BULLETIN 51
NORTH DAKOTA GEOLOGICAL SURVEY
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COUNTY GROUND WATER STUDIES 12
NORTH DAKOTA STATE WATER COMMISSION
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Geology and Ground Water Resources of WELLS COUNTY

Part III
GROUND WATER RESOURCES

by
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Prepared by the United States Geological Survey
in cooperation with the North Dakota State
Water Commission, the North Dakota Geological Survey,
and the Wells County Water Management District.
1970

This is one of a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. The reports are in three parts; Part I describes the geology, Part II presents ground water basic data, and Part III describes the ground water resources. Parts I and II have been published previously.

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GEOLOGY AND GROUND WATER RESOURCES OF
WELLS COUNTY, NORTH DAKOTA
PART III - GROUND WATER RESOURCES

by

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ABSTRACT

The residents of Wells County obtain most of their water from aquifers in the glacial drift and underlying Cretaceous rocks.

Aquifers in the glacial drift have the greatest potential for large ground-water withdrawals. These aquifers consist of sand and gravel deposits underlying surficial outwash plains and channels, and in buried valleys. Nine major drift aquifers were mapped and described. They are the Rusland, Pipestem Creek, Rocky Run, Heimdal, New Rockford, Carrington, Rosefield, Manfred, and South Fessenden aquifers. Yields in excess of 500 gallons per minute are possible from the New Rockford aquifer, a buried valley aquifer. Yields of as much as 500 gallons per minute are obtainable in places from the Manfred and Heimdal aquifers, and as much as 250 gallons per minute in other aquifers.

In most parts of the county, ground water also is available from Cretaceous rocks underlying the drift. Although little is known concerning the water-bearing properties of these rocks, it is not expected that yields could be obtained comparable to those from the drift aquifers.

Water from the glacial drift aquifers is generally very hard, but only moderately saline. Most is suitable for domestic and livestock use and also for irrigation use with good drainage. Water from the Cretaceous rocks generally is soft, but rather saline. It is generally unsuitable for irrigation.

INTRODUCTION

Purpose and Scope

The study was made to determine the occurrence, availability, and quality of ground water in Wells County, east-central North Dakota (fig. 1). This report describes the location and extent of the various sources of ground water in the county, discusses the chemical quality of the water available from each source, and evaluates the potential of each ground-water source for future development.

Other parts of the investigation consisted of a study of the geology of Wells County and its relationship to ground water (Bluemle and others, 1967), and an inventory of wells, springs, and test holes, including water-level data and chemical analyses of water samples (Buturla, 1968).

The investigation was made by the U. S. Geological Survey as part of a program of ground-water studies in North Dakota in cooperation with the North Dakota State Water Commission, North Dakota Geological Survey, and Wells County Water Management District.

The geologic nomenclature used in this report is that of the North Dakota Geological Survey and may differ from that of the U. S. Geological Survey.

Previous Investigations

The geology and ground-water resources of Wells County were briefly discussed in a report by Simpson (1929, p. 262-265), which described ground-water conditions in North Dakota during 1911-13.

Abbott and Voedisch (1938, p. 86-87) published a report on the municipal ground-water supplies of North Dakota that included data on several wells in Wells County.

Unpublished data on the ground-water conditions in the vicinity of Fessenden were prepared in 1945 by T. G. McLaughlin, in cooperation with the North Dakota Geological Survey and North Dakota State Department of Health. Part of McLaughlin's work was included in a report by Filaseta (1946).

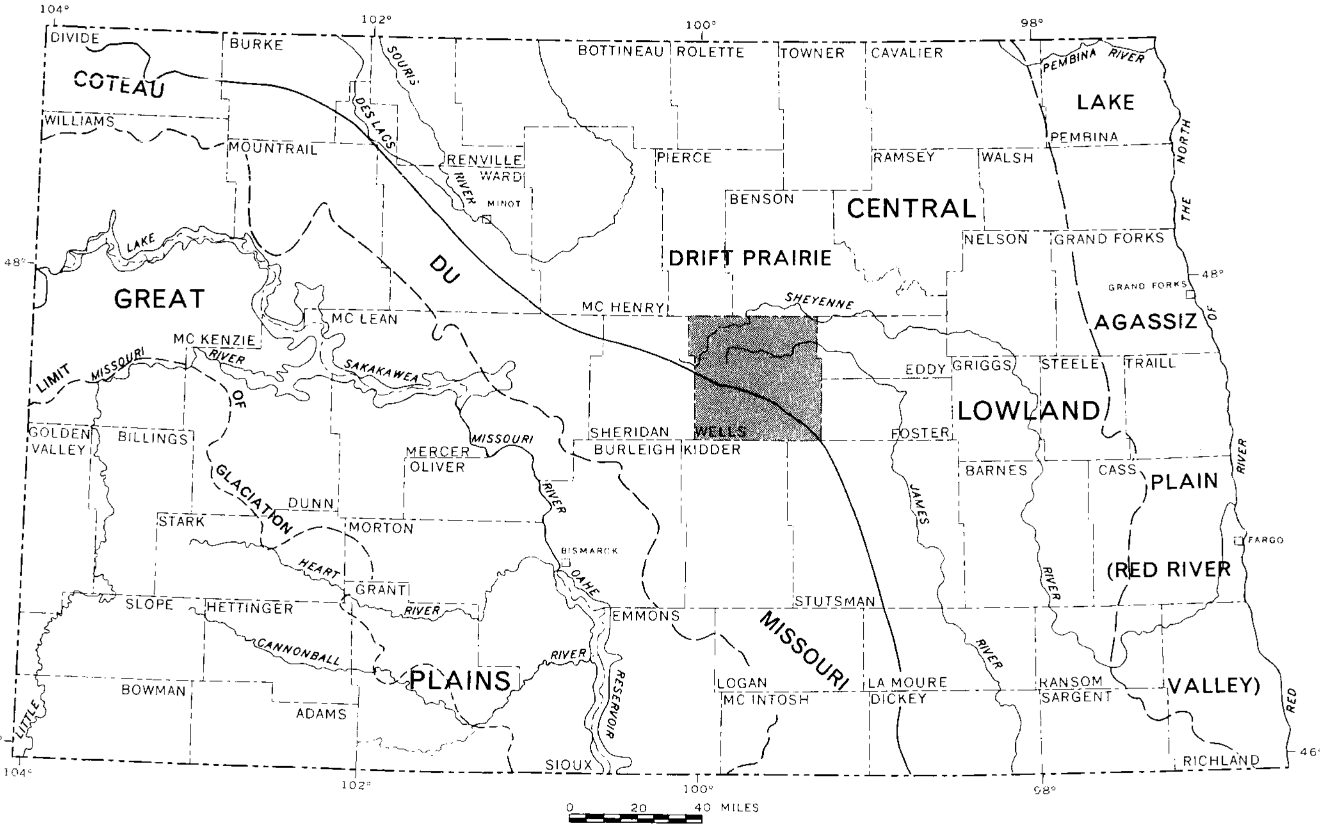

FIGURE 1. Physiographic divisions in North Dakota and location of report area.

Well-Numbering System

The well-numbering system used in this report (fig. 2) is based on the federal system of rectangular surveys of the public lands. The first numeral denotes the township, the second the range, and the third the section in which the well, spring, or test hole is located. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarter section or, by double and triple letters, the quarter-quarter section and quarter-quarter-quarter section (10-acre tract). Thus, well 150-72-15aaa is located in the NE 1/4 NE 1/4 NE 1/4 sec. 15, T. 150 N., R. 72 W. The same numbering system is used in this report for the location of small areas.

Area, Population, and Economy

Wells County has an area of approximately 1,300 square miles. The 1960 census lists the population of the county as 9,237. Fessenden, the county seat, and Harvey are the principal population centers with 920 and 2,365 people, respectively (U. S. Bureau of the Census, 1960). Agriculture is the main economy–more than 90 percent of the farms produce cash grain crops consisting of spring wheat, durum, and flax.

Climate

The climate is a midlatitude continental type typical of the Great Plains. Frequent passages of weather systems cause a wide variation in seasonal and monthly temperatures. The average annual temperature at Fessenden is 40° F; however, the average monthly temperature ranges from 6.5° F for January to 70.1° F for July. The average annual precipitation at Fessenden is 17.27 inches, of which about three-fourths falls in the growing season April through September. Wide variations in annual precipitation are common. In 1964 Fessenden had 23.50 inches and in 1959 only 13.73 inches (U. S. Weather Bureau, 1959-68). Figure 3 summarizes the precipitation record at Fessenden.

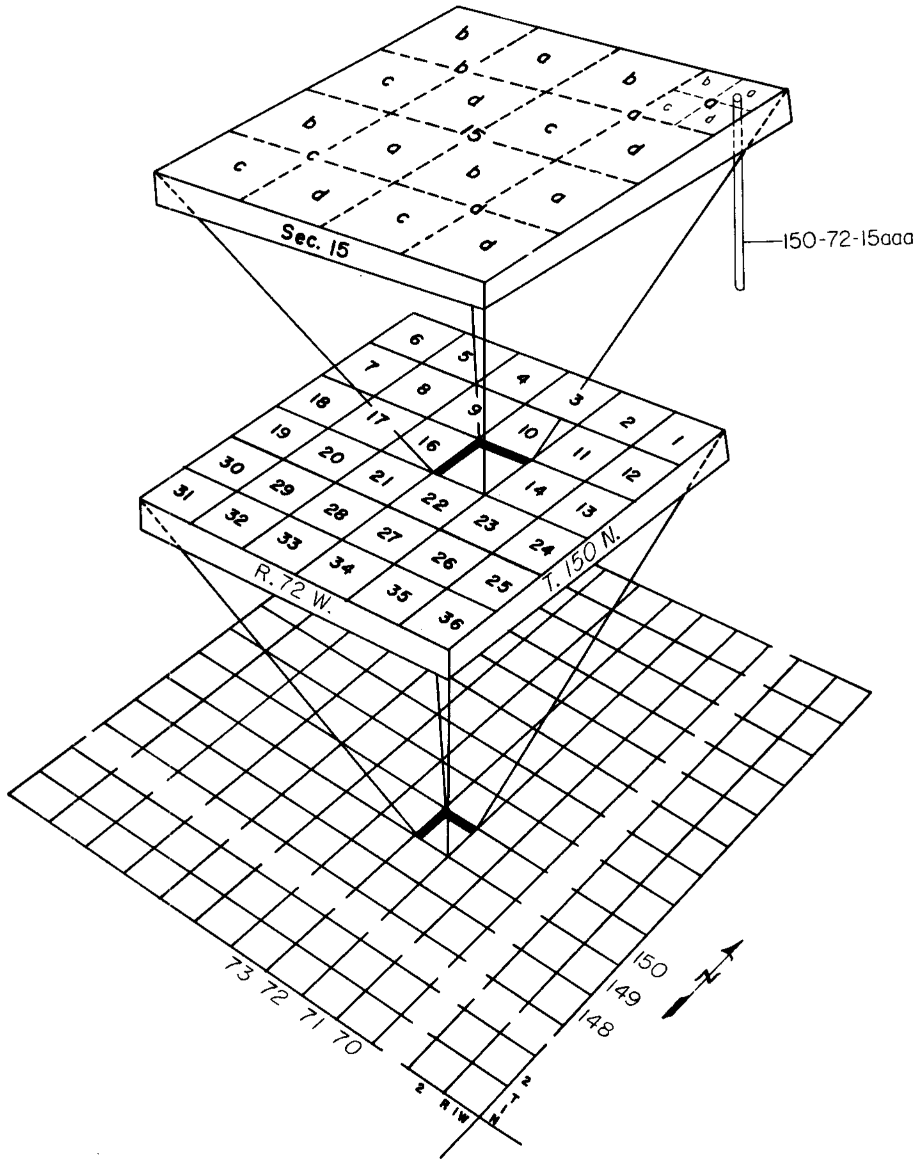

FIGURE 2. System of numbering wells, springs, and test holes.

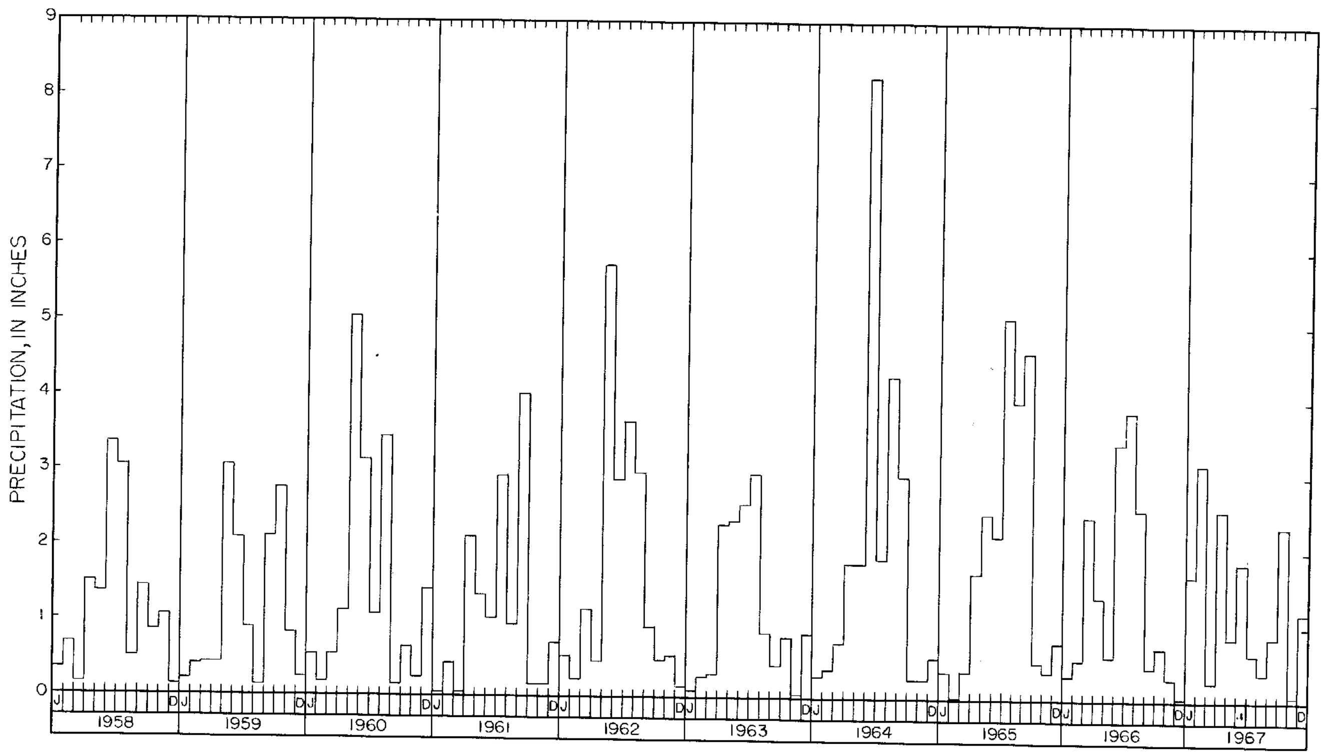

FIGURE 3. Monthly precipitation at Fessenden, 1958-67.

Physiography and Drainage

Wells County lies in two physiographic provinces (fig. 1). Approximately 60 percent of the county is in the Drift Prairie section of the Central Lowland physiographic province and is characterized by a northeastward-sloping plain with a few low hills and shallow depressions. The remainder of the county is in the glaciated Missouri Plateau and the terrain consists of steep-sided hills and depressions, referred to as the Coteau du Missouri (Hills of the Missouri).

Relief ranges from 5 to 20 feet per mile on the Drift Prairie and from 25 to 200 feet per mile on the Coteau du Missouri. The highest altitude is more than 2,300 feet above msl (mean sea level) in the southwestern part of the county and the lowest is about 1,420 feet above msl in the northeastern part of the county, in the Sheyenne River valley where the river leaves Wells County.

Drainage is of two types; interior or unintegrated drainage in the Coteau du Missouri, and integrated drainage in the Drift Prairie. The numerous undrained depressions are commonly referred to as sloughs or prairie potholes. Each depression represents a small closed drainage basin, but some of the depressions fill up and spill over into lower ones, especially during spring thaws following winters of above normal snowfall. Many of the depressions contain water for only a few months during the spring and early summer, but others, having drainage areas of several hundred acres or more, may contain water throughout the year.

Integrated drainage in the Drift Prairie is generally toward the east and consists of the Sheyenne and James Rivers, Rocky Run, and Pipestem and Little Pipestem Creeks. These streams generally flow only during the spring and early summer.

PRINCIPLES OF GROUND-WATER OCCURRENCE

All ground water of economic importance in Wells County is derived from precipitation. After the precipitation falls on the earth's surface, part is returned to the atmosphere by evaporation, some runs off to the streams, and the remainder sinks into the ground. Much of the water that sinks into the ground is held temporarily in the soil and is returned to the atmosphere either by evaporation or by transpiration. The water that infiltrates downward to a saturated zone (zone of saturation) becomes ground water.

Ground water moves under the influence of gravity from areas where water enters the ground (recharge) to areas where water leaves the aquifer (discharge). Ground-water movement is generally very slow; it may be only a few feet per year. This rate of movement is governed by the permeability of the deposits through which the water moves and by the hydraulic gradient or slope of the water table or piezometric surface.

Definitions

Porosity is the ratio of the volume of the open or pore space in a rock to its total volume and is an index of the storage capacity of the material. Elsewhere in this report, estimates of storage based on areal extent, thickness, and porosity are given for each of the major aquifers. However, these quantities are given only as a means of volumetric comparison. They do not refer to the amount of water that can be withdrawn from the aquifers through wells. Such determinations would require a great deal of quantitative hydrologic data and are beyond the scope of this study.

Permeability refers to the ease with which a fluid will pass through porous material, and is determined by the size and shape of the pore spaces in the rock and their interconnection. Gravel, well-sorted medium or coarse sand, and fractured lignite beds generally are highly permeable. Well-cemented deposits and fine-grained materials such as silt, clay, and shale usually have low permeability, and may act as barriers that impede the movement of water into or out of more permeable rocks.

The coefficient of transmissibility is a measure of the rate of flow through porous material and is expressed as the number of gallons of water that will move in 1 day under a unit hydraulic gradient (1 foot per foot) through a vertical strip of the aquifer 1-foot wide extending the full saturated height of the aquifer.

The coefficient of permeability is the rate of flow in gallons per day through 1 square foot of the aquifer under a unit hydraulic gradient. Thus, the field coefficient of permeability is equal to the coefficient of transmissibility divided by the thickness of the aquifer. The field coefficient of permeability is measured at the prevailing water temperature.

The coefficient of storage is the volume of water released from or taken into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface. Under artesian or confined conditions, the coefficient of storage is equal to a very small fraction of the porosity. However, under water-table or unconfined conditions, the coefficient of storage is much larger and is practically equal to the specific yield, which is the ratio of the volume of water released by gravity drainage to the volume of the material drained. The specific yield may be as much as half the total porosity.

The upper surface of the zone of saturation is called the water table. This surface is irregular and is controlled by the topography, geology, and hydrology of the area. Water-table conditions refer to a ground-water environment that is not confined by overlying impermeable beds, and the water is free to move in response to gravity. If an aquifer is overlain by relatively impermeable beds, the water is confined under pressure exerted by water at higher elevations and by the confining beds. The water level will rise above the level at which it is first encountered; wells supplied from this type of aquifer are said to be artesian.

The water level in a well fluctuates in response to recharge to and discharge from the aquifer. Atmospheric pressure changes and land surface loadings also cause minor water-level fluctuations in confined aquifers. The static level is the water level in the well when it is not being pumped. When water is withdrawn from a well, the water level near the well is lowered; the water-level surface around the well resembles a cone called the cone of depression. The amount of water-level drawdown, or the difference between the static and pumping levels, is controlled by the hydraulic properties of the aquifer, the physical characteristics of the well, and the rate and duration of pumping. During constant and uniform discharge from a well, the water level declines rapidly at first and then continues to lower at a decreasing rate as the cone of depression expands.

Specific capacity, which is a measure of well performance, is determined by dividing the rate of pumping, in gallons per minute, by the drawdown, in feet. Specific capacity is expressed as gallons per minute per foot of drawdown.

The water level in a pumping well must decline in order that water may flow from the aquifer to the well. The amount of water-level decline may become serious if (1) it causes water of undesirable quality to move into the aquifer, (2) the yield of the well decreases because of interference from other wells or from aquifer boundaries, (3) the pumping lift increases to the point where pumping becomes uneconomical, or (4) the water level declines below the top of the screen. When pumping is stopped, the water level rises in the well and in its vicinity at a decreasing rate until the water level again approaches the static level.

Under natural conditions, over a long period of time, the rate of discharge from an aquifer approximately equals the rate of recharge.

Withdrawal of water from an aquifer eventually causes one or a combination of the following: (1) a decrease in the rate of natural discharge, (2) an increase in the rate of recharge, or (3) a reduction in the volume of water in storage. The maximum rate of ground-water withdrawal that can be maintained indefinitely is related directly to the rate of recharge. However, recharge is regulated largely by climate and geologic controls and may not be possible to evaluate quantitatively without large amounts of data.

QUALITY OF WATER

All natural water contains dissolved solids. Rainfall begins to dissolve mineral matter as it falls to the earth and continues to dissolve it as the water infiltrates through the earth. The amount and kind of mineral matter dissolved depends upon the solubility and types of rocks or other mineral matter encountered, the length of time the water is in contact with them,and the amount of carbon dioxide and soil acids in the water. Water that has been underground a long time, or has traveled a long distance from the recharge area, generally is more highly mineralized than water that has been in transit for only a short time and is withdrawn near the recharge area. Ground water usually contains more dissolved minerals than water from streams.

The dissolved mineral constituents in water are usually reported in parts per million (ppm) or grains per U. S. gallon. A part per million is a unit weight of a constituent in a million unit weights of water. Parts per million can be converted to grains per gallon by dividing the parts per million by 17.12. Equivalents per million (epm) is the unit chemical combining weight of a constituent in a million weights of water. These units are usually not reported, but are necessary to calculate percent sodium, the sodium-adsorption ratio (SAR), or to check the accuracy of a chemical analysis.

The suitability of water for various uses is determined largely by the kind and amount of dissolved mineral matter. The chemical properties and constituents most likely to be of concern to residents of Wells County are: (1) dissolved solids and the related specific conductance, (2) sodium-adsorption ratio, (3) hardness, (4) iron, (5) sulfate, (6) nitrate, and (7) fluoride. The relative importance of the above properties and constituents of water depends primarily on the use of the water. For example, hardness has very little effect on the suitability of water for drinking, but it can make water undesirable for laundry use. Additional information may be found in "Drinking Water Standards" published by the U. S. Public Health Service (1962).

Table 1, modified from Durfor and Becker (1964, table 2), shows the major constituents in water, their major sources, and their effects upon usability. Most, if not all, of the minerals shown in the major source column are present in the glacial drift or in the bedrock directly underlying the drift in Wells County.

The chemical analyses of water in Wells County were listed by Buturla (1968, table 5). The data are summarized in this report in the discussion of the major aquifers.

Dissolved Solids and Specific Conductance

The concentration of dissolved solids is a measure of the total mineralization of water. The dissolved solids concentration is significant because it may limit the use of water for many purposes. In general, the suitability of water decreases with an increase in dissolved solids. The limits shown in table 1 for drinking water were originally set for common carriers in interstate commerce. Residents in areas where dissolved solids are as high as 2,000 ppm have consumed the water with no noticeable ill effects. Livestock has been known to survive on water containing 10,000 ppm. However, growth and reproduction of livestock may be affected by water containing more than 3,000 ppm of dissolved solids.

The specific conductance of water is a measure of the water's ability to conduct an electrical current; it is a function of the amount and kind of dissolved mineral matter. Specific conductance usually is reported in micromhos. An estimate of the total dissolved solids in parts per million can be obtained by multiplying specific conductance by 0.65; however, the conversion factor may range from 0.55 to 0.75, depending upon the type and amount of dissolved minerals.

TABLE 1.–Major chemical constituents in water–their sources, concentrations, and effects upon usability

(Concentrations are in parts per million)

(Modified after Durfor and Becker, 1964, table 2)

Constituents	Major source	Effects upon usability	U. S. Public Health Service recommended limits for drinking water[1]
Silica (SiO_2)	Feldspars, ferromagnesium, and clay minerals.	In presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat transfer.	
Iron (Fe)	Natural sources: Amphiboles, ferromagnesium minerals, ferrous and ferric sulfides, oxides, and carbonates, and clay minerals. Man-made sources: well casings, pump parts, storage tanks.	If more than 0.1 ppm iron is present, it will precipitate when exposed to air; causing turbidity, staining plumbing fixtures, laundry and cooking utensils, and imparting tastes and colors to food and drinks. More than 0.2 ppm is objectionable for most industrial uses.	0.3 ppm
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, dolomite, and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, and clay minerals.	Calcium and magnesium retard the suds-forming action of soap. High concentrations of magnesium have a laxative effect.	
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 ppm sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	
Potassium (K)	Feldspars, feldspathoids, some micas, and clay minerals.		
Boron (B)	Tourmaline, biotite, and amphiboles.	Many plants are damaged by concentrations of 2.0 ppm.	
Bicarbonate (HCO_3)	Limestone and dolomite	Upon heating, bicarbonate is changed to steam, carbonate, and carbon dioxide.	
Carbonate (CO_3)		Carbonate combines with alkaline earth (principally clacium and magnesium) to form scale.	
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation of sulfide minerals.	Combines with calcium to form scale. More than 500 ppm tastes bitter and may be a laxative.	250 ppm
Chloride (Cl)	Halite and sylvite.	In excess of 250 ppm may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 ppm.	250 ppm
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Recommended limits depend on average of maximum daily temperature. Limits range from 0.6 ppm at 90.5°F to 1.7 ppm at 50°F.
Nitrate (NO_3)	Nitrogenous fertilizers, animal excrement, legumes, and plant debris.	More than 100 ppm may cause a bitter taste and may cause physiological distress. Concentrations greatly in excess of 45 ppm have been reported to cause methemoglobinemia in infants.	45 ppm
Dissolved solids	Anything that is soluble.	More than 500 ppm is not desirable if better water is available. Less than 300 ppm is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500 ppm

[1]U. S. Public Health Service, 1962.

Irrigation Indices

Two indices used to show the suitability of water for irrigation in arid and semiarid regions are SAR and specific conductance. SAR is related to the sodium hazard; the specific conductance is related to the salinity hazard. The hazards increase as the numerical values of these indices increase. Figure 4 shows the SAR versus the specific conductance indicated by analyses of water from major drift aquifers in Wells County. Most of the samples are in the low to medium range in sodium hazard, but in the high to very high range in salinity hazard. Thus, it appears that the water is of marginal quality for irrigation; however, high sodium or high salinity waters have been used successfully for selected crops where ideal soil conditions and drainage exist and the irrigation is supplemental to rainfall.

Another index used to evaluate irrigation water is the residual sodium carbonate (RSC). This quantity is determined by subtracting the equivalents per million of calcium and magnesium from the sum of equivalents per million of bicarbonate and carbonate. If the RSC is between 1.25 and 2.5 epm, the water is considered marginal for irrigation. An RSC of more than 2.5 epm indicates that the water is not suitable for irrigation purposes. Generally the water in Wells County has an RSC index of less than 2.5 epm. Good management practices might make it possible to use successfully some of the marginal RSC water for irrigation. For further information, the reader is referred to "Diagnosis and Improvement of Saline and Alkali Soils" (U. S. Salinity Laboratory Staff, 1954).

Hardness

The hardness of water determines its usefulness for laundries and for some industries. The U. S. Geological Survey rates hardness as follows: water having a hardness of 0 to 60 ppm calcium carbonate is soft, between 61 and 120 ppm is moderately hard, between 121 and 180 ppm is hard, and more than 180 ppm is very hard. Hardness does not seriously interfere with the use of water for most purposes, but it does increase the consumption of soap. Its removal by a softening process can be profitable for domestic uses, for laundries, and for some industries. Water from the glacial drift in Wells County is generally very hard; whereas water from the Cretaceous rocks is generally soft.

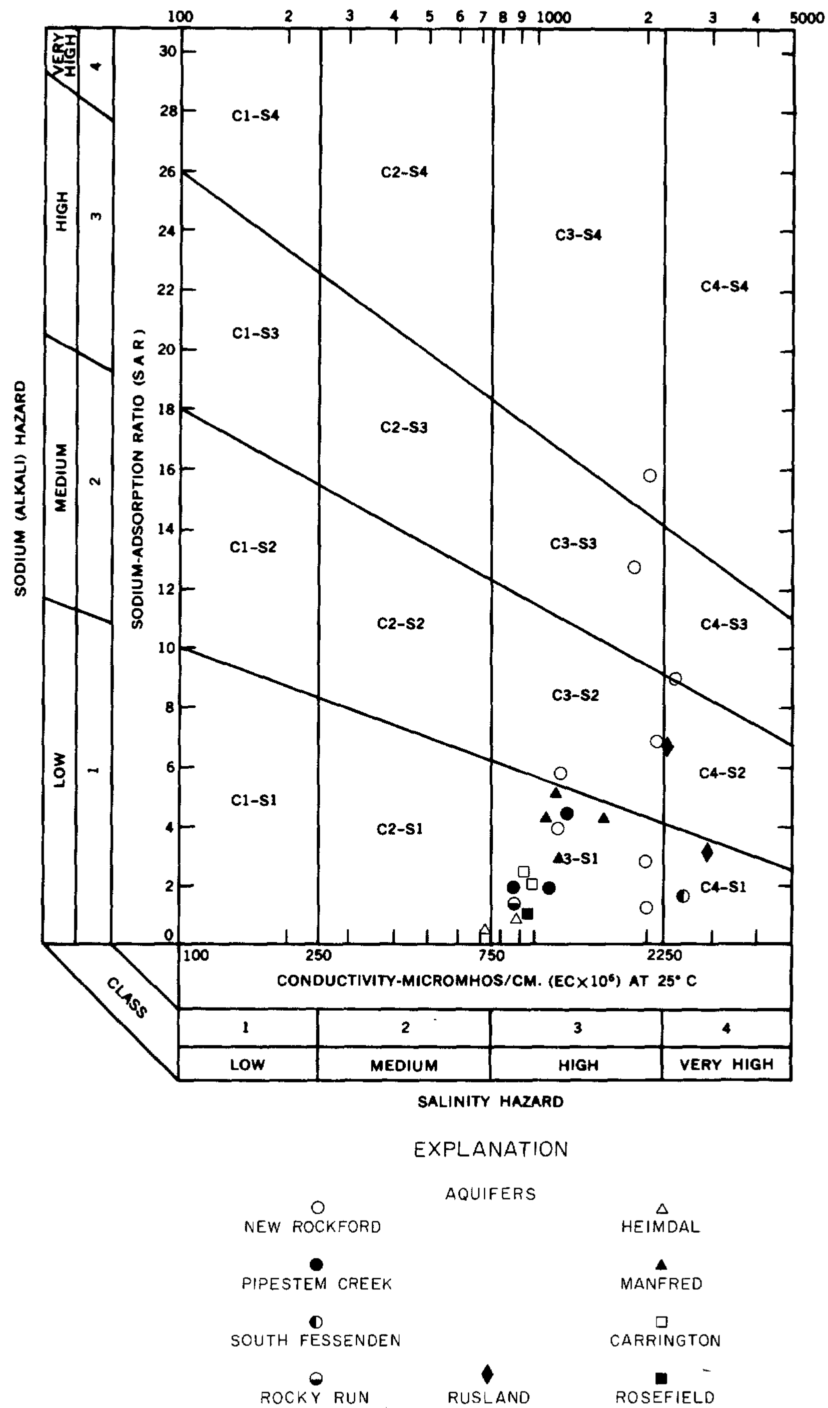

FIGURE 4. **Salinity and sodium classification of selected water samples (from U. S. Salinity Laboratory Staff, 1954).**

GEOLOGIC SETTING

The sedimentary rocks of Wells County that contain aquifers overlie a Precambrian basement consisting of igneous and metamorphic rocks. Pre-Cretaceous rocks are too deep and the water in them is too highly mineralized to be considered an important source of ground water. Rocks of Cretaceous and Quaternary age contain the more important aquifers in the area, and a review of their geology is important to understanding their potential as aquifers.

Preglacial Geology

According to Blumle and others (1967, p. 4), about 4,100 to 6,000 feet of sedimentary rocks underlie Wells County. These rocks consist of shales, limestones, sandstones, and dolomites, and range in age from Ordovician to Cretaceous. The geology of the more important water-bearing bedrock units is described below.

Dakota Group

The name Dakota Group, for the purpose of this report, is applied to the stratigraphic interval of Cretaceous rocks that in North Dakota probably includes the Lakota, Fuson, Fall River, Skull Creek, Newcastle, and Mowry Formations (Hansen, 1955a, p. 15). Bluemle and others (1967, p. 3) recognized the Fall River-Lakota interval and the Mowry Formation in Wells County, and indicated that the top of the sequence lies at a depth of about 1,700 feet near the eastern edge of the county and at about 2,400 feet near the western edge. Thus, the apparent dip would be about 20 feet per mile toward the west.

Simpson (1935, p. 18) described the "Dakota sandstone" as consisting of a "...fine light-gray to white sand and sandstone with interstratified beds of clay, shale, and limestone." An oil-test well at 148-73-13bdd reportedly penetrated 296 feet of rocks of Dakota age, which consisted of medium to coarse sandstone (Nelson, 1954). An oil-test well at 146-73-27ddd, about 15 miles south, reportedly penetrated 190 feet of Dakota rocks consisting mainly of shale and only 12 feet of sandstone (Strassberg, 1953). In general, the drilling samples are rather poor indicators of the formation. The sandstone is very friable and the shale is so soft that the cuttings are mixed in the drilling mud. The average thickness of the Dakota Group as determined from oil-test logs is about 280 feet. Using the lithologic sample descriptions that are available, the average percentage of sandstone present in any given thickness is approximately 30 percent.

Pierre Formation

The Pierre Formation crops out along the bank of the Sheyenne River in northeastern Wells County and underlies the till in most of the eastern half of the county (fig. 5). The formation is composed principally of olive-gray to olive-black fissile, noncalcareous shale. Oil tests in Wells County indicate that the thickness of the Pierre Formation ranges from 550 to 1,100 feet.

Fox Hills Formation

The Fox Hills Formation crops out along the Sheyenne River in western Wells County and underlies most of the western half of the county, except in deeply cut buried valleys. A small outlier of the formation occurs in the south-central part of the county (fig. 5).

The thickness of the formation in Wells County ranges from 0 to about 250 feet. The greatest thickness is in the southwestern part of the county. Test holes drilled into the formation penetrated blue-green to olive-gray sandy clay and brittle blocky siltstone. Generally the material is calcareous.

Hell Creek Formation

The Hell Creek Formation overlies the Fox Hills Formation in extreme southwestern Wells County. Only one test hole is known to have penetrated the formation. This test hole, at 145-73-24ddc, penetrated 42 feet of greenish-black to dusky-blue-green shale or siltstone from 273 to 315 feet below land surface. Bluemle and others (1967, p. 6) report that the Hell Creek Formation is composed of siltstone ranging from 0 to 50 feet in thickness in Wells County. The formation is not known to be water bearing in Wells County, although wells tapping sandstone beds in the formation in Burleigh County yield water (Randich and Hatchett, 1966, p. 29).

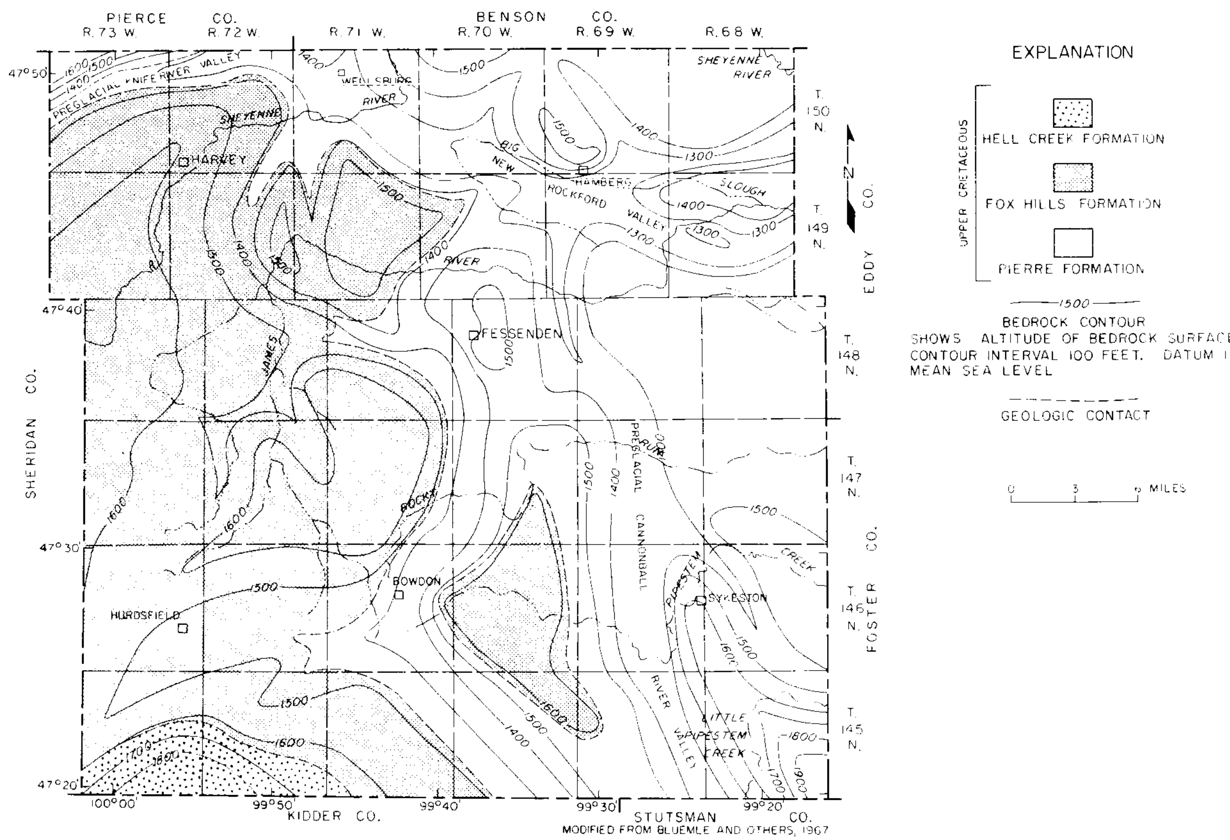

FIGURE 5. Bedrock geology.

Wells County is extensively covered with glacial drift that has an average thickness of about 100 feet, but exceeds 400 feet in buried valleys. The surficial deposits probably are of Wisconsin age, and were formed during the last phases of the Pleistocene Epoch. The age of an end moraine in the lower southwestern corner of the county was determined to be 11,650±310 years (Bluemle and others, 1967, p. 12). The glacial drift contains the most important aquifers in the county.

The major types of glacial drift in Wells County are shown on figure 6. Deposits of dead-ice moraine, which consist mainly of till and resulted from the slow melting of large masses of debris-covered stagnant or "dead" ice, cover approximately 400 square miles in the southwestern part of the county. Ground moraine deposits, which are widespread accumulations of drift consisting chiefly of till, cover the largest part of the county. Approximately 100 square miles of the county is covered by end moraine, which resulted from glacial deposition at the margin of a glacier. The end moraine deposits generally are composed of bouldery till.

Substantial areas of the county, particularly in the northwest, are underlain by glacial outwash. These deposits were formed by debris-laden streams issuing from the melting ice.

Prior to and during glaciation, numerous stream valleys were cut into the soft shales and sandstones that form the bedrock of Wells County. These valleys, which in most places are covered with glacial deposits, are shown in figure 5.

Two major preglacial drainage systems (fig. 5) are inferred to have been present in Wells County, and are represented by the preglacial Knife and Cannonball River valleys. These and the New Rockford valley, which may have been a glacial diversion channel, merit further discussion.

Deposits in the Buried Preglacial Knife River Valley

According to Bluemle and others (1967, p. 5) the preglacial Knife River valley enters the northwestern corner of Wells County near Harvey (fig. 5). The main valley contains drift that is more than 300 feet thick and averages nearly 250 feet in thickness (pl. 1, in pocket). The base of the valley is approximately 1,300 feet above msl and slopes eastward. Although test holes penetrating the preglacial Knife River valley west of Wellsburg encountered deposits of glaciofluvial material, the main aquifer occurs at the intersection of the Knife River and New Rockford valleys and seems to be related to the latter.

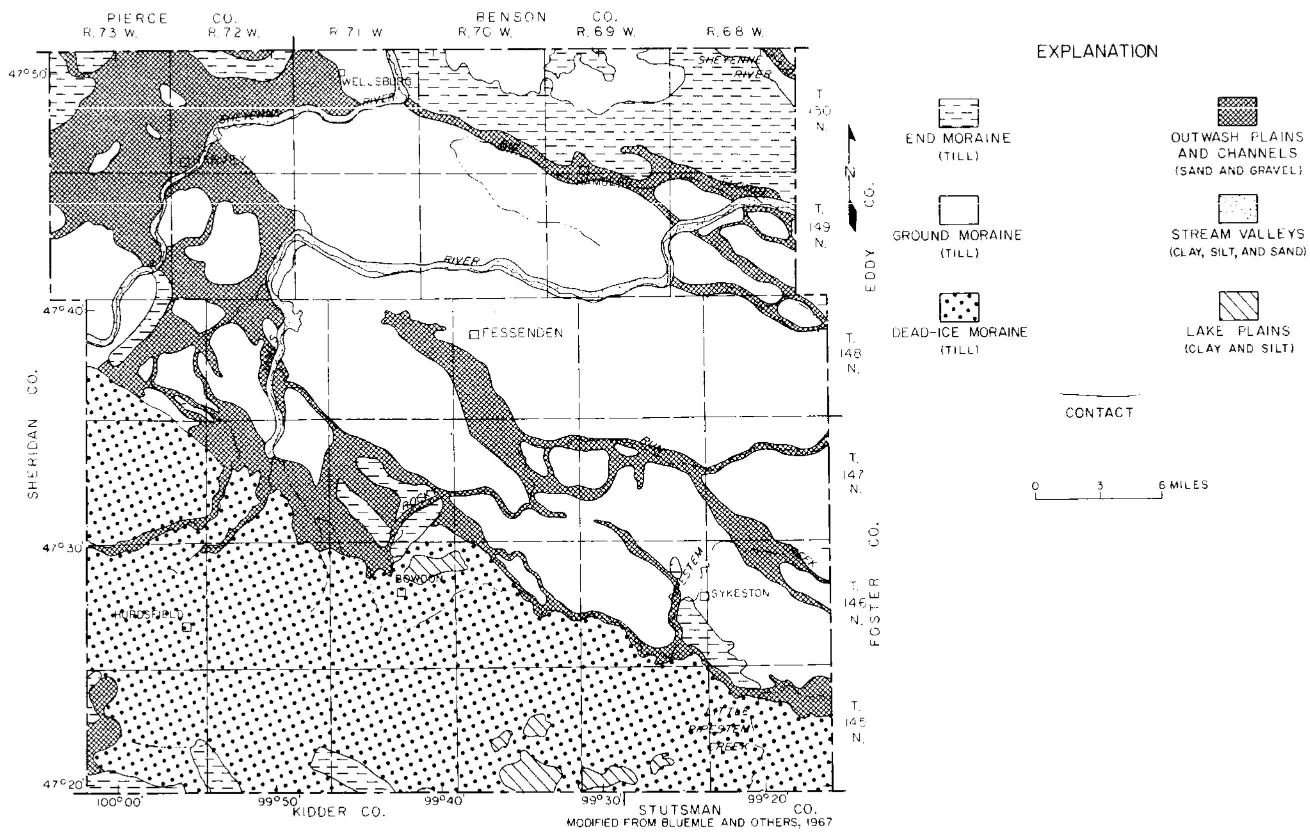

FIGURE 6. Generalized surface features and underlying deposits.

Deposits in the Buried Preglacial Cannonball River Valley

The preglacial Cannonball River valley was traced by Winters (1963, p. 16) into northwestern Stutsman County from eastern Kidder County. From northwestern Stutsman County it enters Wells County south of Sykeston (fig. 5). The drift covering the valley is over 400 feet thick in the Coteau du Missouri and approximately 300 feet thick in the Drift Prairie (pl. 1). East of Fessenden, the base of the valley is less than 1,300 feet above msl. The valley, which is intersected by the New Rockford valley south of Hamberg, may trend east-northeastward from this point and leave Wells County in the southeast corner of T. 150 N., R. 68 W. (fig. 5). Numerous side streams enter the main drainage system, forming a dendritic drainage pattern.

No significant amounts of sand and gravel were encountered in any test hole drilled into the preglacial Cannonball River valley in Wells County.

Deposits in the Buried New Rockford Valley

A broad, deeply buried valley enters Wells County north of Wellsburg and extends eastward across the northern part of the county. Bluemle and others (1967, p. 6-8) discuss the formation of this feature and refer to it as the Heimdal trench. Trapp (1968, p. 41), in his study of the ground-water resources of Eddy and Foster Counties, renamed the Heimdal trench the New Rockford channel to avoid confusion with the Heimdal diversion channel, a surficial melt-water feature named by Lemke (1960, p. 112) in his study of the geology of the Souris River area. Trapp's terminology is used in this report, except that the term valley is preferred as informal usage.

In Wells County, the New Rockford valley is more than 2 miles wide and contains drift that generally is between 250 and 300 feet thick. The drift is more than 300 feet thick, however, at the intersections with the preglacial Knife and Cannonball River valleys. The New Rockford valley has a southeasterly gradient and the valley floor is generally below 1,300 feet (msl).

Glaciofluvial deposits are common throughout the New Rockford valley. As much as 216 feet of sand and gravel has been penetrated by test drilling. The deposits are the major source of ground water in Wells County.

Of the 4,100 to 6,000 feet of consolidated rock in Wells County, only the Dakota Group, Pierre, and Fox Hills Formations yield water to wells. The Hell Creek Formation may be a potential aquifer but no wells are known to tap it.

Ground water in the bedrock generally has a high sodium content, which ranges from 80 to 99 percent of the total cations. However, it is relatively soft compared to water in the glacial drift. The high sodium results from the chemical process of ion exchange in which sodium in the clay minerals of the bedrock is exchanged for calcium and magnesium in the water that percolates down from the overlying drift (Hem, 1959, p. 219-223).

Dakota Aquifer

The water-bearing beds of sandstone and sand in the Dakota Group are herein collectively referred to as the Dakota aquifer. The Dakota aquifer comprises one of the largest ground-water reservoirs in the United States. It underlies nearly all of North Dakota except for the eastern part of the State where rocks of the Dakota Group were eroded prior to glaciation.

The depths to the Dakota aquifer in Wells County are shown on figure 7. Drillers in North Dakota generally report encountering three different flows of water from different sandstone layers in the Dakota. Both Simpson (1935, p. 19) and Wenzel and Sand (1942, p. 15) differentiated these flows on the basis of water quality. According to Wenzel and Sand (1942, p. 15), the water from the upper part of the Dakota aquifer is soft and somewhat salty. It generally becomes harder and lower in chloride content as the deeper layers are penetrated. The deepest sandstone layers produce very highly mineralized water.

Two flowing wells (149-72-7aaa and 148-70-13baa) tap aquifers in the Dakota in Wells County. A study of the reported water levels from the Dakota wells in the county indicates that the artesian head rises to approximately 1,600 feet above msl. Consequently, a well drilled to the Dakota from a land surface altitude of 1,600 feet or less should flow.

Water from the Dakota aquifer in Wells County is soft, but highly mineralized and generally unsatisfactory for domestic use. The water differs from a sodium sulfate chloride to a sodium sulfate type. The average concentration of selected constituents from six samples of Dakota water is as follows:

Iron	0.9 ppm
Calcium	5.6 ppm
Magnesium	1.9 ppm
Sodium	1,070 ppm
Bicarbonate	630 ppm
Carbonate	15 ppm
Sulfate	1,180 ppm
Chloride	430 ppm
Fluoride	4.6 ppm
Hardness	22 ppm
Dissolved solids	3,020 ppm

By U. S. Public Health Service standards, the water contains excessive amounts of chloride, fluoride, iron, and sulfate. The water is highly toxic to most domestic plants and small grain crops.

Very few quantitative data are available on the hydrologic properties of the Dakota aquifer. Kelly (1966, p. 22) gives a general range of 12,000 to 16,000 gpd (gallons per day) per foot for the coefficient of transmissibility and 0.0007 for the coefficient of storage for the Dakota aquifer in Barnes County.

Water from the Dakota aquifer is being used as a public water supply by the city of Bowdon, and previous to 1930 the city of Harvey also used it for a water supply.

Pierre Aquifer

Although the Pierre Formation is not a major aquifer in Wells County, there are certain areas in the county where it is the only available source of ground water without drilling to aquifers in the Dakota Group. These areas are generally in the southeastern quarter of the county.

Only small quantities of water are available from the Pierre. The formation, which consists of shale and mudstone, has a very low permeability and water movement through the Pierre is restricted to openings along joint systems and cleavage planes that have developed in the upper part of the shale. These fractures were produced by weathering and, perhaps, glacial erosion. Most of the water in the Pierre enters by seeping down through the overlying drift.

Six water samples were collected from wells that probably tap the Pierre aquifer. The water type differs from sodium bicarbonate to sodium chloride, with sodium sulfate and calcium bicarbonate also being reported. Chloride averages 380 ppm and dissolved solids average 1,850 ppm.

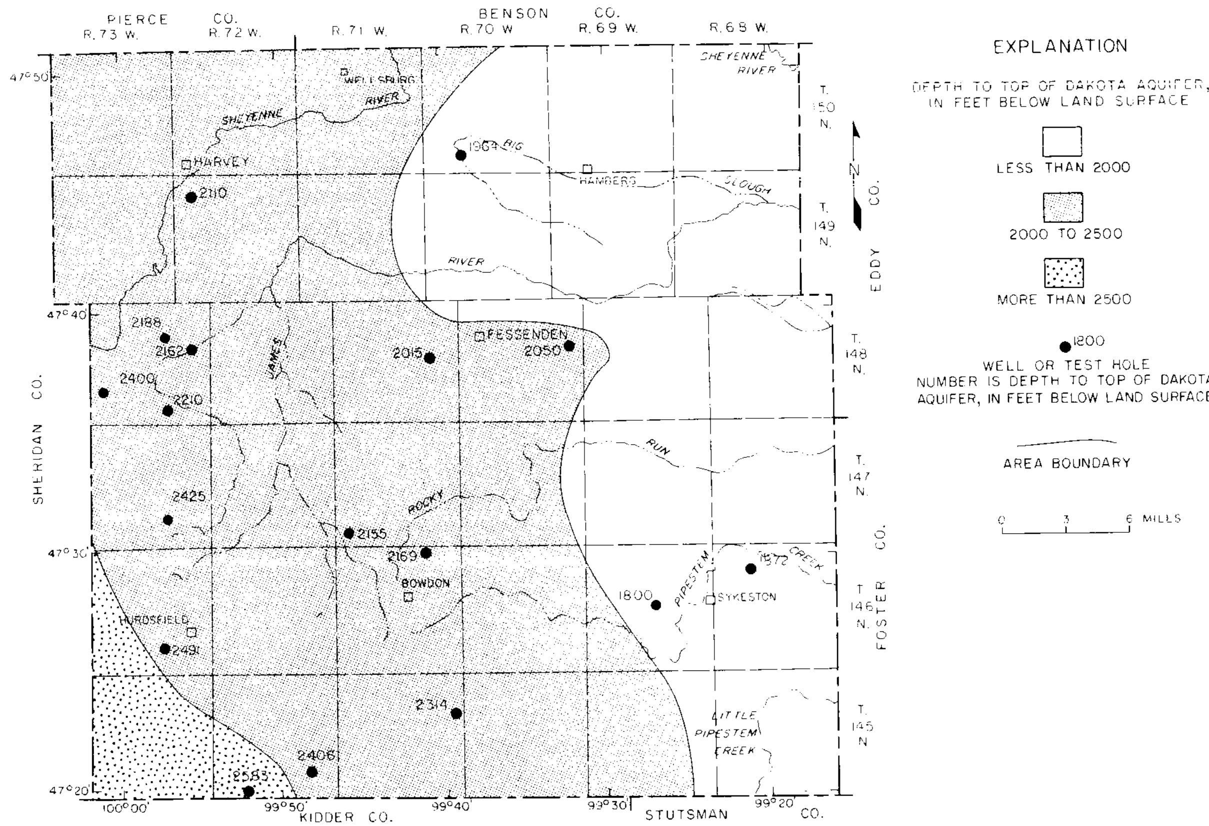

FIGURE 7. Depth to Dakota aquifer.

A detailed study of the Pierre aquifer was made at Michigan City, North Dakota (Aronow and others, 1953). Although the study area is approximately 55 miles northeast of Wells County, the data may be applicable to Wells County because of the uniform lithology of the Pierre. The coefficients of transmissibility obtained from pumping tests conducted on wells penetrating the Pierre in the Michigan City area ranged from 490 to 900 gpd per foot and averaged 710 gpd per foot. Values for the coefficient of storage ranged from 2.8×10^{-4} to 5.8×10^{-4} and averaged 4.2×10^{-4} (Aronow and others, 1953, p. 76). On the basis of these low values, the Pierre aquifer should be expected to yield only small quantities of water to wells.

Fox Hills Aquifer

The Fox Hills aquifer is present throughout the western part of Wells County and supplies a large part of the water requirements for domestic and farm needs in that area. The water is yielded from permeable layers of sand or sandstone present throughout the formation.

Water in the Fox Hills aquifer is confined under considerable hydraulic pressure and many of the wells tapping the aquifer will flow at land surface. Most of these are in the southwestern part of the county, but one is located at 148-71-33add in the central part. Water-level fluctuations in selected observation wells are shown in figure 8.

Recharge to the Fox Hills aquifer probably occurs in areas of shallow drift cover in Wells County and farther west.

The water from the Fox Hills in Wells County generally is a sodium bicarbonate type, although samples of sodium sulfate and calcium bicarbonate water were collected. Dissolved solids averaged 1,690 ppm and hardness ranged from 10 ppm at 149-72-7ddd to 555 ppm at 149-71-28dab. Where the Fox Hills aquifer is covered by less than 50 feet of drift, the water generally has a chloride content of less than 50 ppm; whereas, where the Fox Hills is covered by 100 feet or more of drift, the water contains more than 100 ppm chloride. This suggests that the water in the Fox Hills underlying shallow drift cover is a mixture of water percolating downward through the drift and water moving laterally through the Fox Hills Formation.

In many parts of Wells County, water from the Fox Hills is of better quality than that found in the glacial drift. One method of distinguishing Fox Hills water from water in the glacial drift is by comparison of boron content. Samples taken from wells in the Fox

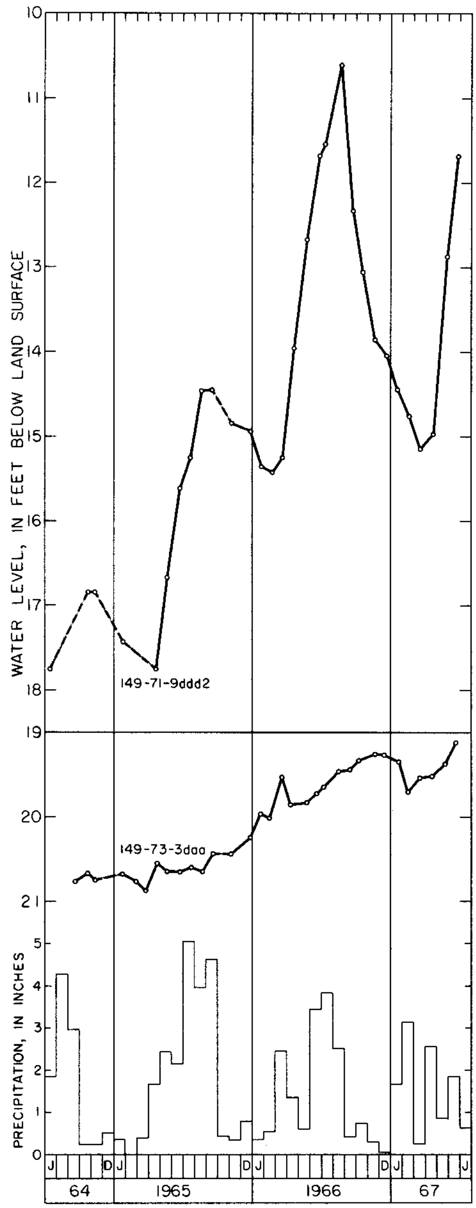

FIGURE 8. Water-level fluctuations in the Fox Hills aquifer and precipitation at Fessenden.

Hills Formation in Wells County averaged 1.83 ppm boron; whereas, water from drift wells in the county generally averaged less than 1 ppm boron.

Wells penetrating the sandy zones in the formation will produce from 5 to 10 gpm (gallons per minute), which is adequate for most domestic and livestock needs. However, in some areas of the State, yields of 50-100 gpm are possible from the Fox Hills.

Hell Creek Aquifer

Data are not available concerning the water-bearing properties of the Hell Creek Formation in Wells County. In Burleigh County, Randich and Hatchett (1966, p. 29) report that the formation generally contains sandy members having a high porosity but low permeability. If these sandy zones are present in Wells County, small quantities of water should be obtainable from the formation.

GROUND WATER IN THE GLACIAL DRIFT

The glacial drift contains the most important aquifers in Wells County. The aquifers consist of unconsolidated sand and gravel deposits. Some of these deposits are surficial and underlie outwash plains or melt-water channels (fig. 6). Others lie deep beneath younger deposits in buried bedrock valleys, or occur as widespread sheetlike layers of sand and gravel essentially unrelated to bedrock topography.

Water from the glacial drift aquifers typically contains about 1,200 ppm dissolved solids. The water is generally very hard with a minimum sampled hardness of 139 ppm and a maximum of 2,700 ppm. Sodium content is generally less than 50 percent of total cations, which distinguishes it from the higher sodium waters of the bedrock.

Potential yields from the glacial drift aquifers are from a few gallons per minute to more than 500 gpm. Plate 2 (in pocket), which shows the potential yields from the major aquifers, was prepared largely on the basis of known thickness and estimated permeabilities of the water-bearing materials, according to a method outlined by Trapp (1968, p. 36-40). The test-hole logs from which the permeability evaluations were made were given by Buturla (1968, table 4) and are not repeated in this report.

Several aquifers (New Rockford, Heimdal, Rusland, and Manfred) in the northern part of the county may be interconnected in places, and stress on one by pumping may influence the others to a greater or lesser degree. Pumping from an unconfined or water-table aquifer such as the Heimdal generally does not affect water levels any great distance away from the pumped well; however, pumpage from confined aquifers such as the Manfred can affect water levels as much as several miles distant from the pumped well. How much the water levels are affected depends upon hydrogeologic conditions and the rate and duration of pumping. For example, pumping in a well field in the Manfred aquifer south of the Sheyenne River might affect water levels in the Rusland aquifer. In addition, the pumping could cause reversal of the regional ground-water gradient that normally is toward the north and thus reduce the quantity of underflow to the New Rockford aquifer.

Outwash-Plain Aquifers

Outwash is sorted and stratified drift–usually sand and gravel–deposited by water from melting glacial ice. Some outwash may be only a few feet thick and lie above the zone of saturation. The sand and gravel there would be dry, and a well drilled in such a location would not yield water from these deposits. In other areas the outwash may be thicker and partly saturated, as in the area around Harvey and south of Fessenden, but not have sufficient saturated thickness to yield more than a few gallons per minute.

Only one area in Wells County is underlain by outwash-plain deposits of sufficient thickness to be mapped as a major aquifer. It has been named the Rusland aquifer.

Rusland Aquifer–The Rusland aquifer is associated with an outwash deposit in a tributary valley of the James River and adjacent lowlands in west-central Wells County. The aquifer underlies an outwash plain described by Bluemle and others (1967, p. 27). As shown in plate 2, the aquifer underlies approximately 6 square miles. The aquifer probably is closely related to, and may have a hydrologic connection with, the Manfred aquifer.

Five test holes penetrated the Rusland aquifer. Test holes 148-72-15aba and 149-72-24ddb penetrated more than 90 feet of clean, medium to very coarse sand. Other test holes near the western edge of the aquifer penetrated 20 to 30 feet of saturated material. The aquifer thins to the northwest away from the James River.

Generally the water table in the Rusland aquifer is from 2 to 7 feet below land surface. The hydrographs of water-level fluctuations in the aquifer (fig. 9) show an annual cycle of highs in late spring or early summer and lows in the late winter or early spring. The maximum range of water-level fluctuation for the period of record was about 4 feet.

Assuming an average saturated thickness of 50 feet and a porosity of 0.3, approximately 60,000 acre-feet of water is stored in the aquifer; only a part of this quantity, however, would be available to wells. (See the section in this report dealing with principles of ground-water occurrence.)

In the shallow western segment of the aquifer, the water contains an average of 2,000 ppm dissolved solids and is a calcium sodium to sodium calcium sulfate type. The water is extremely hard with about 900 ppm hardness. A large part of the hardness is permanent (noncarbonate) hardness.

Water in the aquifer near the James River and Manfred aquifer contains less than 1,000 ppm dissolved solids and is a sodium bicarbonate to a calcium sodium bicarbonate type. The irrigation classifications of two samples were C4-S1 and C4-S2. Generally the better irrigation water is in the eastern section, which receives recharge from the James River.

Only a few stock wells are presently (1968) developed in the Rusland aquifer.

Estimated yields range from a low of about 50 gpm along the margins of the aquifer to about 250 gpm in the central part.

Melt-Water Channel Aquifers

As the glaciers in Wells County melted and receded toward the north, water flowed from the margin of the ice and cut a series of melt-water channels. In Wells County the regional slope of the topography is northeastward and, at first, the melt water tended to flow in this direction; but due to readvances of glacial ice from the north, most of the melt water was diverted southeastward along the ice margins.

Outwash deposited in these channels consists of coarse sand and gravel as much as 70 feet thick. However, most of the melt-water channels contain only thin veneers of outwash, which may be thick enough in places to provide small amounts (1-10 gpm) of water for domestic or livestock use. Three of the melt-water channels in Wells County contain sufficient thicknesses of outwash material to yield

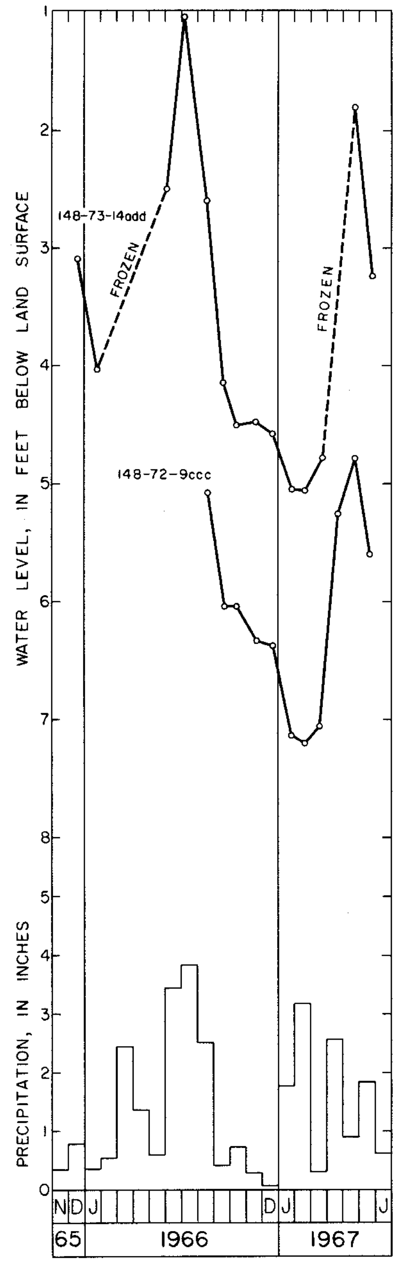

FIGURE 9. **Water-level fluctuations in the Rusland aquifer and precipitation at Fessenden.**

more than 50 gpm to wells. These are the Pipestem Creek, Rocky Run, and Heimdal aquifers.

Water-table conditions generally prevail, and water levels are close to the land surface. Locally the water-bearing materials may be covered by impermeable clays or silts and artesian conditions occur.

Pipestem Creek Aquifer–The Pipestem Creek aquifer consists of deposits of outwash in the valleys of Pipestem and Little Pipestem Creeks in southeastern Wells County. Approximately 13 square miles of the aquifer is included in the county. Trapp (1968, p. 86-88) mapped about 9 square miles of the aquifer in adjacent Foster County.

Four test holes were drilled into the aquifer in Wells County; the average thickness was about 20 feet. The material ranged from medium to coarse sand and gravel.

The water level in the aquifer is 5 to 12 feet below land surface. Figure 10, hydrographs of two observation wells (145-68-10bcc and 145-68-12add) in the aquifer, shows a rise of water levels in the spring, indicating recharge. The recharge results largely from direct infiltration of precipitation and streamflow from Pipestem and Little Pipestem Creeks.

A short-term (330 minutes) aquifer test was made using well 146-70-13ccc. The data are too incomplete to determine aquifer coefficients, but a specific capacity of 5 gpm per foot of drawdown was obtained for the well. Considering that the well was not screened but constructed of pipe slotted with a hacksaw, a figure of 4 or 5 times this amount would seem reasonable for a properly constructed production well at the same site.

Approximately 50,000 acre-feet of water is in storage in the Pipestem Creek aquifer in Wells County. However, only a part of this quantity would be available to wells.

Water in the Pipestem Creek aquifer contains an average of 780 ppm dissolved solids and differs from a calcium sodium bicarbonate type to a sodium bicarbonate type. The water has an average hardness of 420 ppm, which places it in the very hard classification. As shown in figure 4, the water is in the C3-S1 irrigation class and may be used on soils having adequate drainage.

The city of Sykeston and a few domestic and stock wells presently withdraw water from the Pipestem Creek aquifer. Based on pumpage figures at Sykeston and the number of people and cattle served by other wells tapping the aquifer, approximately 7,500,000 gallons per year is withdrawn from the aquifer in Wells County.

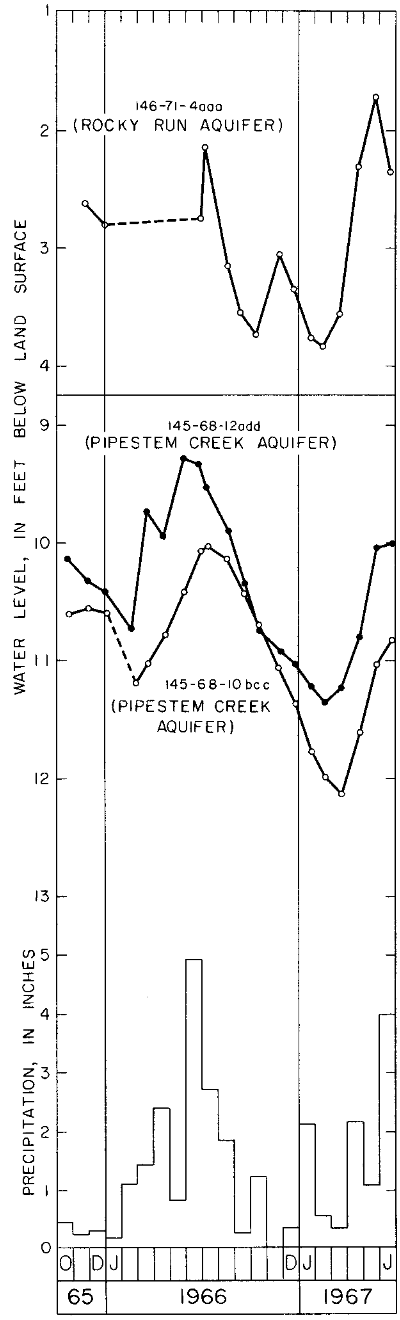

FIGURE 10. Water-level fluctuations in the Pipestem Creek and Rocky Run aquifers and precipitation at Sykeston.

Rocky Run Aquifer–The Rocky Run aquifer is a surficial outwash deposit in Rocky Run, a glacial melt-water channel. The deposit covers approximately 5 square miles in the south-central part of the county. The aquifer is generally confined to the valley formed by Rocky Run but underlies substantial areas of an outwash plain bordering the valley.

Two test holes were drilled into the aquifer. Test hole 146-71-4aaa penetrated 48 feet of saturated medium to very coarse sand and fine gravel. Test hole 147-70-19add penetrated 72 feet of saturated gravelly sand composed mainly of shale particles. The aquifer probably thins where the channel merges into the outwash plains.

The water level in an observation well constructed at the site of test hole 146-71-4aaa averages approximately 3 feet below land surface. The hydrograph of this well (fig. 10) shows a rise in the water level in November 1966, corresponding to an increase in precipitation in October at Sykeston. Since the soil was not frozen, the precipitation that fell in October reached the aquifer as direct infiltration. During the spring and summer, evapotranspiration from growing plants normally uses up most of the precipitation before it can reach the aquifer as recharge. Precipitation and streamflow from Rocky Run are the major sources of recharge to the Rocky Run aquifer.

A rough approximation of the amount of water stored in the Rocky Run aquifer, based on a thickness of 60 feet and a porosity of 0.3, is about 60,000 acre-feet. However, only a part of this quantity would be available to wells. A water sample from observation well 146-71-4aaa contains 570 ppm dissolved solids, 360 ppm carbonate hardness, and is a calcium bicarbonate type. Figure 4 shows that the water is in the C3-S1 irrigation class and would be usable for irrigation on soils with adequate drainage. Wells developed in parts of the aquifer composed of detrital shale sands may yield water of poorer quality than those developed in the quartz and limestone sands and gravels.

Heimdal Aquifer–The Heimdal aquifer is composed of outwash deposits in a glacial melt-water channel that trends approximately northwest-southeast in the northern part of Wells County. Lemke (1960, p. 112), who named the channel the Heimdal diversion channel, states that it formerly carried glacial melt water from glacial Lake Souris. The aquifer covers about 15 square miles in Wells County. It is more than 1 mile wide in some localities, has an average thickness of 40 feet, and consists mainly of very coarse sand.

The Heimdal aquifer is closely associated with and may be hydrologically connected to the deeply buried sand and gravel of the New Rockford aquifer (pl. 2). Recharge from the Heimdal aquifer probably enters the New Rockford aquifer in localities where the aquifers are in contact or are separated by thin layers of till.

In most places the aquifer is unconfined and water-table conditions prevail. Water levels in the aquifer vary from near land surface to 7 feet below land surface. Direct infiltration of precipitation is the primary source of recharge, and water levels closely follow the precipitation pattern, as shown in figure 11.

Assuming a saturated thickness of 40 feet and a porosity of 0.3, approximately 100,000 acre-feet of water is stored in the aquifer. However, only a part of this quantity would be available to wells.

The water in the aquifer typically contains about 500 ppm dissolved solids. It is a calcium bicarbonate type and is very hard, averaging about 400 ppm carbonate hardness and approximately 130 ppm noncarbonate hardness. Figure 4 shows that the irrigation index ranges from C2-S1 to C3-S1, indicating that the water can safely be used under most conditions of irrigation.

The villages of Heimdal, Hamberg, and Bremen are the major users of water from the Heimdal aquifer. The aquifer formerly supplied water for steam engines on the Great Northern Railway. The railroad well at Bremen was reported by Simpson (1929, p. 264) to have yielded 264,000 gpd, and the railroad well at Heimdal was reported to have yielded 150,000 gpd (Filaseta, 1946, p. 9-10).

Yields of as much as 250 gpm can be expected from properly designed wells in localities where the aquifer is 30 or more feet thick. Wells that intersect both the Heimdal and the underlying New Rockford aquifer can be expected to yield as much as 500 gpm.

Buried Aquifers

Two types of buried aquifers occur in Wells County; they are buried valley deposits and buried outwash-plain deposits.

Buried valley deposits consist of glaciofluvial material in deep bedrock valleys overlain by younger drift. These valleys, shown in figure 5, were formed during the early part of or before the Pleistocene Epoch. During deglaciation, the valleys carried large volumes of glacial melt water that deposited thick beds of sand and gravel as well as silt and clay. Some of these deposits in Wells County are more than 200 feet thick.

Buried outwash-plain deposits consist of sheetlike glaciofluvial materials deposited over relatively wide areas, apparently unrelated to bedrock topography. The deposits were subsequently covered by

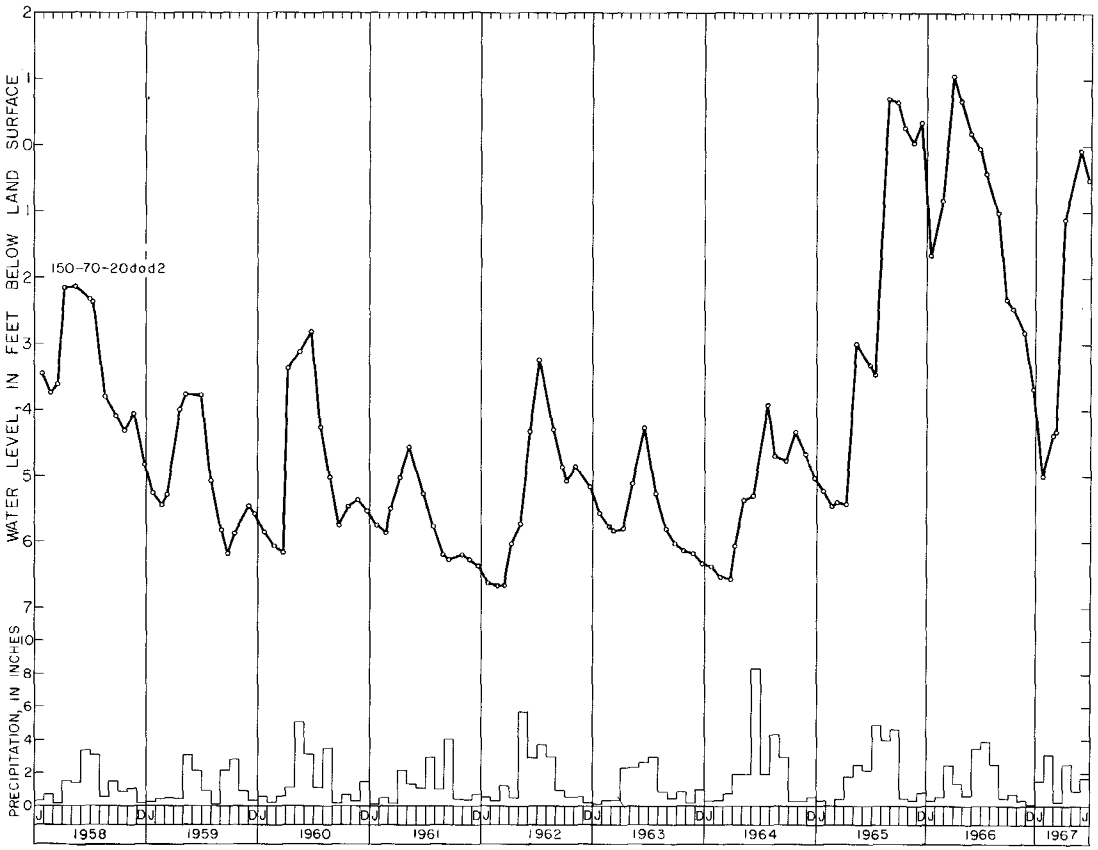

FIGURE 11. Water-level fluctuations in the Heimdal aquifer and precipitation at Fessenden.

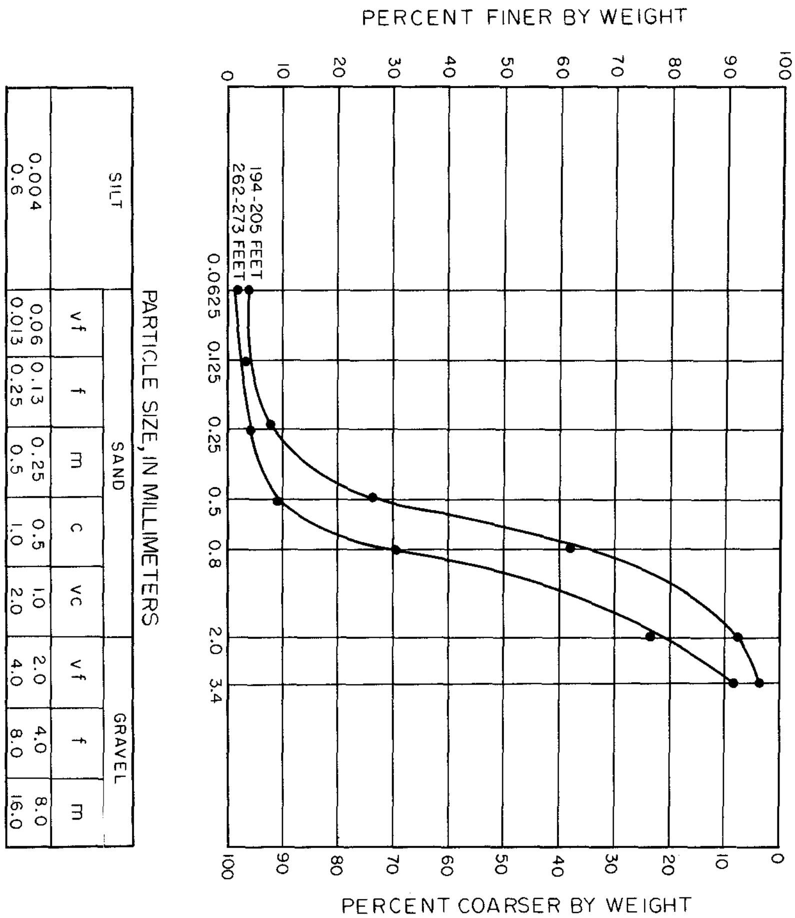

FIGURE 12. Particle-size distribution at depths of 194-205 and 262-273 feet in the New Rockford aquifer at test hole 150-70-31cdd.

younger drift. The buried outwash-plain deposits range in thickness from about 5 feet to as much as 70 feet. They may underlie an area as small as 1 acre, or as large as several square miles.

The buried aquifers generally are confined and the water is under pressure, but flowing wells are uncommon. Some of the small isolated pocketlike aquifers can be pumped nearly dry in a relatively short period, while others will support large yields sufficient to meet municipal or irrigation demands for years.

New Rockford Aquifer–The New Rockford aquifer is a buried valley aquifer that underlies parts of Wells, Eddy, Foster, and possibly Griggs Counties. Its northern extent is unknown, but it probably extends into Benson County. The aquifer has an average width of 2 miles and underlies approximately 70 square miles in northern Wells County. Trapp (1968, p. 41) reports that the aquifer underlies 82 square miles in Eddy and Foster Counties.

The aquifer has been delineated on the basis of 26 test holes in Wells County. Of these, 14 were drilled as part of this study and the other 12 had been drilled previously.

The New Rockford aquifer in Wells County has an average thickness of 120 feet. The aquifer is buried under an average thickness of 134 feet of glacial drift, which consists mainly of till.

The deposits, as they appear in the drill cuttings, consist of mixed sand and gravel. The predominant material is medium to coarse sand with considerable amounts (about 25 percent) of shale and lignite particles. Particle size may generally increase downward in the aquifer, as illustrated in the particle-size distribution graph for test hole 150-70-31cdd (fig. 12).

The New Rockford aquifer probably receives recharge as underflow from the Manfred and Heimdal aquifers, downward infiltration of precipitation through the overlying drift, and underflow from the adjacent bedrock deposits.

The principal areas of underflow are (1) south of Wellsburg where the Manfred aquifer intersects the New Rockford aquifer, and (2) south of Hamberg where ground water from the adjacent, but higher, Heimdal aquifer migrates southward into the New Rockford aquifer (fig. 13). The water-level contours indicate that ground water moves from the vicinity of Wellsburg southeastward toward a low south of Heimdal. From the other recharge area south of Hamberg, the ground water moves both westward toward the low south of Heimdal and eastward toward the county boundary.

Although the New Rockford aquifer is overlain by more than 100 feet of fine-grained glacial drift (mainly till), recharge probably enters

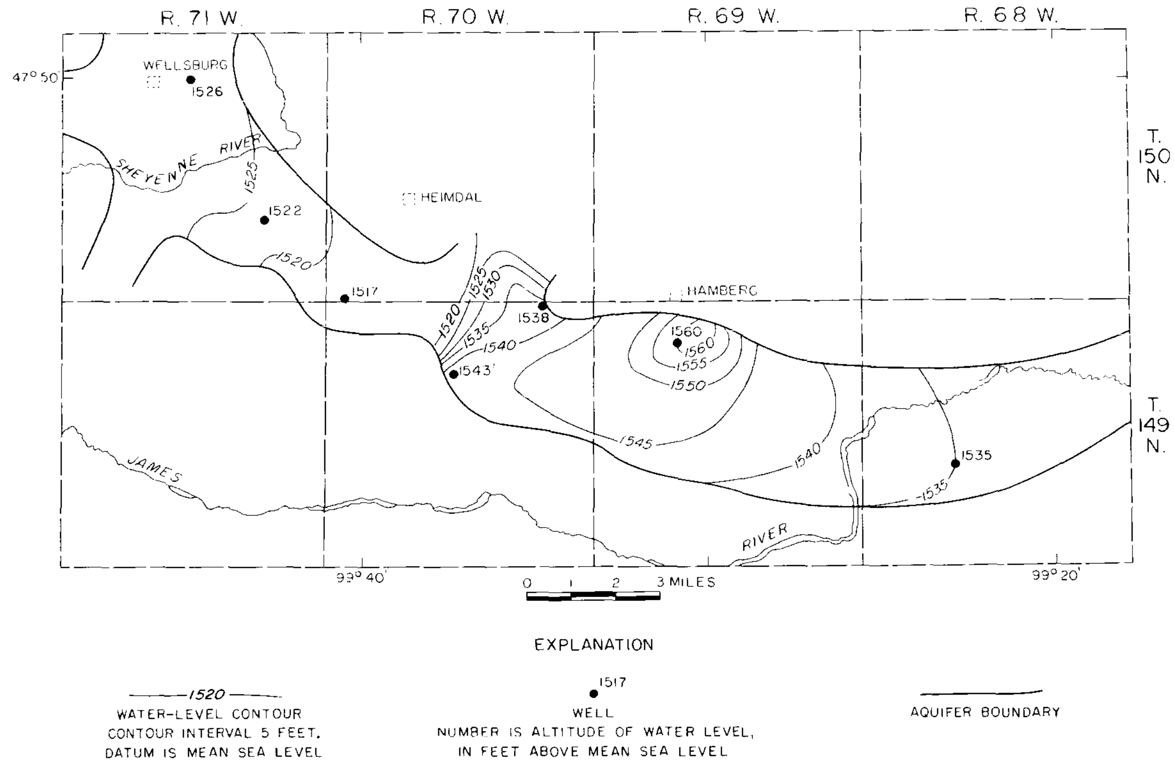

FIGURE 13. Altitudes of water levels in the New Rockford aquifer, August 1966.

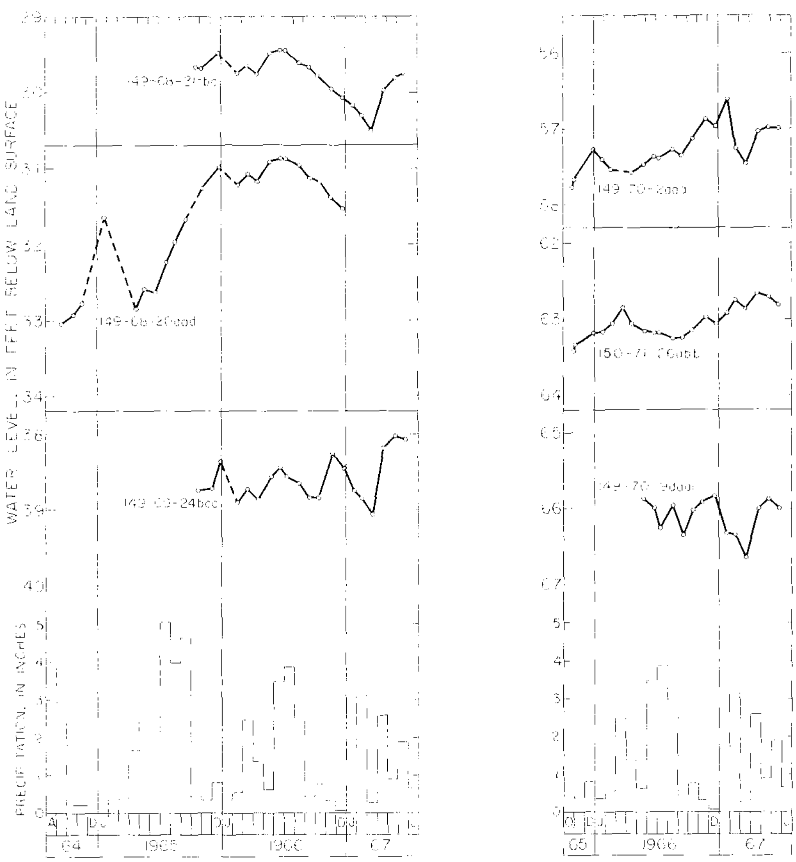

FIGURE 14. Water-level fluctuations in the New Rockford aquifer and precipitation at Fessenden.

the aquifer by infiltration from the overlying deposits. Hydrographs of selected observation wells in several parts of the New Rockford aquifer generally do not show a close correlation with precipitation, although long-term rises and declines of a year or more in duration are evident (fig. 14). In places, sand beds in the confining deposits may have direct connection with the deeper buried sands.

Recharge from the bedrock is indicated by a quality-of-water deterioration downgradient. Figure 15 shows an increase in chloride downgradient from the recharge area south of Hamberg, and figure 16 shows an increase in the SAR (sodium-adsorption ratio). Water from the bedrock in Wells County normally contains several hundred parts per million chloride and has a very high SAR.

Figure 13 indicates an area of relatively low water levels south of Heimdal. The area is located at the intersection of the New Rockford valley with a bedrock valley that trends more-or-less at right angles to it. Possibly ground water is being discharged from the New Rockford aquifer at this point.

In 1947 an aquifer test was made using the city of Fessenden's well (149-70-4daa2), which taps the New Rockford aquifer. Analysis indicated a boundary condition developing early in the test, which would be expected because the well is located near the south edge of the aquifer.

Trapp tested the New Rockford aquifer at New Rockford in Eddy County (1968, p. 51), and determined an average transmissibility of 260,000 gpd per foot and a coefficient of storage of 0.0004.

The New Rockford aquifer contains the greatest amount of recoverable ground water stored in Wells County. Based on an area of 70 square miles, an average thickness of 120 feet, and an assumed porosity of 0.3, approximately 1,800,000 acre-feet of water is in transient storage within the county. Trapp (1968, p. 43) estimated storage of 1,700,000 acre-feet of water in Eddy and Foster Counties. Thus, there is about 3,500,000 acre-feet of ground water stored in the 3-county area. However, only a part of this quantity would be available to wells.

Yields of 250-500 gpm should be obtainable in most parts of the aquifer, and in excess of 500 gpm in the thicker parts such as in areas south of Heimdal and Bremen (pl. 2). However, yields will be less along the flanks of the aquifer in localities where the thickness is less.

In Wells County the quality of water in the New Rockford aquifer differs substantially from place to place. The quality of water that any given well will yield depends on its location with respect to a recharge area. Figures 15 and 16 show the deterioration of water quality as measured by its chloride content and its SAR as the water moves

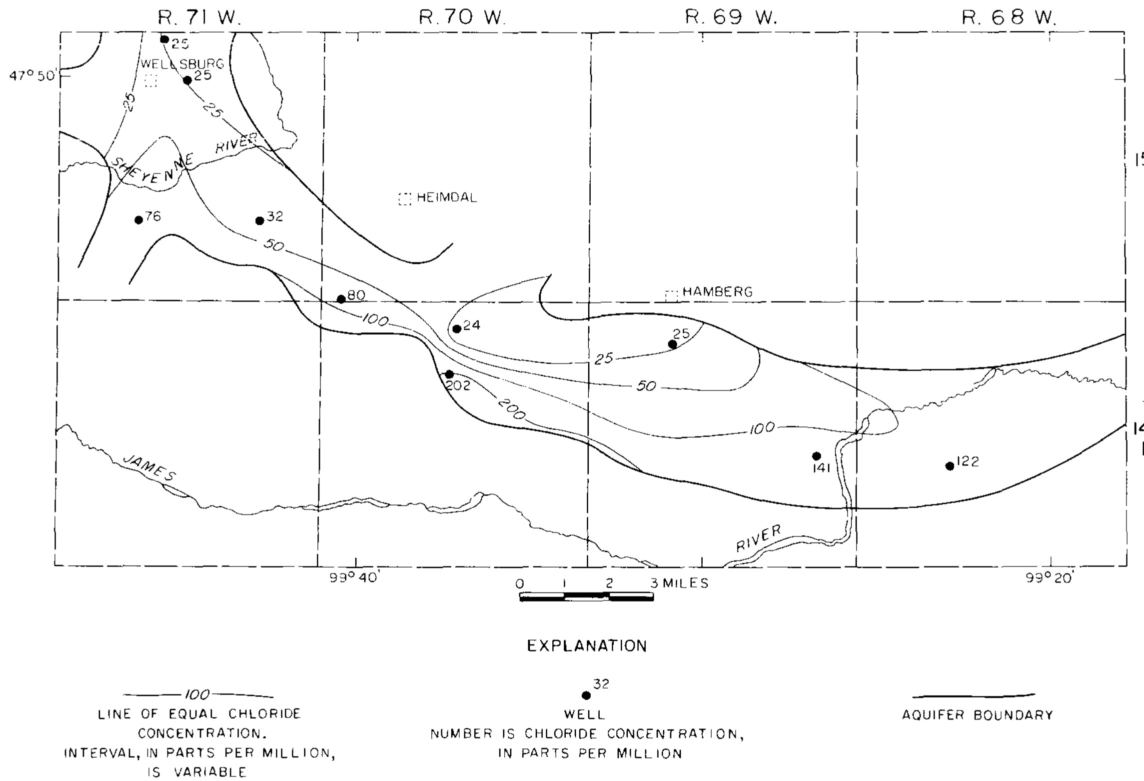

FIGURE 15. Chloride content (in parts per million) in the New Rockford aquifer, 1965-66.

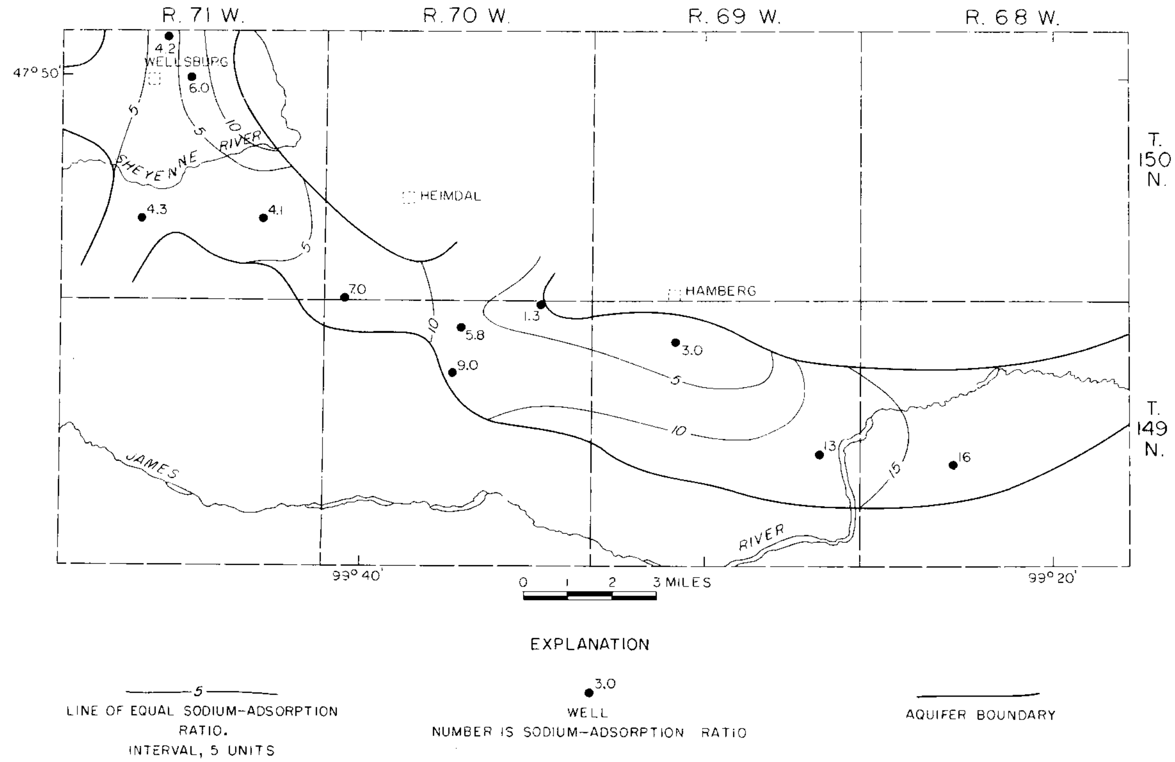

FIGURE 16. Sodium-adsorption ratio of water in the New Rockford aquifer.

through the aquifer from the recharge area south of Hamberg. The higher SAR and chloride content near the edges of aquifer indicate recharge from the bedrock.

The average dissolved solids content of the samples analyzed was 1,200 ppm, and most of the samples indicated a sodium bicarbonate type water. The average carbonate hardness of the water sampled was 420 ppm. Irrigation indices, as shown on figure 4, range from C3-S1 to C4-S3. In most cases the water is marginal for irrigation, but may be used for supplemental irrigation with proper management.

Although the New Rockford is the most productive aquifer in Wells County, it has had only slight development. The city of Fessenden, which is the major user of the aquifer within the county, withdraws an average of 20,000,000 gallons of water per year from their wells located at 149-70-4daa. Presently (1968) the only other use of the aquifer in Wells County is for domestic and livestock needs. On the basis of very general estimates of the number of wells, people, and livestock, approximately 30,000,000 gallons of water was pumped from the New Rockford aquifer in Wells County in 1965. Water use probably is far less than the recharge, and future development of the aquifer may depend principally on the quality of water needed.

Carrington Aquifer–The Carrington aquifer is a buried outwash deposit that underlies approximately 10 square miles in eastern Wells County. Trapp (1968, p. 58) reports that the Carrington aquifer underlies 48 square miles in northwestern Foster County. Bluemle and others (1967, p. 9) describe the origin of the Carrington aquifer as glacial outwash deposited on a bedrock lowland. The aquifer is completely buried by younger glacial deposits in Wells County, but Trapp (1968, p. 58) reports that the aquifer crops out in Scotts Slough (Foster County) 3 miles north of Carrington.

Three test holes penetrated the aquifer in Wells County. The maximum thickness penetrated was 48 feet in test hole 147-68-22aaa2. At this location the aquifer consisted of gravelly sand and was covered by 109 feet of younger drift, mainly till. The aquifer thins towards its edges, and test hole 147-68-1bbb, believed to be near the north edge, penetrated only 20 feet of medium to coarse sand. In most places in Wells County, the aquifer is about 40 feet thick and is covered by about 60 feet of till.

The relatively thick till cover probably impedes recharge to the Carrington aquifer. A principal area of recharge is Scotts Slough, in western Foster County, where the aquifer is at or near land surface. The hydrograph of well 147-67-19cbc, which is in Foster County (Trapp, 1966, p. 95; Buturla, 1968, p. 30) but very near the county line, shows a general rise in water level from 1964 to 1967 (fig. 17). This indicates that net recharge has exceeded discharge for the period.

Assuming an average saturated thickness of 40 feet and a porosity of 0.3, approximately 80,000 acre-feet of water is stored in the Carrington aquifer in Wells County. Trapp (1968, p. 58) has estimated that 400,000 acre-feet of water is in storage in Foster County. This would indicate that Wells County contains approximately 15 percent of the Carrington aquifer's storage. However, only a part of this quantity would be available to wells.

No aquifer tests were made of the Carrington aquifer in Wells County, but Trapp tested the aquifer at Carrington Irrigation Branch Station at well 147-66-31acc1 in Foster County. The test indicated a coefficient of transmissibility of 120,000 gpd per foot and a coefficient of storage of 0.032 (Trapp, 1968, p. 63).

Water from the Carrington aquifer contains an average of 640 ppm dissolved solids and is a sodium calcium bicarbonate type. The water is very hard, the average being 338 ppm. Figure 4 shows the water to be in the C3-S1 irrigation class, indicating that it could be used on soils having adequate drainage.

Several domestic and stock wells presently (1968) withdraw water from the Carrington aquifer in Wells County. Estimates based on the number of people and livestock using the wells that tap the aquifer indicate that 1,000,000 gallons per year is withdrawn from the aquifer in Wells County. In addition, large quantities of water are withdrawn from the aquifer in Foster County for municipal purposes (Trapp, 1968, p. 99-100) as well as irrigation.

There appears to be considerable potential for future development of the aquifer in Wells County, and well yields of as much as 250 gpm should be available in favorable localities.

Rosefield Aquifer--The Rosefield aquifer consists of buried outwash deposits that underlie an unnamed tributary of the James River in eastern Wells County. The aquifer underlies approximately 2 square miles in the northeastern part of Wells County and approximately 8 square miles in western Eddy and Foster Counties (Trapp, 1968, p. 66). Rasmussen (1945, p. 2-3), in a report on possible irrigation locations in North Dakota, briefly described the aquifer as a small artesian basin in Eddy County. The Rosefield aquifer may join and become continuous with the Carrington aquifer in extreme southwestern Eddy County.

Only one test hole (148-68-10ada) penetrated the aquifer in Wells County. At this location the aquifer consisted of 48 feet of saturated

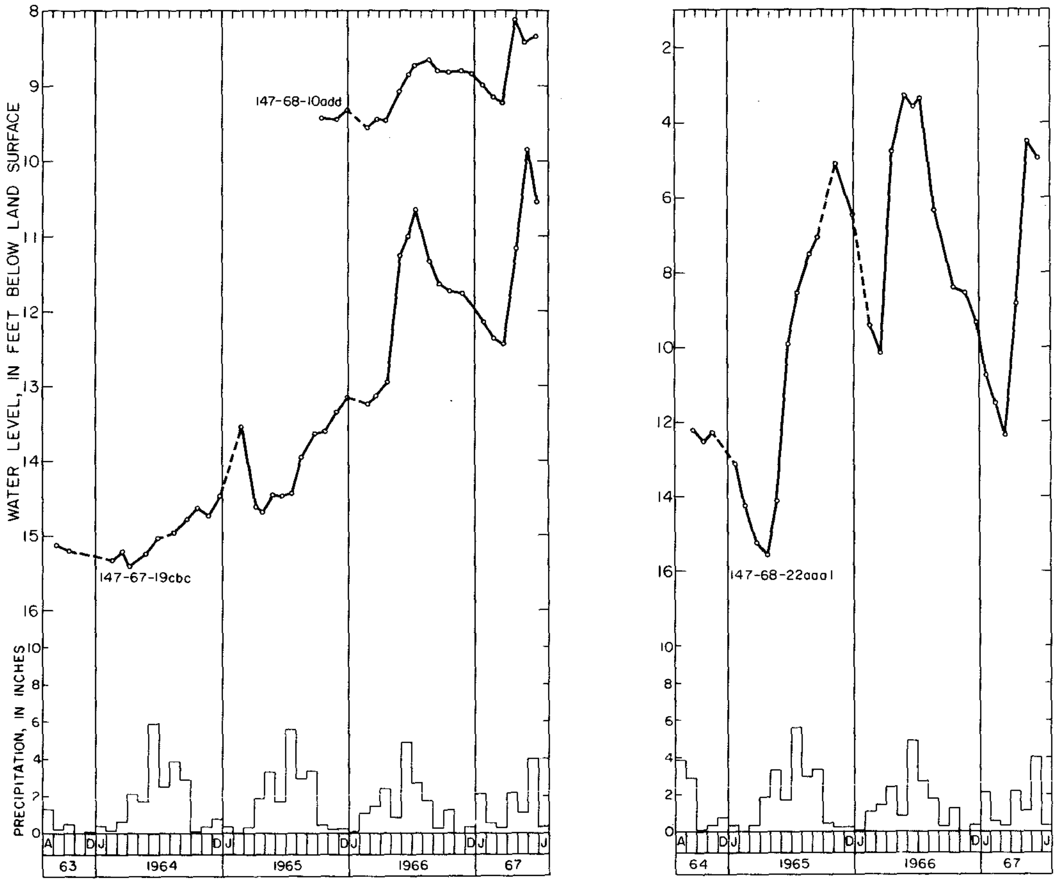

FIGURE 17. Water-level fluctuations in the Carrington aquifer and precipitation at Sykeston.

medium to coarse sand, overlain by 11 feet of sandy till. Test drilling indicates that the glaciofluvial materials probably thin westward.

Using a thickness of 48 feet, as penetrated in test hole 148-68-10ada, and a porosity of 0.3, approximately 20,000 acre-feet of water is stored in the Rosefield aquifer in Wells County. However, only a part of this quantity would be available to wells.

A water sample taken from the Rosefield aquifer contained 739 ppm dissolved solids and was a calcium bicarbonate type. The water had a hardness of 495 ppm. The irrigation index is C3-S1, indicating that it could be used on soils with adequate drainage.

Only a few stock and domestic wells presently (1968) tap the Rosefield aquifer in Wells County. In favorable localities, yields of as much as 250 gpm should be available from properly designed and constructed wells.

Manfred Aquifer–The Manfred aquifer is a buried valley deposit that underlies approximately 16 square miles in western Wells County. It lies in a narrow, sinuous, north-south-trending channel that may have been tributary to the preglacial Knife River or New Rockford valleys (fig. 5). The aquifer is hydraulically connected with the New Rockford aquifer near the Sheyenne River south of Wellsburg as well as to the river itself.

The thickness and nature of the water-bearing materials differed greatly in the 14 test holes that penetrated the aquifer (pl. 2). Test holes drilled into the southern part of the aquifer (south of Highway 15) penetrated medium to very coarse gravel with extremely large amounts of detrital lignite. Test hole 148-71-19cdd encountered 71 feet of sandy gravel from the surface down. Test drilling in the northern part penetrated mainly sand mixed with clay and silt layers covered by approximately 40 feet of younger glacial drift. South of Highway 15, the aquifer also is generally buried by younger drift, but does not seem to contain the silt and clay zones. The average thickness of the aquifer is about 70 feet.

Water levels range from less than 1 foot below land surface at 148-73-35daa to approximately 12 feet at 148-72-34dad (Buturla, 1968, p. 37-38). A few widely spaced water-level altitudes indicate a northward gradient toward the Sheyenne River.

Recharge to the Manfred aquifer is derived both from direct infiltration of precipitation and from seepage from the James River where it crosses the aquifer. In those localities where the aquifer is unconfined and has a direct connection with the surface, as in 148-71-19cdd, precipitation percolates readily into the aquifer.

Based on an average saturated thickness of 70 feet and a porosity of 0.3, approximately 200,000 acre-feet of water is in storage in the Manfred aquifer. However, only a part of this quantity would be available to wells.

Water from the Manfred aquifer generally is a sodium bicarbonate type, although well 148-72-34dad, which is in an area of recharge, yielded a calcium bicarbonate type. Dissolved solids content of the water averages 850 ppm. The water is hard, with an average hardness of 350 ppm. Generally the water is in the C3-S1 irrigation class, indicating that it could be used on soils having good drainage.

Only a few domestic and stock wells presently (1968) withdraw water from the aquifer, and there appears to be good potential for future development. Wells constructed in the northern part of the aquifer may yield as much as 500 gpm.

South Fessenden Aquifer--The South Fessenden aquifer consists of a small buried glaciofluvial deposit that underlies approximately 3 square miles in central Wells County. The aquifer is distinguished from the Fessenden aquifer, a small aquifer consisting of fine sand underlying the city of Fessenden described by Filaseta (1946, p. 11-12). The Fessenden aquifer was depleted in the early 1940's and is not considered further in this report.

The South Fessenden aquifer was penetrated by two test holes. Test hole 148-71-24ddd penetrated 57 feet of medium-to coarse-grained saturated sand overlain by 31 feet of till. Test hole 148-70-32ccb, farther south, drilled in 1945 for the study of the Fessenden area (Filaseta, 1946), encountered 100 feet of silty sand and 10 feet of medium to coarse gravel with 70 feet of overlying till.

Water levels measured monthly from November 1966 until July 1967 at observation well 148-71-24ddd (Buturla, 1968, p. 37) indicated that the water level ranged from 10 to 12 feet below land surface.

Using an average thickness of 80 feet and a porosity of 0.3, approximately 50,000 acre-feet of water is estimated to be in storage in the aquifer. However, only a part of this quantity would be available to wells.

Water sampled from well 148-71-24ddd was of the calcium sulfate type and contained 2,100 ppm dissolved solids. The water was extremely hard, containing 1,260 ppm carbonate hardness and 1,000 ppm noncarbonate hardness. The sulfate content was 1,190 ppm, which is excessive; also, the water is in the C4-S1 irrigation class (fig. 4) and salt accumulations in the soil would be a definite hazard if the water were used for irrigation.

Only a few domestic and stock wells are presently (1968) withdrawing water from the aquifer. Potential use of the aquifer would be rather limited because of the small areal extent and poor quality. However, a few wells yielding as much as 250 gpm should be possible.

Undifferentiated Aquifers in the Glacial Drift

Two test holes, 145-69-8aaa and 145-69-26bbb, penetrated substantial thicknesses of glaciofluvial material that may yield as much as 50 gpm to properly constructed wells. These test holes were drilled along the western edge of the buried preglacial Cannonball River valley, but further test drilling along the valley failed to encounter any sizeable aquifer.

Test hole 145-69-8aaa penetrated 40 feet of fine to coarse sand and 53 feet of sandy gravel buried under 73 feet of till. The aquifer lies between altitudes of 1,624 to 1,717 feet above msl. No water sample or water-level data was obtained at this location.

Test hole 145-69-26bbb penetrated 56 feet of gravel and sand buried by 213 feet of drift. The aquifer lies between altitudes of 1,542 to 1,598 feet above msl and thus does not appear to be connected to the material at 145-69-8aaa. The water level in observation well 145-69-26bbb is approximately 40 feet below land surface.

A water sample taken at 145-69-26bbb indicated a calcium magnesium sulfate type with 1,410 ppm dissolved solids. The water is extremely hard with 760 ppm carbonate hardness. The irrigation class is C3-S1.

A small but highly productive aquifer occurs in the Sheyenne River valley northeast of Harvey. The aquifer may be less than 100 acres in area, but test drilling by the city of Harvey indicated that it is as much as 90 feet thick in places. According to the drillers' logs, the aquifer is made up mostly of clayey sand and gravel deposits.

Test drilling in other parts of the Sheyenne River valley indicates that sand and gravel deposits are rather sporadically distributed and discontinuous along the valley. Generally they can be located only by detailed test drilling, which was not feasible during this study.

An aquifer test made by C. A. Simpson and Son, Bisbee, N. Dak., for the city of Harvey indicated a transmissibility of 80,000 gpd per foot (written communication). At the present time (1968) the city of Harvey is the only large user of water from this source.

UTILIZATION OF GROUND WATER

Most of the water used in Wells County is from ground-water sources. There are no large manufacturing industries or irrigation projects in the county, and the major use is for municipal, domestic, and livestock needs. Of the total population of 9,237 (1960 census), approximately 3,760 live in municipalities having public water supplies and 5,477 live in rural areas without access to public supplies. The municipal usage is estimated to be about 275,000 gpd (300 acre-feet per year) and the rural usage about 450,000 gpd (500 acre-feet per year). The rural usage consists of about 275,000 gpd for domestic purposes, based on an estimated per capita usage of 50 gpd, and about 170,000 gpd for livestock needs, based on the following data furnished by the North Dakota Crop and Livestock Reporting Service (1962).

Type	Number	Water use per head (gallons per day)	Total use (gallons per day)
Milk cows	6,900	20	138,000
Hogs	3,000	3	9,000
Stock sheep	10,500	2	21,000
Chickens	55,000	.04	2,200
Total livestock use			170,000

The municipal supplies and usages are given in the following sections.

Bowdon

Bowdon's water supply serves approximately 260 people. An estimated 2,600,000 gallons of water a year is withdrawn from two wells, one in the Dakota Group and one in the glacial drift. The water from the Dakota well is of poor quality and the glacial drift well has a very limited yield. Future development could be sustained by a well in the Rocky Run aquifer, which extends to within a mile of the city.

The following is a list of partial chemical analyses of the water from the city system, as reported in parts per million.

Year	Dissolved solids	Total hardness	Iron	Sulfate	Chloride
1962-63[1]	1,400	520	0.9	350	18
1965[2]	2,750	20	.10	1,230	294

[1] Drift well, 295 feet. Analysis by North Dakota State Dept. of Health, 1964, p. 2-3.
[2] Dakota Group well.

Harvey

Harvey (population 2,365) is the largest water user in Wells County. The city's needs are supplied by two shallow wells that tap alluvial or glaciofluvial deposits in the Sheyenne River valley. The main production well presently in use is 36 feet deep and supplies approximately 460 gpm. The other well, which is used during peak demand periods, is 65 feet deep.

Production figures for the Harvey Water Plant, as supplied by Mr. L. R. March, water superintendent, are:

1963	76,697,000 gallons
1964	69,419,000 gallons
1965	65,979,000 gallons
Average for 3-year period:	70,698,333 gallons per year.

Although the city supply is obtained directly from a ground-water source, the aquifer probably receives infiltration from the Sheyenne River. Figure 18 shows water-level fluctuations in well 150-72-21cdc for the period 1965-67. The well, which is near the city supply wells, shows marked rises during the early spring. These rises correspond very closely to flood stages in the Sheyenne River, indicating a hydraulic connection between the aquifer and the river.

Pollution of the Sheyenne River above the city probably would result in pollution of the aquifer also. The North Dakota State Department of Health (1964, p. 9) reported nitrate concentrations of over 100 ppm in water samples taken from the well supply at Harvey. The high nitrates may have resulted from upstream contamination of the Sheyenne River. In 1967, both wells were sampled and nitrates were detected, but were below 15 ppm.

The following is a list of partial chemical analyses of the untreated water from the city supply, as reported in parts per million.

FIGURE 18. Water-level fluctuations in well 150-72-21 cdc near Harvey.

Year	Dissolved solids	Total hardness	Iron	Sulfate	Chloride
1965[1]	1,170	400	2.4	240	46
1967[2]	1,060	338	1.9	216	37

[1]65-foot well.
[2]46-foot well.

Fessenden

Fessenden's water supply serves approximately 920 people and has been in operation since 1947. Approximately 20,000,000 gallons per year is withdrawn from two wells located 7 miles north of the city. The wells tap the New Rockford aquifer and additional wells could be constructed to meet future growth. The South Fessenden aquifer, although closer to the city, does not yield water of suitable quality for municipal use.

The following is a list of partial chemical analyses of the untreated water from the city, as reported in parts per million.

Year	Dissolved solids	Total hardness	Iron	Sulfate	Chloride
1962-63[1]	1,525	420	1.0	180	21
1965	1,130	426	5.2	188	24

[1]Analysis by North Dakota State Department of Health, 1964, p. 6-7.

Sykeston

The water supply at Sykeston serves 225 people and has been in operation since 1940. One well in the Pipestem Creek aquifer supplies the requirements of the city, which have been approximately 6,600,000 gallons per year.

The following is a list of partial chemical analyses of the water from the city, as reported in parts per million.

Year	Dissolved solids	Total hardness	Iron	Sulfate	Chloride
1962-63[1]	1,150	390	0.4	238	15
1965	821	372	2.3	254	18

[1]Analysis by the North Dakota State Department of Health, 1964, p. 22-23.

SUMMARY AND CONCLUSIONS

Ground water in Wells County is obtained from sandstone and shale aquifers of Cretaceous age and from sand and gravel aquifers of Pleistocene age. Cretaceous rocks that yield water in Wells County are the Dakota Group, and the Pierre and Fox Hills Formations. The Hell Creek Formation of Cretaceous age also is present in the county, but the lithology consists of siltstone and it is not known to yield water.

Water from the Cretaceous rocks is rather saline and has undergone an exchange of calcium and magnesium ions for sodium ions present in the shales and clays, resulting in a soft, high sodium water that is unsuitable for many uses. Water from the Dakota aquifer is not suitable for domestic or irrigation use, but is used for livestock watering. The Pierre and Fox Hills aquifers can supply small amounts of water suitable for domestic and livestock needs.

The aquifers with the greatest potential for municipal, irrigation, and light-industry needs are those in the glacial drift. Approximately 2.4 million acre-feet of ground water is stored in glacial drift aquifers under 140 square miles of Wells County. The principal aquifers, each of which contains at least 60,000 acre-feet of water, are the New Rockford, Manfred, Heimdal, and Carrington aquifers.

Water from the glacial drift aquifers is generally hard and has a sodium content below 50 percent. With the exception of water from the New Rockford aquifer, water from these sources can be safely used for irrigation in addition to domestic and livestock uses. The water quality from the New Rockford aquifer differs with respect to recharge areas and may not be suitable for irrigation in certain localities.

SUMMARY OF DATA FOR GLACIAL DRIFT AQUIFERS

Aquifers	Areal extent (square miles)	Average saturated thickness (feet)	Water in storage (acre-feet)	General type of water	General irrigation class
Rusland	6	50	60,000	Calcium sodium sulfate to sodium bicarbonate	C3-S2 to C2-S1
Pipestem Creek	13	20	50,000	Calcium to sodium bicarbonate	C3-S1
Rocky Run	5	60	60,000	Calcium bicarbonate	C3-S1
Heimdal	15	40	100,000	Calcium bicarbonate	C2-S1 to C3-S1
New Rockford	70	120	1,800,000	Sodium bicarbonate	C3-S1 to C4-S3
Carrington	10	40	80,000	Sodium calcium bicarbonate	C3-S1
Rosefield	2	48	20,000	Calcium bicarbonate	C3-S1
Manfred	16	70	200,000	Sodium bicarbonate	C3-S1
South Fessenden	3	80	50,000	Calcium sulfate	C4-S1

Yields from the glacial drift aquifers depend to a large extent upon the permeability and saturated thickness of the water-bearing materials and probably exceed 500 gpm in parts of the New Rockford aquifer. The glacial drift aquifers capable of yielding between 250 and 500 gpm include the New Rockford and parts of the Heimdal and Manfred aquifers. Hydrologic data for all of the major drift aquifers described in this report are summarized in the preceding table.

Nearly all of the water used in Wells County is from ground water sources. All cities and communities in the county use ground-water sources for their public water supplies. The combined domestic and livestock water use for Wells County is approximately 800 acre-feet per year.

Ground water is one of the most valuable resources of Wells County and is largely untapped; supplies are available in large quantities at places within the county. Unfortunately the aquifers are unevenly distributed and in some areas of the county it will not be possible to obtain large quantities of acceptable quality ground water. With proper management, ground water can supply the future agricultural, municipal, and industrial needs of Wells County.

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