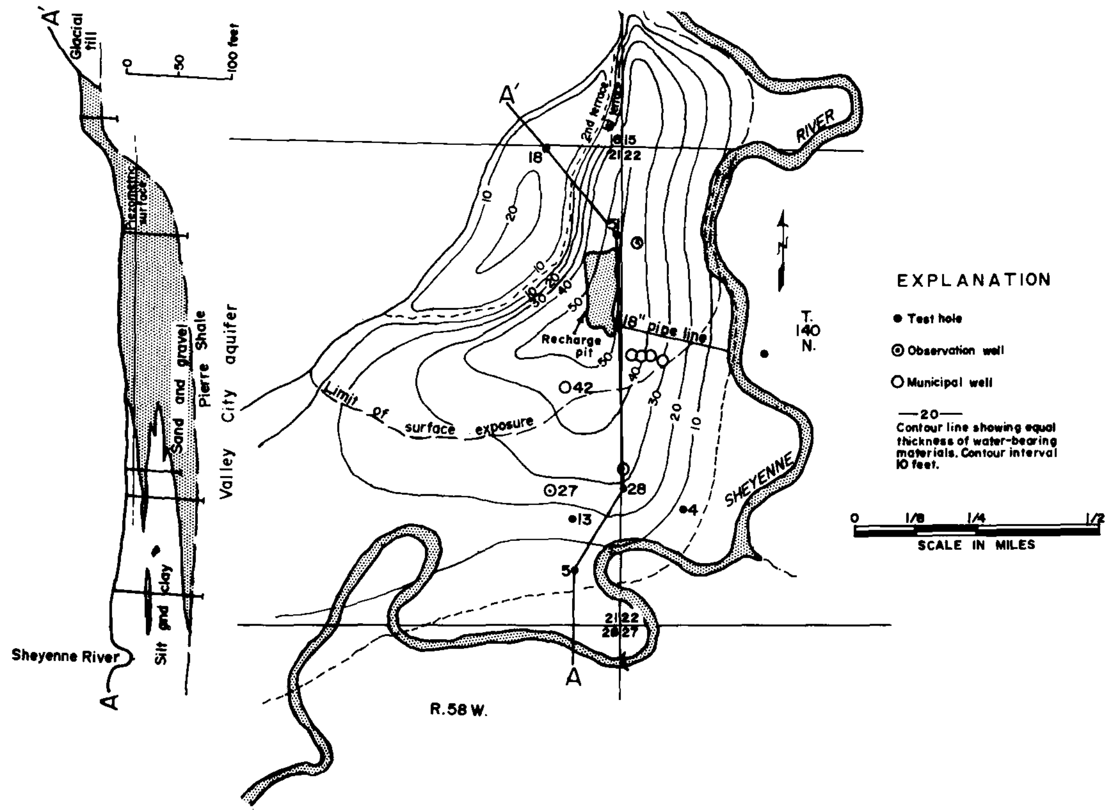


Figure 22. Isopach map and section of the Valley City aquifer.

Artificial Recharge

The Valley City recharge system was established in February 1932 as the result of prolonged drought, during which water levels in the municipal wells declined rapidly. An 18-inch pipeline was laid from the Sheyenne River to an abandoned gravel pit that had been dug in the outwash deposits to a depth of approximately 6 feet below river level (Federal Emergency Administration of Public Works, 1936, p. 36). The river level is maintained by a 12-foot dam located approximately half a mile downstream from the pipeline. The inlet of the pipeline is approximately 2 feet below river level.

Prior to 1957, water flowed through the pipeline by gravity from the river to the recharge pit. The maximum measured rate of free flow is 2,600 gpm; the flow rate is a function of head difference between river and recharge pit. During years of normal pumpage, the pipeline was opened in the late fall or winter, when the pumpage was light and the water table rose rapidly (fig. 23). By early summer the water table was within 6 or 8 feet of the surface, at which time the pipeline was closed. This was sufficient to maintain the municipal supply for the remainder of the year.

Because of an increased demand for water, the city installed a pump and valve system on the pipeline in February 1957. The valve system permits the water level in the pit to be raised approximately 5 feet above river level. Thus the recharge can be accomplished in a shorter period of time, and it is possible to raise the water level higher than had been possible previously. The gravity-feed system can be used when large quantities of recharge are not needed.

During periods of low water use, only one municipal well is pumped. The pumping of the well produces a troughlike cone of depression (fig. 24). North of the pumped well, the trough is restricted between the recharge pit and the river. It is in this area that the recharge is greatest, inasmuch as the recharge pit and river both serve as recharge areas. South of the pumped well, the trough encompasses a much larger area because of a thinning of the aquifer and a smaller amount of available recharge.

The size of the ground-water mound beneath the recharge pit depends upon the elevation of the water level in the pit. During periods of peak recharge, the mound is much more pronounced than that shown on figure 24.

Water-level measurements have been made in the well field at irregular intervals since July 1930 (O.N. Bergman, Sr., oral communication, 1963). During the 1 1/2 years prior to installation of the recharge system, in February 1932, the water level in the aquifer declined 3 1/2 feet (fig. 25). During the next 4 1/2 years the piezometric surface had only minor fluctuations. This relative stabilization was produced by use of small quantities of recharge which prevented continued decline of the piezometric surface. However, the lack of sufficient runoff in the Sheyenne River greatly restricted the use of surface water for recharge. Since 1936 the Sheyenne has maintained sufficient flow to operate the recharge

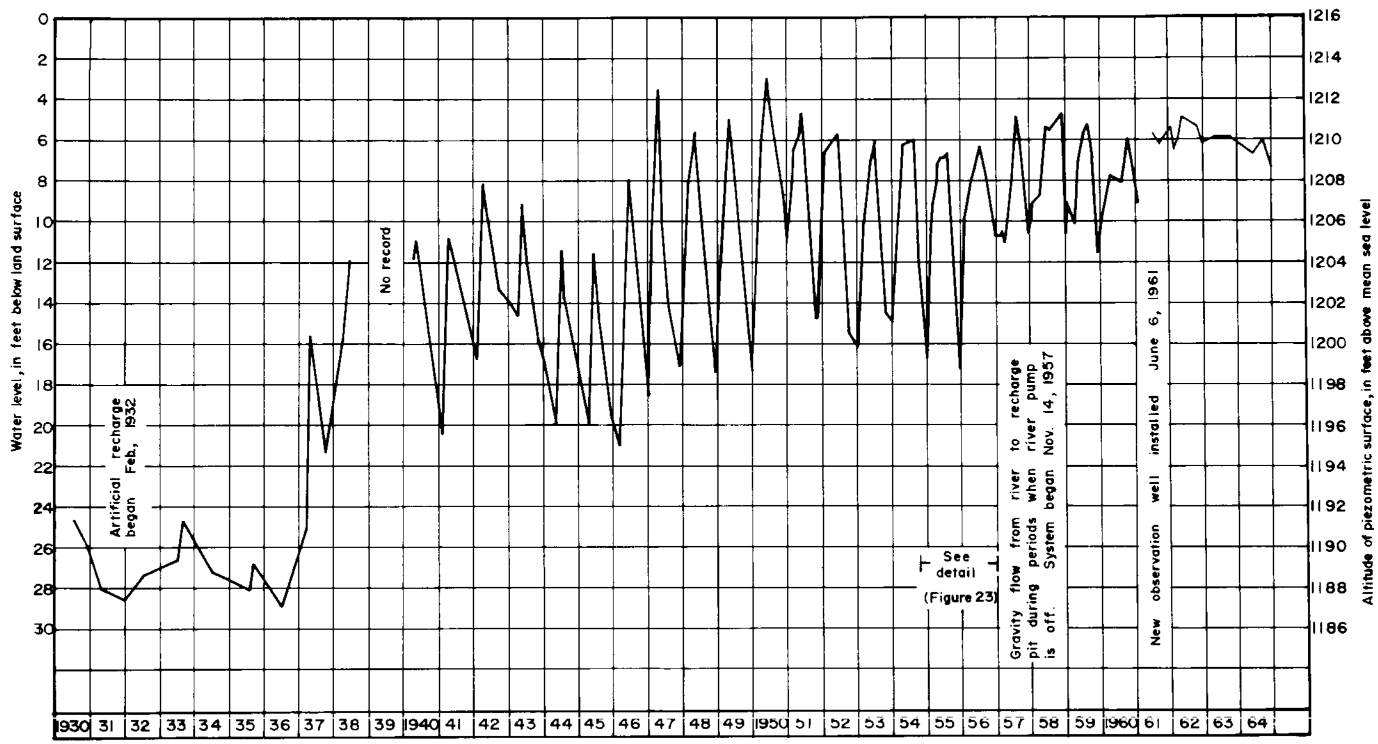


Figure 23. Effect of artificial recharge on the piezometric surface of the Valley City aquifer. Measurements by O. N. Bergman, Sr., Municipal Utilities Co., Valley City.

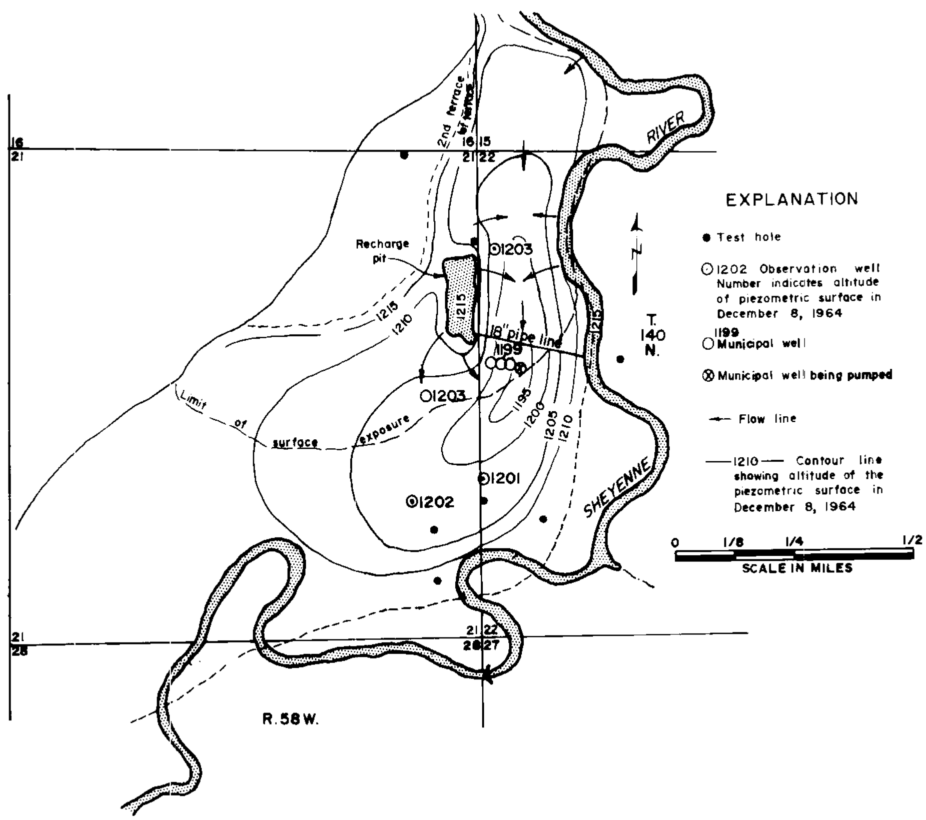


Figure 24. Configuration of the piezometric surface of the Valley City aquifer, December 8, 1964.

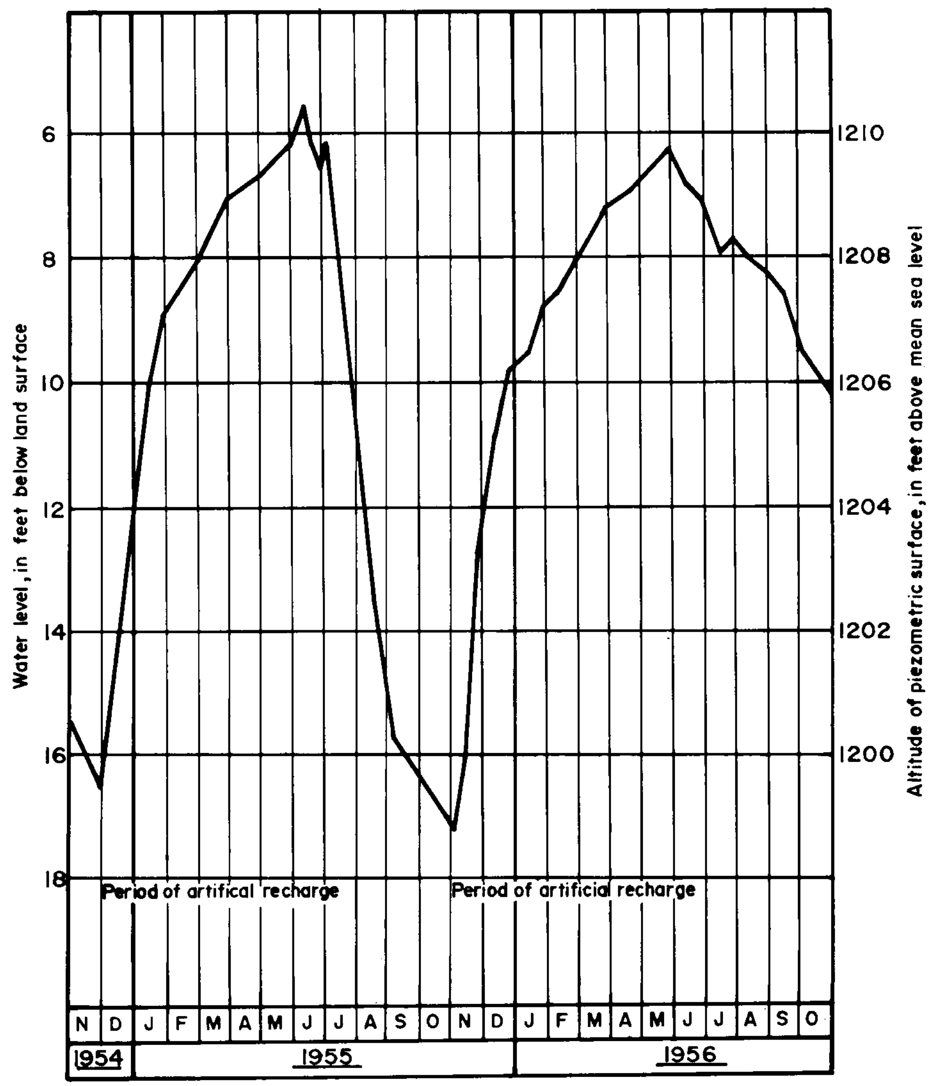


Figure 25. Piezometric surface fluctuations in the Valley City aquifer.

system at capacity; the flow has been regulated since 1949 by Baldhill Dam, approximately 13 miles upstream.

The piezometric surface in the Valley City aquifer rose approximately 22 feet between 1932 and 1964 and more than 18 feet between June 1936 and May 1940 (fig. 25). Only a partial record is available for the latter interval; however, the general rise is shown as are the accompanying periodic water-level fluctuations corresponding to intermittent periods of recharge and discharge. Semiannual reversals in trends of the water level, controlled by artificial recharge, have continued to the present. The average semiannual fluctuation is approximately 10 feet; greatest fluctuations occurred between December 13, 1946, and May 26, 1947, when the piezometric surface rose 14.7 feet.

Fluctuations that have occurred since 1956 are more subdued than earlier water-level changes. This is due to supplemental gravity recharge when a large quantity of recharge is not necessary. Consequently the water level in the recharge pit declines only until it is in equilibrium with the river level. Thus a constant supply of recharge is available to the aquifer, and decline of the piezometric surface is minimized.

Owing to the artificial recharge practiced by Valley City, the quality of the water in the aquifer is affected by the chemical quality of the water of the Sheyenne River. Although the quality of the water changes as the river stage fluctuates, both the river and the aquifer usually contain a sodium bicarbonate type water. The total dissolved solids of the river water increase as much as 200 ppm by solution of minerals from the aquifer, and all the chemical constituents except iron and potassium increase during recharge. However, generally the water is of good quality.

SAND PRAIRIE AQUIFER

Location and Thickness

The Sand Prairie aquifer is located in T. 137 N., R. 58 W., in southern Barnes County and extends into adjacent Ransom County (fig. 26). The aquifer underlies the so-called Sand Prairie, a wide, flat plain characterized by sandy, highly permeable soils. As early as 1912, Hard (p. 99-100) foresaw the irrigation potential of the area; However, in 1962, there were fewer than 25 small-capacity wells utilizing water from the aquifer in Barnes County. Thus, the aquifer remains a relatively untapped source of large quantities of ground water.

The Sand Prairie was formed as an outwash plain by a stream flowing southeastward in the channel now occupied by Stoney Slough. In southern Barnes County, the stream left its channel and the deposits were spread over a large area now occupied by the Sand Prairie. These outwash deposits can be readily mapped at the surface, and they are known to extend from sec. 18, T. 137 N., R. 58 W., Barnes County, to secs. 32 and 33, T.136 N., R. 58 W., Ransom County.

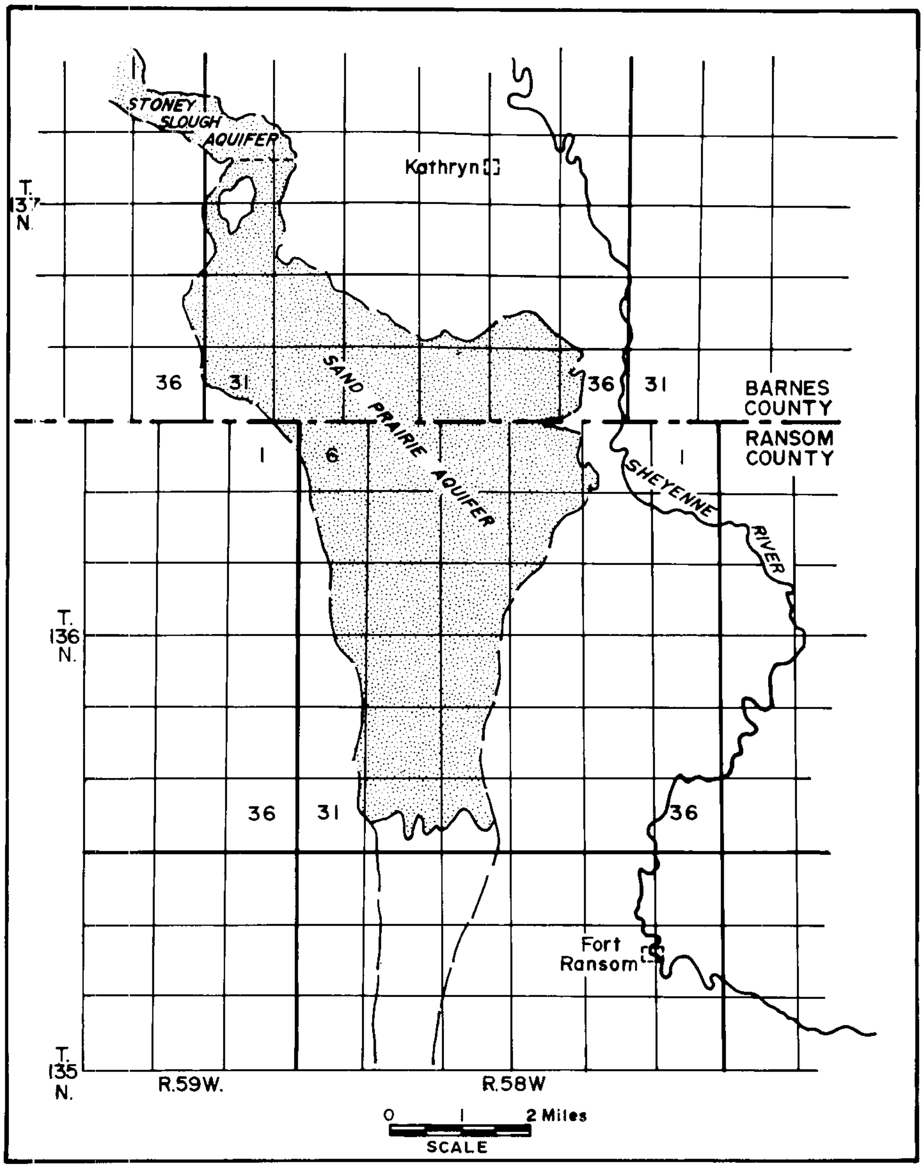


Figure 26. Sand Prairie aquifer in Barnes and Ransom Counties.

Thus the Sand Prairie has an areal extent of more than 22 square miles; approximately 8 square miles is in Barnes County.

Test hole 2110 (137-58-34ccc) was drilled near the center of the aquifer and penetrated 26 feet of fine to very coarse sand (Kelly, 1964b, p. 71). More than 30 feet of sand and gravel is exposed in a roadcut in the southwest quarter of sec. 36 of the same township, and the deposits may exceed 50 feet in thickness near the northern boundary of the Sand Prairie. The outwash thins toward the east and west.

Little information is available on the thickness of the outwash in Ransom County. Although glacial till probably underlies much of the outwash, in test hole 2110 and at the roadcut in sec. 36 the deposits lie directly on the Pierre Shale.

In general, the outwash deposits composing the Sand Prairie aquifer consist of fine to coarse sand, but locally they include small amounts of fine gravel. The sand is well sorted and contains very little silt and clay. Calcium carbonate cement is present in thin, discontinuous strata.

Reservoir Characteristics

Only minor water-level fluctuations have occurred in the Sand Prairie aquifer during the period of record extending from April 1963 to January 1965 (table 2).

Date	Obs. well 137-58-34ccc (feet below land surface)	Spring 137-58-36ccc	
		Discharge (gpm)	Temperature, °F
April 26, 1963	10.08		
May 17	10.12		
30	10.15		
June 27	10.18		
July 30	10.19	4.0	60°
Sept. 5	10.21	3.8	58°
Oct. 2	10.30	3.7	52°
Nov. 13	10.38	3.4	44°
Dec. 2	10.40	3.3	40°
Jan. 6, 1964	10.41	Frozen	..
Mar. 4	10.56	Frozen	..
May 5	10.48	3.0	48°
June 1	10.54	3.4	50°
July 2	10.44	3.6	58°
30	10.34	4.0	58°
Sept. 1	10.23	3.5	58°
29	10.26	3.5	52°
Oct. 27	10.31	3.1	49°
Nov. 25	10.37	3.0	40°
Jan. 6, 1965	10.46	2.8	38°

Table 2. Water-level measurements, spring discharge, and temperature of ground water in the Sand Prairie aquifer.

Only a vague correlation exists between precipitation and water-level fluctuation. Spring and summer rainfall produces a slight rise in the water table, which is followed by a decline through the remainder of the year. There are no abrupt fluctuations of the water table, and the greatest monthly change during the period of record was a rise of 0.11 foot in August 1964.

There are two principal controls acting on the water table of the Sand Prairie aquifer: The high porosity of the deposits, and the natural discharge.

Precipitation on the sandy soil is rapidly absorbed and part of the water enters the aquifer. Deposits similar to those in the Sand Prairie have porosities exceeding 30 percent (Meinzer, 1923b, p. 11). It is probable that the average porosity of the aquifer is of this magnitude and that the specific yield is rather high; consequently, large quantities of water can be absorbed without changes in the water table.

The second control on the water table of the Sand Prairie aquifer is the natural discharge of ground water through springs. Large quantities of water are discharged from the aquifer in sec. 36, T. 137 N., R. 58 W., and sec. 3, T. 136 N., R. 58 W. A stream flowing through Little Yellowstone Park (SE 1/4 sec. 36, T. 137 N., R. 58 W.) is derived primarily from ground water discharged from the Sand Prairie aquifer. In June 1963 the combined discharge of these springs exceeded 1,000 gpm; the discharge decreases in the winter.

One of the small springs in the park has been developed to serve as a water supply for the recreation area. Both the spring discharge and the water temperature fluctuate during the year. In general, the peak discharge of the spring coincides with the peak water level in test hole 2110 (observation well 137-58-34ccc), as shown in table 2. The position of the water table and the amount of spring discharge indicate that the two are directly related and that, locally, the water table controls the amount of loss from the aquifer through springs. Where water is not discharged through springs, the direction of subsurface flow is toward the south.

No tests have been made to determine the transmissibility of the aquifer. It is probable that large quantities of water could be pumped from it, provided that a sufficient saturated thickness of sand is present. A coefficient of transmissibility of 165,000 gpd per foot was calculated for a Ransom County aquifer of lithology similar to that of the Sand Prairie aquifer. This high-yielding well penetrated 34 feet of saturated sand and gravel.

The Sand Prairie aquifer contains approximately 50,000 acre-feet of ground water in transient storage. This value is based on an assumed porosity of 30 percent and a saturated thickness of 10 feet. As much as 1,000 gpm of this water is lost from the aquifer through springs. Therefore, it would be possible to remove this quantity of water from the aquifer without removing any ground water from storage.

In general, water from the Sand Prairie aquifer is the least mineralized water in Barnes County (fig. 8). It is a calcium bicarbonate type water that is relatively soft. The dissolved-iron concentration is rather high and locally exceeds the maximum recommended by the U.S. Public Health Service, but generally the quality of the water is good. Most of the water samples fall within the medium salinity-low sodium (C2-S1) class (fig. 7). This water can be used for irrigation of most crops with little danger of salt accumulations in the soil.

STONEY SLOUGH AQUIFER

Location and Thickness

The Stoney Slough aquifer occupies a surficial outwash channel in the southwestern quarter of Barnes County (pl. 1). The name is derived from the Stoney Slough, a southeast-trending intermittent stream which occupies the outwash channel. The Stoney Slough drainage system extends from T. 141 N., R. 60 W., to T. 137 N., R. 58 W. The drainage system consists primarily of four small channels that coalesce to form the Stoney Slough channel, which drains into the Sheyenne River. Runoff in the Stoney Slough is greatest during the spring, and there is little surface runoff during the remainder of the year. This stream discharge is retarded by Trager Dam, an earth-filled structure located in secs. 32 and 33, T. 138 N., R. 59 W. (pl. 1). The dam is used to impound surface runoff and to divert it into the Stoney Slough Wildlife Refuge. When water needs of the Refuge have been satisfied, the sluice gate is opened and is not closed until the following spring.

The Stoney Slough aquifer occupies that part of the drainage system north of sec. 18, T. 137 N., R. 58 W. The areal extent of the aquifer exceeds 20 square miles, approximately 12 square miles of which is confined to relatively narrow channels. A broad, flat plain was formed in Tps. 138 and 139 N., R. 60 W., where three of the tributary channels coalesce. This plain has an area of approximately 8 square miles.

The thickness of Stoney Slough outwash increases from less than 1 foot along the edges of the deposits to 40 feet in test hole 16L in the NW1/4 sec. 10, T. 137 N., R. 59 W. (Akin, 1952, p. 42). The average thickness penetrated by 13 test holes is 15 feet, and in general the thickness increases from the edge toward the center of the channels.

The predominant lithology of the Stoney Slough is fine to coarse sand, but gravel is abundant locally. The lithology varies abruptly. Much of the gravel is composed of shale pebbles, usually rather poorly sorted. Silt and clay are minor constituents and are in thin, discontinuous strata. The aquifer overlies glacial till throughout most of its extent; however, in three test holes the aquifer lies directly on Pierre Shale.

Reservoir Characteristics

Water-level fluctuations within the Stoney Slough aquifer were monitored between May 1962 and December 1964. During this period, the fluctuations generally reflected local precipitation (fig. 27). There has been a gradual decline

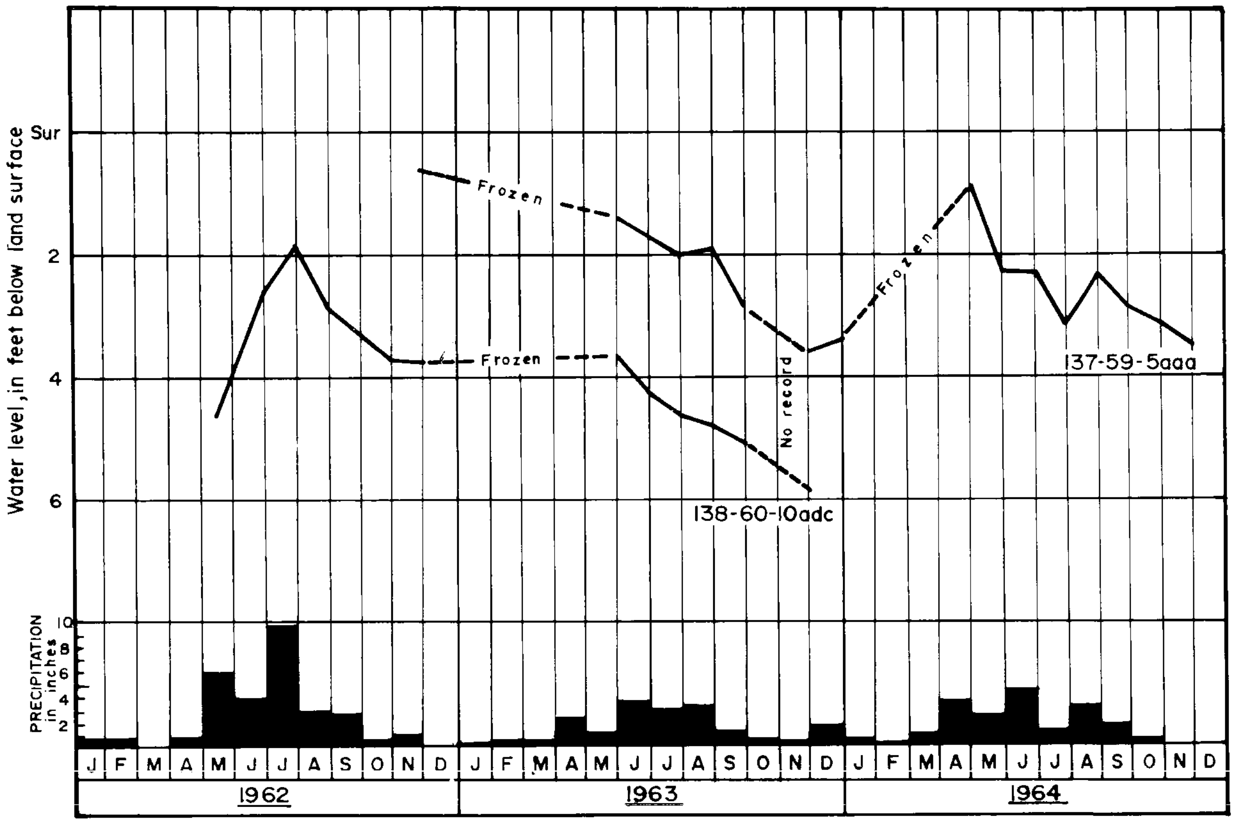


Figure 27. Relation of the water-table fluctuations in the Stoney Slough aquifer to precipitation at Litchville.

in water level since June 1962; however, intermittent periods of recharge have been superimposed on the general downward trend. The water table in the aquifer is quite shallow, usually less than 10 feet below land surface. The shallow depth of the water table enables the vegetation to utilize large quantities of water, which is ultimately lost by transpiration.

Because of the shallow depth of the water table, it is not uncommon for the water in unprotected wells to freeze during the winter; this makes it difficult to obtain an accurate record of water-level fluctuations during a 12-month period.

In general, subsurface flow follows the southeastward course of the Stoney Slough channel. The underflow is retarded by Trager Dam, where the water table is forced to the surface; and there is a constant flow of water through the sluice gate. This discharge enters the subsurface and continues to move as subsurface flow. Inasmuch as the dam is an earth-filled structure, some ground water undoubtedly moves through it, although at a much slower rate than through the permeable aquifer. Although Akin (1952, p. 21) suggested that Trager Dam would prevent the passage of ground water downstream, the dam probably only retards ground-water underflow. Also, the dam impounds surface runoff for only a short time during the spring. Therefore, it probably has little effect on the Stoney Slough aquifer, and this only for relatively short periods of time during the spring when the water table is at its highest level.

Approximately 25 wells have been developed in the Stoney Slough aquifer, all of which are small-capacity domestic and stock wells. Most of the wells are less than 20 feet deep, but none is reported to pump dry during normal usage. Although no pumping tests have been made to determine the productivity of the Stoney Slough aquifer, it is probable that large quantities of water could be produced from the thicker parts of the aquifer. If it has a saturated thickness of 10 feet and a porosity of 20 percent, the Stoney Slough aquifer contains an estimated volume of 25,600 acre-feet of water in transient storage. Nearly all this water is derived from precipitation that falls on the drainage basin of the Stoney Slough. Small amounts of recharge enter the aquifer by underflow from the confining till.

Water obtained from the Stoney Slough aquifer is generally of good chemical quality (fig. 8). It is a calcium bicarbonate type water. The concentrations in all the samples analyzed from this aquifer were below the maximums recommended by the U.S. Public Health Service. Most of the water samples from the Stoney Slough aquifer fall within the high salinity-low sodium (C3-S1) classification, although several are of the medium salinity-low sodium (C2-S1) class (fig. 7). In general this water is satisfactory for irrigation. Inasmuch as the aquifer directly overlies the Pierre Shale, it is probable that the quality of the water decreases with depth, owing to contamination by water from the shale.

UTILIZATION OF GROUND WATER

The rural population of Barnes County is dependent mainly upon ground water for its domestic and stock needs. Four incorporated communities obtain their water supplies from wells. In addition, Valley City obtains its municipal supply from wells, but the aquifer is recharged by surface water from the Sheyenne River. Thus the two principal uses of ground water are for domestic and stock requirements by the rural population and for public supply in the incorporated communities. Although the use of water for irrigation is now of minor importance, it will undoubtedly increase in the future. The availability of water from major aquifers in Barnes County is shown on plate 1.

Domestic and Stock Use

Most of the domestic and stock wells in the county are hand-dug or large-diameter bored wells; they generally range in depth from 10 feet to 250 feet and usually do not penetrate below the first water-bearing zone. Consequently, the yield of a particular well is often a function of the productivity of the shallowest aquifer.

Most of the rural wells obtain water from till and associated sand and gravel deposits. Yields of several hundred gallons per minute are reported, but, in general, the stock and domestic wells yield less than 10 gpm. This yield is generally sufficient for domestic use or for small herds of stock. Deepening the well, however, increases the possibility of penetrating a more productive aquifer, and the additional well chamber serves as a reservoir for water storage.

Water for stock use can be obtained from wells drilled to the Dakota Sandstone. These wells usually flow at the surface, and although the flow is often quite low, the wells can support relatively large herds of cattle. Domestic use of water from the Dakota Sandstone has declined in recent years, because of the poor quality of the water.

Public Supply

Four of the 14 incorporated communities in Barnes County have municipal water supplies: Valley City, Wimbledon, Litchville, and Kathryn. Valley City and Kathryn have adequate supplies of good water. Litchville utilizes water from the Dakota Sandstone, which is of poor quality, and Wimbledon's water supply is inadequate. Residents of the other communities are dependent upon privately owned wells or must haul water from the nearest available source.

VALLEY CITY

The municipal supply for Valley City is adequate at the present time. Since the installation of the artificial recharge system in 1932, the water table has risen 22 feet (fig. 25), and the population of the urban area has increased by approximately 2,500 during the same interval. This indicates that the municipal water supply should be adequate for any foreseeable increase in demand. The Valley City water supply can be expanded by increasing the amount of recharge through an additional recharge pit. The only restriction on the recharge system is the amount of surface water available in the Sheyenne River, but the supply of water for recharge is virtually assured by the presence of Baldhill Dam upstream from Valley City.

WIMBLEDON

It has been shown that in recent years the water level in the Wimbledon aquifer is declining at the rate of approximately 1 foot per year (fig. 17). Total decline of the water level since 1950 has been more than 30 feet, and development of an additional source will be necessary. A study of the water resources in the Wimbledon area revealed the presence of four potential aquifers (Dennis, 1948, p. 32). Subsequently, the municipal well was constructed in the aquifer nearest to the city. It is apparent, however, that future expansion of the municipal supply will require development in another aquifer.

LITCHVILLE

The village of Litchville is dependent solely upon water from the Dakota Sandstone. Although adequate quantities are available, the water is of rather poor quality and generally not satisfactory for culinary purposes. The average daily pumpage is less than 50,000 gallons.

A study of the resources in the vicinity of Litchville showed that two sources of water are available, provided that the well field is properly developed (Akin, 1952, p. 16-22). One of these aquifers occupies an unnamed outwash channel approximately 5 miles west of Litchville (pl. 1). The second proposed source is the Stoney Slough aquifer, approximately 4 miles northeast of the community. Provided that a sufficient thickness of saturated deposits is available, the Stoney Slough aquifer would offer the most reliable supply of water because of its relatively large area of recharge.

KATHRYN

The municipal water supply of Kathryn is obtained from springs that flow from the walls of the Sheyenne River valley. These springs reportedly have a combined discharge of 10 gpm; surface storage capacity is 28,500 gallons. This supply is adequate for the community except when large quantities of water are used for irrigation of lawns and gardens. The system can be expanded by developing additional springs and by expanding the storage capacity.

SANBORN

The village of Sanborn does not have a municipal supply. A study of the ground-water resources in the vicinity of Sanborn revealed two buried aquifers in the area (Huxel, 1961a, p. 5). The shallower aquifer has been contaminated by private sewage disposal systems; the other aquifer was penetrated by six test holes drilled west of Sanborn, but subsequent drilling by the village has failed to define adequately the eastern edge of the aquifer near the village.

Test hole 2063 (141-60-27ccc) was drilled approximately 5 miles northwest of Sanborn and penetrated relatively thick water-bearing deposits. Upon completion of the well, the static water level was more than 150 feet above the top of the aquifer, and it remained relatively stable during the 2-year period beginning in October 1962. It is probable that this aquifer would yield sufficient water for the village of Sanborn; but additional test drilling is desirable in order to define the aquifer limits.

Inasmuch as shale is present at relatively shallow depths beneath the community, there seems to be little possibility of obtaining an adequate municipal supply unless one of the aquifers west or northwest of town is developed.

DAZEY

Dazey is located over the center of the Spiritwood channel, unfortunately one of the few places from which the Spiritwood aquifer is absent (pl. 1). Test hole 2093, which was drilled 1 1/2 miles west of Dazey, penetrated 104 feet of the aquifer. Two miles east of Dazey the aquifer is 84 feet thick in test hole 2095, and additional evidence indicates that the Spiritwood aquifer is generally present elsewhere in the area. More test drilling is necessary, however, in order to define the aquifer in the vicinity of Dazey. It is probable that an adequate water supply could be developed in the aquifer within 2 miles of the village.

FINGAL

The southeastern Barnes County community of Fingal does not have a municipal water supply. An adequate supply could be obtained from the sand and gravel deposits confined in the outwash channel south of the village, provided that a sufficient saturated thickness is present. These deposits contain substantial quantities of ground water farther south, but little is known of their water-bearing characteristics in the Fingal area.

Several test holes drilled in the vicinity of Fingal penetrated isolated deposits of sand and gravel confined by till. Further test drilling may reveal sufficient thickness of water-bearing deposits in the area to support a municipal supply.

OTHER COMMUNITIES

There are seven other villages in Barnes County: Oriska, Nome, Rogers, Pillsbury, Eckelson, Leal, and Sibley. None of these have municipal water supplies, but several of the villages have a ground-water source available.

Test hole 2153 (140-56-17ccc) was drilled near the east edge of Oriska and it penetrated 8 feet of gravel at a depth of 64 feet. It is possible that a well tapping this aquifer would yield sufficient water for Oriska.

The village of Nome is located in an area underlain by more than 110 feet of till. Sand and gravel deposits within the till might yield an adequate water supply for Nome. Additional test drilling is needed.

Logs of test holes drilled in the vicinity of Rogers show that the village is near the edge of the Spiritwood channel. Although the Spiritwood aquifer does not extend as far east as Rogers, all the test holes penetrated sand and gravel deposits within the till. Test drilling is necessary in order to determine whether or not these deposits are present beneath the village. It is also possible that a municipal well could be developed in the sand and gravel deposits located approximately 1 mile west of town. These deposits yield abundant water to farm wells that tap the aquifer.

Test hole 2144 (143-56-16cbb), which was drilled at the village of Pillsbury, did not penetrate any significant thicknesses of water-bearing deposits. Also, there are no surficial deposits in the vicinity of Pillsbury capable of yielding an adequate water supply for the village. Consequently, it is probable that the village could not establish a municipal well.

It is difficult to obtain an adequate domestic water supply in the community of Eckelson. Wells drilled completely through the drift did not penetrate any aquifer, but the outwash channel 1 mile west of Eckelson contains more than 40 feet of sand (Kelly, 1964b, p. 115). Although there is little information available concerning these outwash deposits, it is probable that an adequate water supply could be developed in them.

The village of Leal is located near the center of the Spiritwood aquifer. Undoubtedly, an adequate water supply could be obtained from this aquifer.

Sibley, a resort community in northern Barnes County, obtains its water from several shallow wells developed in terrace gravel. Inasmuch as the gravel is recharged by water from Lake Ashtabula, these wells should be able to supply the village during periods of peak use.

Irrigation

Although a variety of factors influence the suitability of an area for irrigation, probably the most important is an adequate supply of suitable water. In 1964, two irrigation systems, both of which utilize water from the Spiritwood aquifer, began operation in Barnes County. Results of the early operation indicate that irrigation can be practiced satisfactorily in Barnes County.

The Spiritwood aquifer offers the greatest potential for irrigation in the county (pl. 1). This aquifer underlies much of the northwest quarter of the county, it contains vast quantities of water, and the quality is satisfactory for irrigation. None of the other buried aquifers in Barnes County is as large or productive as the Spiritwood aquifer. It is possible, however, that smaller buried aquifers, which could support irrigation on a small scale, are present in the county.

There are several areas in Barnes County where water from surficial sand and gravel deposits could be used for irrigation. The largest of these areas is in the northeastern part of T. 138 N., R. 60 W., where the Stoney Slough aquifer is most widespread. The Stoney Slough channel deposits, as well as the other outwash deposits in the county, are potential irrigation areas. The Sand Prairie aquifer probably would yield adequate water for small-scale irrigation operations.

In all types of aquifers the water yield is a function of the permeability, saturated thickness, and rate of recharge. Consequently, any anticipated irrigation project must be preceded by a more detailed study of the area in order to determine the water yield of the aquifer at a particular site.

SUMMARY AND CONCLUSIONS

The lithology and distribution of the geologic units control availability and occurrence of ground water in Barnes County. There are two types of aquifers in the county--those in the bedrock formations and those in the glacial drift.

The Spiritwood aquifer, a buried glacial drift aquifer, is the most important water-bearing deposit in the county. This aquifer underlies more than 200 square miles of western Barnes County, as well as portions of adjacent counties. Average thickness of the aquifer is 50 feet. The water is under artesian pressure and rises more than 100 feet above the top of the aquifer. Aquifer-test data indicate that potential yields of 1,000 gpm are available from the thicker parts of the Spiritwood aquifer. An estimated 3 million acre-feet of water is in transient storage within the Barnes-Stutsman County segment of the aquifer.

The Sand Prairie aquifer is located in southern Barnes County and adjacent Ransom County. Although very little water is utilized by wells, as much as 1,000 gpm is lost from the aquifer by natural discharge through springs. The water table in the aquifer is stable and fluctuates less than 1 foot per year. It is estimated

Artificial Recharge

The Valley City recharge system was established in February 1932 as the result of prolonged drought, during which water levels in the municipal wells declined rapidly. An 18-inch pipeline was laid from the Sheyenne River to an abandoned gravel pit that had been dug in the outwash deposits to a depth of approximately 6 feet below river level (Federal Emergency Administration of Public Works, 1936, p. 36). The river level is maintained by a 12-foot dam located approximately half a mile downstream from the pipeline. The inlet of the pipeline is approximately 2 feet below river level.

Prior to 1957, water flowed through the pipeline by gravity from the river to the recharge pit. The maximum measured rate of free flow is 2,600 gpm; the flow rate is a function of head difference between river and recharge pit. During years of normal pumpage, the pipeline was opened in the late fall or winter, when the pumpage was light and the water table rose rapidly (fig. 23). By early summer the water table was within 6 or 8 feet of the surface, at which time the pipeline was closed. This was sufficient to maintain the municipal supply for the remainder of the year.

Because of an increased demand for water, the city installed a pump and valve system on the pipeline in February 1957. The valve system permits the water level in the pit to be raised approximately 5 feet above river level. Thus the recharge can be accomplished in a shorter period of time, and it is possible to raise the water level higher than had been possible previously. The gravity-feed system can be used when large quantities of recharge are not needed.

During periods of low water use, only one municipal well is pumped. The pumping of the well produces a troughlike cone of depression (fig. 24). North of the pumped well, the trough is restricted between the recharge pit and the river. It is in this area that the recharge is greatest, inasmuch as the recharge pit and river both serve as recharge areas. South of the pumped well, the trough encompasses a much larger area because of a thinning of the aquifer and a smaller amount of available recharge.

The size of the ground-water mound beneath the recharge pit depends upon the elevation of the water level in the pit. During periods of peak recharge, the mound is much more pronounced than that shown on figure 24.

Water-level measurements have been made in the well field at irregular intervals since July 1930 (O.N. Bergman, Sr., oral communication, 1963). During the 1 1/2 years prior to installation of the recharge system, in February 1932, the water level in the aquifer declined 3 1/2 feet (fig. 25). During the next 4 1/2 years the piezometric surface had only minor fluctuations. This relative stabilization was produced by use of small quantities of recharge which prevented continued decline of the piezometric surface. However, the lack of sufficient runoff in the Sheyenne River greatly restricted the use of surface water for recharge. Since 1936 the Sheyenne has maintained sufficient flow to operate the recharge

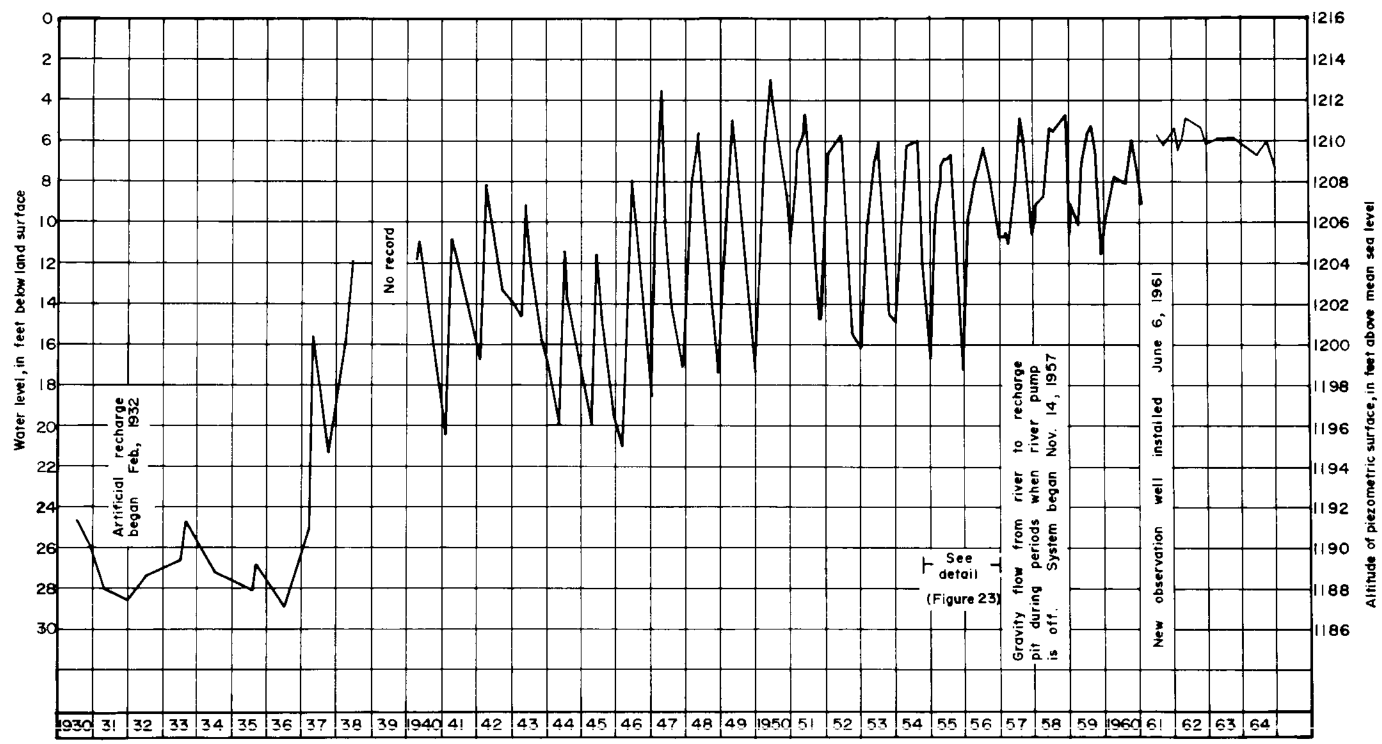
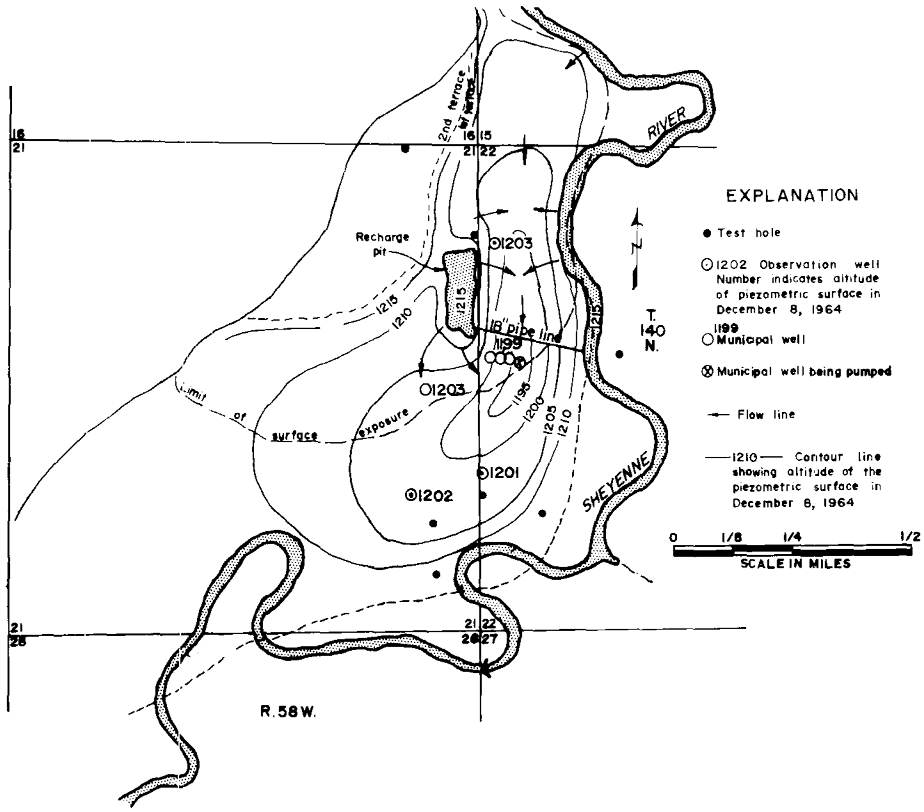


Figure 23. Effect of artificial recharge on the piezometric surface of the Valley City aquifer. Measurements by O. N. Bergman, Sr., Municipal Utilities Co., Valley City.



igure 24. Configuration of the piezometric surface of the Valley City aquifer, December 8, 1964.

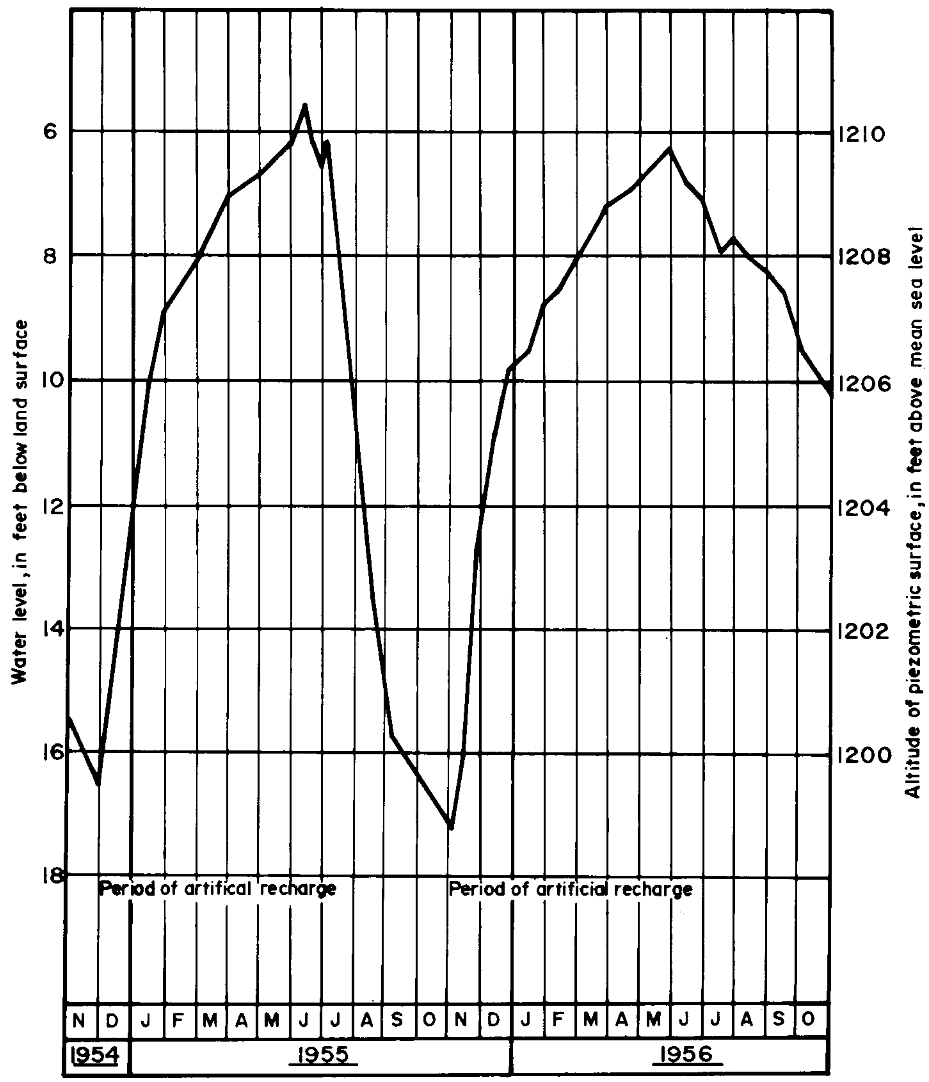


Figure 25. Piezometric surface fluctuations in the Valley City aquifer.

system at capacity; the flow has been regulated since 1949 by Baldhill Dam, approximately 13 miles upstream.

The piezometric surface in the Valley City aquifer rose approximately 22 feet between 1932 and 1964 and more than 18 feet between June 1936 and May 1940 (fig. 25). Only a partial record is available for the latter interval; however, the general rise is shown as are the accompanying periodic water-level fluctuations corresponding to intermittent periods of recharge and discharge. Semiannual reversals in trends of the water level, controlled by artificial recharge, have continued to the present. The average semiannual fluctuation is approximately 10 feet; greatest fluctuations occurred between December 13, 1946, and May 26, 1947, when the piezometric surface rose 14.7 feet.

Fluctuations that have occurred since 1956 are more subdued than earlier water-level changes. This is due to supplemental gravity recharge when a large quantity of recharge is not necessary. Consequently the water level in the recharge pit declines only until it is in equilibrium with the river level. Thus a constant supply of recharge is available to the aquifer, and decline of the piezometric surface is minimized.

Owing to the artificial recharge practiced by Valley City, the quality of the water in the aquifer is affected by the chemical quality of the water of the Sheyenne River. Although the quality of the water changes as the river stage fluctuates, both the river and the aquifer usually contain a sodium bicarbonate type water. The total dissolved solids of the river water increase as much as 200 ppm by solution of minerals from the aquifer, and all the chemical constituents except iron and potassium increase during recharge. However, generally the water is of good quality.

SAND PRAIRIE AQUIFER

Location and Thickness

The Sand Prairie aquifer is located in T. 137 N., R. 58 W., in southern Barnes County and extends into adjacent Ransom County (fig. 26). The aquifer underlies the so-called Sand Prairie, a wide, flat plain characterized by sandy, highly permeable soils. As early as 1912, Hard (p. 99-100) foresaw the irrigation potential of the area; However, in 1962, there were fewer than 25 small-capacity wells utilizing water from the aquifer in Barnes County. Thus, the aquifer remains a relatively untapped source of large quantities of ground water.

The Sand Prairie was formed as an outwash plain by a stream flowing southeastward in the channel now occupied by Stoney Slough. In southern Barnes County, the stream left its channel and the deposits were spread over a large area now occupied by the Sand Prairie. These outwash deposits can be readily mapped at the surface, and they are known to extend from sec. 18, T. 137 N., R. 58 W., Barnes County, to secs. 32 and 33, T.136 N., R. 58 W., Ransom County.

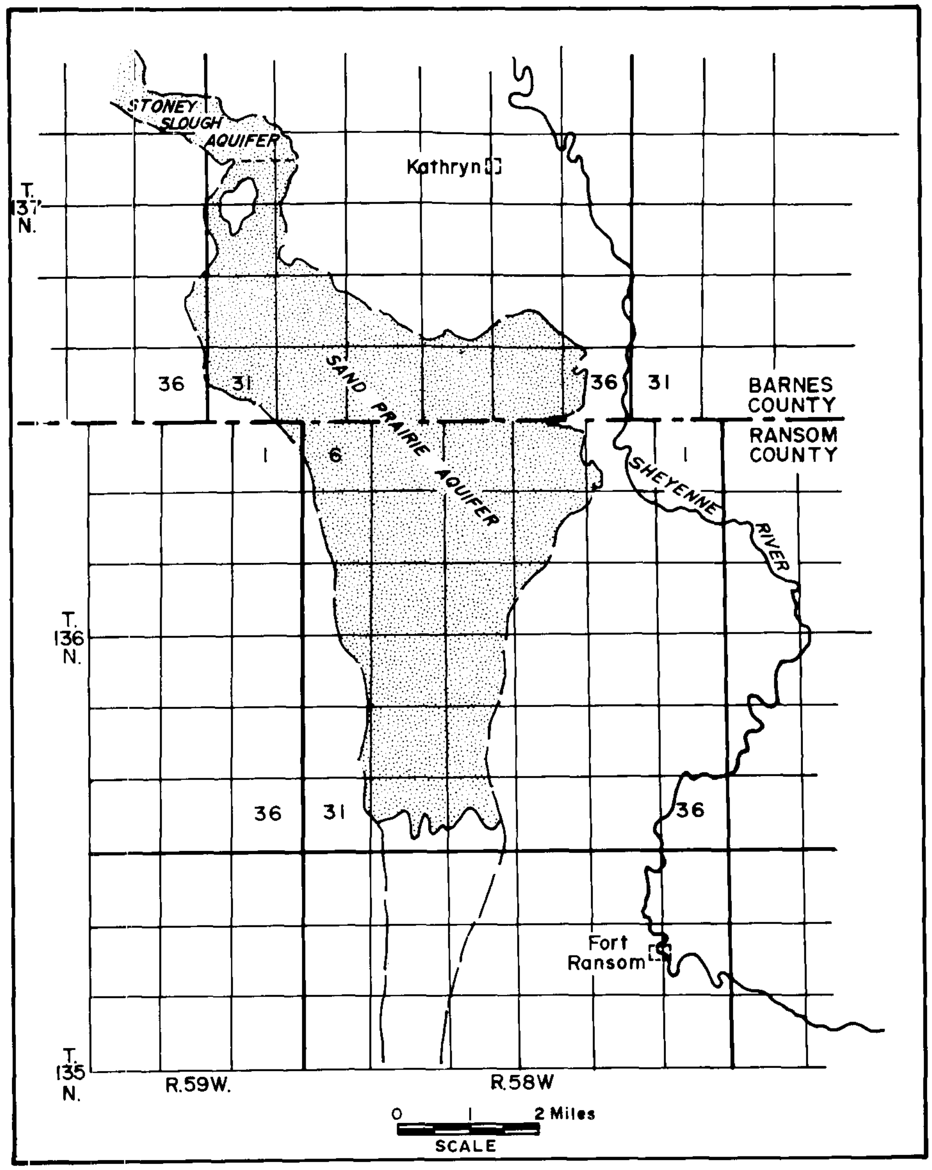


Figure 26. Sand Prairie aquifer in Barnes and Ransom Counties.

Thus the Sand Prairie has an areal extent of more than 22 square miles; approximately 8 square miles is in Barnes County.

Test hole 2110 (137-58-34ccc) was drilled near the center of the aquifer and penetrated 26 feet of fine to very coarse sand (Kelly, 1964b, p. 71). More than 30 feet of sand and gravel is exposed in a roadcut in the southwest quarter of sec. 36 of the same township, and the deposits may exceed 50 feet in thickness near the northern boundary of the Sand Prairie. The outwash thins toward the east and west.

Little information is available on the thickness of the outwash in Ransom County. Although glacial till probably underlies much of the outwash, in test hole 2110 and at the roadcut in sec. 36 the deposits lie directly on the Pierre Shale.

In general, the outwash deposits composing the Sand Prairie aquifer consist of fine to coarse sand, but locally they include small amounts of fine gravel. The sand is well sorted and contains very little silt and clay. Calcium carbonate cement is present in thin, discontinuous strata.

Reservoir Characteristics

Only minor water-level fluctuations have occurred in the Sand Prairie aquifer during the period of record extending from April 1963 to January 1965 (table 2).

Date	Obs. well 137-58-34ccc (feet below land surface)	Spring 137-58-36ccc	
		Discharge (gpm)	Temperature, °F
April 26, 1963	10.08		
May 17	10.12		
30	10.15		
June 27	10.18		
July 30	10.19	4.0	60°
Sept. 5	10.21	3.8	58°
Oct. 2	10.30	3.7	52°
Nov. 13	10.38	3.4	44°
Dec. 2	10.40	3.3	40°
Jan. 6, 1964	10.41	Frozen	..
Mar. 4	10.56	Frozen	..
May 5	10.48	3.0	48°
June 1	10.54	3.4	50°
July 2	10.44	3.6	58°
30	10.34	4.0	58°
Sept. 1	10.23	3.5	58°
29	10.26	3.5	52°
Oct. 27	10.31	3.1	49°
Nov. 25	10.37	3.0	40°
Jan. 6, 1965	10.46	2.8	38°

Table 2. Water-level measurements, spring discharge, and temperature of ground water in the Sand Prairie aquifer.

Only a vague correlation exists between precipitation and water-level fluctuation. Spring and summer rainfall produces a slight rise in the water table, which is followed by a decline through the remainder of the year. There are no abrupt fluctuations of the water table, and the greatest monthly change during the period of record was a rise of 0.11 foot in August 1964.

There are two principal controls acting on the water table of the Sand Prairie aquifer: The high porosity of the deposits, and the natural discharge.

Precipitation on the sandy soil is rapidly absorbed and part of the water enters the aquifer. Deposits similar to those in the Sand Prairie have porosities exceeding 30 percent (Meinzer, 1923b, p. 11). It is probable that the average porosity of the aquifer is of this magnitude and that the specific yield is rather high; consequently, large quantities of water can be absorbed without changes in the water table.

The second control on the water table of the Sand Prairie aquifer is the natural discharge of ground water through springs. Large quantities of water are discharged from the aquifer in sec. 36, T. 137 N., R. 58 W., and sec. 3, T. 136 N., R. 58 W. A stream flowing through Little Yellowstone Park (SE 1/4 sec. 36, T. 137 N., R. 58 W.) is derived primarily from ground water discharged from the Sand Prairie aquifer. In June 1963 the combined discharge of these springs exceeded 1,000 gpm; the discharge decreases in the winter.

One of the small springs in the park has been developed to serve as a water supply for the recreation area. Both the spring discharge and the water temperature fluctuate during the year. In general, the peak discharge of the spring coincides with the peak water level in test hole 2110 (observation well 137-58-34ccc), as shown in table 2. The position of the water table and the amount of spring discharge indicate that the two are directly related and that, locally, the water table controls the amount of loss from the aquifer through springs. Where water is not discharged through springs, the direction of subsurface flow is toward the south.

No tests have been made to determine the transmissibility of the aquifer. It is probable that large quantities of water could be pumped from it, provided that a sufficient saturated thickness of sand is present. A coefficient of transmissibility of 165,000 gpd per foot was calculated for a Ransom County aquifer of lithology similar to that of the Sand Prairie aquifer. This high-yielding well penetrated 34 feet of saturated sand and gravel.

The Sand Prairie aquifer contains approximately 50,000 acre-feet of ground water in transient storage. This value is based on an assumed porosity of 30 percent and a saturated thickness of 10 feet. As much as 1,000 gpm of this water is lost from the aquifer through springs. Therefore, it would be possible to remove this quantity of water from the aquifer without removing any ground water from storage.

In general, water from the Sand Prairie aquifer is the least mineralized water in Barnes County (fig. 8). It is a calcium bicarbonate type water that is relatively soft. The dissolved-iron concentration is rather high and locally exceeds the max-