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COUNTY GROUND WATER STUDIES 7

# GEOLOGY AND GROUND WATER RESOURCES

## RICHLAND COUNTY, NORTH DAKOTA

## PART III

## GROUND WATER RESOURCES

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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.

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# GEOLOGY AND
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# of Richland County, North Dakota

## Part III - Ground Water Resources

**by Claud H. Baker, Jr., and Q. F. Paulson**

## ABSTRACT

Water supplies in Richland County are obtained mainly from ground water. The most important sources are the shoreline deposits of glacial Lake Agassiz. These deposits contain two main aquifers -- identified as the Sheyenne delta aquifer and the Hankinson aquifer, which have a combined area of about 400 square miles. They consist of well-sorted deposits of sand that are at least 50 feet thick in most places and as much as 100 feet thick near the western boundary of the county. Grain-size analyses indicate possible well yields of at least 50 gallons per minute in most places and as much as 1,000 gallons per minute in a few places. The aquifers are relatively undeveloped and water levels are only a few feet below land surface. The Sheyenne delta aquifer contains an estimated 4 million acre-feet of ground water in storage and receives about 50,000 acre-feet of recharge during a year of average precipitation. The water in the Sheyenne delta and Hankinson aquifers generally contains less than 500 parts per million dissolved solids, and, although hard, is usable for most purposes.

Aquifers of less importance are associated with the till deposits, and in the bedrock formations, chiefly the Dakota Sandstone. The aquifers in or associated with the till generally are smaller and less productive. Aquifers in the bedrock yield water that is of rather poor chemical quality. However, wells developed in these sources may be capable of yielding 500 gallons per minute in places.

# INTRODUCTION

## Scope and purpose

This is the third in a series of three reports describing the results of a study of the geology and ground-water resources of Richland County. The study was requested and supported by the Richland County Board of Commissioners and was made under the cooperative program of the U.S. Geological Survey, the North Dakota State Water Commission, and the North Dakota Geological Survey.

The primary purpose of the study was to determine the occurrence, availability, and quality of ground water in Richland County. 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.

Much of the basic data on which this interpretive report is based has been tabulated in an earlier report entitled "Geology and Ground Water Resources of Richland County, North Dakota, Part II, Basic Data." Another report -- "Geology and Ground Water Resources of Richland County, North Dakota, Part I, Geology" -- describes the geology of the county and provides a framework for evaluating the ground-water resources. The three reports are meant to complement each other, and the usefulness of any of them will be greatly enhanced by having all three available for reference.

## Location and extent

Richland County is in the southeastern corner of North Dakota, bounded on the east by Minnesota and on the south by South Dakota (fig. 1). The county has an area of approximately 1,450 square miles, and the population in 1960 was 18,824. The principal occupation in the county is farming.

The southwestern one-fifth of the county is in the Drift Prairie; the remainder is in the Red River Valley, which is part of the former floor of glacial Lake Agassiz. The entire county is in the drainage basin of the Red River of the North.

## Previous work and acknowledgments

The statewide reports of ground-water resources by Simpson (1929) and by Abbott and Voedisch (1938) contain sections on ground water in Richland County.

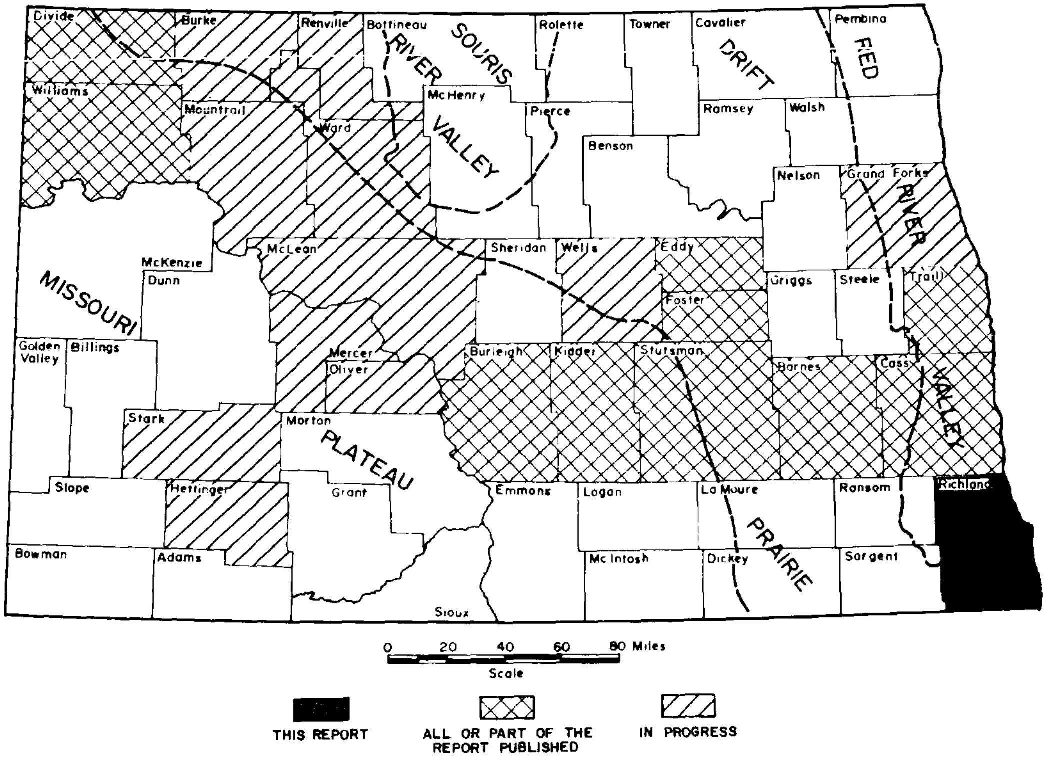

**Figure 1.** County ground-water studies and physiographic provinces in North Dakota

Three earlier ground-water studies have been completed in the county in the areas of Fairmount (Paulson, 1953), Wyndmere (Dennis and others, 1949), and Hankinson (Powell, 1956). A study in the area of Kindred, Cass County, (Dennis and others, 1950), included part of Richland County. Information from the earlier studies was used in compiling this report.

Special thanks are due to Hans M. Jensen of the U.S. Geological Survey and Roger Fuller, a former U.S. Geological Survey employee, who collected most of the well inventory data. The chemical analyses were performed in the North Dakota State Laboratories in Bismarck. The citizens of Richland County were especially helpful in furnishing much of the information on which this report is based.

## Well-numbering system

Wells and test holes in North Dakota are numbered according to their location within the United States land survey system (fig. 2). North Dakota is in the area surveyed from the fifth principal meridian and its base line; townships are all north of the base line and ranges all west of the meridian. The first numeral of the well number indicates the township, the second numeral the range, and the third numeral the section in which the well or test hole is located. The letters following the section number locate the well within the section; the first denotes the quarter section, the second the quarter-quarter section, and the third the quarter-quarter-quarter section or 10-acre tract. In each case, the letters a, b, c, and d refer to the northeast, northwest, southwest, and southeast elements of the division. If more than one well or test hole is recorded within a single 10-acre tract, numbers 1, 2, 3, etc., are added after the letters. Thus, well number 132-50-15daa2 is the second well in the NE 1/4 NE 1/4 SE 1/4 sec. 15, T. 132 N., R. 50 W. The system is somewhat complicated in Richland County by the presence of a portion of the Wahpeton and Sisseton Indian Reservation. Section lines within the reservation do not correspond with those outside it, and some sections (129-52-9, for example) occur both inside and outside the reservation. Locations within the reservation are indicated by the notation LTL (Lake Traverse Lands) following the range-township section descriptions.

## Climate

The climate of Richland County is of the continental type, with short summers and long cold winters. The average annual precipitation in the county is about 20 inches, but it is somewhat greater near the eastern edge of the county than near the western edge. At Wahpeton, on the eastern border of the county, the average

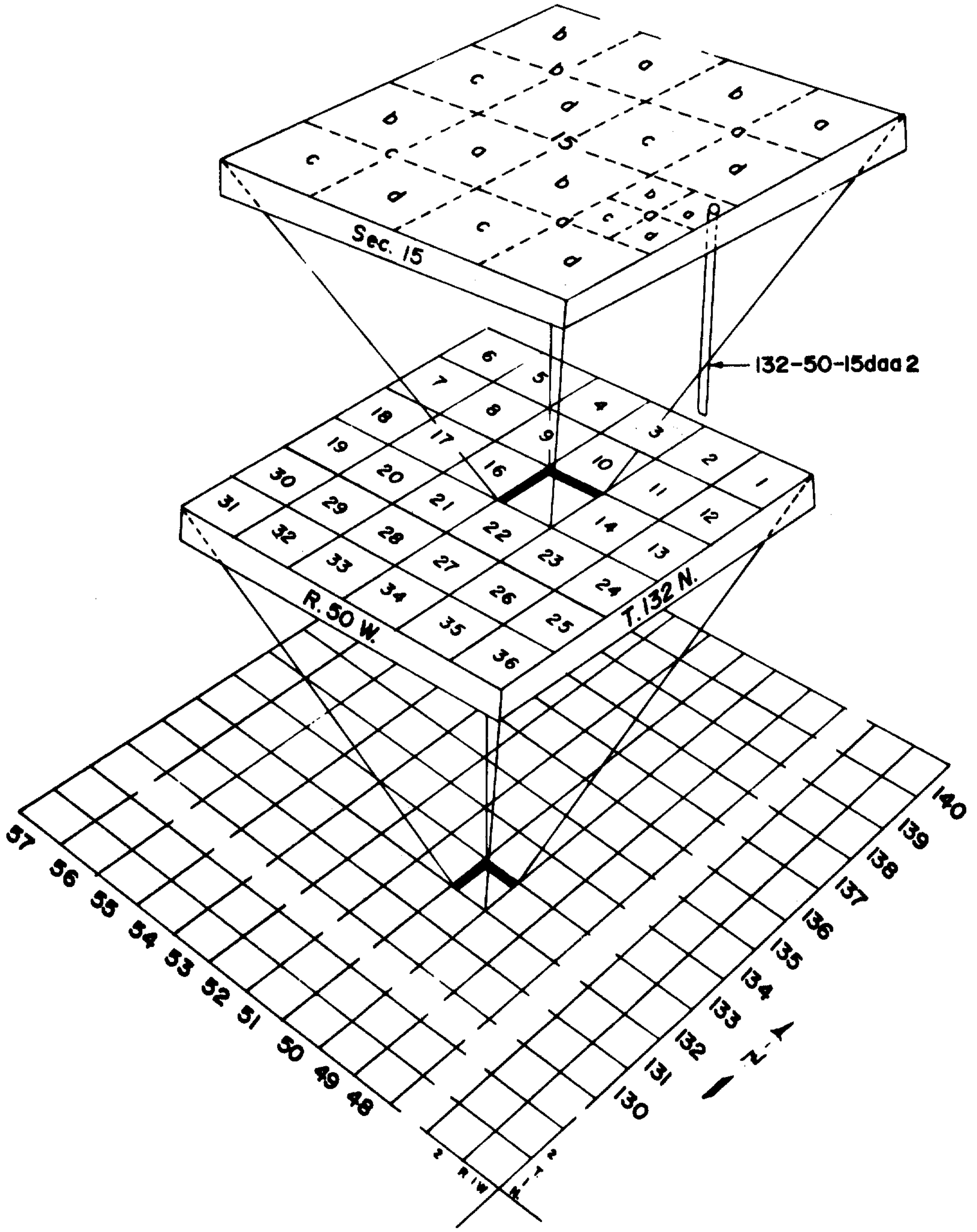

Figure 2. System of numbering wells and test holes.

precipitation for the period 1931-1960 was 20.59 inches per year. At McLeod weather station, near the western border of the county, the average for the same period was 19.16 inches per year. The monthly precipitation at Wahpeton and McLeod for the years 1956-65 is shown in figure 3.

Most of the precipitation falls as rain during the spring and summer months. Precipitation during the late fall, winter, and early spring months is mainly in the form of snow. The total annual snowfall averages about 30 inches, but the moisture content of the snow is small. Precipitation during November through March averages less than 1 inch of moisture per month.

## Principles of ground-water occurrence

A thorough discussion of the principles of ground-water hydrology is beyond the scope of this report. The reader who is interested in a more thorough treatment of the subject is referred to Todd (1959), Wisler and Brater (1959), or Tolman (1937).

Any body of rock material that will yield water to wells in sufficient quantity to be used as a source of supply is called an aquifer.

All ground water of economic importance is derived ultimately from precipitation. Water from rain or melting snow enters the ground directly or through the sides and bottoms of streams and lakes. Water added to an aquifer is called recharge, and the places where recharge enters are recharge areas.

Water moves downward and laterally through an aquifer from areas of recharge to areas of discharge -- places where water is removed or discharged from the aquifer. Ground water is discharged through springs and wells, by seepage into streams or ponds, by evaporation where the ground-water level is near the surface, and by transpiration--water released to the atmosphere by plants.

The amount of water that rock materials can hold is determined by the size and number of pores or void spaces within the rock materials. The ratio of pore space to total volume, expressed as a percentage, is called porosity. Unconsolidated material, such as clay, sand, and gravel is generally more porous than consolidated rocks; some consolidated rocks, however, are highly porous.

The permeability of rock material refers to the ease with which fluids will pass through it. Permeability is determined by the size, shape, and degree of interconnection between pores. Hence, coarse gravel, which has large interconnected pores, allows water to pass through it freely and is highly permeable; but clay, which has very small pores, allows water to move very slowly, and is said to be impermeable. The clay, however, may have the greater total porosity. The coefficient of permeability of a material is the amount of water, in gallons per day, that will pass through a cross-sectional area of 1 square foot under unit hydraulic gradient.

The transmissibility of an aquifer is a measure of the ability of the aquifer as

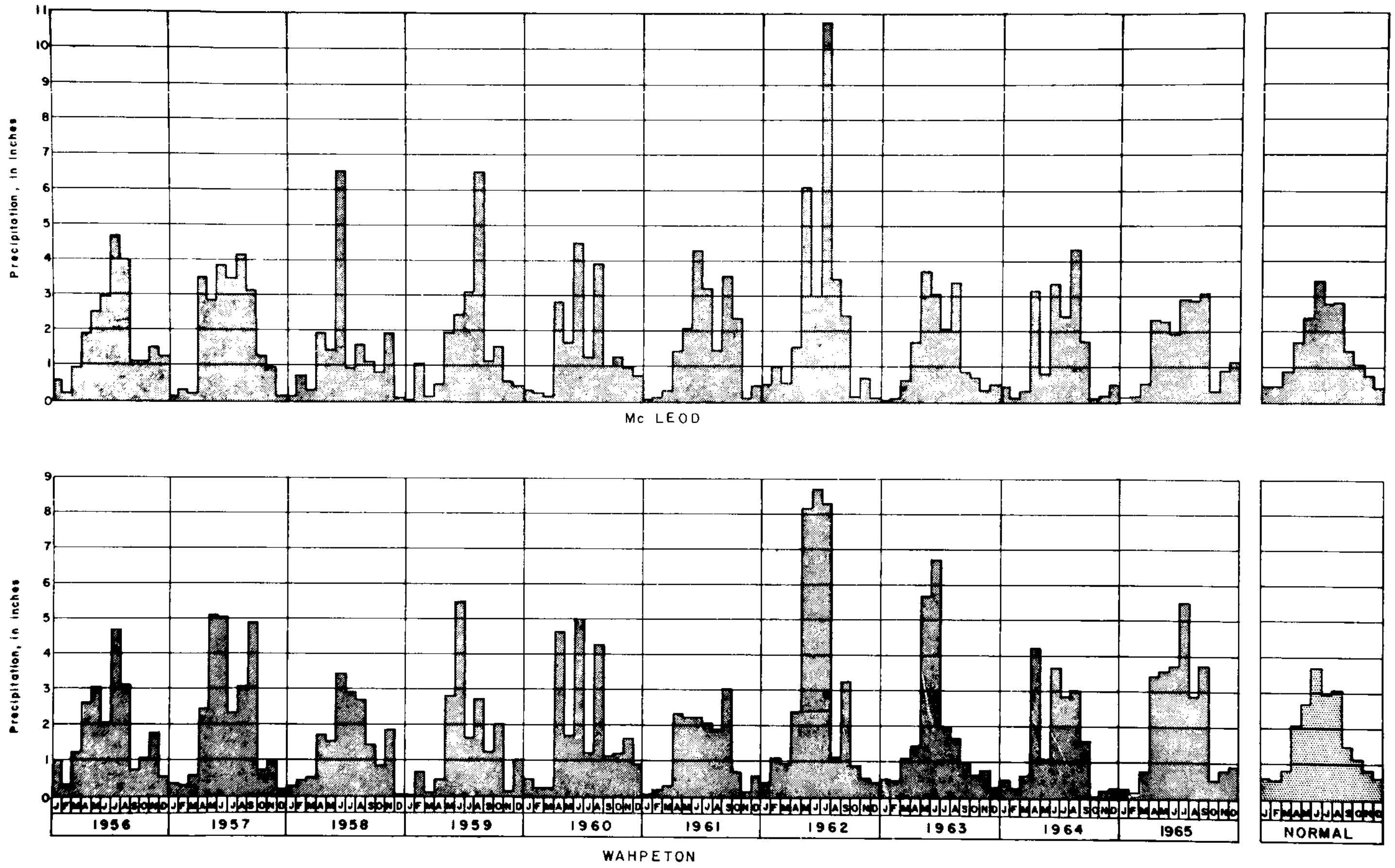

**Figure 3.** Precipitation at the McLeod and Wahpeton weather stations, 1956-65.

a whole to transmit water. The coefficient of transmissibility is equal to the coefficient of permeability of the aquifer material multiplied by the thickness of the aquifer.

If an aquifer is not confined by overlying impermeable material, the water in the aquifer is said to be under water-table conditions. The water table is the upper surface of the water in the unconfined aquifer; it is the level at which water will stand in wells that penetrate the aquifer. Under these conditions, water is obtained from the aquifer by gravity drainage when the water table is lowered in the vicinity of a pumping well.

The amount of water that an aquifer will yield by gravity drainage is less than its total porosity, because a film of water is held on the surfaces of the particles by molecular forces. The smaller the pores, the greater the proportion of water held and the smaller the proportion of water that can be removed by gravity drainage. The effective porosity or specific yield of an aquifer is the amount of water that can be removed from it by gravity drainage, expressed as a percentage of the total volume drained.

Water is under artesian conditions if it is confined in an aquifer by overlying impermeable material. Under artesian conditions, hydrostatic pressure will raise the water in a well penetrating the aquifer to a level above the top of the aquifer. As water is removed from an artesian aquifer, the aquifer remains saturated; water is yielded because the aquifer is compressed and the water expands (slightly) as the pressure is decreased. Thereis no gravity drainage under normal artesian conditions.

As the pressure is lowered in an artesian aquifer, the amount of water released is determined by the coefficient of storage, which generally is much smaller than the specific yield of the same material under water-table conditions. The coefficient of storage of an aquifer is defined as the volume of water that the aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Properly, the concept of the coefficient of storage is applicable to water-table aquifers too, but the amount of water released from a water-table aquifer by compression of the aquifer and expansion of the water is a very small proportion of the total water released. The coefficient of storage of a water-table aquifer, therefore, is practically equal to its specific yield.

In summary, the suitability of an aquifer as a dependable source of water supply is governed by its volume, its transmissibility, its capacity to store and release water, and its accessibility to recharge. Recharge to the aquifer must be considered in establishing a supply because even a small rate of withdrawal will eventually deplete the water in storage if there is no recharge. Before any large ground-water development is made, the aquifer should be thoroughly investigated in order to determine its recharge potential as well as its immediate capabilities.

# Chemical quality of ground water

The chemical quality of water yielded by an aquifer commonly has as much bearing on the suitability of the aquifer as a source of water supply as do the physical factors outlined in the previous section.

Several factors determine the concentration and character of the mineral constituents of ground water. The most important are the mineral composition of the rock material through which the water has passed and the length of time that the water has been in contact with the rock material. Precipitation as rain dissolves gases from the air. The part of precipitation that becomes ground water reacts with rock particles, dissolving some substances and forming new compounds. The amount of dissolved solids in water generally increases with depth, because the deeper water generally has been in contact with rock materials longer than has water at shallow depth.

The suitability of water for domestic use or public supply is generally judged by standards that have been established by the U.S. Public Health Service (1962b, p. 7-8) for drinking water used on interstate carriers. The suitability of water for irrigation is judged by standards defined by the U.S. Salinity Laboratory Staff (1954, p. 69-82). Standards for drinking water for livestock have not been established. Water for industrial use is evaluated in accordance with standards that are determined by the particular process for which the water will be used.

The most abundant substances commonly found in ground water are calcium, magnesium, sodium, potassium, bicarbonate, sulfate, and chloride. Less abundant constituents reported in most analyses are silica, iron, carbonate, fluoride, nitrate, and boron. In addition, most analyses report total dissolved solids, hardness, percent sodium, sodium-adsorption ratio, specific conductance, and pH. Most analyses report dissolved solids in parts per million by weight. Some analyses are reported in milligrams per liter. For total concentrations of less than 7,000 milligrams per liter, milligrams per liter can be considered equal to parts per million.

Compounds of calcium and magnesium are common rock forming minerals, and most ground water contains these elements. Neither element is known to be harmful either to people or to livestock, and the Public Health Service standards do not include recommended limits. Calcium and magnesium are, however, the principal causes of hardness in water, and hardness (which will be discussed later in this section) is an undesirable property of water for many domestic and industrial uses. Neither element is harmful in irrigation water; in fact, they are beneficial to certain types of soil.

Sodium and potassium have similar chemical properties, and are sometimes reported together in water analyses. Sodium is much more abundant than potassium, and generally sodium and potassium reported as combined is largely sodium. Sodium and potassium are not known to be generally harmful to people or animals, and no standards have been set for maximum permissible concentrations. Sodium is decidedly harmful in irrigation water. The evaluation of irrigation water for sodium hazard will be discussed later in this section in connection with percent sodium and sodium-adsorption ratio.

Bicarbonate is a common constituent of ground water. It is not known to be harmful to people or to animals, and no standards have been established for maximum concentration. Bicarbonate is not generally deleterious in irrigation water, but very high concentrations of bicarbonate may cause calcium and magnesium to be precipitated in soil, thereby increasing the sodium-adsorption ratio and sodium hazard.

Most sulfate compounds are readily soluble in water, and therefore most ground water contains some sulfate. The Public Health Service standards recommend that water containing more than 250 ppm (parts per million) of sulfate should not be used if better water is available. The taste of water containing more than 250 ppm of sulfate is generally objectionable to people who are not accustomed to it. In addition, water that contains more than about 600 ppm of sulfate commonly has a laxative effect on the user, particularly on persons who are not accustomed to the water (U.S. Public Health Service, 1962b, p. 34). Sulfate is not considered to be harmful in irrigation water.

Nearly all chloride compounds are readily soluble, and chloride is commonly present in ground water. Chloride imparts an objectionable salty taste to water, and the Public Health Service standards recommend that water containing more than 250 ppm of chloride should not be used if better water is available. Water containing concentrations of chloride large enough to be harmful to people or animals is usually too unpalatable to be consumed.

Silica is an abundant constituent of rocks, but most silica compounds are poorly soluble and large concentrations of silica in ground water are rare. Silica is not known to be harmful to people or livestock, nor to be deleterious in irrigation water. Silica contributes to the formation of scale in high-pressure boilers, and is therefore objectionable for many industrial uses.

Iron is one of the most abundant rock constituents, but most iron compounds are only slightly soluble, and ground water commonly contains only small amounts of iron. Iron is highly objectionable in water for either domestic or industrial use. Very small concentrations of iron are sufficient to give a bitter taste and to stain laundry and plumbing fixtures. For these reasons, the Public Health Service has established a limit of 0.3 ppm for the maximum recommended concentration of iron in water for domestic use. Water containing much larger concentrations of iron is often used and is not known to be harmful to people or livestock, or detrimental in irrigation water.

Carbonate is only slightly soluble, and is not generally present in very large concentrations in ground water. No standards for maximum concentration have been established.

Fluoride is not an abundant constituent of natural waters, but it is generally present in small amounts in most ground water. Above certain concentrations, fluoride in water has marked effects on people who drink the water, and presumably on livestock as well. The optimum concentration of fluoride depends on the amount of water consumed, and consumption of water is closely related to average annual temperature. For the average annual temperature of Wahpeton, the optimum concentration is about 1.5 ppm. Children, particularly, who consume the optimum amount of fluoride show a marked reduction in the incidence of dental caries (cavities). If the intake of fluoride exceeds the optimum, however, there is an increase in the incidence of dental fluorosis (mottled enamel). High concentrations of fluoride (more than 8 ppm) cause extensive bone damage.

Nitrate is not a common rock constituent, and water from deep sources generally contains little or no nitrate. The most common source of nitrate to shallow ground water is contamination from surface sources. The decomposition of organic materials is an abundant source of soluble nitrate. A second source, especially in rural areas, is inorganic nitrate fertilizers spread on fields through which water infiltrates. Contamination from organic sources is such a common cause of nitrate in shallow ground water that if water from wells contains more than about 10 ppm of nitrate, it is wise to have the water analyzed for the presence of harmful bacteria.

Very large concentrations of nitrate are known to be toxic to both people and animals. The effects of nitrate in concentrations commonly found in ground water on adult people or animals is not well established. However, water containing more than about 45 ppm of nitrate is generally believed to cause methemoglobinemia ("blue baby" disease) in infants who drink the water. For this reason the Public Health Service recommends a maximum concentration of 45 ppm of nitrate in drinking water. No harmful effects are known from nitrate in irrigation water.

Boron is a minor constituent of most rocks, and most ground water contains only small concentrations of boron. It is not known to be harmful to people or to livestock in concentrations generally found in ground water, and the Public Health Service standards do not include a recommended maximum for boron. Plants, however, are very sensitive to boron, and concentrations as low as 1 ppm in irrigation water are harmful to some plants. Concentrations of more than about 3.5 ppm are toxic to most plants.

Most analyses of water report total dissolved solids as both sum and residue on evaporation. The sum is simply the total of the concentration of the various constituents determined; the residue on evaporation is obtained by evaporating a weighed sample of the water at 180° C and weighing the residue. The residue on evaporation is commonly slightly different from the sum. The Public Health Service standards recommended a maximum for total solids of 500 ppm. This recommendation is based primarily on consideration of taste.

Hardness is a property of water that is difficult to define and is not attributable to any one substance. Hardness is generally associated with the effects observed in the use of soap. Hard water forms insoluble compounds with soap. Hard water also tends to form incrustations on vessels in which it is heated.

The principal cause of hardness in water is the presence of calcium and magnesium. Hence, hardness is generally reported in terms of an equivalent amount of calcium carbonate. Many analyses also report hardness separately as calcium - magnesium hardness and as noncarbonate hardness. Calcium - magnesium hardness is computed from the concentrations of calcium and magnesium in the water. Any excess of total hardness over hardness computed from bicarbonate and carbonate concentration is reported as noncarbonate hardness. Many analyses report hardness in grains per gallon of equivalent calcium carbonate. One grain per gallon is equal to about 17.1 ppm.

Hardness is a relative term; what is hard water in one area may be regarded as very soft in another. No recommended limits for hardness have been established by the Public Health Service, and hardness is not considered harmful in drinking water for men or animals. Hardness does not adversely affect the usefulness of water for irrigation. Hardness is objectionable for domestic water because of the soap-consuming and scale-forming properties, which increase with increased hardness. Hardness can be reduced by the use of commercial softening devices.

Percent sodium and sodium-adsorption ratio (SAR) are used to evaluate the effects of irrigation water on the soil. Sodium in irrigation water replaces calcium in soil by base exchange. Soils high in sodium have undesirable properties for farming. Hence, the danger of damaging soil for farming by the application of sodium-high irrigation water is termed the sodium hazard of the water. Generally, the sodium hazard of irrigation water increases as percent sodium or SAR increases. The total dissolved solids in irrigation water must also be considered in evaluating irrigation water, however, because the sodium hazard of water at a given SAR value increases as total solids concentration increases. Water having an SAR value of more than about 10 is generally of marginal usefulness for irrigation.

Specific conductance is a measure of the ability of water to conduct an electric current. Pure water does not conduct electricity, and the specific conductance of water increases as the total amount of dissolved solids increases. The electrical conductance of water solutions varies with the temperature, so specific conductance is generally determined at (or corrected to) a standard temperature of 25° C. Specific conductance provides a quick,convenient estimate of the total amount of dissolved solids in water. The specific conductance multiplied by 0.65 appromimates the total solids concentration in parts per million.

The pH value of water is a measure of the concentration of hydrogen ions in the water. Most natural water has a pH value of 5.5 to 8.0.

# PRINCIPAL AQUIFERS OF RICHLAND COUNTY

The aquifers in Richland County are divided into two groups--bedrock aquifers and glacial drift aquifers. The locations of the major aquifers are shown on plate 1.

## Ground water in the bedrock

Only two of the bedrock units of Richland County are known to yield water to wells--the Precambrian "granite" and the Dakota Sandstone. The Dakota Sandstone is by far the more productive of the two.

### DAKOTA SANDSTONE

The Dakota Sandstone is one of the most extensive water-bearing formations in North America. Many of the deep flowing wells in North Dakota and adjacent states tap this formation or its equivalent.

The Dakota Sandstone underlies about two-thirds of Richland County (fig. 4). The formation was eroded from the central and northern parts of the county prior to glaciation. Wells penetrating the Dakota range in depth from 200 to 900 feet; the deepest are in the southwestern part of the county and the shallowest are in the southeastern part. The known thickness of the formation in Richland County ranges from 0 to 238 feet, but the formation is not all water bearing.

In Richland County the water-bearing beds in the Dakota Sandstone are either fine-grained sugary white sand or coarse angular quartz and muscovite sand. The fine-grained sugary white sand is found in most of the county and is generally described by drillers as the water sand. However, in local areas, especially in the southwestern part of the county, the formation contains beds of coarse angular quartz and muscovite sand. Gravel is reported at the base of the sand near Fairmount (Paulson, 1953, p. 30).

Where the formation is thick, the water-bearing sand may be in two or more beds that are separated by beds of light-colored shale or siltstone. Generally, the individual sand beds are between 5 and 30 feet thick, but as much as 82 feet of sand was penetrated in test hole 130-52-20bbb. The total thickness of sand and sandstone with interbedded clay and shale penetrated by this test hole was 172 feet.

The water in the Dakota Sandstone is under artesian pressure that is great enough to cause the water to flow at land surface in most parts of the county. However, pressures have greatly diminished since the early years of development when they were large enough to produce heads of 200 feet above land surface in the southwestern part of the county (Simpson, 1929, p. 212). It seems doubtful that large pressures ever were encountered in the eastern part of the county. The

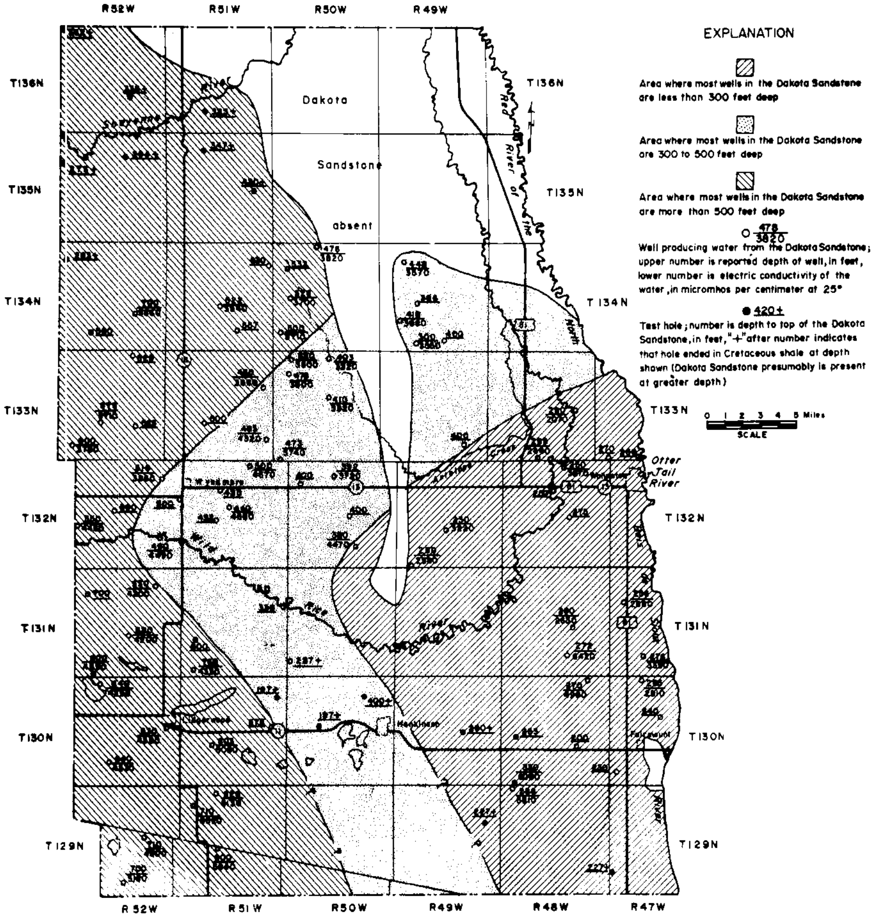

**Figure 4.** Hydrogeology of the Dakota Sandstone.

absence of thick confining shale beds in this area has resulted in upward leakage of water from the sand beds and dissipation of artisian pressures.

Quantitative data on the hydrologic properties of the Dakota Sandstone in eastern North Dakota are scarce. Kelly (1966), summarized the available information and concluded that the coefficient of transmissibility generally is between 12,000 and 16,000 gpd per foot (gallons per day per foot) and the coefficient of storage between 0.0001 and .001. These coefficients are probably applicable to the formation in most parts of Richland County. However, in the vicinity of test hole 130-52-20bbb and in other areas underlain by thick sand or sandstone beds, the transmissibility may be considerably higher, perhaps as much as 50,000 gpd per foot.

Most wells tapping the Dakota Sandstone in Richland County have small yields. They have small diameters (commonly 2 inches or less) and are screened in only a few feet of the water-bearing sand. In general, the flowing wells at the time of county inventory (1962-63) yielded less than 5 gpm (gallons per minute), but a few yielded more than 20 gpm (Baker, 1966c, table 1).

The largest pumping yields from the Dakota are 50 gpm and 35 gpm from Wahpeton municipal wells 132-47-8acb and 8abd, respectively (Baker, 1966c, table 1). The sand beds in the Dakota are rather thin and very fine grained in the vicinity of Wahpeton. Furthermore, the relatively shallow depth of the sand beds (less than 300 feet) and the low hydraulic head restrict the amount of available drawdown to the wells in the vicinity of Wahpeton. Considerably greater yields can be obtained from wells tapping the Dakota in the southwestern part of the county because of the larger thicknesses of sand beds, higher permeabilities, and greater hydraulic heads. For example, an efficiently designed and developed Dakota well in the vicinity of test hole 130-52-20bbb probably could be pumped at a rate of at least 500 gpm for sustained periods.

Water from the Dakota Sandstone in Richland County is highly mineralized (table 1); the dissolved solids content is generally more than 2,500 ppm. The concentrations of both chloride and sulfate are generally from 2 to 4 times the Public Health Service recommended maximums for drinking water. The high chloride content makes the water unpalatable to many; the salty taste is particularly objectionable in hot drinks. The high sulfate content may have a laxative effect on the drinker. The concentration of fluoride is much above the recommended optimum; in southwestern Richland County the fluoride concentration is the highest reported in the State (Wenzel and Sand, 1942, p. 23 and pl. 3). The water also is high in sodium, which renders it unsuitable for irrigation. However, Dakota water is softer than other water in the county and may be desirable for laundry and other purposes for which soft water is preferable.

Although water from the Dakota Sandstone is not generally used for human consumption, it is extensively used for watering livestock. Flowing wells have the advantage of no pumping costs and minimum danger of freezeup during the

TABLE 1.--Chemical analyses of ground water in Richland County

[Analytical results in parts per million except as indicated]

| Location | Depth (feet) | Date of collection | Temperature (°F) | Silica (SiO$_2$) | Total iron (Fe) | Calcium (Ca) | Magnesium (Mg) | Sodium (Na) | Potassium (K) | Bicarbonate (HCO$_3$) | Carbonate (CO$_3$) | Sulfate (SO$_4$) | Chloride (Cl) | Fluoride (F) | Nitrate (NO$_3$) | Boron (B) | Dissolved solids |  | Hardness as CaCO$_3$ |  | Percent sodium | Sodium-adsorption-ratio | Specific conductance (micromhos at 25°C) | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | Sum | Residue on evaporation at 180°C | Calcium, magnesium | Noncarbonate |  |  |  |  |
| **Cheyenne delta deposits** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 132-52- 14dd | 55 | 1-12-65 | 49 | 21 | 0.70 | 140 | 57 | 90 | 12 | 706 | 0 | 205 | 2.0 | 0.4 | 1.7 | 0.00 | 876 | 883 | 585 | 6 | 25 | 1.6 | 1,250 | 7.8 |
| 133-52-13ccc | 63 | 10-2-63 | .. | 20 | .09 | 70 | 44 | 22 | 7.8 | 459 | 0 | 12 | 0 | .1 | 0 | 0 | 402 | 412 | 356 | 0 | 12 | .6 | 778 | 8.1 |
| 134-51-29ccc | 52 | 9-27-63 | .. | 23 | .27 | 72 | 28 | 16 | 3.9 | 371 | 0 | 30 | 0 | .2 | 0 | .60 | 356 | 359 | 294 | 0 | 10 | .4 | 618 | 7.7 |
| 134-52-31bbb | 63 | 9-25-63 | .. | 20 | .34 | 48 | 18 | 72 | 4.0 | 225 | 0 | 120 | 32 | .9 | 4.0 | .21 | 425 | 415 | 194 | 10 | 44 | 2.2 | 706 | 7.8 |
| 135-51-23aaa | 59 | 9-24-63 | .. | 22 | .07 | 53 | 34 | 26 | 6.9 | 332 | 0 | 34 | 6.0 | .1 | 0 | 0 | 346 | 371 | 272 | 0 | 16 | .6 | 645 | 7.9 |
| 136-51- 2aab | 105 | 7-31-64 | 51 | 25 | 1.8 | 99 | 37 | 206 | 12 | 466 | 0 | 232 | 145 | .3 | 48 | .60 | 1,040 | 1,040 | 400 | 18 | 52 | 4.5 | 1,510 | 7.7 |
| 136-52-22ddd | 42 | 10-8-63 | .. | 22 | .48 | 74 | 23 | 9.2 | 4.0 | 293 | 0 | 55 | 0 | .4 | 1.0 | 0 | 332 | 328 | 280 | 40 | 7 | .2 | 570 | 7.8 |
| **Hankinson aquifer** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 129-48-27ccc | 32 | 7-22-64 | .. | 23 | 1.3 | 103 | 34 | 18 | 6.2 | 376 | 0 | 114 | 12 | .5 | .0 | .00 | 497 | 517 | 396 | 88 | 9 | .4 | 807 | 7.9 |
| 129-49- 9bcb | 35 | 7-22-64 | 52 | 25 | .80 | 62 | 27 | 4.0 | 4.7 | 328 | 0 | 12 | 1.0 | .5 | .0 | .00 | 298 | 326 | 268 | 0 | 3 | .1 | 531 | 8.2 |
| 130-50- 3aab | 68 | 1-19-65 | 49 | 24 | .09 | 82 | 18 | 7.6 | 4.3 | 332 | 0 | 26 | 6.0 | .3 | 1.5 | .35 | 333 | 330 | 278 | 0 | 6 | .2 | 536 | 7.6 |
| 131-50-21dac | 75 | 7-22-64 | .. | 26 | .12 | 55 | 12 | 31 | 8.6 | 244 | 0 | 63 | 1.0 | .4 | .0 | .00 | 317 | 324 | 186 | 0 | 26 | 1.0 | 515 | 7.7 |
| **Milnor channel** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 130-50-17ddd | 60 | 10-20-64 | .. | 21 | 3.2 | 78 | 107 | 38 | 13 | 260 | 0 | 497 | 4.0 | 0.3 | 0.0 | 0.00 | 889 | 932 | 635 | 422 | 11 | 0.6 | 1,250 | 8.2 |
| 130-52-10cca | 50 | 7-22-64 | .. | 25 | .28 | 147 | 48 | 65 | 69 | 605 | 0 | 218 | 6.0 | .4 | 1.0 | .00 | 827 | 836 | 565 | 69 | 19 | 1.2 | 1,240 | 7.4 |
| 130-52-12bcb | 40 | 10-14-64 | .. | 25 | .20 | 94 | 29 | 27 | 6.8 | 339 | 0 | 127 | 5.5 | .3 | .0 | .00 | 482 | 514 | 352 | 125 | 14 | .6 | 750 | 7.6 |
| 130-52-13bcb | 65 | 1-18-65 | 50 | 25 | .08 | 154 | 40 | 175 | 19 | 559 | 0 | 450 | 22 | .4 | 3.2 | .50 | 1,160 | 1,170 | 550 | 92 | 40 | 3.2 | 1,660 | 7.5 |
| **Brightwood aquifer** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 129-50- 5bbb | 140 | 10-22-64 | .. | 22 | .21 | 80 | 28 | 49 | 8.8 | 149 | 0 | 302 | 1.0 | .2 | .0 | .00 | 564 | 632 | 314 | 192 | 25 | 1.2 | 857 | 8.1 |
| 129-51- 1bbb | 140 | 10-28-64 | .. | 21 | .31 | 85 | 52 | 27 | 9.4 | 198 | 0 | 318 | 2.5 | .3 | .0 | .00 | 613 | 674 | 425 | 263 | 12 | .6 | 882 | 8.0 |
| 130-50-27bbb | 100 | 10-20-64 | .. | 22 | .32 | 112 | 57 | 35 | 9.6 | 405 | 0 | 261 | 3.0 | .4 | .0 | .00 | 699 | 735 | 515 | 183 | 13 | .9 | 1,030 | 7.6 |
| **Fairmount aquifer** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 130-47-21dba | 115 | 5-8-65 | .. | 22 | .06 | 64 | 35 | 168 | 5.0 | 628 | 0 | 89 | 36 | .5 | 15 | .55 | 744 | 772 | 302 | 0 | 54 | 4.2 | 1,190 | 7.9 |
| **Colfax aquifer** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 134-49-20bab | 96 | 7-23-64 | 48 | 23 | .86 | 96 | 32 | 652 | 19 | 273 | 0 | 1,060 | 345 | 2.9 | 1.0 | 1.9 | 2,360 | 2,390 | 370 | 146 | 78 | 15 | 3,630 | 7.9 |
| 135-49-30cdd | 100 | 7-23-64 | .. | 23 | 1.3 | 118 | 35 | 538 | 19 | 295 | 0 | 895 | 325 | .6 | 3.0 | 1.3 | 2,100 | 2,160 | 440 | 198 | 72 | 11 | 3,220 | 7.7 |
| **Small gravel bodies in the till** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 131-49- 5bbb | 126 | 7-22-64 | .. | 24 | 1.7 | 128 | 52 | 405 | 48 | 354 | 0 | 950 | 146 | .7 | 3.0 | .40 | 1,930 | 1,940 | 535 | 245 | 60 | 7.6 | 2,620 | 7.7 |
| 131-51-15ccb | 45 | 7-22-64 | .. | 28 | .15 | 199 | 56 | 66 | 20 | 518 | 0 | 439 | 5.0 | .3 | 4.5 | .00 | 1,090 | 1,100 | 725 | 300 | 16 | 1.1 | 1,510 | 7.3 |
| 132-48-29bcb | 90 | 7-21-64 | 47 | 23 | 4.8 | 69 | 65 | 177 | 11 | 411 | 0 | 398 | 60 | .6 | 6.5 | .00 | 1,020 | 1,030 | 440 | 103 | 46 | 3.7 | 1,460 | 8.1 |
| 133-47-17ddd | 80 | 9-16-64 | .. | 24 | .31 | 128 | 63 | 9.6 | 7.1 | 423 | 0 | 246 | 6.0 | .5 | 2.0 | .00 | 694 | 738 | 580 | 234 | 3 | .2 | 1,120 | 8.0 |
| 135-48-19ddd | 75 | 7-23-64 | 48 | 25 | 2.7 | 109 | 104 | 95 | 11 | 720 | 0 | 305 | 8.0 | .5 | 8.4 | .65 | 1,020 | 1,040 | 700 | 110 | 22 | 1.6 | 1,530 | 7.4 |
| 136-49- 6bab | 78.4 | 7-31-64 | 50 | 23 | 1.8 | 197 | 69 | 321 | 28 | 376 | 0 | 765 | 290 | .5 | .0 | 1.2 | 1,880 | 1,930 | 775 | 467 | 46 | 5.0 | 2,790 | 7.5 |
| **Dakota Sandstone** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 129-51- 7aaa | 710 | 7-22-64 | 65 | 7.5 | 0.84 | 14 | 7.8 | 1,270 | 15 | 446 | 0 | 1,280 | 821 | 5.9 | 6.9 | 4.0 | 3,640 | 3,680 | 66 | 0 | 97 | 68 | 5,520 | 8.2 |
| 130-48-31dcd | 330 | 7-21-64 | 67 | 6.2 | 1.4 | 33 | 16 | 1,390 | 16 | 307 | 0 | 1,450 | 1,020 | 4.4 | 7.0 | 3.5 | 4,090 | 4,140 | 150 | 0 | 95 | 49 | 6,060 | 8.2 |
| 131-52-32ccc | 800 | 7-22-64 | 63 | 6.8 | .72 | 14 | 3.9 | 1,020 | 21 | 544 | 0 | 1,170 | 443 | 6.3 | 5.5 | 3.4 | 2,950 | 2,980 | 50 | 0 | 97 | 63 | 4,290 | 8.1 |
| 132-50- 6dcb | 530 | 7-31-64 | 47 | 7.0 | 1.5 | 30 | 18 | 1,250 | 21 | 315 | 0 | 1,230 | 970 | 5.1 | .0 | 4.9 | 3,680 | 3,730 | 150 | 0 | 94 | 44 | 5,800 | 7.4 |
| 132-52-19cbb | 550 | 7-30-64 | 57 | 6.8 | 1.2 | 5.2 | 6.6 | 1,010 | 10 | 546 | 0 | 1,200 | 405 | 5.6 | .0 | 4.0 | 2,930 | 2,950 | 40 | 0 | 98 | 69 | 4,460 | 8.1 |
| **Precambrian "granite"** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 134-48-9dab | 390 | 7-23-64 | 56 | 22 | .19 | 6.4 | 2.9 | 325 | 9.0 | 438 | 7 | 217 | 110 | .4 | 3.0 | 1.2 | 918 | 934 | 28 | 0 | 95 | 27 | 1,380 | 8.4 |

winter. Water from the Dakota is used in the municipal water supply at Wahpeton, but it is mixed with treated surface water from the Ottertail River.

### PRECAMBRIAN "GRANITE"

Precambrian crystalline rock, generally called "granite," is the basement rock under Richland County, and is the bedrock directly underlying the glacial drift in much of the northeastern part of the county. In most places the upper part of the "granite" is strongly decomposed, and consists of varying thicknesses of varicolored kaolinitic (?) clay (Paulson, 1953, p. 36). The decomposed "granite" is not water bearing, and drilling is generally stopped when it is reached. In a few places in eastern Richland County, however, reported well depths indicate that the water is coming from the "granite."

Eleven wells in Tps. 134 and 135 N., R. 48 W., reportedly obtain water from depths greater than 300 feet (Baker, 1966c, fig. 2). A test hole (134-48-9baa) in the area revealed decomposed "granite" at a depth of 317 feet, overlain by glacial till. Probably the 11 deep wells pass through the decomposed zone into hard "granite," and obtain their water from fractures in the rock. All of the 11 wells have considerable hydraulic head--that is, the water either flows at the surface or rises to near the surface.

The analysis of a sample of water from one of the flowing wells (134-48-9dab) is included in table 1. The water is soft and of fair quality for drinking, although slightly higher in dissolved solids than the Public Health Service recommendations. The sodium content is high enough to cause the water to be generally unsuitable for irrigation.

## Ground water in the glacial drift

Richland County is covered by rather thick glacial drift, and most of the water used in the county is obtained from aquifers in the drift. The drift ranges in thickness from 154 to 490 feet (Baker, 1966b). The glacial drift aquifers in Richland County are divided into two categories: (1) aquifers associated with the Lake Agassiz deposits and (2) aquifers associated with the glacial till.

### AQUIFERS ASSOCIATED WITH THE LAKE AGASSIZ DEPOSITS

Deposits associated with glacial Lake Agassiz cover about four-fifths of Richland County. Two main sources of water are found in the Lake Agassiz deposits -- the Sheyenne delta deposits and the Lake Agassiz beach deposits. In addition, some water may be obtained from the silt unit that locally composes the upper part of the lake-floor deposits.

### Aquifer in the Sheyenne delta

*Location and extent.* -- The Sheyenne delta contains the largest and potentially the most productive aquifer in Richland County. The delta proper includes an area of about 750 square miles, of which about 500 square miles is in northwestern Richland County. However, the water-bearing portion of the delta in Richland County has an area of about 300 square miles.

*Thickness and lithology.* -- The maximum thickness of the delta deposits is about 200 feet, but the average thickness in Richland County is about 150 feet (Baker, 1966b). In Richland County the deposits can be divided into three units: (1) a lower unit of silt interbedded with clay and sand, which is thickest near the eastern margin of the delta and thins westward; (2) an upper unit of well-sorted sand, which is thickest in the west and thins eastward; and (3) a thin layer of wind-blown sand, which covers the entire delta. The lower silty unit is more than 150 feet thick at the eastern edge of the delta, less than 50 feet thick near the Richland-Ransom County boundary, and is entirely absent near the western edge of the delta in Ransom County. The sand unit is as much as 100 feet thick near the Richland-Ransom County boundary and is absent at the eastern edge of the delta. Its average thickness in Richland County is about 60 feet. The grain size of the sand generally decreases eastward from medium and coarse along the Richland-Ransom County boundary to very fine in the eastern part of the delta near Walcott. The thickness of the wind-blown surficial sand is generally less than 10 feet, but may be as much as 50 feet in the highest dunes.

*Hydrologic characteristics.* -- The upper unit of well-sorted deltaic sand and the overlying deposits of wind-blown sand form the main part of the Sheyenne delta aquifer. The lower silt unit generally is too fine grained to yield water to wells. The water is under water-table conditions. The water table fluctuates considerably, but most of the time and in most places it is less than 10 feet below the surface. The water table usually is lowest in late winter just before the spring thaw. Figure 5 shows the depth to water on March 9-10, 1964; in most places it was between 5 and 10 feet below land surface. During the spring thaw there usually is a sharp rise in the water table, and the yearly high often occurs within a month or two after the yearly low. Figure 6 shows the depth to water on April 28, 1964; in most places it was between 1 and 5 feet below land surface.

Following the high in spring or early summer, the water levels generally decline through the summer, fall, and winter. However, unusually large amounts of precipitation in the summer or fall will cause a lessening in the rate of decline or may even produce slight rises in water levels (fig. 7). Winter precipitation has little or no immediate effect because the frost in the ground impedes the infiltration of water. Also, there is little precipitation and that mainly in the form of snow.

The water table in the Sheyenne delta is well above the lake plain around the delta, and also above the bottom of the Sheyenne valley, which has been eroded

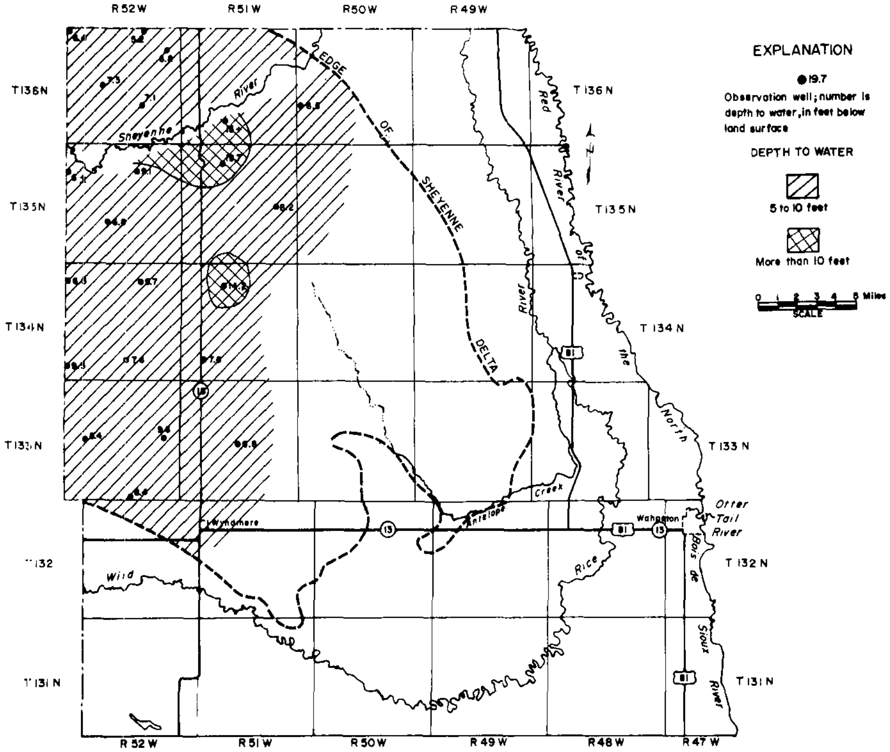

Figure 5. Depth to water in Sheyenne delta on March 9-10, 1964.

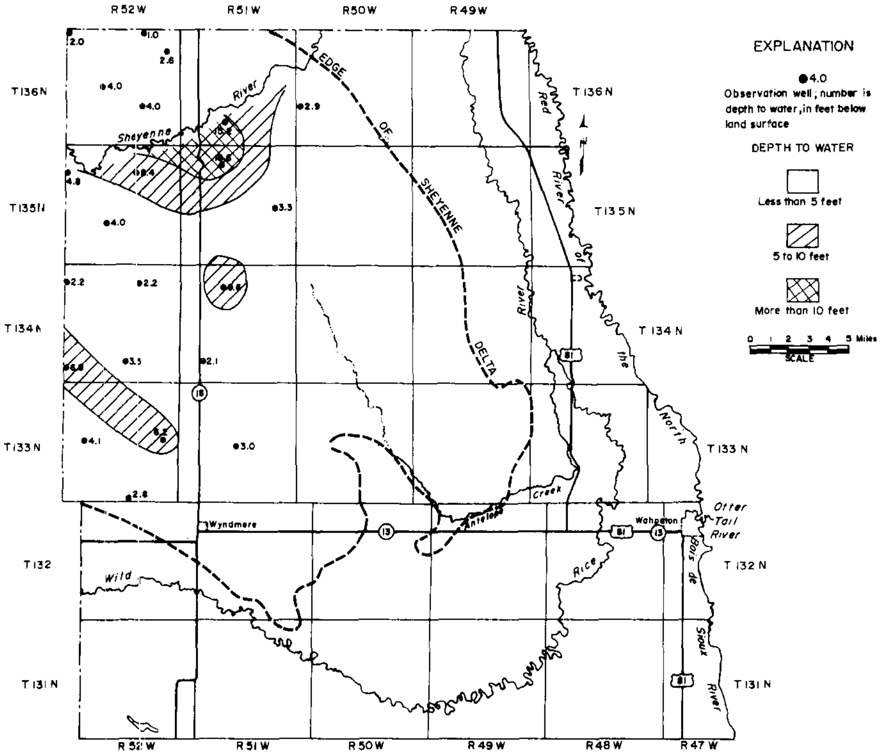

**Figure 6.** Depth to water in Sheyenne delta on April 28, 1964.

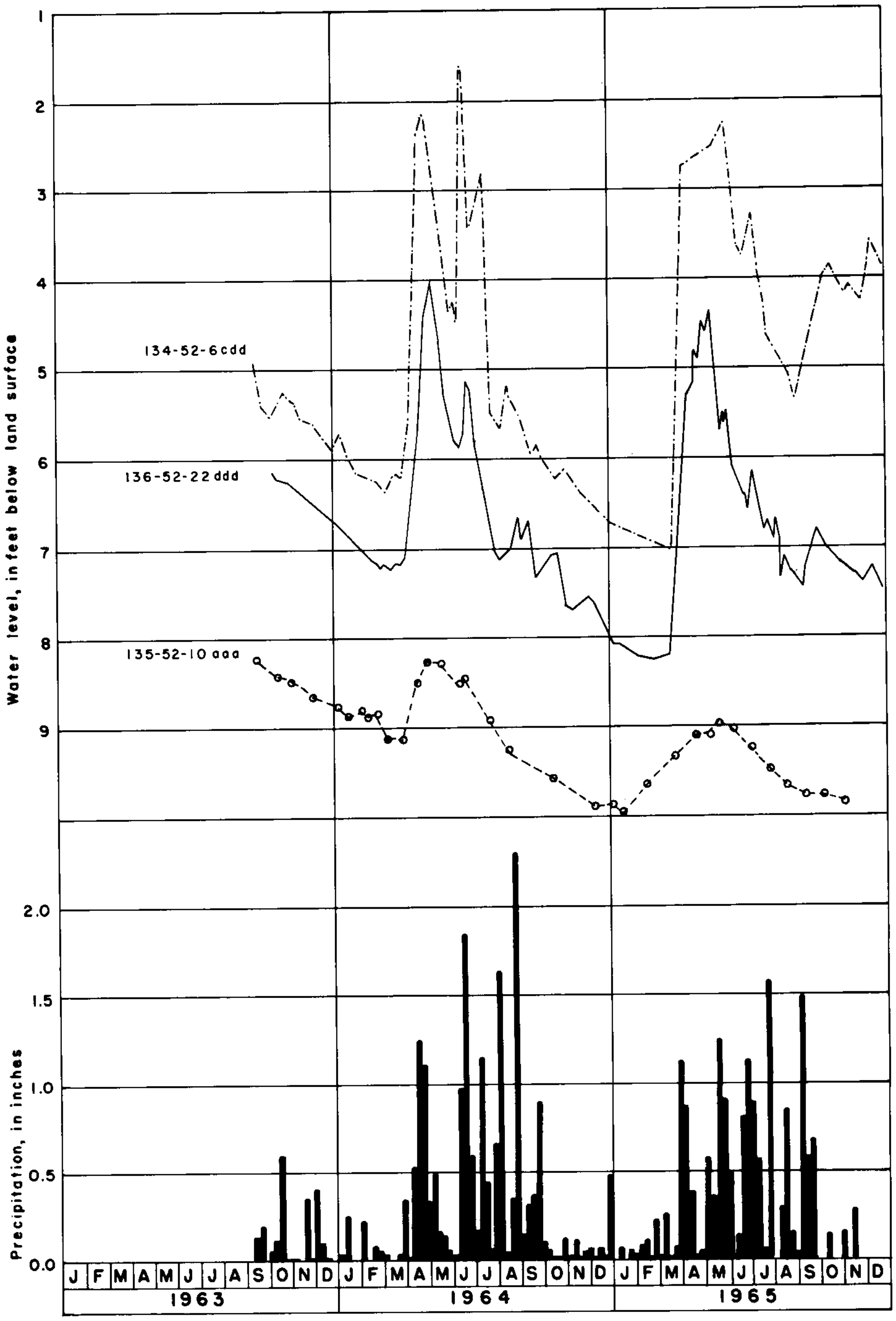

**Figure 7.** Water-level fluctuations in wells in the Sheyenne delta.

as much as 120 feet below the surface of the deposits. Accordingly, the water table slopes toward the Sheyenne valley and toward the delta edges (fig. 8).

To 1966 no large capacity wells had been drilled in the delta deposits in Richland County. Consequently, aquifer tests were not conducted to determine the water-bearing properties of the aquifer. However, the Lake Agassiz beach deposits northwest of Hankinson are similar in character to the deposits of the Sheyenne delta. In fact, originally these deposits were mapped as part of the delta (Powell, 1956, pl. 1). but were later mapped as beach deposits (Baker, 1966b, pl. 1). The aquifer associated with these deposits has been named the Hankinson aquifer and is described further on in this report. An aquifer test near Hankinson determined the coefficients of transmissibility and storage for the beach deposits to be 18,000 gpd per foot and 0.17, respectively (Powell, 1956, p. 20).

The transmissibility of the delta deposits (fig. 9) was estimated mainly from grain-size analyses and lithologic descriptions of test-hole samples. These estimates were made according to a method described by Keech (1964, p. 16-17). Laboratory determinations of permeability were made on cores taken at relatively shallow depths at five locations.

As shown in figure 9, the transmissibility probably is more than 30,000 gpd per foot near the Richland-Ransom County boundary where the upper sand unit is more than 100 feet thick, and less than 500 gpd per foot in the southeastern part of the delta where the upper unit is absent.

The porosity of the cores from the deltaic sand deposits in the western part of the county (fig. 9) ranged from 40 to 48 percent and averaged 43 percent. Using the average value of 43 percent, the area of the deltaic sand in Richland County as 300 square miles, and the average saturated thickness as 50 feet, the total volume of water stored in the sand deposits of the Sheyenne delta is about 4 million acre-feet. However, because much of the deposits are fine grained, probably only half of this amount, or less, could be extracted by pumping from wells.

The specific yield of the four cores ranged from 25 to 40 percent, which seems rather high for the deltaic sand deposits as a whole, but may be representative of the coarser facies. The coefficient of storage (or specific yield) reported for the Hankinson aquifer test was 0.17 after 52 hours of pumping. As stated earlier, the Hankinson aquifer materials are very similar to parts of the Sheyenne delta deposits. Possibly the lower value for the specific yield was due to slow drainage of the water-bearing materials and it would have increased into the 25 to 40 percent range had pumping been continued for a sufficient period.

An estimate of specific yield for the upper part of the deposits may be made by comparing the rise in water levels in observation wells with precipitation. The average rise in water levels in the 22 observation wells shown in figure 10 during the period March 9-10 to April 28, 1964, was 3.4 feet. The rise was caused chiefly by infiltration of April rains and to a lesser extent by melt water from

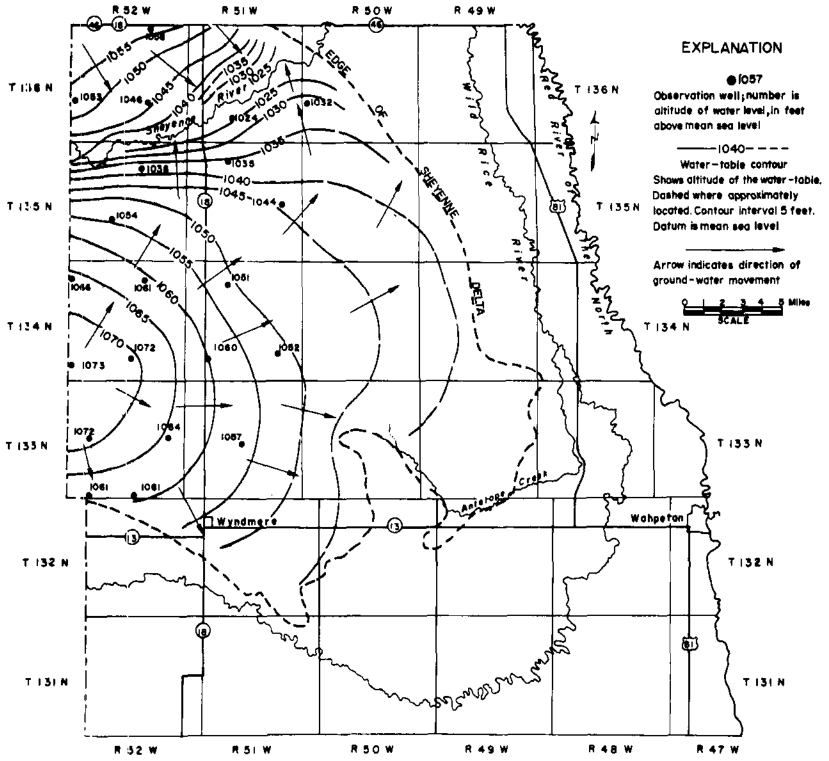

**Figure 8.**

Configuration of the water table and direction of ground-water movement in Sheyenne delta.

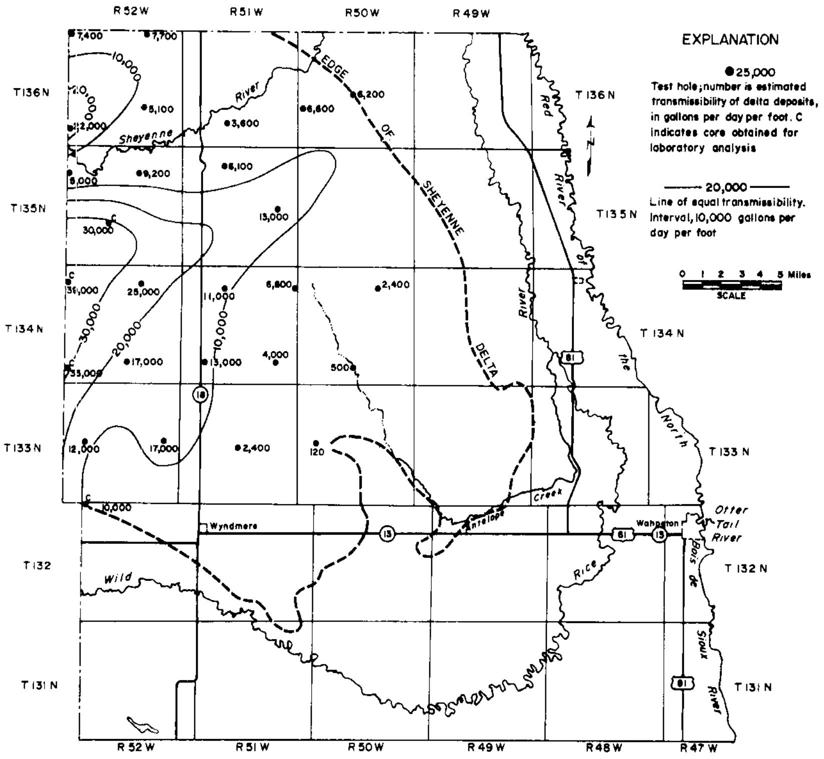

**Figure 9.** Transmissibility of the Sheyenne delta deposits.

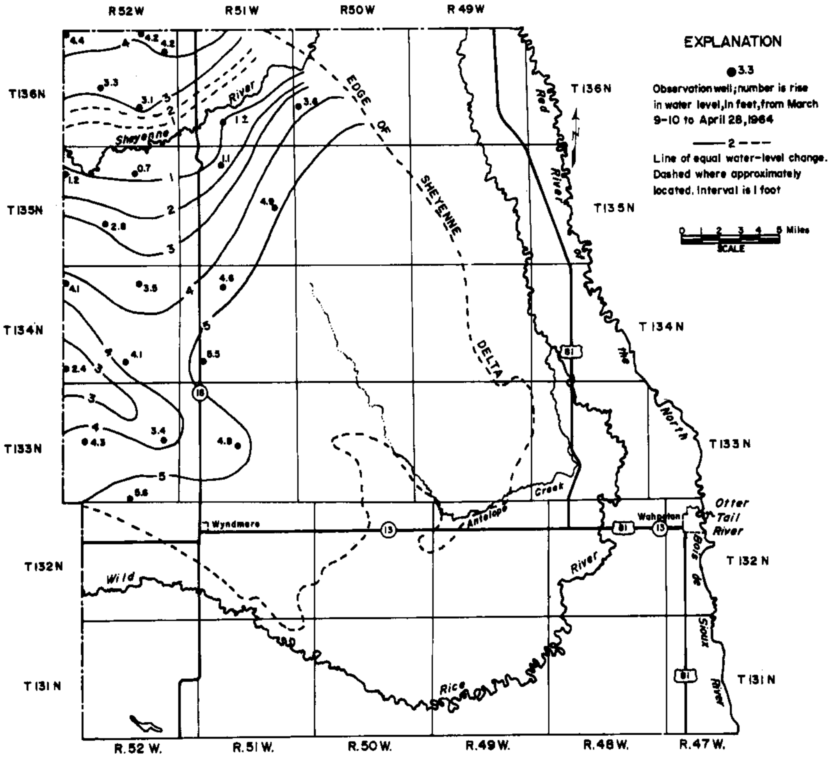

**Figure 10.** Rise in water levels in Sheyenne delta from March 9-10 to April 28, 1964.

snow and ice that had accumulated on frozen ground during the preceding winter months. The total amount of precipitation recorded since November 1, 1963, was 5.03 inches or 0.42 feet. (Precipitation that occurred prior to November probably did not contribute directly to the April rise in water levels.) However, some of the snow was sublimated during the winter and was not available for recharge. The U.S. Weather Bureau reported that total snowfall at the McLeod station during the winter of 1963-64 was 25 inches, but only 7 inches remained on the ground at the end of March when the spring thaw began (Climatological Data, North Dakota, Nov. 1963-April 1964). However, the 7 inches of snow probably was compacted and may have been equivalent to about an inch of water. The April rainfall was 3.20 inches, so that the total amount available for infiltration and runoff probably was at least 4 inches, or 0.33 feet. The amount contributed by each is not known, but even if all of the precipitation and melt water infiltrated, the average coefficient of storage for the upper part of the deposits apparently cannot be greater than about 10 percent $\left(\frac{0.33}{3.4}\right)$ and may be considerably less.

In summary, the specific yields obtained from the laboratory analyses and the Hankinson test may be representative for the more permeable and (or) deeper parts of the delta deposits, but probably are higher than the average for the delta deposits as a whole.

*Recharge-discharge relationships.* -- The Sheyenne delta is recharged directly by precipitation falling on the delta surface and moving downward to the water table. Because the surface of the delta is irregular and the surface materials are sandy, there is very little overland runoff, and most of the precipitation eventually is absorbed into the deposits. The recharge in the spring of 1964 may be expressed as the product of the average rise in water levels (3.4 feet), specific yield (probably between 5 and 10 percent), and the aquifer area (about 192,000 acres). Thus it appears that about 50,000 acre-feet of water was recharged. Well 133-52-24cdd, which showed a rise of 5.6 feet, has been measured at least weekly since 1937. The average spring rise of water level in this well for the period of record has been 5.4 feet, which indicates that 1964 may have been a near normal year for recharge.

Over a period of years, the quantity of water stored in the Sheyenne delta is relatively uniform; that is, recharge is balanced by discharge. Water is discharged from the delta chiefly through (1) wells, (2) springs along the edge of the delta and along the Sheyenne River valley, and (3) evapotranspiration.

The amount of water discharged from the Sheyenne delta through wells is very small as compared to the natural discharge. The largest yield of any well tapping the delta deposits in Richland County is that of the municipal well at Wyndmere, which yields about 50,000 gpd or 55 acre-feet per year. The combined total yield of the Wyndmere well and the many small-capacity wells in the delta (used mostly for domestic and stock needs) probably does not exceed 200 acre-feet per year.

The discharge from the delta through springs is large, but it is difficult to make an accurate estimate of the total amount. Paulson (1964) studied ground-water discharge into the Sheyenne River during periods of low flow. He found that during the period October through February, when both precipitation gains and evaporation losses are at a minimum, the flow of the river increased substantially between Lisbon, 10 miles upstream from the delta, and Kindred, 5 miles downstream from the delta. For the 5-year period 1957-62, the average increase in river flow for this reach of the Sheyenne during the period October through February amounted to 0.16 cfs (cubic feet per second) per river mile. This increase in river flow is mainly due to ground-water discharge into the river, because there is normally little or no surface runoff during that period. The Sheyenne River flows through the delta for a distance of 30 river miles in Richland County, therefore, the average discharge of ground water to the river in the county would amount to 4.8 cfs or more than 9 acre-feet per day. During a period of special measurements study September 13-November 19, 1963, the average discharge from the delta to the same reach of river was 12.5 cfs (Paulson, 1964, table 2).

These figures, however, represent only a fraction of the total discharge by springs from the delta deposits. During the fall and winter months, the water table in the delta is falling, and spring discharge is near minimum. In the spring and summer months, the difference in the discharge of the Sheyenne River at Lisbon and at Kindred is often as great as 100 cfs. During this period, however, precipitation, surface runoff, and evapotranspiration all act to make the contribution to river flow from ground-water discharge difficult to estimate. Moreover, Paulson's study considered only the Sheyenne River, but ground water is also discharged from numerous springs around the eastern edge of the delta. The total discharge from the Sheyenne delta through springs may be 5 to 10 times as great as the fall and winter discharge to the Sheyenne River. Even so, the annual discharge through springs is probably less than half of the estimated annual recharge.

The remainder of the estimated recharge must be discharged by evapotranspiration. The Sheyenne delta is well covered with vegetation, including many trees, shrubs, and other deep-rooted plants, and the water table is only a few feet below surface throughout much of the year. Consequently, evapotranspiration losses are very large, probably accounting for more than half of the total ground-water discharge from the deposits.

*Quality of water.* -- Water from the Sheyenne delta deposits generally is of good quality, although hard. Dissolved solids commonly are less than 500 ppm. Sulfate, nitrate, chloride, and fluoride all are well below the Public Health Service recommended maximums. Locally, iron is objectionably high, and softening is desirable for such domestic uses as laundry. The water generally is of satisfactory quality for irrigation. Representative analyses of water from the Sheyenne delta are included in table 1.

At a few locations in the Sheyenne delta (for example, see analysis 136-51-2aab), water from shallow wells is relatively high in sodium, sulfate, and chloride. These locations probably indicate areas of contamination from Dakota wells that have been allowed to flow or are leaking water into the subsurface through ruptured or corroded casings. Such contamination can be reduced by closing off, or otherwise repairing, the flowing wells. If this were done, the quality of the water from the affected shallow wells probably would improve within a few years.

*Utilization and potential.* -- Water from the Sheyenne delta is used for the municipal supply of the city of Wyndmere. Nearly all of the farms on the delta have one or more shallow wells for domestic use and for watering livestock. In addition, much stock water is obtained from "tanks" --shallow ponds dug to intercept the water table. All of these uses combined, however, are negligible compared to the amount of water available from the delta. Thus, the potential for development of ground water from the Sheyenne delta aquifer is very great. Individual well yields of as much as 1,000 gpm should be possible from the more permeable parts of the aquifer, which are in the western part of Richland County.

### Aquifers in the beach deposits

*Hankinson aquifer.* -- The higher beaches of Lake Agassiz form a broad belt of sand and gravel extending from the Wild Rice River north of Hankinson southeastward to the South Dakota border (fig. 11). Upham (1895, pl. 27) included this area of sand and gravel in the Sheyenne delta and later workers (Leverett, 1932; Powell, 1956) followed Upham's map. Recent mapping, however, has shown that the deposits are separated from the Sheyenne delta by an area of till and lake clay (Baker, 1966b, pl. 1). This belt of beach deposits is herein called the Hankinson aquifer.

Near Hankinson the aquifer deposits are more than 100 feet thick, but they thin toward the southeast and are only a few feet thick near the South Dakota border. The average thickness over the area shown in figure 11 is about 40 feet.

The aquifer materials range from poorly sorted sandy gravel to well-sorted fine sand. The coarser deposits are near the south end of the county and the material becomes finer grained toward the north. In the vicinity of Hankinson, the deposits include little or no gravel.

The water in the Hankinson aquifer is under water-table conditions, and the water table is generally less than 10 feet below the surface.

An aquifer test was made at a well in the southwest quarter of sec. 2, T. 130 N., R. 50 W., and reported by Powell (1956, p. 20). The transmissibility of the aquifer was reported as 18,000 gpd per foot and the coefficient of storage as 0.17. The aquifer at the test site is about 100 feet thick, hence the coefficient of permeability may be about 180 gpd per square foot. The specific yield should about equal the coefficient of storage.

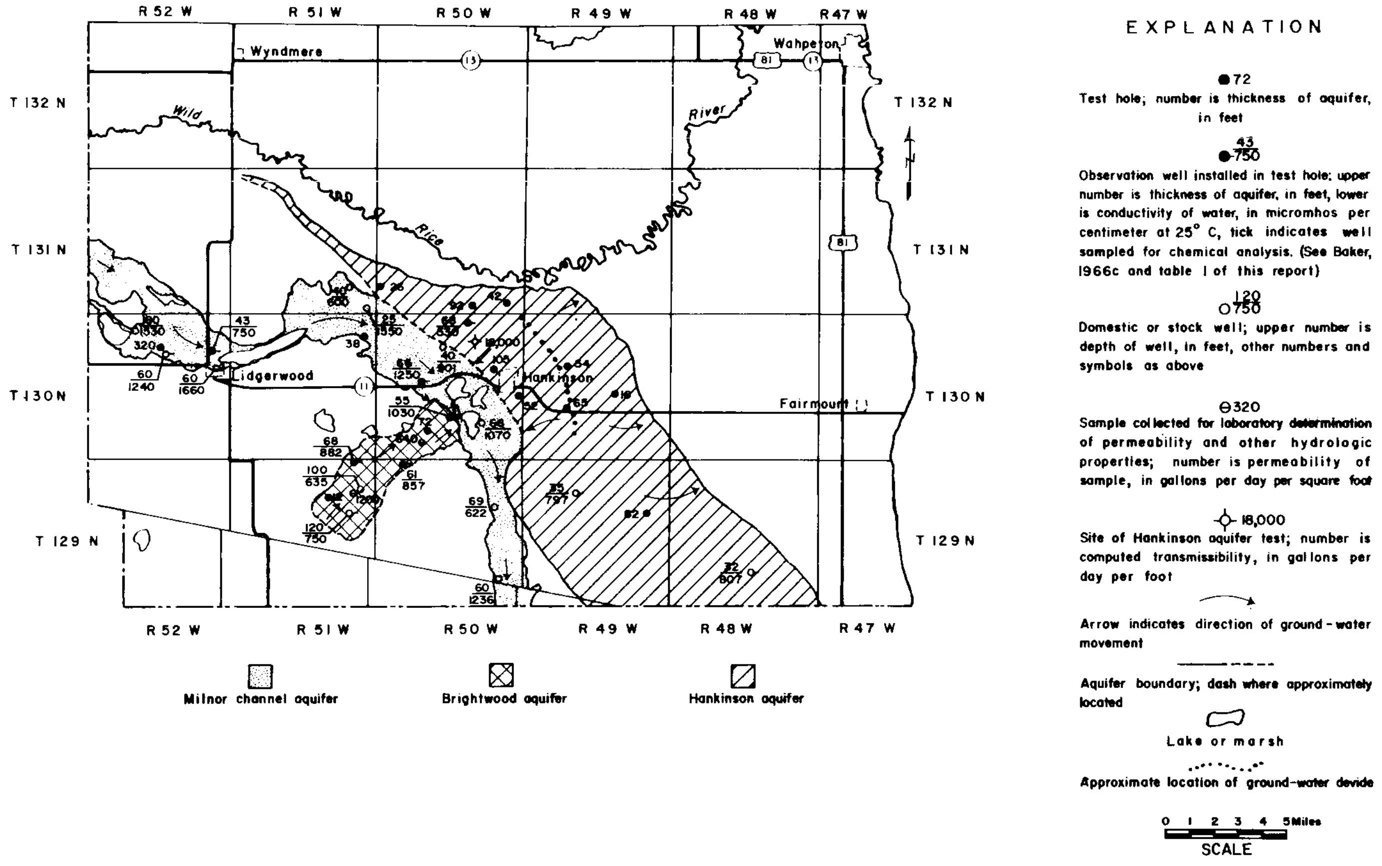

**Figure 11.** Hydrogeology of Hankinson, Milnor channel, and Brightwood aquifers.

The total area of the beach deposits is about 100 square miles. If the average saturated thickness is 30 feet and the specific yield 17 percent, the total volume of water theoretically available from the aquifer is about 330,000 acre-feet.

Generally, water is recharged to the Hankinson aquifer directly by precipitation falling on the area, and little or no water moves into the aquifer by subsurface migration. Some water is discharged in springs at the foot of the higher slopes, but most of the natural discharge is by evapotranspiration.

Chemical analyses of water from the Hankinson aquifer are included in table 1. The water is hard, but otherwise of generally good quality for drinking. One sample (129-48-27ccc) contained enough iron to be troublesome for some uses. The quality of the water from the aquifer is suitable for irrigation, but the quantity would probably be inadequate except in the vicinity of Hankinson.

The city of Hankinson has two municipal wells that tap the aquifer, and the city is by far the largest water user tapping this source. The pumping capacity of both wells combined is reported to be between 500 and 550 gpm. Most of the farms in the area use water from the Hankinson aquifer. Because of the thinness of the deposits near the south end of the area, the probable yields there are small, but large supplies of water (several hundred gallons per minute per well) could be developed in the vicinity of Hankinson.

*Minor beach aquifers.* -- Several small beach aquifers lie outside the Hankinson aquifer. These isolated aquifers are only a few feet thick and a few tens of feet wide, but they are highly permeable and will yield small quantities of water to shallow, large-diameter wells. The sole source of recharge is the precipitation that falls on them, and because of their small size, their storage capacity is not great. The quality of water is probably similar to that in the Hankinson aquifer. Only a few farms in Richland County obtain water from isolated beach aquifers.

### Lake-floor deposits

About 450 square miles in the northeastern part of Richland County is covered with lake-floor deposits. In most places, the lake-floor deposits consist of clay, but in some places, the upper part of the deposits is composed of silt. The silty facies is generally less than 10 feet thick, but where present it may yield small quantities of water to large-diameter wells. The water is under water-table conditions. In general, ground water cannot be obtained from the clayey facies of the lake-floor deposits.

No chemical analyses of water from the lake-floor deposits are available. However, the lake clays locally contain abundant crystals of calcium sulfate, and water from the deposits would probably be hard and objectionably high in sulfate. No wells are known to produce water from the lake-floor deposits in Richland County.

## AQUIFERS ASSOCIATED WITH GLACIAL TILL

Four major aquifers and numerous minor ones are associated with the glacial till in Richland County. The major aquifers are herein named the Milnor channel, Brightwood, Fairmount, and Colfax aquifers. Minor aquifers include a group of kames near the southwestern corner of the county, many small buried gravel bodies, and the glacial till itself.

### Milnor channel aquifer

The Milnor channel is marked at the surface by a long, rather sinuous, shallow valley that extends from the Sheyenne valley in Ransom County to the vicinity of Lake Traverse in South Dakota (Baker, 1966a). It probably represents the course of an ice-marginal stream that was active during the Pleistocene. The extent of the Milnor channel in Richland County is shown in figure 11.

The deposits in the Milnor channel consist of sand, sandy gravel, and sandy silt. The known range in thickness is from 8 to 66 feet. Probably the 66 feet is near maximum, and the average thickness is about 40 feet. The water in the deposits is under water-table conditions and the water level is generally within 10 feet of the surface, but varies seasonally. Hydrographs of two wells in the Milnor channel aquifer showed a rise in water level of about 3 feet from the low in January to the high in July 1965 (fig. 12).

A sample of the water-bearing deposits in the Milnor channel, taken about 2 miles northwest of Lidgerwood, was analyzed in the laboratory to determine its hydrologic properties. The coefficient of permeability was 320 gpd per square foot; if the average saturated thickness is taken as 30 feet, the transmissibility would be nearly 10,000 gpd per foot. The specific yield of the sample was 20.8 percent.

Using an area of 40 square miles, an average saturated thickness of 30 feet, and a specific yield of 20 percent, the total volume of available water in the aquifer is computed to be more than 150,000 acre-feet.

Recharge to the Milnor channel aquifer in Richland County is from at least three sources: (1) direct precipitation on the aquifer and adjacent areas that drain to it, (2) water moving into Richland County through the aquifer from the northwest, and (3) inter-aquifer movement from the Brightwood aquifer. In addition, some ground water may move into the aquifer from the beach deposits near Hankinson, and small amounts may be contributed by the till adjacent to the channel.

The amount of water recharged to the aquifer is difficult to determine, but the amount of discharge can be estimated. Net changes in the water table are small, so recharge should be about equal to discharge.

Water is discharged from the aquifer in Richland County primarily as under-

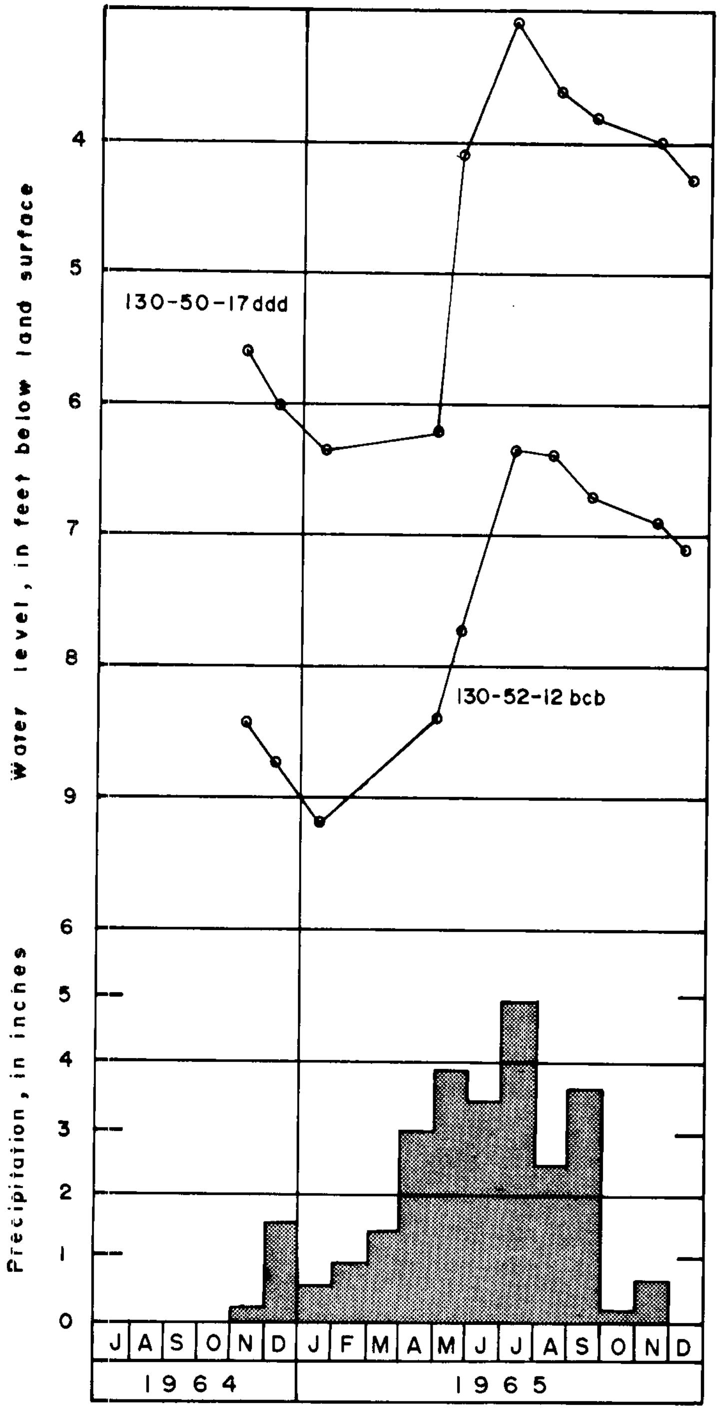

**Figure 12.** Water-level fluctuations in the Milnor channel aquifer.

flow through the channel and by evaporation and transpiration. The amount of water discharged through wells is very small.

The Milnor channel is about 1-1/2 miles wide where it leaves Richland County. Taking the transmissibility as 10,000 gpd per foot and the hydraulic gradient as 10 feet per mile, the underflow through the channel would amount to about 150,000 gpd or 170 acre-feet per year.

The Milnor channel contains water-table lakes and ponds with a total area of about 5-1/2 square miles. The average evaporation from a free-water surface in this area is about 31 inches per year (DeWiest, 1965, figs. 2-18). Thus, the evaporation from the lakes and ponds would be about 9,100 acre-feet per year.

The area of the Milnor channel exclusive of the lakes and ponds is about 35 square miles. Much of this area is marsh, and evapotranspiration from a marsh approaches evaporation from a free-water surface. Taking the average evapotranspiration from the channel as 2 feet per year, the volume of water thus discharged would be 45,000 acre-feet per year.

Thus, the total natural discharge from (and recharge to) the Milnor channel aquifer probably amounts to more than 50,000 acre-feet per year.

Four chemical analyses of water from the Milnor channel aquifer are included in table 1. The water is hard, but otherwise of fair quality for domestic use. Three of the four samples contained less than 1,000 ppm dissolved solids. Two of the four samples contained rather large amounts of sulfate, which might impart an objectionable taste. The water is suitable for irrigation.

The municipal wells at Lidgerwood tap the Milnor channel deposits and make the only large withdrawals of water from the aquifer. Much of the aquifer underlies low marshy ground, and only a few farms have wells in it. Withdrawals of water for human use could be increased greatly without exceeding the capacity of the aquifer. Individual well yields of as much as 500 gpm should be possible in the thicker and more permeable parts of the Milnor channel deposits.

### Brightwood aquifer

The Brightwood aquifer, which lies southwest of Hankinson (fig. 11) is in a thick body of glacial outwash enclosed by deposits of stagnation moraine (Baker, 1966b). The outwash body, which has an area of about 13 square miles, crops out in a high steep face near Lake Elsie on the west side of the Milnor channel in Brightwood Township. Most of the outwash deposit is above the level of the Milnor channel.

The thickness of the outwash deposits ranges from 70 to 130 feet, and averages about 100 feet. The material consists of coarse sand to medium gravel, and is generally well sorted. The deposits are only partly covered by glacial till, and the water generally is under water-table conditions. Water from the aquifer is

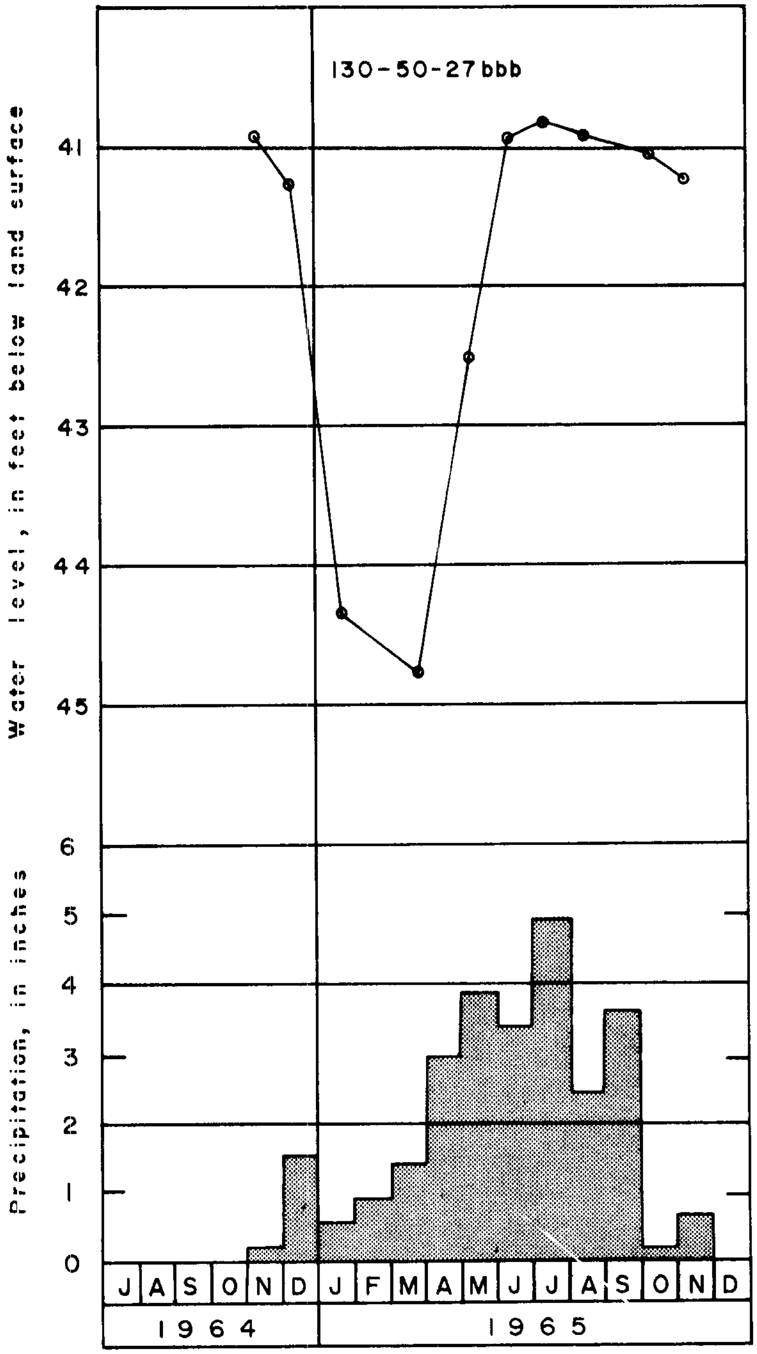

**Figure 13.** Water-level fluctuations in the Brightwood aquifer.

discharged into adjacent lakes which have elevations below the top of the sand and gravel deposit. The water level in the aquifer is 50 to 65 feet below the surface of the ground. A hydrograph of a well in the Brightwood aquifer showed a rise in water level of about 4 feet from the low in March to the high in July 1965 (fig. 13).

Samples from two locations in the Brightwood aquifer were submitted for laboratory determination of permeability and specific yield. The laboratory permeabilities of the samples were 640 and 1,200 gpd per square foot. Assuming an average saturated thickness of 40 feet, the transmissibility would be between 25,000 and 48,000 gpd per foot. The specific yield determined by the laboratory was 38 percent. Using the area of 13 square miles, the saturated thickness of 40 feet, and an average specific yield of 30 percent, the volume of available water in the aquifer is about 100,000 acre-feet.

Recharge to the Brightwood aquifer is derived mainly from local precipitation. Water moves eastward through the aquifer to discharge into Lake Elsie and adjcaent lakes, and into the Milnor channel.

Chemical analyses of three samples from the Brightwood aquifer are included in table 1. Dissolved solids in the three samples were 564, 613, and 699 ppm. The water is hard and relatively high in sulfate, but should be satisfactory for most uses.

There are no large-scale users of water from the Brightwood aquifer. Farms in the area tap the aquifer for domestic and stock water. The present withdrawals from the aquifer are much below its capacity, and much greater development is possible. Individual well yields of as much as 500 gpm should be possible in places.

### Fairmount aquifer

The buried outwash (?) deposit described by Paulson (1953, p. 21-26) in the vicinity of Fairmount is here called the Fairmount aquifer. No test holes drilled during the present study penetrated this aquifer, but on the basis of well depths the aquifer can be extended south from Paulson's mapping to the South Dakota border. The location of the aquifer is shown on figure 14.

According to Paulson (1953, p. 22), the Fairmount aquifer lies at a depth of 80 to 110 feet; the thickness ranges from 9 to 18 feet and averages 14 feet. The aquifer is composed of fine to medium gravel overlain by fine clayey sand. The water in the aquifer is under artesian conditions, and the water level is near land surface.

An aquifer test was conducted at one of the Fairmount village wells during April 22-25, 1956. The well was pumped for about 24 hours at a rate of 145 gpm. The transmissibility of the aquifer, calculated from data gathered during

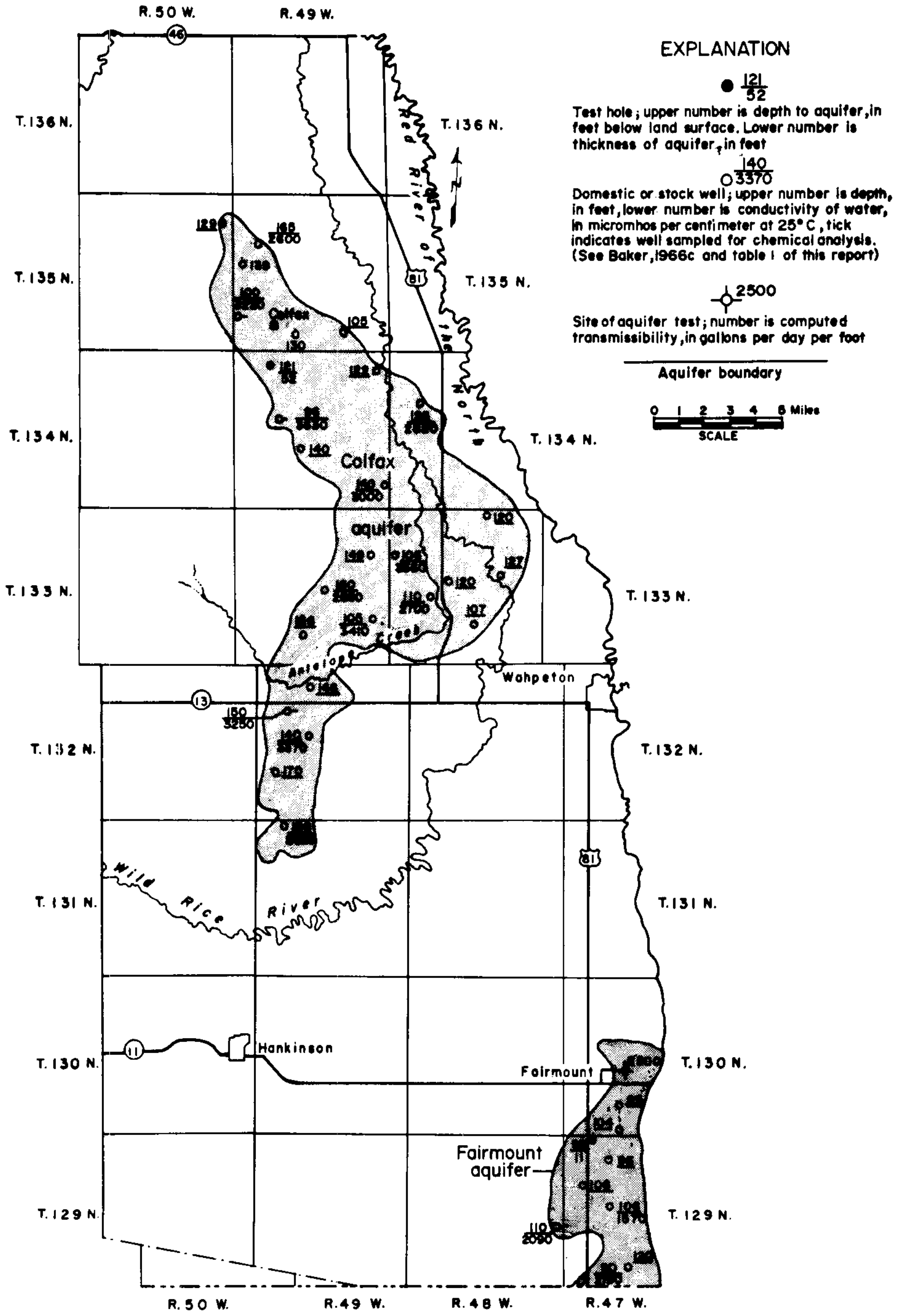

Figure 14. Hydrogeology of Fairmount and Colfax aquifers.

this test, was about 2,500 gpd per foot, and the storage coefficient was 0.000035.

The only sources of recharge to the Fairmount aquifer in North Dakota are the overlying till and the underlying Dakota Sandstone. The quality of water indicates that there is little leakage from the Dakota Sandstone. The aquifer extends into Minnesota and South Dakota, however, and there may be other sources of recharge in these areas.

An analysis of water from the Fairmount village well is included in table 1. The water is generally of good quality for drinking and domestic use, but, like most water in the county, it is relatively hard. The water should be suitable for irrigation of most crops likely to be grown in the area.

The only large user of water from the Fairmount aquifer is the village of Fairmount. Many farm wells in the vicinity tap the aquifer for domestic water. Probably the aquifer will support considerably larger withdrawals of water than are presently being made. Individual well yields of as much as 250 gpm should be possible in places.

### Colfax aquifer

A large number of wells in the vicinity of Colfax and southward end in sand at depths between 100 to 150 feet below the surface (Baker, 1966c, fig. 3). All of these wells have considerable head, and many of them flow. A test hole (134-49-5cdd) drilled near Colfax penetrated 52 feet of medium to coarse sand between 121 and 173 feet below the surface. Probably this sand is the source of water to the wells in the area and represents a sizeable body of buried outwash, here called the Colfax aquifer (fig. 14).

The hydrologic properties of the Colfax aquifer are not known, but the medium to coarse sand encountered in the test hole appears to have good permeability and moderate to large yields may be possible.

Analyses of two samples of water from wells in the Colfax aquifer are included in table 1. Dissolved solids were 2,160 and 2,390 ppm. The water is high in sodium, sulfate, and chloride, and is of rather poor quality for drinking. In one sample the fluoride content is well above optimum. The hardness is similar to that of water from most other drift aquifers in the county.

The chemical character of the water indicates that the Colfax aquifer is probably recharged by leakage partly from the surrounding till and partly from the underlying Dakota Sandstone. The hardness of the water is typical of water from the glacial drift, but the high sodium and chloride content suggests Dakota water. The hydraulic head also may be partly derived from Dakota leakage.

There are no large users of water from the Colfax aquifer. The village of Colfax has no municipal water system. Farms in the area withdraw only small amounts from the aquifer for domestic and stock water. However, individual well yields of as much as 250 gpm may be possible in places.

### Kames

In the southwest corner of Richland County, an area of gently-rolling topography underlain by till, includes many low conical hills (kames) of poorly sorted sand and gravel. The average height of the kames is about 40 feet and each covers an area of a few acres.

The kames contain ground water under water-table conditions. Because of the small volume of each kame, the amount of water in storage is small, and the kames are of only minor importance as aquifers. A few farms in the area obtain domestic water from the kames.

No quantitative hydrologic data are available for the kames, but it is safe to assume that the yield from each would be small and probably not adequate for any but small domestic needs. The quality of the water is probably similar to that of water from the Milnor channel and Brightwood aquifers.

### Small gravel bodies in the drift

Many wells in Richland County do not penetrate any of the aquifers previously discussed, but yield ample supplies of water for domestic and stock use. Most of these wells end in small bodies of sand and gravel enclosed in the glacial till. Such sand and gravel bodies are thin, small, discontinuous, and randomly located at varying depths. At present, there is no reliable means of locating these small aquifers except by test drilling.

The water in most of the aquifers is under artesian conditions. There are a few flowing wells that penetrate such an aquifer, but the water level in most wells stands well above the top of the aquifer. Seasonal fluctuations of water levels in these small gravel bodies are smaller than in water-table aquifers. Hydrographs for three wells showed rises of about 1.7, 2.4, and 2.6 feet from the seasonal lows in February to the highs in July and August 1965 (fig. 15).

One of these small gravel bodies is exposed in an excavation near the Red River north of Wahpeton. This gravel body has a known area of only about 1 square mile in Richland County, but it probably extends east and north into Minnesota. A test hole (133-47-17ddd) through the deposit penetrated 68 feet of sand and gravel. The aquifer crops out in the channel of the Red River and is hydraulically connected to the river, hence it is likely that large quantities of water could be pumped on a sustained basis. Individual well yields of as much as 250 gpm should be possible. With heavy pumping, the quality of the water would approximate that of river water, which is generally less highly mineralized than

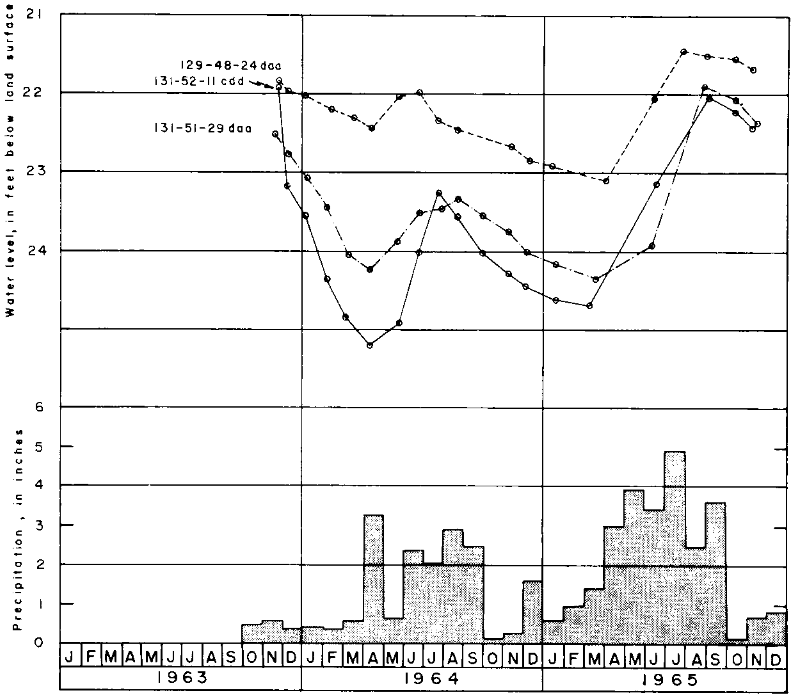

Figure 15. Water-level fluctuations in minor drift aquifers.

most ground water in the county.

Few data are available on the yields of wells penetrating the small aquifers. Moreover, it is unlikely that data derived from one well would be applicable to another. The aquifer materials commonly reported range from medium sand to medium gravel. Johnson (1963, table 4) gives the typical coefficients of permeability for material in this size range as from 1,000 to 22,000 gpd per square foot. However, the aquifers are small and thin, and they are recharged chiefly by water moving through the surrounding till. Therefore, even those with high coefficients of permeability are easily depleted and are not likely to support large sustained withdrawals of water.

Analyses of water from six wells that tap these small aquifers are included in table 1. All except one contained more than 1,000 ppm of dissolved solids. The water is generally very hard, and of only fair quality for drinking. All of the samples are high in sulfate and four contained more than 1 ppm of iron. Better quality water is not available in many parts of Richland County, however, and water from these small aquifers is widely used for domestic and stock water.

### Till

In many parts of North Dakota, the glacial till itself serves as an aquifer, but only a very few wells in Richland County derive their water from the till. The till is saturated with water within a few feet of ground level and large-diameter dug or bored wells can often produce sufficient water for domestic needs.

The permeability of till is typically very low; Johnson (1963, table 4) gives a range of 0.0003 to 0.5 gpd per square foot. One sample of rather silty till collected in western Richland County (130-51-30bbc) had a permeability of 1 gpd per square foot.

Because very few wells in Richland County obtain water from the till, no samples of till water were collected for chemical analysis. Probably the water obtained from the till is generally similar in quality to that from the small sand and gravel aquifers described above.

## WITHDRAWAL OF GROUND WATER IN RICHLAND COUNTY

It is difficult to determine accurately the daily water use in an area the size of Richland County. However, by combining the estimated pumping rates of the various municipal wells with published averages for rural domestic use and livestock, one can arrive at an estimate that is probably of the right order of magnitude.

Five communities in Richland County have municipal water supplies: Wahpeton, Hankinson, Lidgerwood, Wyndmere, and Fairmount. Only one of these, Wahpeton, uses water from another source in addition to ground water. Wahpeton mixes ground water with water from the Ottertail River.

The discharge of the Wahpeton municipal wells is measured continuously and recorded monthly; the average discharge is about 160,000 gpd. The water commissioners at Wyndmere and Fairmount estimate the municipal pumpage at 50,000 gpd and 35,000 gpd, respectively. The average pumpage at Hankinson is estimated as 60,000 gpd; that at Lidgerwood is estimated as 55,000 gpd. Thus, the total municipal use is about 360,000 gpd.

The 1960 population of Richland County, outside of the five communities named, was 9,335. The U.S. Public Health Service (1962a, table 1) gives the approximate water consumption in one-family dwellings as 50 to 75 gpd per person. Using an average figure of 65 gpd gives a total of about 600,000 gpd for domestic use of the rural population in Richland County.

The North Dakota Crop and Livestock Reporting Service gives the 1960 livestock population for Richland County as follows: dairy cattle - 9,600, other cattle - 44,400; hogs - 29,000; sheep - 14,500; and chickens - 227,000. Again using average consumption figures from the U.S. Public Health Service, the daily water consumption by livestock in the county is: dairy cattle - 340,000 gpd, other cattle - 530,000 gpd; hogs - 120,000 gpd; sheep - 29,000 gpd; and chickens - 18,000 gpd; total consumption by livestock - about 1,000,000 gpd.

Thus, the total withdrawal of ground water for human activities in Richland County is: municipal use - 360,000 gpd, rural and domestic use - 600,000 gpd, and livestock use - 1,000,000 gpd; total - about 2 million gpd.

## SUMMARY AND CONCLUSIONS

The aquifers in Richland County are divided into bedrock aquifers and glacial drift aquifers. The drift aquifers are subdivided into those associated with the deposits of glacial Lake Agassiz and those associated with the glacial till.

The only bedrock units that yield water to wells in Richland County are the Dakota Sandstone and the Precambrian "granite." The "granite" is known to yield water in only one small area--presumably from a local fracture system. Wells in this area are more than 300 feet deep, and all flow or have water levels near the surface.

The Dakota Sandstone is present under about two-thirds of Richland County. The formation is thickest in the southwestern part of the county where yields of as much as 500 gpm probably can be obtained. Most wells that penetrate the Dakota flow. The depth to aquifers in the Dakota Sandstone in Richland County ranges from 200 feet in the east to 900 feet in the southwest.

Water from the bedrock aquifers in Richland County is highly mineralized. The dissolved solids in water from the Dakota Sandstone generally exceeds 2,500 ppm, and in a sample of water from the granite is nearly 1,000 ppm. The principal cation is sodium; the dominant anions are chloride, sulfate, and bicarbonate. Generally water from the bedrock aquifers is of poor quality for drinking and unsuitable for irrigation. Water from the bedrock aquifers in Richland County is used mostly for livestock.

The aquifers in the Lake Agassiz deposits are surficial bodies of sand and gravel at the margin of the lake plain. The largest and most important is the aquifer in the Sheyenne delta.

The Sheyenne delta covers about 500 square miles in northwestern Richland County, and the deposits have an average thickness of about 150 feet. The water-bearing portion of the delta consists of well-sorted deltaic sand overlain by deposits of wind-blown sand. In Richland County the aquifer has an area of about 300 square miles and an average thickness of 50 feet. In places it is as much as 100 feet thick. The water table in most parts of the delta is 5 to 10 feet below land surface at seasonal low and 1 to 5 feet below land surface at seasonal high. The transmissibility probably exceeds 30,000 gpd per foot near the western border of the county, but decreases eastward. It is estimated that the aquifer in the Sheyenne delta in Richland County contains about 4 million acre-feet of water.
About half of this amount would be available to wells. The aquifer is recharged annually by infiltration of rain and snowmelt. The recharge occurs chiefly during the spring and early summer and is estimated to be about 50,000 acre-feet during a year of average precipitation.

The beaches of Lake Agassiz form a broad belt of sand and gravel in the southeastern part of the county. Near Hankinson these deposits contain an important aquifer that has an area of about 100 square miles. The transmissibility of the deposits was computed from an aquifer test as 18,000 gpd per foot and the coefficient of storage as 0.17. The volume of water theoretically available from storage in the Hankinson aquifer is estimated as about 330,000 acre-feet.

The water in the Sheyenne delta and the Hankinson aquifer is of much better quality for most uses than that from the bedrock aquifers. The total amount of dissolved solids generally ranges from 300 to 800 ppm. The principal cations are calcium and magnesium; the principal anions are bicarbonate and sulfate. The water is hard, but otherwise of good quality for drinking; it is suitable for irrigation.

A few isolated beach ridges cross the Lake Agassiz plain in Richland County. Sand and gravel deposits in the ridges will yield small quantities of water; but, because of their small size, they are easily dewatered.

Locally, silt is present in the upper part of the lake-floor deposits of Lake Agassiz. Where present, the silt will probably yield small quantities of water to large-diameter wells. Where the silt is not present, usable quantities of water should not be expected from the lake-floor deposits.

The glacial till includes two large surficial aquifers--the Milnor channel aquifer and the Brightwood aquifer--and a group of small isolated aquifers in kame deposits.

The Milnor channel deposits occupy an ice-marginal channel of glacial origin that crosses the southwestern part of Richland County. The deposits cover an area of about 40 square miles and have an average saturated thickness of about 30 feet. The transmissibility of the aquifer is about 10,000 gpd per foot and the total volume of recoverable water in the aquifer is estimated as about 150,000 acre-feet.

The Brightwood aquifer is in a thick body of partly buried glacial outwash gravel southwest of Hankinson. The area of the deposits is about 13 square miles, and the average thickness is about 100 feet. The water table is about 60 feet below the top of the deposits, and the aquifer thickness is only about 40 feet. The transmissibility is more than 25,000 gpd per foot, and the estimated volume of available water in the aquifer is about 100,000 acre-feet.

A small area in the southwestern corner of the county contains scattered hills of poorly sorted sand and gravel called kames. The kames contain ground water under water-table conditions, but because of the small volume of each kame, the yield of water from them is small.

Water from these surficial aquifers contains from 500 to 900 ppm of dissolved solids. The principal cations are calcium and magnesium; the principal anions are bicarbonate and sulfate. The water is hard but otherwise of generally good quality. The water is suitable for irrigation.

The glacial drift includes numerous sand and gravel bodies that are completely buried within the till and contain water under artesian pressure. The largest known bodies of buried sand and gravel are named the Fairmount aquifer and the Colfax aquifer.

The Fairmount aquifer lies at a depth of 80 to 110 feet and has an average thickness of about 14 feet. The transmissibility was computed from an aquifer test as about 2,500 gpd per foot. The water from the Fairmount aquifer is more highly mineralized than that from the Milnor channel and Brightwood aquifers; the principal ions are sodium and bicarbonate.

The Colfax aquifer lies at a depth of 100 to 150 feet below the surface. The hydrologic properties of the aquifer are not known. The water is rather highly mineralized; the total amount of dissolved solids is more than 2,000 ppm. The principal cations are sodium and calcium; the principal anions are sulfate and chloride. Probably the aquifer is partly recharged by upward leakage from the underlying Dakota Sandstone.

Numerous small bodies of sand and gravel enclosed in glacial till yield small to moderate quantities of water. Such deposits may have good permeability, but because they are enclosed in till of poor permeability, they receive recharge slowly and are easily depleted. The water is of variable quality, but it commonly contains more than 1,000 ppm of dissolved solids. Sodium and calcium are generally the principal cations; and bicarbonate and sulfate the principal anions.

Nearly all of the water used in Richland County is from ground-water sources. The city of Wahpeton uses some surface water from the Ottertail River in its municipal supply, but the river water is mixed with ground water from deep wells. Four other communities in the county (Wyndmere, Hankinson, Lidgerwood, and Fairmount) have municipal water supplies; all use ground water.

The five communities that have municipal water supplies pump an average of about 360,000 gpd. Domestic use by the rural population is estimated as about 600,000 gpd, and water used by livestock in the county is estimated as 1,000,000 gpd. Thus, the total withdrawal of ground water for human activities in Richland County is about 2 million gpd.

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