GROUND-WATER RESOURCES

of

RENVILLE AND WARD COUNTIES

by
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and Renville and Ward Counties Water Management Districts**

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 the ground water basic data, and Part III describes the ground water resources. Part I will be published later.

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ABSTRACT

Two major types of aquifers are present in Renville and Ward Counties--those in the semiconsolidated and consolidated bedrock formations and those in unconsolidated glacial deposits.

Layers of sand and lignite in the Fort Union Group are the principal bedrock aquifers. A few bedrock wells flow, but in others the depth to water may exceed 100 feet. The water is a sodium bicarbonate type, a sodium chloride type, or a mixture. It is unsuitable for many purposes.

Aquifers in the Souris (Mouse) and Des Lacs River valleys are the most productive of the unconsolidated glacial deposits. Individual well yields of more than 500 gallons per minute are available locally, and the water is generally of good quality. Numerous other surficial and buried glacial aquifers, however, contain water of poor chemical quality.

INTRODUCTION

Purpose and Scope of the Investigation

This report is the result of a 4-year investigation by the U.S. Geological Survey in cooperation with the North Dakota State Water Commission, the North Dakota Geological Survey, and Renville and Ward Counties. The purpose was to determine the availability, quantity, and quality of the ground-water resources in the counties. The availability of water for municipal use and for irrigation was of primary interest.

The investigation began in July 1963 and the fieldwork was completed in August 1966. The report on the geology of the counties will be published as Part I. The basic-data report was published as Part II (Pettyjohn, 1968a) and includes logs of test holes; records of wells, springs, and test holes; water-level measurements; and chemical analyses of ground water. This report (Part III) describes the location, extent, chemical quality, and quantity of water in storage; the relationship between surface water and ground water; water use; and aquifer yields. It also discusses the suitability of the ground water for irrigation, municipal supply, industrial use, and domestic and stock use. Basic data used in this report are from Part II (Pettyjohn, 1968a), unless otherwise referenced.

The classification and nomenclature of the rock units in this report conform to the usage of the North Dakota Geological Survey.

Location and Extent of the Area

Renville and Ward Counties cover 2,949 square miles in the north-central part of North Dakota (fig. 1). The area is bounded on the north by Canada, on the west by Burke and Mountrail Counties, on the south by McLean County, and on the east by Bottineau and McHenry Counties.

Physiography and Drainage

Renville and Ward Counties can be divided into three distinct parts: the ground-moraine plain, the valleys of the Souris and Des Lacs Rivers, and the Coteau du Missouri. The northeast-sloping ground-moraine plain of the Drift Prairie extends from the northeast edge of the Coteau du Missouri to Canada and includes much of Ward County and nearly all of Renville County. The plain is traversed by the Souris River upstream from Burlington. The Des Lacs River and the Souris River downstream from Burlington flow near its southwestern border. The topography is gently rolling, and the local relief is generally low. A few intermittent streams in ice-marginal channels cross the plain and potholes are abundant throughout the area. The potholes may contain water, some throughout the year and others for only a few days or weeks.

The Souris and Des Lacs River valleys are sufficiently distinct to warrant a separate discussion in this report. Most of Renville and Ward

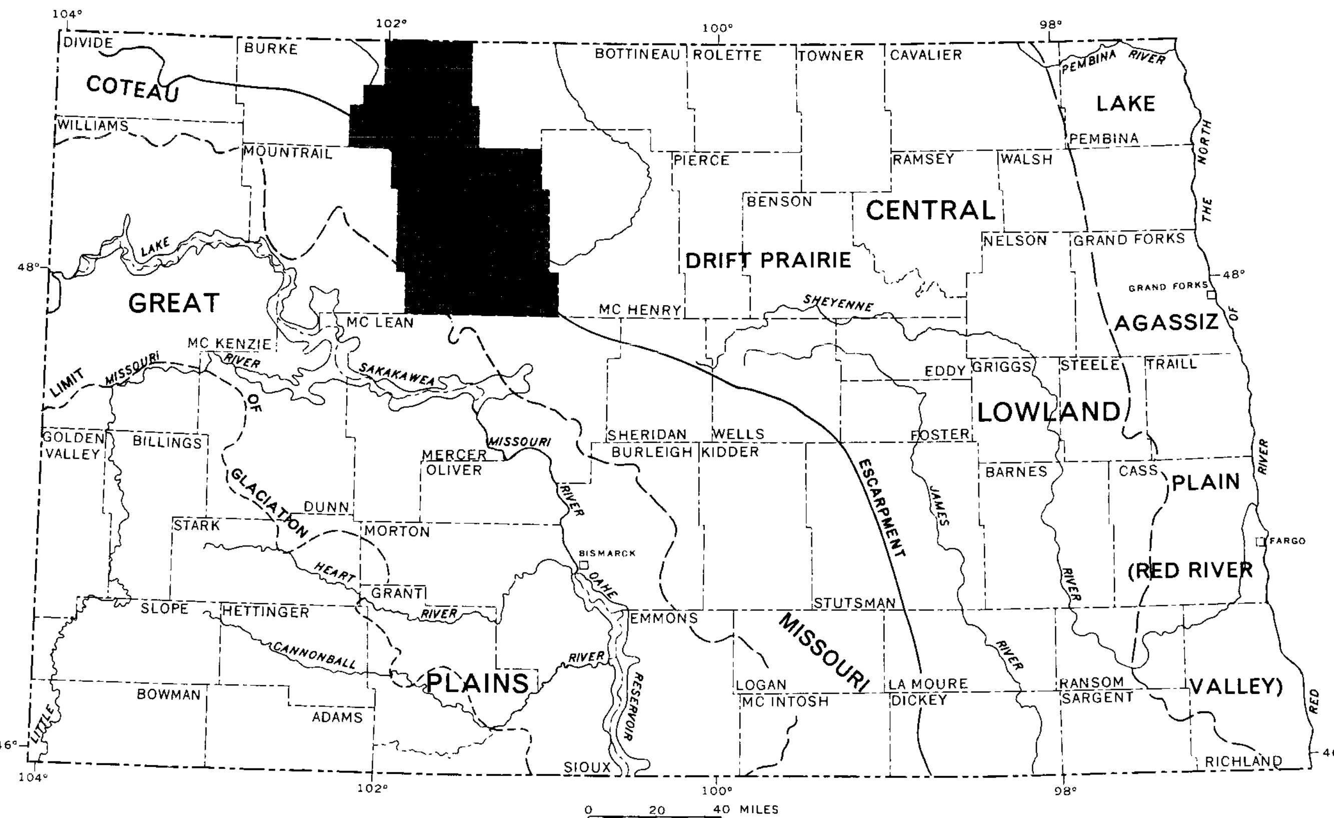


FIGURE 1. Physiographic divisions in North Dakota and location of report area.

Counties are drained by these rivers, which form part of the drainage system of the Red River of the North. The Souris and Des Lacs Rivers are the only perennial streams in the counties; although during prolonged droughts, flow in both streams may cease in the reaches above Minot. The river flood plains are wide and nearly flat. There are several dams and reservoirs on each river.

The Coteau du Missouri extends across the southern and western parts of Ward County. It is characterized by very hilly stagnation moraine, end moraines, and small areas of ground moraine. It is poorly drained, as shown by the numerous potholes, small lakes, and sloughs. Many of the small bodies of water are saline. There are several extensive deposits of outwash sand and gravel on the Coteau and many lake chains that represent partly buried valleys. The Missouri Escarpment is the northeastern margin of the Coteau du Missouri. The "escarpment" is generally a rather gentle slope (about 50 feet per mile) from the higher level of the Coteau du Missouri to the lower level of the Drift Prairie. In some localities, however, the slope is much steeper. It generally forms a band several miles wide that is dissected several tens of feet by tributaries of the Souris and Des Lacs Rivers.

Previous Investigations

Apparently the earliest report concerning the ground-water resources in Renville and Ward Counties was by Simpson (1929), who presented data on water wells in glacial deposits and bedrock formations. Logs and chemical analyses of selected wells are included in Simpson's report. Andrews (1939) reported on the lignite deposits in southern Ward County. Robinove, Langford, and Brookhart (1958) gave a general discussion of the saline water in the counties. A geologic report (Lemke, 1960) describes the Souris River area, including Renville County and most of Ward County. A large quantity of ground-water basic data for Renville and Ward Counties, north of the Souris River, is given in a report by LaRocque and others (1963a). The basic data were utilized in a subsequent interpretive report (LaRocque and others, 1963b).

Local ground-water studies have been made in several parts of Renville and Ward Counties. Akin (1947) studied the ground-water conditions in Minot, and Pettyjohn (1967a) added subsequent interpretations based on additional data (Pettyjohn and Hills, 1965). Akin (1951) described the geology and ground-water conditions in the Mohall area, which includes parts of Renville and Bottineau Counties.

Jensen (1962) discussed the geology and occurrence of ground water in the vicinity of Bowbells, which includes parts of Burke and Ward Counties. Armstrong (1963) investigated the ground-water resources near Max in McLean and Ward Counties, and Schmid (1963) studied the occurrence of ground water in the Ryder area in southwestern Ward County. The geology and ground-water resources in the vicinity of Berthold were described by Randich (1963). An evaluation of the ground water in the Surrey area in eastern Ward County was made by Froelich (1964).

Acknowledgments

The authors are grateful to many of the residents of Renville and Ward Counties for contributing helpful information during the study. Mr. Vern Fahy, City Manager of Minot, and Glen Burg, Supervisor of the Minot Water-Treatment Plant, deserve special mention for their cooperation.

Well-Numbering System

The wells, springs, and test holes in this report are numbered according to a system based on the location in the public land classification of the United States Bureau of Land Management. It is illustrated in figure 2. The first numeral denotes the township north of a base line, the second numeral denotes the range west of the fifth principal meridian, and the third numeral denotes the section in which the well is located. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarter sections, quarter-quarter sections, and quarter-quarter-quarter sections (10-acre tract). For example, well 153-87-15ada is in the NE¼SE¼NE¼ sec. 15, T. 153 N., R. 87 W. Consecutive terminal numerals are added if more than one well is recorded within a 10-acre tract.

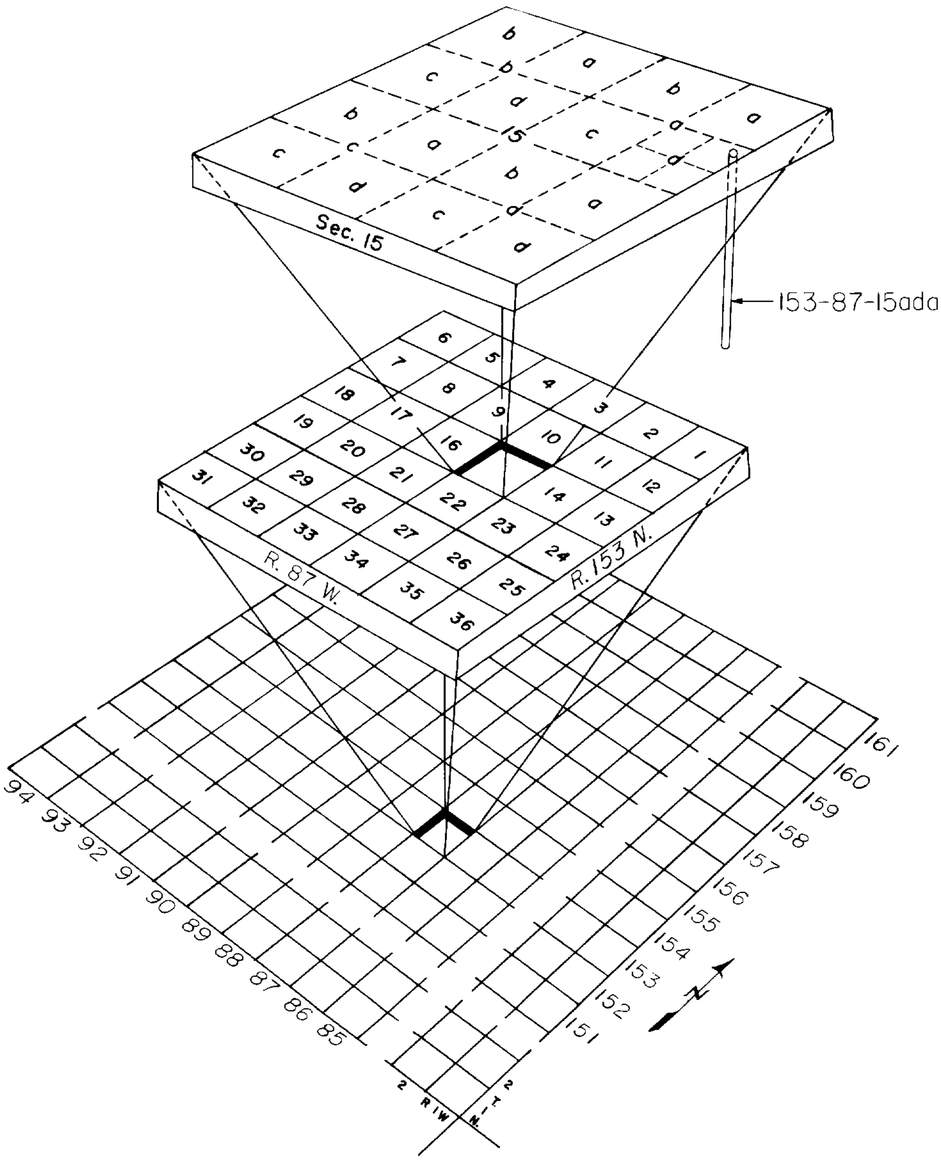


FIGURE 2. System of numbering wells, springs, and test holes.

PRINCIPLES OF GROUND-WATER OCCURRENCE

The ultimate source of ground water is precipitation. After the precipitation falls on the earth's surface, part is returned to the atmosphere by evaporation, some runs into the streams, and the remainder percolates 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 percolates downward to the saturated zone (zone of saturation) becomes ground water. The water table is the top of the saturated zone in an unconfined water body and is free to rise and fall with changes in the amount of water entering and leaving the saturated zone. The water table is not a flat surface, but generally reflects, in a subdued way, the irregularities of topography.

A ground-water reservoir that contains sufficient saturated permeable material to yield water in sufficient quantity to serve as a source of supply is called an aquifer. When water in an aquifer is not confined beneath impermeable material such as clay or shale, it is called a water-table aquifer. If the pressure in an aquifer due to confinement is sufficient for water to rise in a well above the top of the aquifer, it is called an artesian aquifer.

Ground water is held in temporary storage in an aquifer and moves under the influence of gravity from areas of recharge to areas of natural discharge, such as streams and springs, or artificial discharge, such as wells. Under natural conditions and over a long period of time, the rate of recharge approximately equals the rate of discharge.

Ground-water movement is generally very slow and may be only a few feet per year. The rate of movement is governed by the ease with which water can move through a rock and by the differences in water level.

Pumping 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 natural 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 directly related to the rate of recharge.

The water level in a well fluctuates in response to recharge to and discharge from the aquifer. Changes in atmospheric pressure and land-surface loadings also cause minor water-level fluctuations in confined aquifers. The static level is the water level in a well when it is not being pumped. When water is withdrawn from a well, the water level is lowered and the water-level surface around the well resembles a cone. This surface is referred to as 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 decline 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 for water to flow from the aquifer to the well. The amount of water-level decline may become important 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.

Porosity is the ratio of the volume of the open spaces in a rock to its total volume and is an index of the storage capacity of the material.

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 and well-sorted medium or coarse sand 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 permeability is the rate of flow in gallons per day through 1 square foot of the aquifer under a unit hydraulic gradient at a temperature of 60°F (laboratory permeability). The field coefficient of permeability is determined at the prevailing water temperature.

The coefficient of transmissibility is a measure of the rate of flow through porous material and can be 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. Transmissibility is equal to aquifer thickness multiplied by the field coefficient of permeability.

The storage coefficient refers to 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 storage coefficient is equal to a very small fraction of the porosity. However, under water-table or unconfined conditions, the storage coefficient 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 more than half the total porosity.

WATER QUALITY AND ITS RELATION TO USE

All natural water contains dissolved solids. Rainfall, on contact with the earth, begins to dissolve mineral matter, and this process continues as the water moves 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 reported in parts per million (ppm) in this report. A part per million is a unit weight of a constituent in a million unit weights of water. Equivalents per million (epm) is the unit chemical combining weight of a constituent in a million weights of water. This unit is not usually reported, but is necessary to calculate percent sodium, the sodium-adsorption ratio (SAR), or to check the general accuracy of a chemical analysis.

The suitability of water for various uses is largely determined by the kind and amount of dissolved mineral matter. The chemical properties and constituents most likely to be of concern to residents of Renville and Ward Counties are: (1) dissolved solids and the related specific conductance, (2) sodium-adsorption ratio, (3) hardness, (4) iron, (5) sulfate, (6) nitrate, (7) chloride, and (8) 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

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 ef-	
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.

upon usability. Most, if not all, of the minerals shown in the major source column are present in the rock formations underlying Renville and Ward Counties.

The chemical analyses of water in Renville and Ward Counties were listed by Pettyjohn (1968a, tables 5 and 6).

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 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 dissolved-solids content can be described in terms of salinity. The following terms describing salinity are used by the U.S. Geological Survey (Swenson and Baldwin, 1965, p. 20).

Description	Dissolved solids, in parts per million
Slightly saline	1,000 - 3,000
Moderately saline	3,000 - 10,000
Very saline	10,000-35,000
Brine	More than 35,000

The specific conductance of water is a measure of the water's capacity 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 per centimeter at 25°C, or simply 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 0.5 to 1.0, depending upon the type and amount of dissolved minerals (Hem, 1959, p. 40).

Irrigation Indices

Two indices used to show the suitability of water for irrigation 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.

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. Waters having an RSC between 1.25 and 2.5 epm are considered marginal for irrigation. An RSC of more than 2.5 epm indicates that the water is not suitable for irrigation purposes. Generally the ground water in Renville and Ward Counties has an RSC index of less than 2.5 epm. Good management practices might make it possible to successfully use 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.

REGIONAL GROUND-WATER HYDROLOGY

The Renville-Ward County area can be subdivided into three major ground-water areas: (1) the Coteau du Missouri recharge area; (2) the Des Lacs artesian discharge area; and (3) the central recharge area, including the Mohall "gas-lift" subarea (fig. 3).

Coteau du Missouri Recharge Area

The Coteau du Missouri covers an area of about 730 square miles of southwestern Ward County (fig. 3). The area is marked by thousands of small undrained depressions in the glacial till that accumulate large quantities of surface water. Part of the water in these depressions seeps downward to recharge ground-water reservoirs.

Water that moves downward through the till recharges underlying gravel, sand, or lignite aquifers. Upon reaching the aquifers, the water moves laterally to adjacent areas of discharge where ground-water movement is upward.

Data are not available to determine the quantity of natural recharge that the Coteau du Missouri area provides to the regional ground-water flow system. Apparently the quantity is not as great as the ground-water withdrawal in adjacent areas because many of the wells that formerly flowed must now be pumped and many of the springs have ceased to flow.

Although the Coteau du Missouri is a regional ground-water recharge area, there are many small areas of local discharge. Ground-water discharge in these areas is indicated by seeps and springs, saline lakes and salt flats, and increased head with depth in wells, indicating upward movement of ground water, or discharge.

Des Lacs Artesian Discharge Area

The Des Lacs artesian discharge area was first described by Simpson (1929). It is a belt of about 870 square miles, approximately parallel to the northeastern edge of the Coteau du Missouri, in which wells flow or once flowed. The area ranges from 6 to 9 miles in width along the Des Lacs River and widens to nearly 20 miles in the southeastern part of Ward County (fig. 3).

The gradient of the potentiometric surface in this area ranges from 40 to 70 feet per mile to the northeast, being steeper in the northwestern part. The regional gradient is much steeper than in any other part of Renville and Ward Counties. The slope of the regional potentiometric surface steepens markedly near the Des Lacs and Souris River valleys.

Ground water discharges as springs and seeps along the major river valleys. Base flow in the rivers and their tributaries is negligible,

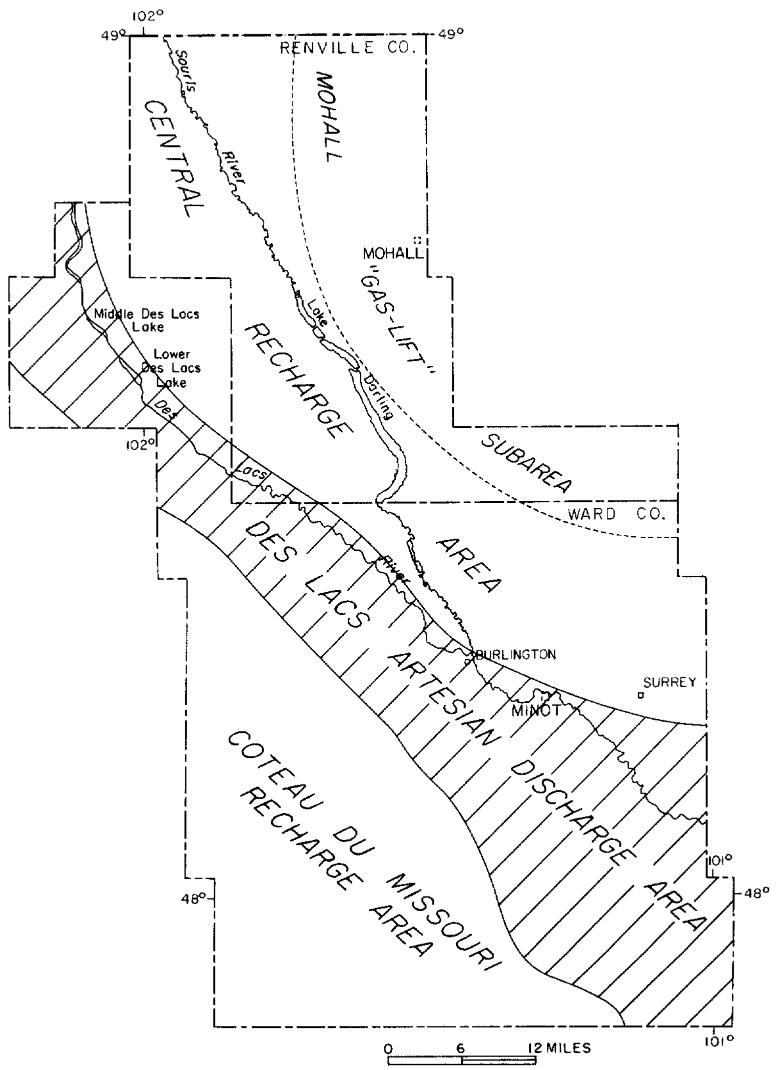


FIGURE 3. Major ground-water recharge and discharge areas.

however, except southeast of Minot, because most of the ground water that discharges from this system is lost by evapotranspiration.

Central Recharge Area

The central recharge area (fig. 3) is a nearly flat expanse of ground moraine that gently slopes to the northeast. It is crossed by several small streams that trend southeastward, generally parallel to the Souris River. This 1,330 square-mile area contains thousands of small, poorly drained, shallow prairie potholes.

Throughout most of the central recharge area, wells tapping the glacial drift have higher water levels than nearby wells in the underlying bedrock. Where two closely adjacent observation wells are constructed in the glacial drift, the shallow observation well has the higher water level. The water-level difference between wells of different depths in the drift rarely exceeds 3 feet.

The higher water levels in progressively shallower wells indicate that ground-water movement is downward and that ground water is being recharged to the deeper aquifers throughout this area.

The Souris River valley, which nearly bisected the area, is a zone of local ground-water discharge, and small seeps and springs are common along the valley walls. The quantity discharged in this manner is small, however, because of the low permeability of the drift. Base flow in the reach of the Souris River above Burlington is negligible during the summer months.

Many scattered wells in the Mohall "gas-lift" subarea (fig. 3) formerly flowed because of the "gas-lift" effect of gas dissolved in the water. The deeper wells may exceed 500 feet in depth and many of those deeper than 150 feet produced at least some gas. A more complete discussion of the "gas-lift" effect is given on page 84.

GROUND WATER IN THE BEDROCK DEPOSITS

Deposits underlying glacial drift and alluvium are referred to as bedrock. Table 2 summarizes the lithology and water-bearing characteristics of the bedrock geologic units of Cretaceous and Tertiary age. Bedrock aquifers yield water to approximately 47 percent of the domestic and stock wells in Renville and Ward Counties.

TABLE 2.–Bedrock geologic units and their water-yielding properties

Era	System	Series	Geologic unit	Physical character	Thickness (feet)	Water-yielding characteristics
Cenozoic	Tertiary	Paleocene	Fort Union Group	Sandstone, silt, shale, and lignite.	0-700	Generally of low permeability. Yields small quantities of water, generally adequate for domestic and stock use. Water may be saline and contain dissolved gas.
Mesozoic	Cretaceous	Upper Cretaceous	Hell Creek Formation	Mudstone, sandy shale, sandstone, and lignite.	200±	Relatively impermeable. May yield very small quantities of water in the area.
			Fox Hills Formation	Sandstone and shale.	235±	Permeable. Yield unknown.
			Pierre Formation	Consolidated bluish-gray to dark-gray marine shale, sandy in places, fossiliferous, contains many concretions in places.	1,200±	Relatively impermeable. May yield very small quantities of water from sand lenses and fractures common in the upper part.
			Colorado Group	Consolidated dark-gray shale, dense, calcareous, and bentonitic; also limestone, which may include alternating layers of shale and sandstone.	1,060±	Relatively impermeable. Not known to yield water in the area. Sandstone may yield limited supplies.
		Lower Cretaceous	Dakota Group	Sandstone, fine to coarse grained; consolidated, calcareous, and very bentonitic shale.	600±	Permeable. Yields large quantities of saline water from depths of 2,500± feet.

Pre-Cretaceous Rocks

The pre-Cretaceous rocks consist of several thousand feet of limestone, sandstone, shale, dolomite, and evaporites. Limestone is the most abundant rock type. Information on the thickness and lithology of these deeper formations is available only from oil-well logs. Although few analyses are available, most of the water from pre-Cretaceous strata is brine, exceeding 57,000 ppm dissolved solids in the Glenburn and SW Arelia oil fields (table 3). In certain areas, the water in some of the formations is under very high artesian pressure.

Rocks older than the Dakota Group are not described in detail in this report because water wells in Renville and Ward Counties are not known to penetrate them.

Cretaceous Rocks

The Dakota Group and younger rocks are described in ascending order from the oldest to the youngest. According to Lemke (1960, p. 11-13), the total thickness of Cretaceous formations penetrated in J. H. Kline well 1 in the SE¼ sec. 16, T. 157 N., R. 85 W., was 3,060 feet.

The Dakota Group underlies the entire area and is composed of sandstone, siltstone, and shale (table 2). The Dakota Group is one of the most widely known aquifer systems in North Dakota. In Renville and Ward Counties, the Dakota Group consists of two sandstone units separated by shale. These sandstones are probably equivalent to the Fall River and Lakota Formations. The upper sandstone is commonly known to well drillers as the "first artesian flow" whereas the lower sandstone is known as the "second artesian flow." The top of the Dakota Group was penetrated at a depth of 3,410 feet and the thickness was 360 feet in J. H. Kline well 1, 20 miles northwest of Minot (Lemke, 1960, p. 13). The potentiometric surface of the Dakota aquifer is only a few feet below land surface in eastern Renville County.

Water from the Dakota Group is generally saline and undesirable for domestic and irrigation uses.

In Renville County, water from the Dakota Group is mainly used for repressurizing oil fields. The quantity of water pumped from the Dakota depends on the demands of the oil fields. The rate of injection depends on the ratio of the oil and water produced in each well field and differs within wide limits. In Renville County, injection by gravity

TABLE 3.–Chemical analyses of water from bedrock aquifers

(Data from files of the North Dakota Geological Survey. Samples collected from drill-stem tests.)

Location	Formation	Depth	Date of collection	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (calculated)	pH
137-76-5daa[1/]	Fox Hills	190	9-17-63	5.6	1.2	610	1,153	42	2.7	256	1,500	8.4
139-80-33bdb[1/]	Hell Creek	240	9-16-49	0.66	6.4	...	991	43.2	510	232.4	......	...
142-81-4adc[1/]	Fox Hills	435	8-62	4.9	2.2	761	1,140	0	1.8	517	1,870	...
156-81-3cb Glenburn field	Ritter zone (top)	4,444-4,460	1958	2,830	680	49,900	132	0	3,490	81,000	138,400	7.4
Do.	Ritter zone (bottom)	4,448-4,480	1958	2,520	570	42,300	132	0	3,160	69,000	117,700	7.3
Do.	Midale-Nesson zone (bottom)	4,351-4,418	1958	2,600	461	18,900	192	0	1,920	33,600	57,700	7.5
Do.	Mission Canyon zone (bottom)	4,526-4,558	1958	7,400	1,700	101,700	204	0	1,000	174,000	286,000	6.4

TABLE 3.–Chemical analyses of water from bedrock aquifers, Continued

Location	Formation	Depth	Date of collection	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (calculated)	pH
157-87-17bc SW Arelia field	Charles	6,668-6,681	1957	17,700	3,340	94,900	600	...	427	186,000	302,900	6.8
158-81-7aa Glenburn field	Dakota	2,700	1962	11	Tr	1,847	1,122	48	351	1,900	4,710	8.2
158-81-7bc Glenburn field	Dakota	2,750	1960	......	......	...	928	56	266	1,534	4,315	8.2
158-81-8cc Glenburn field	Mission Canyon	4,519-4,529	1961	6,800	1,458	106,789	305	...	889	180,000	295,986	7.3
163-83-15dc Eden Valley pool	Madison	4,180	1962	4,950	1,316	85,509	248	0	631	143,821	.....	6.4
163-84-15ba Eden Valley pool	Dakota	2,800	1962	78	32	2,269	1,025	0	258	2,943	.....	8.0

1/ Data from Randich, 1965, table 3.

flow is at an average rate of about 14 gpm (gallons per minute). Larger rates are obtainable when the water is injected under high pressure.

In Renville and Ward Counties the Dakota Group is overlain in ascending order by the Belle Fourche, Greenhorn, Carlile, and Niobrara Formations of the Colorado Group; the Pierre and Fox Hills Formations of the Montana Group; and the Hell Creek Formation. Generally only the Fox Hills and Hell Creek are used for water supplies in the study area. The other formations have limited water-yielding capacities and a detailed description of them is not included in this report.

Lemke (1960, p. 12) reported that the Fox Hills Formation was penetrated at a depth of 915 feet in J. H. Kline well 1, and is about 235 feet thick. It consists of sandstone and shale in about equal proportions. No wells in Renville and Ward Counties are definitely known to produce from the Fox Hills Formation, but many wells produce water from this formation in southwestern North Dakota. The water is under artesian pressure, but generally the wells do not flow. The water from the Fox Hills Formation is slightly to very saline. Fluoride concentration may be high, but the water is generally soft and could be used for domestic and municipal supplies.

According to Lemke (1960, p. 11-12), the Hell Creek Formation in the Minot area is about 205 feet thick, and consists of fine- to medium-grained sandstone, siltstone, and shale. The Hell Creek in North Dakota is not known to yield large quantities of water. However, in some areas several water-bearing zones may be screened and a large yield could be obtained by a single well. The water may be saline and contains a high percentage of iron, sodium, and sulfate.

Tertiary Rocks

In Renville and Ward Counties, the rocks of Tertiary age belong to the Paleocene Fort Union Group. The Fort Union is composed of four formations, which are, in ascending order: Ludlow, Cannonball, Tongue River, and Sentinel Butte. The Ludlow Formation consists of beds of silty sand and clay and contains a few lignite beds. The Cannonball Formation is a marine deposit that consists of dark-gray sand, clay, and a few layers of thin, nodular, fossiliferous limestone. The Tongue River Formation consists of continental deposits of clay, silt, sandstone, and numerous lignite beds. Lemke (1960, p. 11) reported that the Fort Union Group had a total thickness of 615 feet in J. H. Kline well 1. The

Tongue River was penetrated at a depth of 95 feet and had a thickness of 255 feet; and the Ludlow and Cannonball had a total thickness of 360 feet.

The Cannonball and Ludlow Formations were deposited contemporaneously–the Cannonball as a marine deposit and the Ludlow as adjacent continental strata. Owing to numerous fluctuations of the sea margin, it is assumed that sediments of the two formations interfinger in the subsurface. However, it is difficult to differentiate these formations accurately by means of drill-hole cuttings. According to Lemke (1960, p. 29), the Ludlow underlies the Cannonball in J. H. Kline well 1.

The Ludlow Formation is not exposed in Renville and Ward Counties, although it probably underlies the entire area. Where exposed in other parts of the State, it consists of interbedded layers of fine sand and lignitic shale.

The Cannonball Formation crops out along the walls of the Souris River valley in the vicinity of Sawyer, where it consists of sandy shale. Elsewhere it consists of alternating beds of sand and shale. It probably interfingers with the overlying Tongue River Formation as well as the Ludlow in this area.

The Tongue River crops out in many places along the Des Lacs River valley and the Souris River valley as well as in the valleys of many of their tributaries. Lignite seams in the Tongue River are extensively mined on the Missouri Escarpment south of Sawyer. The mined zone may exceed 15 feet in thickness.

The Sentinel Butte Formation is very similar to the underlying Tongue River, the major difference being a more somber color in the Sentinel Butte. The coloring apparently is a weathering phenomena and consequently it cannot be distinguished in the subsurface.

In practice, it is generally difficult or impossible to distinguish the various formations in the Fort Union by the examination of water-well or test-hole data. In fact, the rocks from the base of the glacial drift to the top of the Pierre Formation are so similar that even tentative correlations are difficult, particularly in northern Ward County and in Renville County. Generally, however, the Cannonball Formation contains water that is high in chloride. High-chloride water may also be present in the Fox Hills. In the absence of better information, the combined thickness of the Fort Union Group, Hell Creek Formation, and Fox Hills Formation is treated tentatively as a single aquifer system in this report.

The lignite and fine-grained sandstone layers in the Fort Union Group are a source of water for wells and springs. In many areas, the lignite beds are underlain by clay, which restricts the downward movement of ground water. Consequently, ground water accumulates in the lignite beds and moves laterally to points of discharge. Many springs in the Souris River valley flow from the contact of a bed of lignite with the underlying clay.

Although flowing wells are common in the Fort Union Group, they usually do not yield large amounts of water. Locally, the wells flow because of entrapped gas, originating in seams of lignite.

Aquifers in the Fort Union Group are recharged by underflow from the southwest, by infiltration of precipitation on the outcrops, and, in places, by infiltration of water from the overlying glacial deposits.

Water is discharged by springs and seeps where the Fort Union Formation crops out, by evapotranspiration where the overlying drift is thin or absent, by leakage to adjacent strata, and by pumping from wells.

Generally the water levels in wells tapping aquifers in the Tertiary rocks fluctuate only slightly, and most of the fluctuations are probably due to changes in atmospheric pressure. In some places, the water level in wells may be more than 100 feet below land surface. Locally, however, water in the aquifers is under sufficient artesian or gas pressure to flow at the surface. Most of the flowing wells are south and east of Burlington, although in the 1920's there were many flowing wells at the foot of the Missouri Escarpment. Most of the wells in the Missouri Escarpment area have either been destroyed or ceased to flow. The reduction in water level is probably due to ground-water withdrawal.

The wells that formerly flowed in northeastern Renville County were "gas-lift" wells (fig. 3). The gas pressure has been reduced to such an extent throughout the last 50 years that most wells no longer flow.

The Fort Union Group yields water of three chemical types (fig. 4): (1) sodium bicarbonate, (2) sodium chloride, and (3) a mixture of sodium bicarbonate and sodium chloride. Wells in most of Renville County and northeastern Ward County that tap the Cannonball Formation or the combined Cannonball and Ludlow Formations yield water that is generally a sodium chloride, sodium bicarbonate chloride, or sodium chloride bicarbonate type. Bedrock wells between the Souris River and the Des Lacs River produce from Tongue River or Cannonball-Ludlow aquifers, and bedrock wells in the Coteau du Missouri area produce water from aquifers in the Tongue River or Sentinel Butte Formations. Water from the latter two formations generally is a sodium bicarbonate type.

The average concentrations of the principal ions, expressed as a percentage of the average dissolved solids, further illustrate the differences in the chemical character of water in the Cannonball,

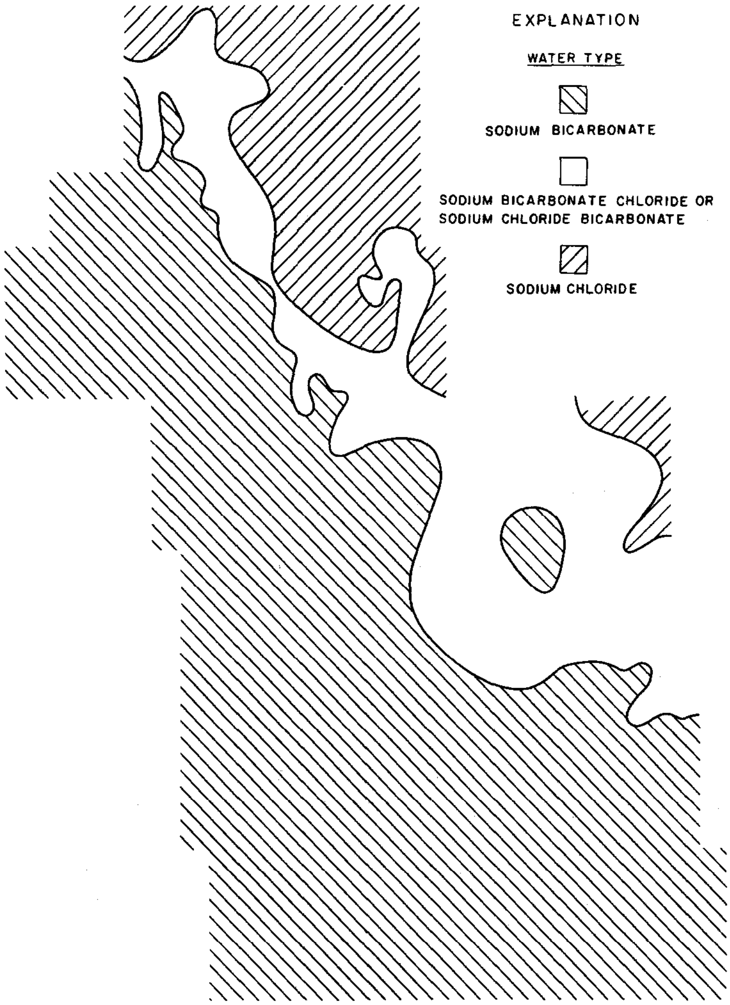


FIGURE 4. Quality of water from wells penetrating the Fort Union Group.

Cannonball-Tongue River, and Ludlow-Tongue River Formations in the Crosby-Mohall area, as shown in the following table:

	Cannonball Formation (33 samples)	Cannonball-Tongue River Formations (8 samples)	Ludlow-Tongue River Formations undifferentiated (45 samples)
Silica (SiO_2)	0.3	0.8	0.7
Iron (Fe)	.1	.4	.2
Calcium (Ca)	1.0	2.9	1.6
Magnesium (Mg)	.3	.9	.6
Sodium (Na)	37.8	35.0	36.5
Potassium (K)	.2	.4	.4
Carbonate (CO_3) (includes bicarbonate as carbonate)	8.7	22.5	33.5
Sulfate (SO_4)	1.1	4.6	19.2
Chloride (Cl)	50.4	32.3	7.1
Fluoride and nitrate ($F+NO_3$)	.1	.2	.2
Total (percent)	100.0	100.0	100.0

Modified from LaRocque and others, 1963b, p. 38.

The average concentration of dissolved solids in the samples of water from the Cannonball Formation was 3,640 ppm; from the Cannonball-Tongue River Formations, 2,090 ppm; and from the Ludlow-Tongue River Formations undifferentiated, 1,790 ppm.

Water from the Cannonball Formation is not generally suitable for human consumption although it can be used for livestock. It is unsuitable for irrigation because of the high concentration of sodium and dissolved solids. In most cases, the chloride content exceeds the concentration of bicarbonate or sulfate.

Water from interfingering aquifers in the Ludlow, Cannonball, and Tongue River Formations is generally intermediate in chemical quality between water from the Cannonball and water from the Tongue River. Although water from these aquifers is used for drinking, it generally contains more chloride than is recommended by the U.S. Public Health Service for human consumption. The water is used for watering livestock, but because of its salinity and high sodium content, it is unsuitable for irrigation.

Water from the Tongue River and Sentinel Butte Formations generally is usable for domestic purposes, although it becomes more mineralized with depth. The water is used for livestock, but is not considered suitable for irrigation because of its generally high dissolved solids and high sodium content. In most cases this water contains larger percentages of sulfate or bicarbonate than chloride.

GROUND WATER IN THE QUATERNARY DEPOSITS

During the Pleistocene ice age, glaciers moved southward over the area at least three times, and covered the bedrock surface with drift that now generally ranges from 0 to 600 feet in thickness.

The glacial deposits consist chiefly of ground moraine, dead-ice moraine, end moraine, outwash, ice-contact deposits, and glacial lake deposits.

Ground moraine has a gently rolling topography with only slight local relief. The prairie potholes on the ground moraine are generally only a few feet deep. Ground moraine is the most widespread deposit in the report area and consists of till, which is a heterogeneous mixture of clay, silt, sand, and larger fragments. This material is mainly unsorted and unstratified and has a very low permeability. Scattered throughout the ground moraine are buried deposits of sand and gravel, which, in some places, become thicker and are important sources of water.

The hummocky areas on the Coteau du Missouri are underlain by dead-ice moraine, which also is largely composed of till. Prairie potholes are abundant in the dead-ice moraine and are generally several feet deeper than those on the ground moraine. Locally, there are many small buried deposits of sand and gravel in the dead-ice moraine that have no surface expression. No large buried sand and gravel deposits were found, however, in the Coteau du Missouri during this investigation.

End moraines on the Coteau du Missouri consist of linear ridges of till or hummocky till hills that average about a mile in width. The tops of the moraines are 40 to 60 feet above surrounding areas. Important aquifers in these deposits are scarce. However, the end moraines in the northwestern part of Minot and north of the Des Lacs River between Donnybrook and Carpio are low hills and ridges that consist of ice-contact deposits of sand and gravel that will provide small water supplies.

Water from melting glaciers carved a complex network of channels, some more than 40 miles long, into the ground moraine and partly filled the channels with sand and gravel. Outwash sand and gravel deposits locally cover large areas in the valleys of the Souris and Des Lacs Rivers and are overlain by thin deposits of alluvium. Most of the outwash on the Coteau is collapsed; that is, the deposits were originally supported by glacial ice and became distorted when the support was removed by the melting of the ice. In a few places these deposits cover large areas. Most of the outwash deposits are highly permeable, and where sufficiently thick, they store large quantities of ground water.

Ice-contact deposits, in the form of kames and eskers, mainly consist of sand and gravel. Kames are mounds or hills as much as 40 feet high. Eskers are narrow sinuous ridges. The ice-contact deposits are highly permeable, but generally water readily drains from them due to small areal extent and steep slopes.

Glacial lake deposits are common on the Coteau du Missouri. They consist chiefly of silt and clay, but may include sand and some gravel, particularly along their margins. Many of the lakes were formed in stagnant glacial ice. The permeability of most lake deposits is very low and only small ground-water supplies are available to wells.

With the exception of deposits in present and ancient stream valleys, there are no widespread buried deposits of water-bearing sand and gravel in Renville and Ward Counties. Although Akin (1947, p. 17) suggested that extensive deposits of sand and gravel were present in the Souris River valley, test drilling indicated that these deposits are limited to the area between Minot and Sawyer.

Most wells that tap aquifers in the glacial deposits have been drilled or dug through the glacial till into sand and gravel deposits. The till generally yields little or no water to wells.

Water from glacial deposits is variable in chemical quality, but is generally very hard. The dissolved solids generally exceed 750 ppm, but as indicated by the specific conductance, may locally be as low as 130 ppm (Pettyjohn, 1968a). Water from surficial sand and gravel is generally less mineralized than water from buried sand and gravel and water from glacial till. The sulfate concentration is locally so high that the water is unsuitable for many uses.

Coteau du Missouri Area

Several surficial-outwash and buried-valley-fill aquifers in the Coteau du Missouri store large quantities of ground water. The surficial-outwash deposits range from small irregular gravel hills to extensive outwash plains that cover several tens of square miles. The surficial-outwash aquifers are readily recharged by infiltration of precipitation and local runoff, but much of the water drains rapidly through springs and seeps. Water from the surficial aquifers is generally of fair to good chemical quality.

The areal extent and thickness of water-bearing sand and gravel in the buried valleys in the Coteau is inferred chiefly from widely spaced test holes and wells. The amount of water stored in the buried-valley aquifers is evidently large, but data are insufficient for accurate determination. Water from buried-valley aquifers is generally more mineralized than that from surficial outwash and it may be saline in some places.

None of the sand and gravel aquifers in the Coteau are used extensively. There are only a few domestic and stock wells in most aquifers, and some aquifers are unused. Consequently, almost all the discharge from these aquifers is by natural processes.

Six major sand and gravel aquifers in the Coteau are shown on plate 1 (in pocket), and at least some ground-water data are available for each. These aquifers are the Douglas, Hiddenwood Lake, Ryder, Ryder Ridge, Tolgen, and Vang aquifers. Several other surficial or buried sand and gravel deposits were penetrated by test drilling, but at present there are insufficient data available to accurately describe them. These are referred to herein as unnamed aquifers in the Coteau du Missouri.

Douglas Aquifer

The Douglas aquifer is in south-central Ward County, and extends southward from the eastern part of T. 153 N., R. 85 W., through T. 152 N., R. 85 W., T. 152 N., R. 84 W., T. 151 N., R. 85 W., and T. 151 N., R. 84 W., and thence into McLean County. The aquifer is about 18 miles long (fig. 5), and varies from a few feet to more than 3 miles in width. It consists of collapsed and buried outwash that partly fills a branching network of valleys.

The outwash material ranges in size from fine sand to coarse gravel and boulders, and can be as much as 70 feet in thickness. Gravel and coarser material are limited to the east flank and north end of the aquifer, whereas fine and medium sand are predominant in the western part.

Water in the aquifer is unconfined throughout most of the area, but is under artesian pressure at the north end of Rice Lake and perhaps in a few other places.

Ground-water movement in the Douglas aquifer is generally in the direction of the arrows on figure 5, but there also is local movement into numerous lakes and undrained depressions in the central part of the aquifer.

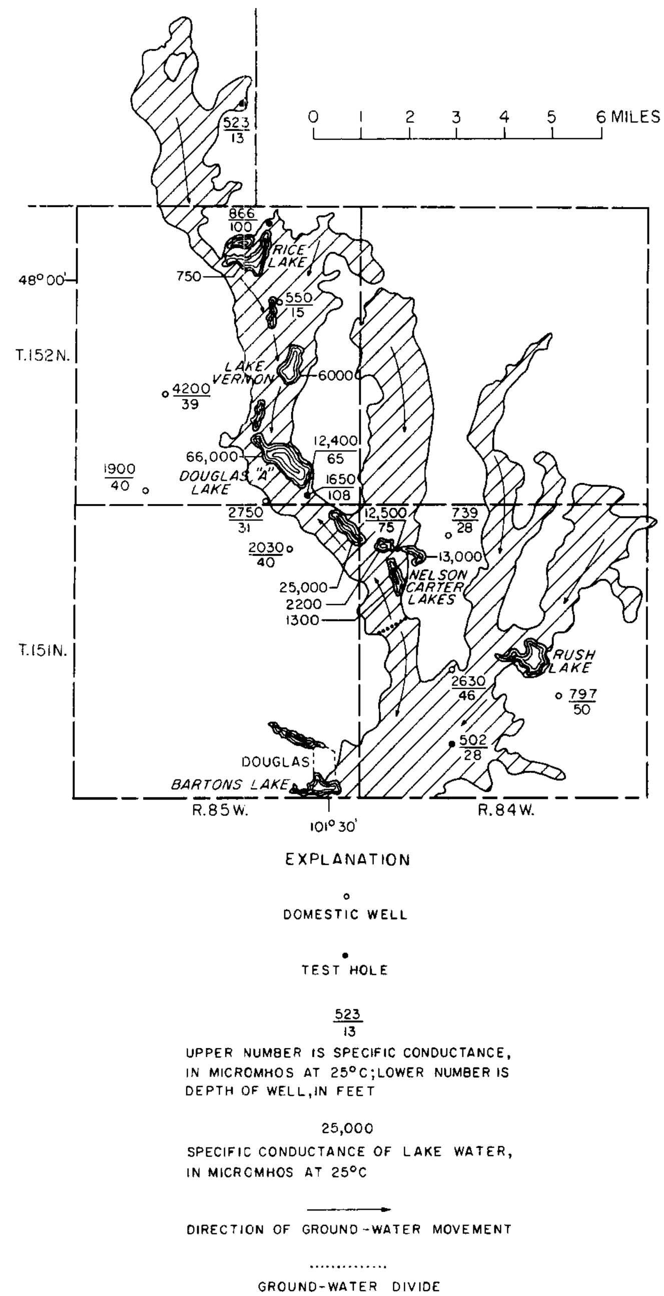


FIGURE 5. Location of the Douglas aquifer (patterned area), ground-water movement, and specific conductance of water from selected wells.

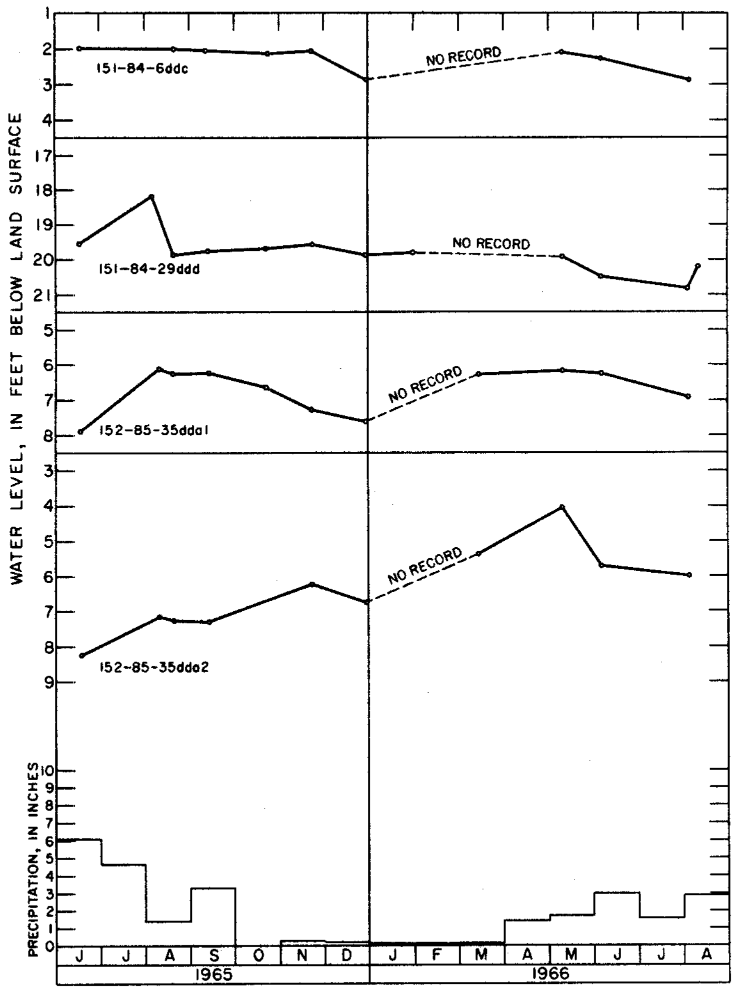


FIGURE 6. Water-level fluctuations in the Douglas aquifer and precipitation at Ryder.

The water levels in wells range in depth from 2 to 45 feet below land surface. The water-level fluctuations in four observation wells in the Douglas aquifer are shown in figure 6.

Natural recharge to the aquifer is provided by: (1) infiltration of precipitation, (2) underflow, (3) springs and seeps issuing from the adjacent moraine, and (4) upward leakage of ground water from deeper sources. Infiltration of precipitation probably accounts for the largest quantity of natural recharge.

The chemical quality of the water in the Douglas aquifer differs within wide limits, with the dissolved-solids content generally increasing toward areas of discharge. Because the lakes receive ground-water discharge from the Douglas aquifer, they can be used to trace the changes in chemical quality of ground water in the aquifer. The water in Rice Lake, for example, had an average specific conductance of 750 micromhos. Southward and in the direction of ground-water movement, Douglas "A" Lake had a specific conductance of 66,000 micromhos in June 1965. The salinity of surface water and ground water also increases from the ground-water divide north of Douglas toward Douglas "A" Lake. Apparently this lake represents a major discharge area for the aquifer.

Ground water is generally of good chemical quality near the flanks of the outwash, or in areas where there is a considerable amount of unrestricted flow. The specific conductance of this water ranged from 502 micromhos in test hole 151-84-29ddd to 866 micromhos in test hole 152-85-2bcb. Water from test holes in the central part of the aquifer generally is highly mineralized. The specific conductance of ground water in this area ranged from 1,650 to 12,500 micromhos (fig. 5). The mineral constituents were predominantly sodium, sulfate, and bicarbonate.

Water in the Douglas aquifer with a specific conductance of less than 900 micromhos falls in the C2-S1 and C3-S1 irrigation classifications. The water has a medium to high salinity hazard and a low sodium hazard. This water probably is suitable for irrigation because of the high permeability of the sandy and gravelly soils in the area. Water in the vicinity of Douglas "A" and Nelson Carter Lakes, however, is unsuitable for all types of irrigation regardless of the soil texture.

The water from test hole 151-84-29ddd met the U.S. Public Health Service (1962) standards for drinking water, except for the iron concentration which was 0.96 ppm (Pettyjohn, 1968a). Water from wells 152-85-35dda1 and 35dda2 exceeded the recommended limits for iron, sulfate, and dissolved solids. Water from the shallower well (dda1) was more mineralized (11,000 ppm).

Water from parts of the Douglas aquifer can be used for domestic, livestock, irrigation, and industrial purposes. However, it provides water to only a few domestic and stock wells. Consequently, the quantity of water available for use is much greater than is now being withdrawn. In some places the aquifer is very permeable and could produce as much as 250 gpm.

Well yields will be restricted in areas where the water-bearing materials are thin or where lenses of less permeable material such as silt or clay are present. In places less than 10 feet of sand and gravel is saturated. If the aquifer is developed for irrigation, the quality of the water should be monitored because pumping could induce highly mineralized water. Water-level measurements and a sound water-management program are essential to avoid overdevelopment of the aquifer.

Hiddenwood Lake Aquifer

The Hiddenwood Lake aquifer is a valley-fill deposit in southwestern Ward County (pl. 1). The valley was cut into the bedrock at least 130 feet below the upland surface and extends from McLean County northward through Hiddenwood Lake to Makoti (fig. 7). In places, beds of the Fort Union Group crop out in the valley walls.

The aquifer material consists of fine to coarse sand and fine to medium gravel. It ranges between 9 to 45 feet in thickness, including a few thin layers of clay. It is overlain by at least 66 feet of glacial drift, predominantly lake deposits, in its southern end (Pettyjohn, 1968a, p. 76) and generally by more than 100 feet of till in its northern end. The aquifer slopes to the north, and has been traced for about 8 miles in Ward County.

The water level in observation well 152-87-28daa averaged about 26 feet below land surface in 1965 and 1966 (fig. 7). This is 116 feet above the top of the aquifer, indicating artesian conditions.

Natural recharge to the aquifer is by direct infiltration of precipitation. The greatest quantity of recharge probably is provided in northern McLean County and in the southern 3 miles of its extent in Ward County.

Chemical analyses of water from test hole 152-87-28daa indicated that the Hiddenwood Lake aquifer contains water of a hard sodium sulfate type with objectionable quantities of iron (0.4 ppm), sulfate (2,650 ppm), and dissolved solids (4,800 ppm). Each of these exceeds the limits recommended by the U.S. Public Health Service (1962) for drinking water. The salinity hazard is too high for the water to be used for irrigation.

Even though the Hiddenwood Lake aquifer contains very permeable materials, it is largely unused. Its poor quality water precludes development except under unusual circumstances.

Ryder Aquifer

The Ryder aquifer extends southeastward from the central part of T. 152 N., R. 86 W., through the northeastern part of T. 151 N., R. 86 W., and thence into the west-central part of T. 151 N., R. 85 W. The

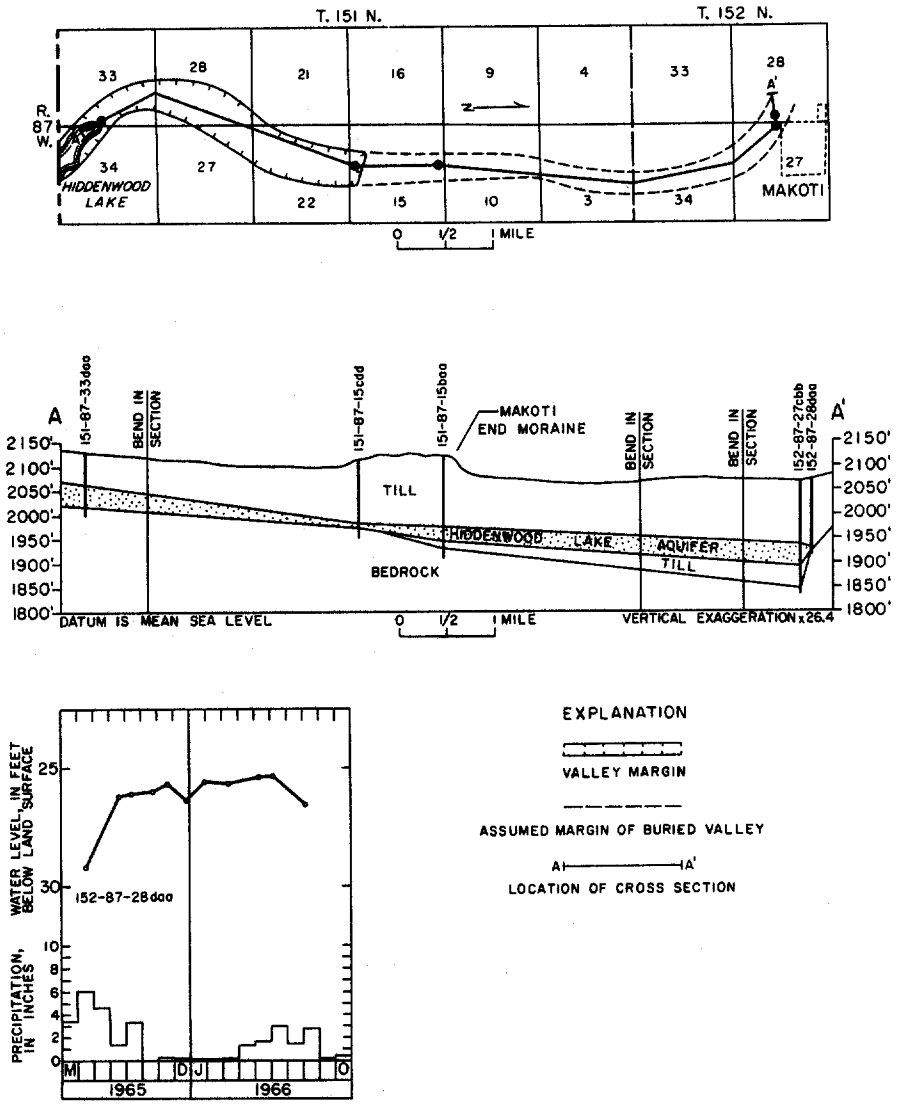


FIGURE 7. Location of the Hiddenwood Lake aquifer, and graph showing water-level fluctuations.

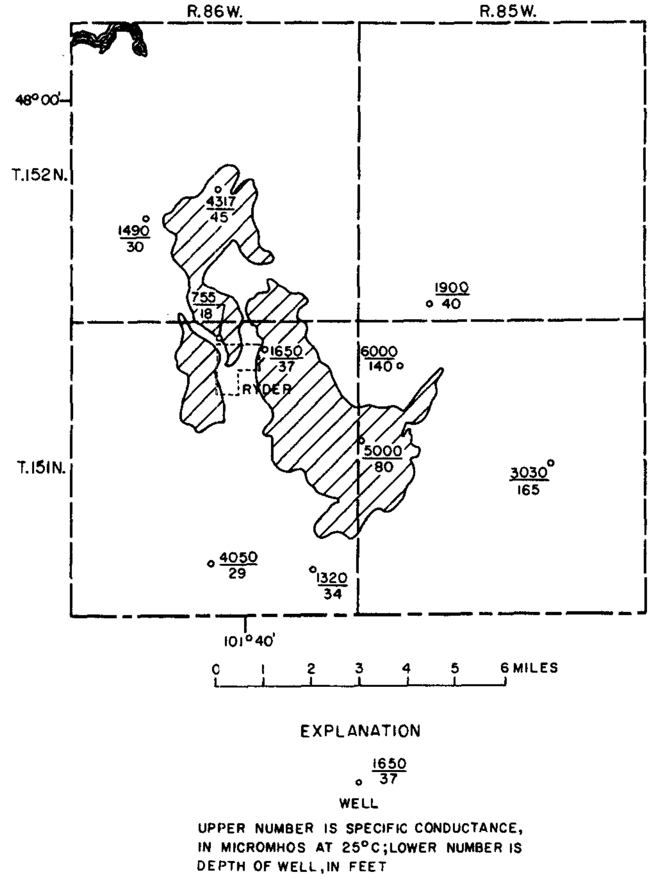


FIGURE 8. Location of the Ryder aquifer (patterned area) and specific conductance of water from selected wells.

aquifer is about 7 miles long and about 2 miles wide at its widest part (fig. 8). The aquifer consists of collapsed glacial lake sediments and kame and esker deposits. The lake deposits rise as much as 25 feet above the surrounding area, and locally are separated by melt-water channels that contain saline lakes and salt flats. The location of the aquifer is uncertain in these places. The lake deposits consist of clayey, silty, very fine to medium sand, although coarser material is present along the margins. The lake deposits may be as much as 29 feet thick (Schmid, 1963, p. 21).

Recharge to the Ryder aquifer probably is small and is derived entirely from infiltration of precipitation and local runoff from adjacent areas. Ground water moves from areas of recharge to areas of discharge along the steep margins of saline lakes and salt flats. Water in wells tapping the aquifer is generally 8 to 25 feet below land surface.

The aquifer is used by the village of Ryder and as a source of domestic and stock water. The village is reported to pump water at an average rate of about 50,000 gpd (gallons per day).

Quality of the water is marginal for most purposes. The specific conductance ranged from 755 to 5,000 micromhos, but may exceed 5,000 micromhos in areas adjacent to the lake deposits. The water is a hard calcium bicarbonate type, except near the lake deposits where it probably is a sodium sulfate type. It is high in dissolved solids, iron, and sulfate.

The small saturated thickness of the aquifer, the dependence on direct precipitation and local runoff for natural recharge, the abundance of clay and silt in the water-bearing material, and the marginal quality of the water for most uses preclude extensive development of the Ryder aquifer. It appears that yields of as much as 250 gpm should be possible, however, in parts of the aquifer (pl. 1).

Ryder Ridge Aquifer

The Ryder Ridge aquifer extends from just west of Ryder, northwestward across the southern part of T. 152 N., R. 87 W., thence into Mountrail County, a distance of about 9 miles (pl. 1). West of Makoti the aquifer apparently overlies the Hiddenwood Lake aquifer. Although the ridge averages about 700 feet in width, it is difficult to trace except at its eastern extreme where it rises about 40 feet above the surrounding land surface.

The Ryder ridge has a core of water-bearing sand and gravel that reaches a total thickness of 55 feet in test hole 151-86-5cbb. The aquifer material ranges in size from fine sand to fine gravel. The top of the aquifer ranges in depth from 46 to 104 feet below land surface, and had a water level between 20 and 28 feet below land surface in 1966 in test hole 151-86-5cbb.

Water from test hole 151-86-5cbb was a moderately hard sodium sulfate type. The irrigation classification (C3-S2) indicates the water has a high salinity and medium sodium hazard. The concentrations of fluoride (3.3 ppm), iron (0.8 ppm), sulfate (672 ppm) and dissolved solids (1,250 ppm) exceeded the U.S. Public Health Service (1962) limits recommended for drinking water. The water is, however, better than most water from buried aquifers in the glacial drift in the Ryder-Makoti area.

No wells are known to produce water from the Ryder Ridge aquifer. Although it contains permeable water-bearing material, the narrowness of the deposit and the poor quality of the water severely limit its use. The fluoride concentration is more than twice the optimum value recommended by the U.S. Public Health Service (1962, p. 8) for the area. The sulfate may have a laxative effect on people unaccustomed to the water and the iron will cause staining of clothes and fixtures. The water may be suitable for livestock, however.

Tolgen Aquifer

The Tolgen aquifer is in southwestern Ward County and extends from T. 154 N., R. 86 W., and T. 154 N., R. 87 W. southwestward about 11 miles through T. 153 N., R. 86 W., and T. 153 N., R. 87 W. (fig. 9).

The aquifer, a complex arrangement of collapsed-outwash and glacial lake deposits, includes one large unit and 12 smaller isolated parts. The large unit has a maximum width of slightly more than 2 miles, but the smaller isolated segments are generally less than a mile wide. Although all parts are not in close hydraulic connection, they were formed in the same manner and time and are more conveniently described as one aquifer.

The aquifer material forming the collapsed-outwash deposit ranges in size from fine sand to coarse gravel and from 0 to at least 27 feet in thickness. Coarse material is more common along the northeastern parts of this deposit, whereas finer material occurs in the more southwestern parts. The lake deposits, in most places, consist of about 5 feet of silt, underlain by lenticular deposits of till, sand, and gravel. The deposits probably do not exceed 50 feet in thickness.

Ground water in the collapsed outwash is unconfined, whereas water in sand and gravel buried within the lake deposits is confined.

Recharge to the Tolgen aquifer is mainly by infiltration of precipitation. Additional recharge is by runoff from adjacent areas. Most of the ground-water flows towards the southwest, but locally flows in other directions. Much of the water in the northeastern part of the aquifer discharges at springs and seeps, and by underflow into a chain of saline lakes in T. 153 N., R. 86 W. Springs and seeps are also common along the margin of the outwash deposits. The water level in wells in the largest unit ranges from 2 to about 10 feet below land surface.

Two observation wells, one 30 feet and the other 65 feet in depth, were constructed in the lake deposits at test hole 153-87-28bbb. The 30-foot well produced water that is somewhat more mineralized than the 65-foot well. In addition, the shallower well has the highest water level. This water-level difference indicates downward movement of

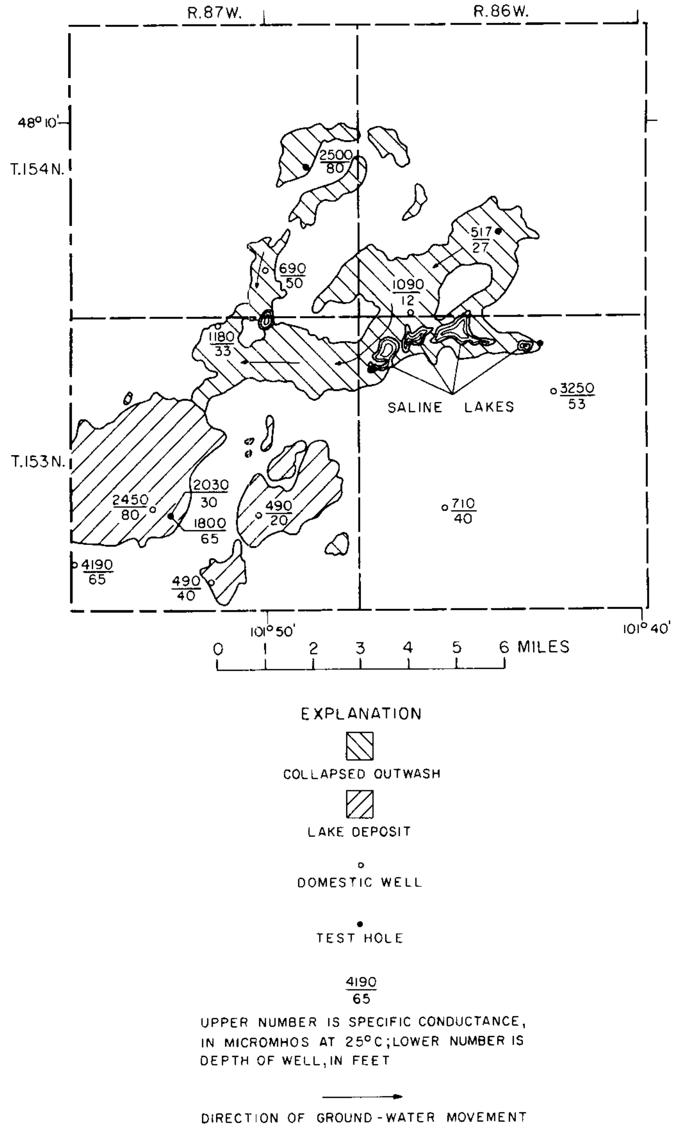


FIGURE 9. Location of the Tolgen aquifer (patterned area) and specific conductance of water from selected wells.

ground water, or recharge, which is to be expected on topographic highs. The difference in chemical composition indicates that either water entering the upper part of the aquifer at this location is more highly mineralized than most water entering the aquifer or, more probably, that at least two flow systems are present.

Owing to the abrupt changes in the aquifer thickness and to the unknown extent of buried, isolated sand and gravel deposits in the perched lake deposits, it is not possible to determine the quantity of water in storage.

Water from the Tolgen aquifer is suitable for most purposes. The specific conductance ranged from 490 to 2,500 micromhos. The water is hard and generally a calcium bicarbonate type in the outwash sediments and a calcium sulfate type in the lake sediments. Water from wells less than 40 feet deep along the higher parts of the aquifer or from small isolated parts, generally has a specific conductance less than 700 micromhos. Wells that range in depth from 40 to 80 feet generally contain water that is more highly mineralized and the conductance exceeds 1,000 micromhos. The dissolved solids increase toward saline lakes, sloughs, and other low areas.

The Tolgen aquifer is tapped by only a few domestic and stock wells. In several small areas, particularly in the northeastern parts of the outwash deposits, properly constructed wells would probably produce as much as 200 gpm for short periods of time, particularly in years of greater than normal precipitation. However, the dependence on precipitation and local runoff for natural recharge and the abrupt changes in saturated thickness of the collapsed sand and gravel limit the potential of the Tolgen aquifer. The lenticular water-bearing sand and gravel deposits buried within the lake sediments are generally present only in small areas.

Vang Aquifer

The Vang aquifer extends southwestward from the west-central part of T. 153 N., R. 85 W., through T. 153 N., R. 86 W., and T. 152 N., R. 87 W., and thence into Mountrail County; a distance of more than 14 miles (fig. 10). The aquifer is a collapsed-outwash deposit that partly fills a glacial drainageway. It ranges from about 1,000 feet in width to slightly more than 2 miles. The aquifer is unconfined throughout its entire area.

The aquifer material ranges in size from fine sand to coarse gravel and ranges in thickness from 0 to at least 28 feet. Gravel and coarser materials are more common in the northeastern part of the deposit, whereas sand and fine gravel predominate in the southwestern part. The average permeability of the entire deposit is probably about 1,500 gpd per square foot.

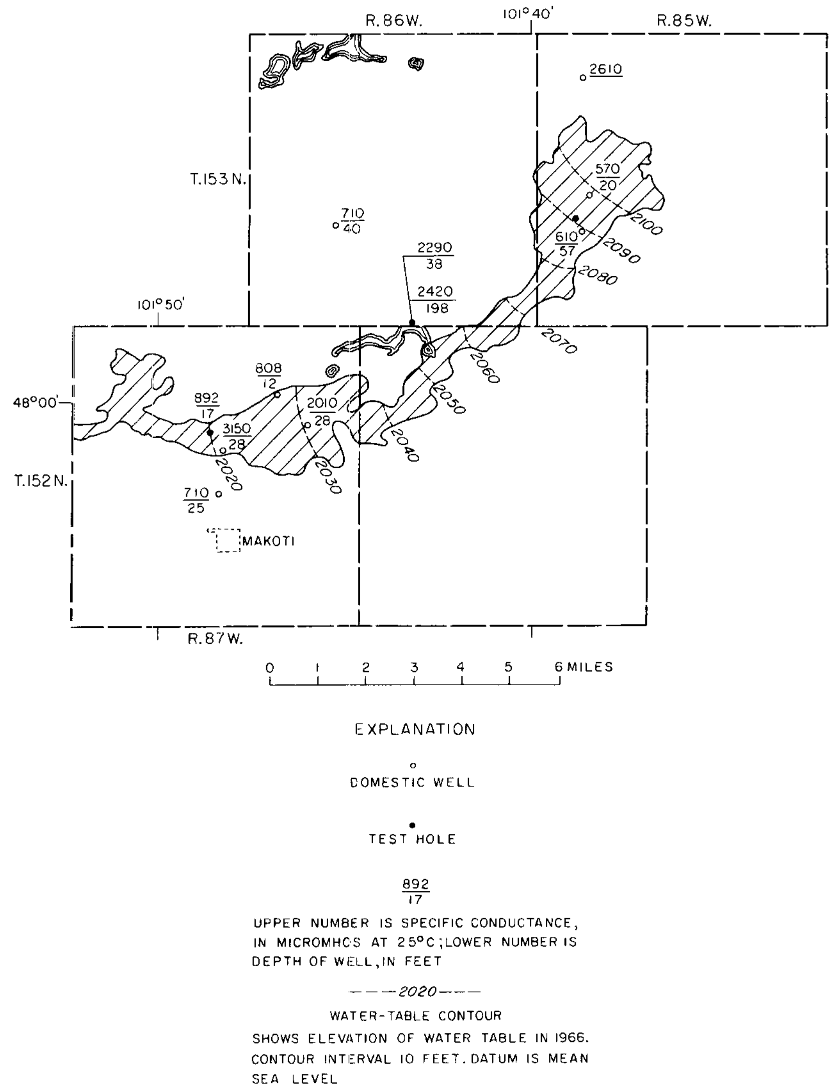


FIGURE 10. Location of the Vang aquifer (patterned area), specific conductance of water, and elevation of the water table.

The water table in the Vang aquifer slopes towards the southwest at nearly 8 feet per mile (fig. 10), and generally ranges from 5 to 20 feet below land surface.

Natural recharge to the Vang aquifer is derived mainly from direct infiltration of precipitation.

Assuming, in the area of test hole 152-87-16aaa, a width of 1,700 feet, an average permeability of 1,500 gpd per square foot, and an average saturated thickness of 8 feet, approximately 31,000 gallons of water per day flows through the aquifer.

The chemical quality of the water in the aquifer, in most places, is suitable for a variety of purposes. The water is a hard calcium bicarbonate type. The specific conductance of water from well 152-87-16aaa was 892 micromhos in 1966 and 808 micromhos from well 152-87-11bdb in 1963.

Two chemical components that locally may appear in large concentrations are iron and nitrate. The iron content in water from test hole 152-87-16aaa was 2.7 ppm. Iron concentrations of this magnitude will cause staining of clothing and plumbing fixtures. Water from well 152-87-11bdb had an iron content of 0.2 ppm, however, which is below the limit recommended for drinking water by the U.S. Public Health Service (1962).

Analyses of water from the Vang aquifer indicate that the nitrate concentration ranges in value from 12 ppm to more than 85 ppm. It is reported that the nitrate concentration increases considerably following periods of precipitation. This indicates leaching and downward movement of nitrogeneous material into the aquifer. Much of the material probably is derived through the leaching of decaying organic material in the small sloughs and potholes that are present throughout the outwash-deposit area. Wells along the flanks of the aquifer probably have less opportunity for nitrate contamination from potholes than those drilled in the low areas.

Water from the Vang aquifer is in the C2-S1 and C3-S1 irrigation classifications. The water has a medium to high salinity hazard, a low sodium hazard, and is suitable for irrigation on well-drained soils.

The Vang aquifer provides water to only a few domestic and stock wells. The quantity of water available is much greater than is now being withdrawn by wells. The water-bearing materials, in places, are very permeable, indicating a good potential for obtaining small to moderate yields from properly constructed wells, especially when the water table is high. In several small areas, wells probably could produce at least 150 gpm for short periods of time.

If the area is developed for any use that requires a large withdrawal, periodic water-level measurements are essential to insure that overdevelopment does not take place. If the aquifer is used as a public supply, the nitrate content should be regularly monitored and kept at a low concentration because of the possible toxic effects on infants.

Unnamed Aquifers

Several aquifers in the Coteau du Missouri area of Renville and Ward Counties are described only in general terms owing to a lack of geologic and hydrologic information. In a few places, small deposits of surface sand and gravel have been mapped (pl. 1). In other places, partly collapsed valleys can be located by a study of aerial photographs. Probably all the buried aquifers in the Coteau du Missouri area have not been discovered.

Surficial sand and gravel deposits--Several relatively small and thin deposits of sand and gravel were mapped that will provide sufficient water of good quality for domestic and stock purposes. The aquifers are in ice-contact deposits, collapsed outwash, and lake deposits.

Records of wells indicate that the water level is usually 5 to 10 feet below land surface. Several of the deposits that lie on till in the topographically highest areas are so thin that they contain only very small quantities of water and drain rapidly.

Available data indicate that these deposits contain water that is only slightly mineralized. Generally the specific conductance ranged between 450 and 650 micromhos. Water in surficial sand and gravel deposits near Ryder, however, is generally more mineralized and may contain large amounts of sulfate.

Unnamed aquifer at Carpenter Lake--A small aquifer trends southwestward across the Coteau near Carpenter Lake for a distance of about 4 miles. Test hole 155-87-17bab penetrated three deposits of sand and gravel (20-40, 75-112, and 148-182 feet) in this aquifer at the northeast end of Carpenter Lake. Observation wells were constructed in the upper two deposits at depths of 38 and 100 feet. The water level in the deep well is about 12 feet below land surface, whereas in the shallow well it is about 19 feet. The higher water level in the deeper well indicates that this is an area of upward ground-water movement.

Records indicate that elsewhere in the Carpenter Lake valley, the domestic and stock wells produce water from the Fort Union and suggest that water-yielding sand and gravel do not extend over the entire valley.

Unnamed aquifer west of Berthold--Test hole 156-87-15cdd, drilled about 5 miles west of Berthold, penetrated 10 feet of fine to coarse gravel from 65 to 75 feet (pl. 1). The water level was about 5 feet below land surface. The water is a sodium bicarbonate type that had a dissolved-solids concentration of 871 ppm. The areal extent of the deposit is unknown.

Des Lacs Artesian Discharge Area

The Des Lacs artesian discharge area is a broad belt that extends southeastward across Renville and Ward Counties roughly parallel to the Des Lacs River and the Souris River below Burlington (fig. 3). The southern boundary of the area generally follows the northeastern margin of the Coteau du Missouri. The northern boundary of the Des Lacs artesian area roughly corresponds to the Des Lacs River. From the confluence of the Souris and Des Lacs Rivers, the boundary extends eastward and includes the flowing wells in the Minot and Surrey areas.

DES LACS RIVER VALLEY

The Des Lacs River begins in Canada about 2 miles north of the international boundary and flows southeastward for about 75 miles to its confluence with the Souris River at Burlington. The river has an average gradient of about 6 feet per mile through Renville and Ward Counties. The channel is entrenched about 15 feet below the valley floor and is generally 10 to 40 feet wide. The river has a drainage area of approximately 1,050 square miles, of which about 400 square miles do not contribute direct runoff to the river system.

Several sand and gravel deposits were penetrated during test drilling in the Des Lacs River valley downstream from Kenmare (pl. 2, cross section A-A', in pocket). Terrace, outwash, and alluvial-fan deposits are also present in several of the tributaries and the main valley. Water-bearing deposits may be as much as 45 feet thick, such as at Foxholm, but they probably have small areal extent.

Well records indicate that many thin deposits of saturated sand and gravel occur at shallow depths in the valley and sufficient ground water for domestic and livestock use is generally available. In a few places, ground water may be sufficiently abundant for small municipal supplies and small-scale irrigation.

The ground-water levels generally range between 3 and 10 feet below land surface, but they fluctuate as much as 3 feet during the year.

The chemical quality of the water from the glacial deposits in the Des Lacs valley varies from a sodium sulfate type to a calcium bicarbonate type. Wells drilled near the valley walls where bedrock is near the surface, tend to have larger concentrations of sodium and sulfate. The higher concentrations are probably the result of natural recharge from beds of sand and lignite in the Fort Union. Water from wells in the central part of the valley, especially those less than 40 feet deep, tends to contain less dissolved solids; calcium and bicarbonate are the major components. Much of this water is derived by infiltration from the river during spring runoff and from precipitation.

Insufficient data are available to accurately determine the ground-water conditions in the Des Lacs River valley north of Kenmare. Cross section G-G' of plate 2 shows about 200 feet of till with discontinuous sand and gravel bodies in the Des Lacs River valley in northwestern Renville County. Elsewhere, records of wells and test holes indicate that in places there are thick accumulations of saturated sand and gravel. Apparently several buried valleys cross the area, but because there is no surface expression, their trends and areal extent are unknown.

Nearly 80 feet of sand and gravel was penetrated in well 161-88-31da, but of the few wells along the upper part of the Des Lacs valley, most are less than 20 feet deep. They are limited to the margins of the valley because Upper Des Lacs Lake, which is only a few feet deep, covers most of the valley floor.

Owing to a general lack of ground-water development, it is assumed that the aquifers in this area are full and that they discharge water into the river. The quantity, however, is probably quite small and much of the discharge is lost through evapotranspiration.

The Des Lacs River valley is an area of ground-water discharge during most of the year. Discharge of ground water into the Des Lacs River is indicated by (1) the abrupt steepening of the potentiometric surface adjacent to the valley, (2) numerous springs and seeps along the valley walls, (3) the abundance of local marshy areas on the flood plain, (4) the base flow of the river, and (5) the progressive lowering of the water level in shallow wells on the flood plain from spring to late winter.

Pollution of ground water is a potential problem in the Des Lacs River valley. Most of the domestic and stock wells on the flood plain are less than 30 feet deep and many are less than 10 feet deep. Most of these wells are close to septic tanks, outdoor privies, manure piles, or other sources of pollution. In several places there are refuse dumps in abandoned meanders or along the river banks. Practices such as these provide ample opportunity for surface-water and ground-water pollution. Consequently, water from shallow wells, particularly dug wells, should be analyzed periodically for the presence of pollutants, especially bacteria.

Kenmare aquifer

Kenmare (population 1,515, 1970 census) obtains its municipal water supply from a buried sand and gravel aquifer beneath the city (pl. 1). The aquifer is at least 200 feet below the Des Lacs River valley and is believed to extend in a northeast-southwest direction. The extent of the Kenmare aquifer is not known beyond secs. 19 and 20, T. 160 N., R. 88 W. (pl. 1; pl. 2, cross section F-F'). C. A. Armstrong (oral commun., 1969) traced a buried channel in southeast Burke County to the east line of sec. 1, T. 161 N., R. 87 W., and designated the gravel deposit as the Kenmare(?) aquifer. Further test drilling is required to determine if this is part of the Kenmare aquifer.

The buried channel is slightly more than a mile wide at Kenmare and is 355 feet deep at test hole 160-88-20caa1. On the uplands at the north end of Kenmare, the depth to the bottom of the channel would probably exceed 550 feet. There is no surface expression of the buried aquifer.

The lower part of the aquifer is as much as 60 feet thick, and consists chiefly of medium to coarse sand, fine to coarse gravel, and boulders. Sand forms the upper part of the deposit. In some places thin layers of till are interbedded with this material.

Data are insufficient to compute the quantity of water in storage or the direction of water movement in the Kenmare aquifer. As more than 200 feet of glacial drift overlies the aquifer, recharge from precipitation probably is small. Most of the recharge probably is by underflow from adjacent areas.

The potentiometric surface of the aquifer is about 250 feet above the top of the aquifer, or about 19 to 48 feet below land surface in the southern part of Kenmare. The aquifer, therefore, is confined under artesian pressure.

Three high-capacity wells have been drilled into the aquifer by the city of Kenmare. Of the three wells, only one (well 2) was in operation in 1967. Although well 2 would probably produce as much as 1,000 gpm, water was pumped from the well into a 3-inch pipe to a storage reservoir and, consequently, the average discharge probably did not greatly exceed 500 gpm.

An aquifer test was conducted on the Kenmare aquifer on September 15-18, 1966, by pumping Kenmare municipal well 2 (160-88-20cbb2). This well is 340 feet deep and completely penetrates the aquifer. It has a 12-inch-diameter steel well casing and 55 feet of 8-inch-diameter gravel-packed screen set in the bottom. The well was equipped with a turbine pump that was powered by a 50-horsepower electric motor. During the test, the water was conveyed through 6-inch-diameter irrigation pipe into a municipal reservoir nearly 200 feet west of the pumped well. The discharge, which was measured by a flowmeter coupled to a chart recorder, was maintained at a constant rate of 500 gpm by an inline valve. The well was pumped for 3,000 minutes and recovery of water levels was measured for 1,350 minutes.

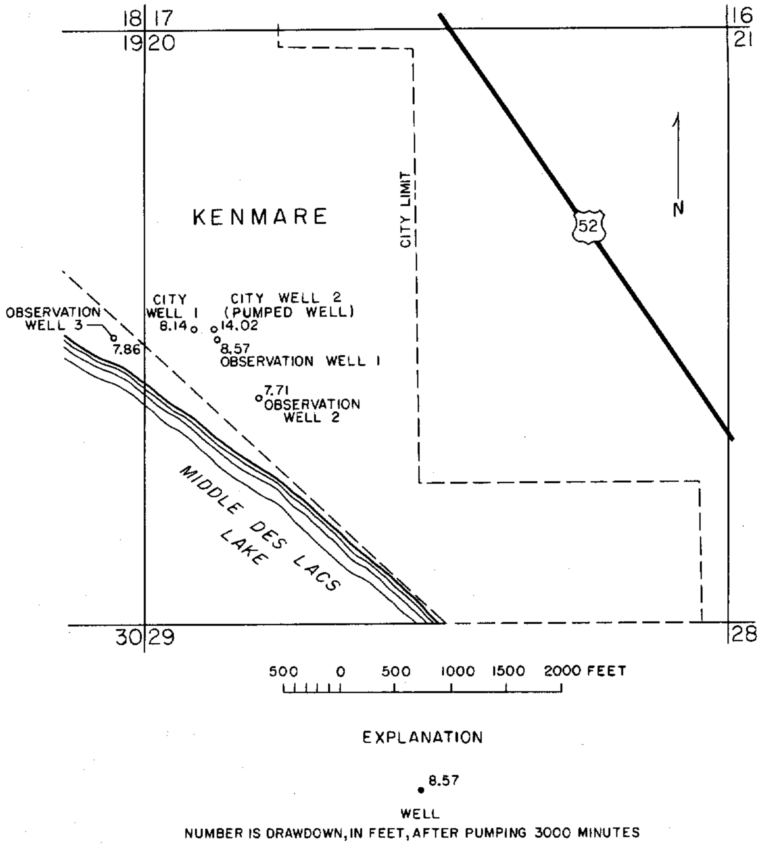


FIGURE 11. Location of wells for Kenmare aquifer test (160-88-20).

Water samples were collected at the pump after 5, 26, and 49-¾ hours of pumping. A chemical analysis was made on the first and last samples collected.

Observation wells were installed at distances of 110 feet (observation well 1), 730 feet (observation well 2), and 900 feet (observation well 3) from the pumped well (fig. 11). Observation well 1 (160-88-20cbb1) was 340 feet deep, the lower 40 feet of the 1¼-inch pipe was slotted and gravel packed, and penetrated 48 feet of sand or gravel in the lower 58 feet. Observation well 2 (160-88-20cba) was 310 feet deep, the lower 40 feet of the 1¼-inch pipe was slotted and gravel packed, and penetrated 59 feet of sand or gravel in the lower 72 feet. Observation well 3 (160-88-19daa) was 325 feet deep, the lower 30 feet of the 1¼-inch pipe was slotted and gravel packed, and penetrated 58 feet of sand or gravel in the lower 68 feet.

Each observation well was equipped with an automatic water-level recorder. Water-level changes in the pumped well and observation wells 1-3 during the aquifer test are shown in figure 12.

Kenmare municipal well 1, which is 175 feet from the pumped well, was also used as an observation well. The screen in well 1 was in very poor condition and the well contained a considerable amount of sand. Consequently, it was slow in reacting to water-level changes during the aquifer test.

Semilog plots of drawdown and recovery versus time and logarithmic plots of drawdown versus time were prepared for the pumped well and observation wells 1-3. The logarithmic plot of time-drawdown data for observation well 2 is shown in figure 13. The values of transmissibility and the storage coefficient were determined from the early part of the drawdown and recovery curves, in most cases less than 40 minutes after pumping started or stopped. This procedure was necessary because of the rapid effects of barrier boundaries, as would be expected of an aquifer that is confined within narrow limits.

The results of the Kenmare aquifer test are summarized in table 4. The analyses indicate that the aquifer transmissibility (average of drawdown and recovery values) ranges from 140,000 gpd per foot to 200,000 and the storage coefficient ranges from 0.00006 to 0.006. The specific capacity of Kenmare well 2 after 24 hours of pumping was 42 gpm per foot of drawdown.

Kenmare well 1 was drilled in 1904 and reportedly flowed at a rate of 140 gpm. The flow rate diminished to only a few gallons per minute in 1950. In 1966 the water level in this well was about 24.5 feet below the top of the pump base, or about 18 feet below the assumed 1950 level. This water-level decline indicates that discharge of water exceeded the natural recharge by less than 10 percent. If the present pumping rate continues in the future, the water level is expected to decline at a diminishing rate.

Records of wells throughout the area indicate that only the Kenmare wells pump from this aquifer. During the early part of this century, several large flowing wells tapped this aquifer at Kenmare and caused the rapid decline of water levels.

Records of municipal pumpage are not available as there are no meters on the wells. It is estimated that the city pumped water at an average rate of about 100,000 gpd (36.5 million gallons per year) in 1967. This average is based on the number of hours per day the pump is

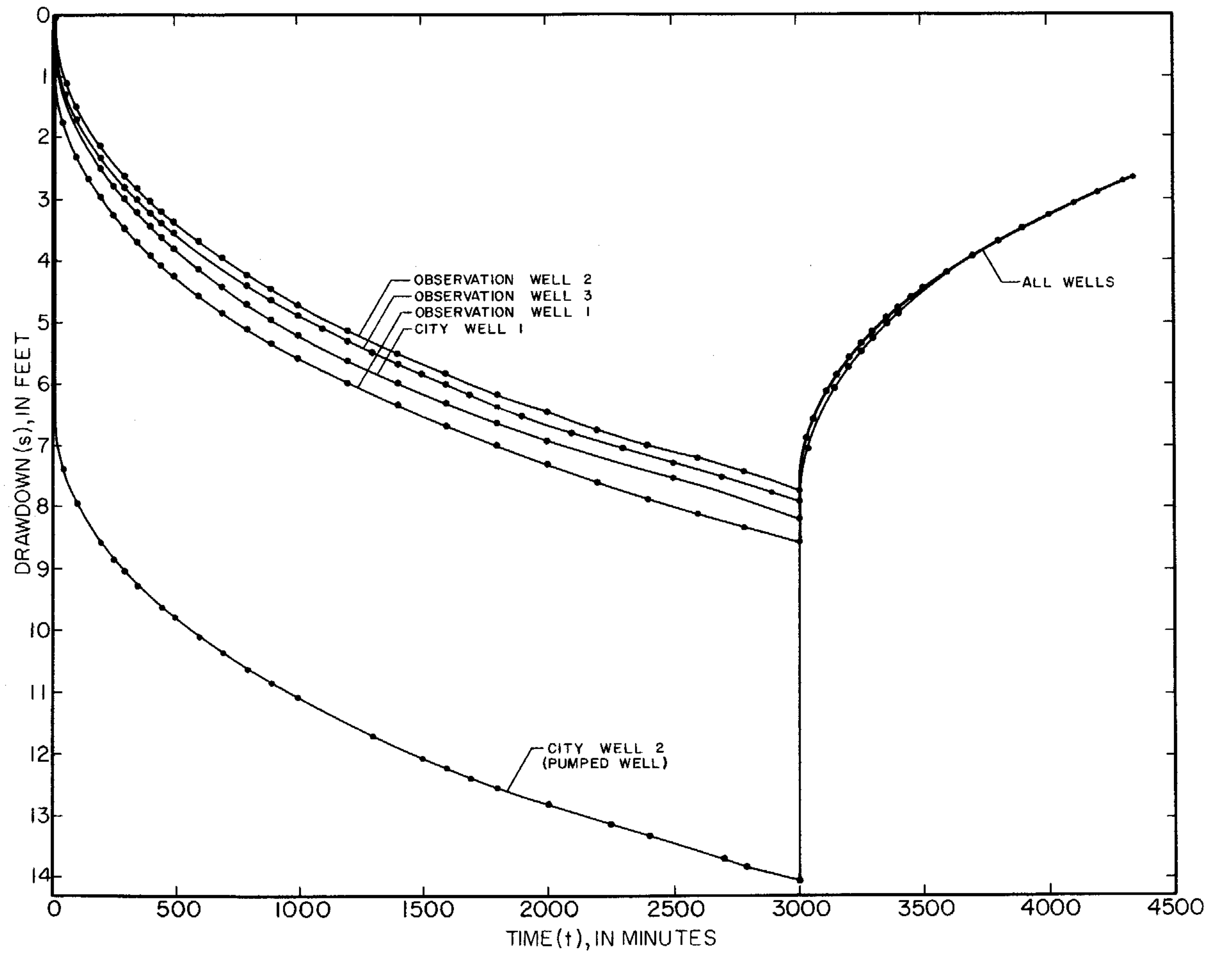


FIGURE 12. Drawdown and recovery curves for the Kenmare aquifer test.

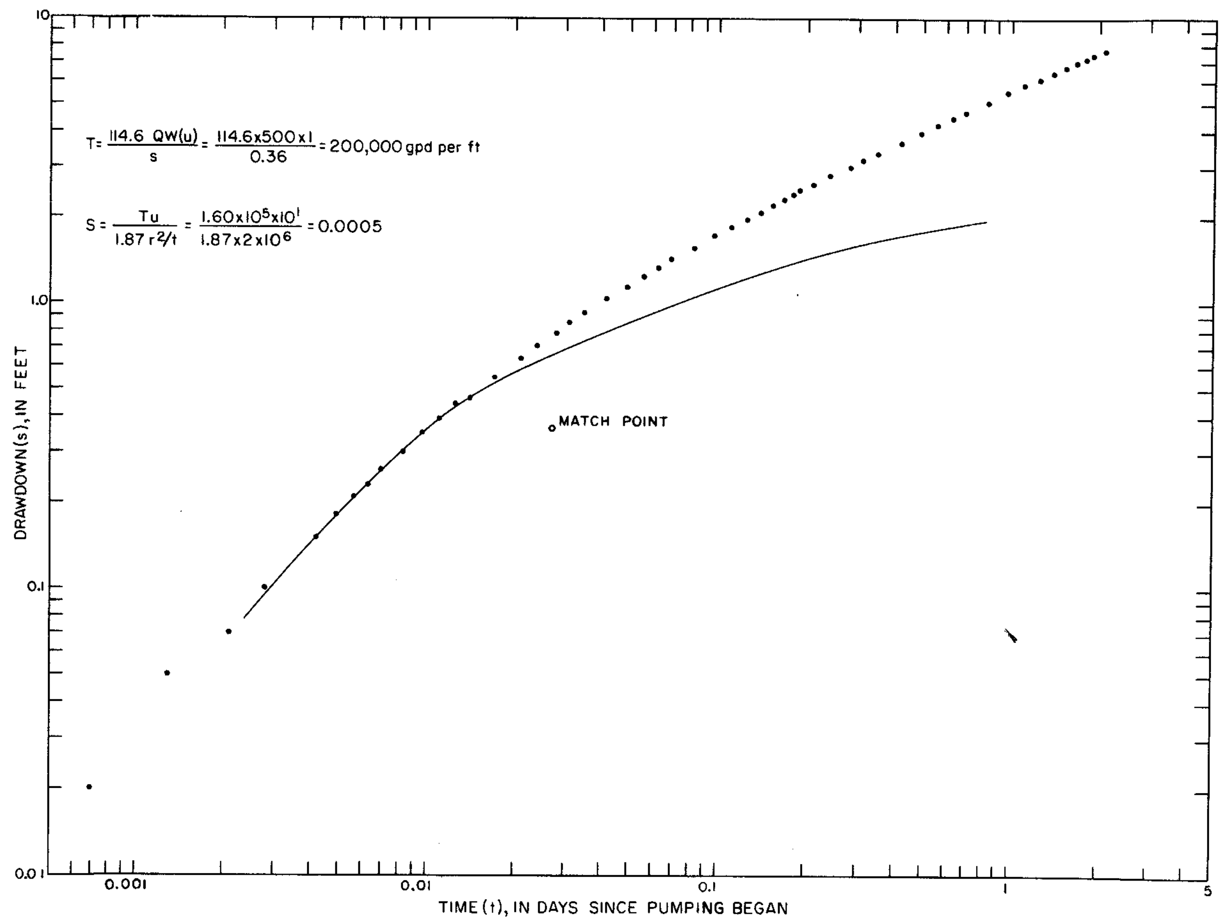


FIGURE 13. Drawdown (s) versus time (t) for observation well 2, Kenmare aquifer test.

TABLE 4.–Results of Kenmare aquifer test

Discharge well	Observation well	Distance from pumped well "r" (feet)	Coefficient of transmissibility "T" in gpd per foot				Storage coefficient
			Semilog solution		Theis type-curve solution	Average	
			Drawdown	Recovery	Drawdown		
160-88-20cbb2	...	...	120,000	230,000	...	180,000	...
	1	110	170,000	180,000	180,000	180,000	0.001
	2	730	160,000	140,000	200,000	170,000	.0005
	3	900	190,000	110,000	200,000	170,000	.00006
	City well 1	175	180,000	...	110,000	140,000	.006

operated and the discharge rate. The discharge rate was estimated by determining the time required to fill two municipal reservoirs.

The Kenmare aquifer can provide a substantial volume of water for future development. In Kenmare the most desirable area for future wells is in the vicinity of observation well 3 (160-88-19daa), where coarse gravel is present. However, wells should be widely spaced to minimize interference. In addition to the higher permeability in this area, the aquifer boundaries are at a greater distance than in other areas.

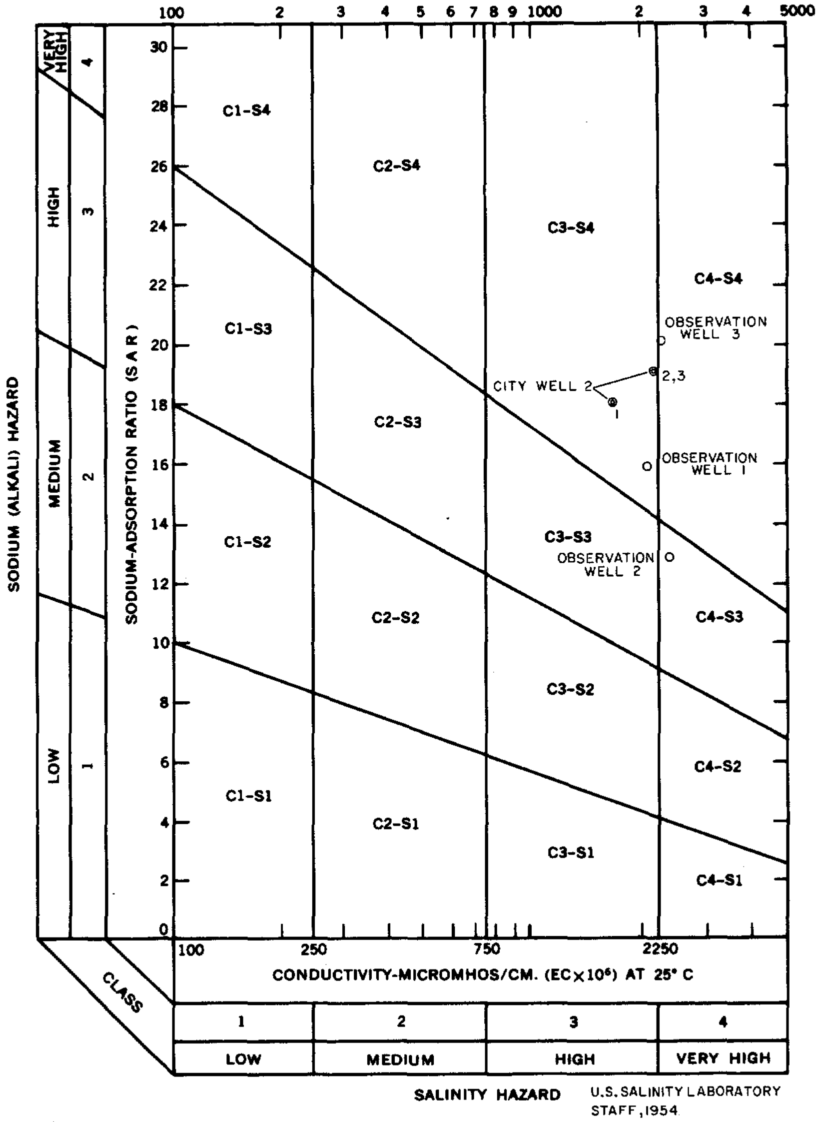
Water from the Kenmare aquifer is a sodium bicarbonate type. The dissolved solids (1,070 to 1,500 ppm) were higher than the maximum standard recommended by the U.S. Public Health Service. Dissolved iron (0.22 to 1.4 ppm) was present in excessive concentrations locally, and will stain clothes and plumbing fixtures. Although the water is moderately hard to very hard by national standards, it is relatively soft in comparison with water from many other aquifers in Renville and Ward Counties. Water from the Kenmare aquifer is generally unsatisfactory for irrigation because of a high to very high salinity hazard and high to very high sodium-hazard (fig. 14).

Apparently the quality of the water becomes poorer with time during pumping, indicating recharge of undesirable water from adjacent sources. The amount of chemical components in the water is nearly 20 percent less in the sample collected after 5 hours of pumping as compared to those taken after 26 and 49-¾ hours. The composition of the water after 26 and 49-¾ hours of pumping is nearly identical (fig. 14).

SOURIS RIVER VALLEY

The Souris River enters the United States from Canada near the northwest corner of Renville County, and flows southeastward across Renville and Ward Counties. The river occupies a large flat-floored valley, which lies as much as 150 feet below the upland surface. The valley is about half a mile wide at the international border but averages about three-quarters of a mile in width through the study area. A complex meander pattern has been developed by the river. Swampy areas and lakes cover part of the valley floor above Burlington. Lake Darling, an artificial lake in southeast Renville County, is about 20 miles long and has a maximum depth of about 15 feet. Below the confluence of the Des Lacs River at Burlington there are only a few small artificial lakes.

Upstream from Burlington, the tributary streams are few and short. The main valley is incised to a depth of about 150 feet and has an average gradient of about 1 foot per mile.



EXPLANATION

AQUIFER-TEST WATER SAMPLES

1 COLLECTED AFTER PUMPING 5 HOURS
2 COLLECTED AFTER PUMPING 26 HOURS
3 COLLECTED AFTER PUMPING 49-3/4 HOURS

FIGURE 14. Classification of water from the Kenmare aquifer for irrigation use.

The valley of the Souris River downstream from Burlington is cut in bedrock, which, in places, forms the lower one-third to one-half of the walls. The valley is deepest near Minot where there is as much as 200 feet of relief from the valley floor to the uplands. Generally, the north valley wall is lower than the south wall because of the northeast slope of the upland. Steep-sided tributaries that may be several miles in length are incised into the upland area south of the valley. Tributaries on the north side, however, are few and short because the slope of the upland causes the water to drain away from this side of the valley. The gradient of the valley floor is about 2.3 feet per mile.

Two stream-gaging stations provide useful data to interpret the surface-water-ground-water relationships in the Souris River valley. The gaging-station record above Minot (155-83-17dbb) indicates the general hydrologic conditions of the upper stretches of the Souris and Des Lacs Rivers, and a downstream gage near Verendrye (154-78-17cb) in McHenry County provides information concerning the interchange between ground and surface water below the Minot gage. Other gages on the Souris River include a station 0.8 mile downstream from the international border near Sherwood and a station 15.4 miles downstream from Lake Darling near Foxholm.

The Minot gage record is used to compute the drainage from approximately 10,600 square miles of the Souris River watershed; however, about 6,700 square miles of this area probably is noncontributing. Based on 62 years of record, the discharge has ranged from no flow in some years to a maximum of 12,000 cfs (cubic feet per second) during the April 1904 flood. The average discharge at this station was 136 cfs (U.S. Geological Survey, 1965a).

The daily mean discharge of the Souris River above Minot from October 1964 through September 1965 is shown in figure 15. During this period, the minimum flow was 0.1 cfs (March 25-27), the maximum flow was 1,200 cfs (June 17). Prior to the construction of the Lake Darling dam, the greatest discharge was in April during the spring runoff and thereafter it decreased until late fall, except for short periods after heavy rains fell in the drainage basin. Since the construction of the dam, however, flow has been almost completely regulated.

The weather was unusually dry during the period 1962-64 and for weeks at a time no river flow was recorded at the Minot gage. Residents between Burlington and Minot reported that water levels in their shallow wells declined substantially at that time and a few wells required deepening. The lack of recharge and the high rate of evapotranspiration of water from the nearly dry river channel and the adjacent valley floor were largely responsible for the water-level decline. Consequently, many thousands of acre-feet of ground water were lost

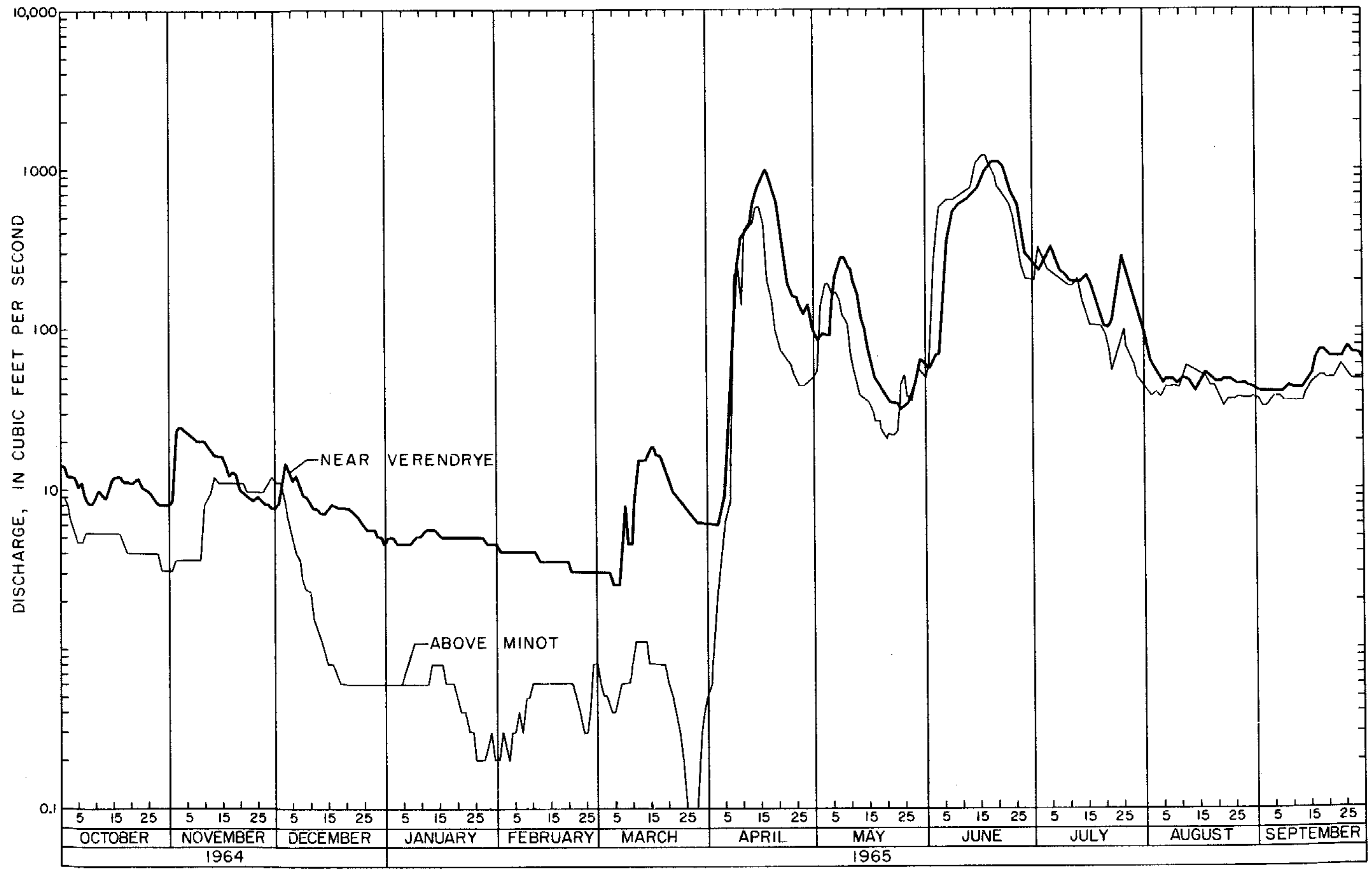


FIGURE 15. Discharge of the Souris River above Minot and near Verendrye, October 1, 1964, to September 30, 1965.

in consumptive use, and by June 1964, there were areas of serious ground-water depletion in the Souris River valley.

A series of releases from Lake Darling commenced on June 16, 1964, but only small quantities of the combined flow from the Des Lacs River and Lake Darling (fig. 16) reached the Minot gage, 41 river miles below the dam. For at least 2 months, streamflow was lost from these reaches of the Souris and Des Lacs Rivers. Much of the water went into aquifer storage or was pumped directly from the river. By late summer the aquifer was largely replenished and streamflow losses diminished.

The Verendrye gage record is used to compute the drainage from about 11,300 square miles of the Souris River watershed; however, approximately 6,900 square miles of this area probably is noncontributing. The average discharge at this station was 147 cfs over a 28-year period of record (U.S. Geological Survey, 1965a). The minimum discharge recorded was 0.3 cfs in 1937 and 1939. The maximum recorded discharge was about 4,200 cfs during the April 1949 flood.

The daily mean discharge of the Verendrye gage from October 1964 through September 1965 is shown in figure 15. During this period the maximum flow was 1,140 cfs (June 20-21) and the minimum was 2.5 cfs (March 5-6). Commonly the discharge increases slightly after the first widespread killing frost in the fall.

Streamflow losses occur in the Souris River from the Minot gage to the central part of Minot because of local ground-water conditions. Prior to 1916, the aquifers in this reach had water levels higher than the river and ground water discharged into the river. Ground-water withdrawals since that time have reversed the direction of flow and water is now induced into the aquifers. In addition, the city of Minot withdraws a substantial quantity of water from the river for municipal purposes.

Downstream from Minot, ground-water discharge increases the flow of the river. Several springs on the flood plain, particularly between Logan and Sawyer, mainly flow during the spring and early summer. Several springs and seeps also discharge along the valley walls. Flow from tributaries in the south wall of the Souris River valley also add to the river.

The chemical quality of the water in the Souris River varies within wide limits (fig. 17). From late fall to early spring, when most of the flow may be attributed to ground-water discharge, the water is more mineralized than during other times of the year. The water generally has the highest concentration of dissolved solids in November and December; whereas, the lowest concentrations generally are in April during the spring runoff (U.S. Geological Survey, 1965b).

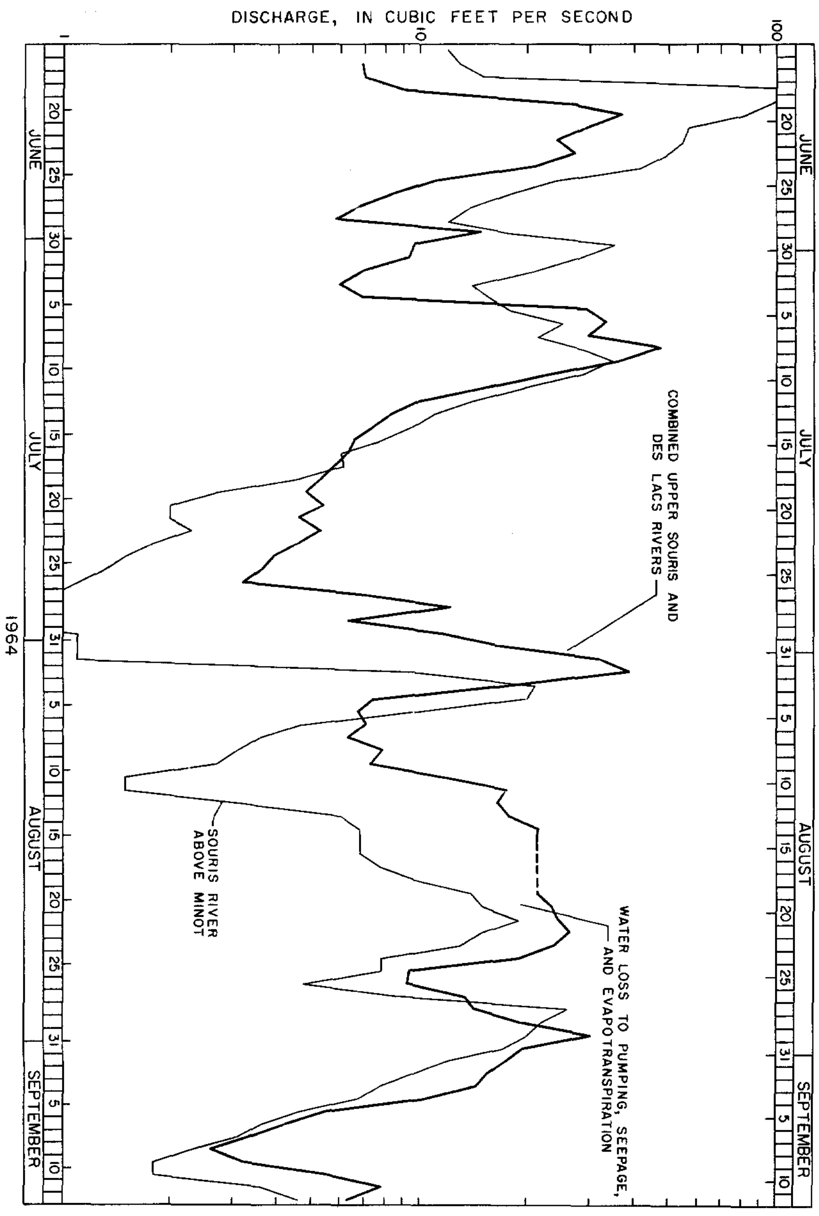


FIGURE 16. Combined discharge of the Des Lacs and Souris Rivers at the Foxholm gages and the Souris River at the Minot gage, June 16, 1964, to September 12, 1964.

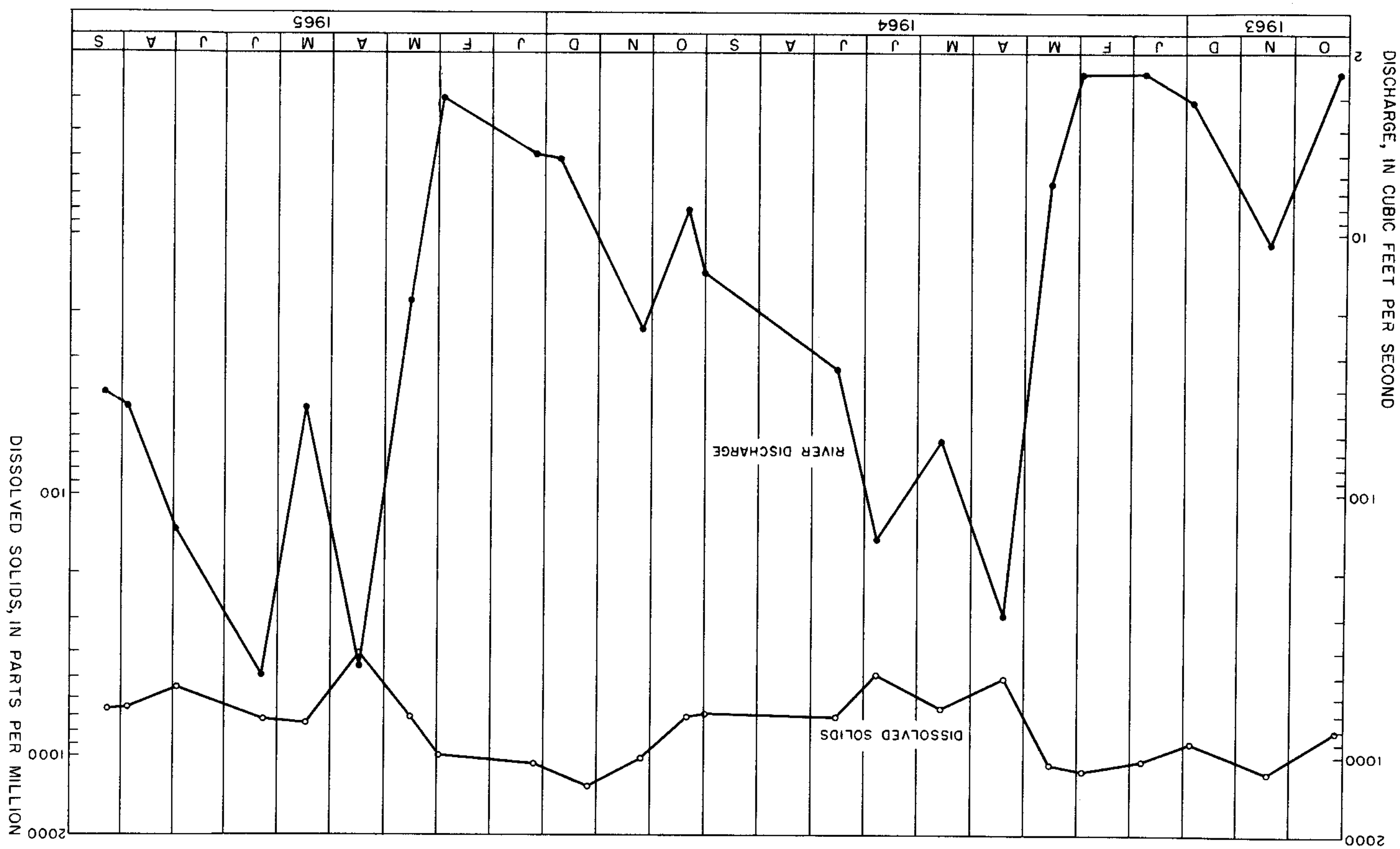


FIGURE 17. Discharge and dissolved solids of the Souris River at Verendrye, October 1963 through September 1965.

Potential sources of ground-water pollution in the Souris River valley include septic tanks, cesspools, outdoor privies, dry wells, manure piles, and refuse dumps. Water from shallow wells in the vicinity of pollution sources such as these should be periodically checked for the presence of bacterial contamination.

Records of wells and test holes indicate that deposits of sand and gravel are locally present, generally at shallow depths, throughout the Souris River valley. Test drilling between Burlington and McHenry County shows that the valley fill material ranges from 54 to 248 feet in thickness and consists mainly of till and outwash (pl. 2, cross section H-H'). A deposit of water-yielding sand and gravel in the lower part of the valley fill extends from Burlington to at least Logan and may continue as thin sand lenses as far as Sawyer. The most productive aquifers, however, extend from Minot nearly to Logan.

Burlington aquifer

The Burlington aquifer is located near the confluence of the Souris and Des Lacs Rivers in the vicinity of Burlington (pl. 1). A combined thickness of 88 feet of sand and gravel was penetrated in test hole 155-84-1bcd (pl. 2, cross section D-D'). Lesser amounts of sand and gravel were encountered in three other test holes in this area. This buried aquifer may extend nearly the full width of the valley, about three-quarters of a mile. The aquifer probably extends at least 3 miles up the Souris River valley from Burlington (pl. 2, cross section C-C'), and at least 1½ miles to the south. The aquifer thins substantially southward and is poorly connected with the Minot aquifer.

As of 1967, no high-capacity wells had tapped the Burlington aquifer and little is known of its hydraulic properties. The water level probably is as much as 10 feet below land surface in some places, and the quality of the water is likely to be similar to water in the Minot aquifer.

The Burlington aquifer probably would provide an adequate municipal supply for Burlington or sustain a small irrigation system. Care should be taken, however, to monitor changes in water level and quality if the aquifer is developed.

Lower Souris aquifer

The Lower Souris aquifer is an artesian system that extends southeastward from Minot (Pettyjohn, 1967a, p. 18). Although the aquifer may be thin or absent in a few places, it probably extends at least to Sawyer (fig. 18). It is confined to the Souris River valley and is underlain and overlain by glacial till (pl. 2, cross section H-H'). It is composed of sand and gravel that probably was deposited as outwash. The aquifer ranges in thickness from 10 to 81 feet, and is buried from

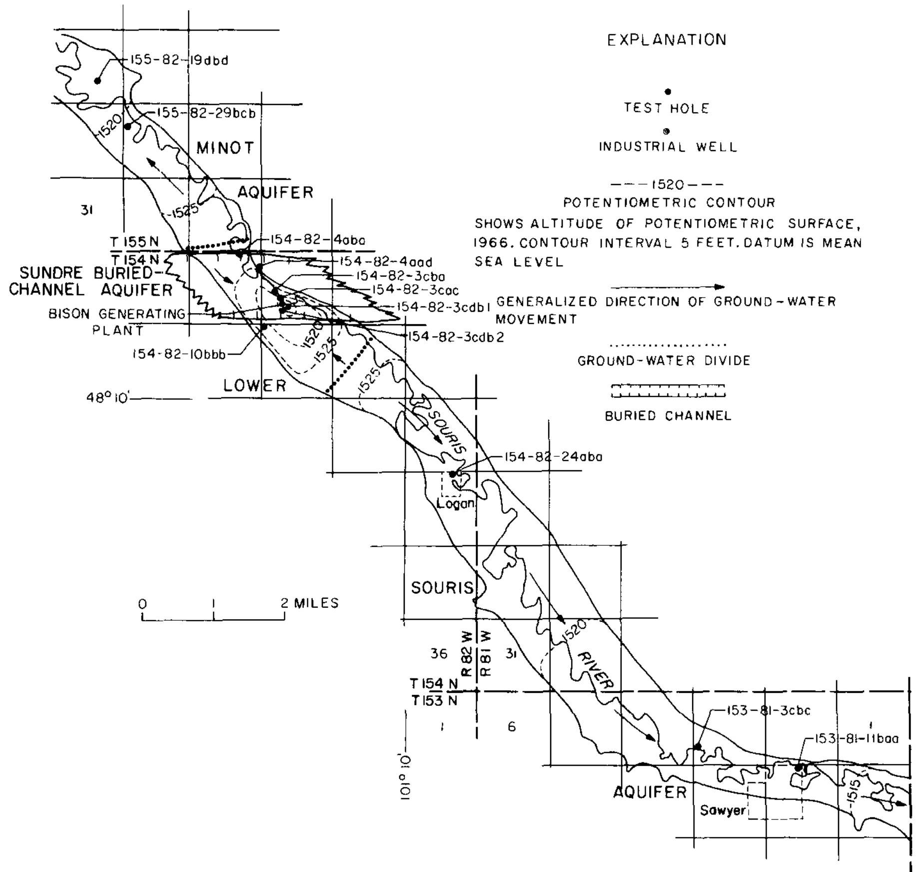


FIGURE 18. Locations of the Lower Souris and Sundre Buried-Channel aquifers, and selected hydrologic data.

12 to 87 feet below land surface. The aquifer may be thin or absent near the walls of the river valley and locally in the central part of the valley.

Natural recharge to the aquifer probably takes place by seepage from the Souris River, from adjacent glacial drift, and, in places, from the Fort Union Group.

There is about 3,000 acre-feet of ground water in storage per linear mile of the aquifer.

Prior to development, the ground-water movement in the Lower Souris aquifer was probably to the southeast. However, pumpage at

Minot and at the Bison Generating Plant, about 3 miles southeast of Minot, has caused reversals in the direction of ground-water movement and ground-water divides have been formed (fig. 18). The ground-water gradient northwest of the divide in sec. 11, T. 154 N., R. 82 W., is toward the northwest at more than 7 feet per mile. The gradient southeast of the divide is toward the southeast at about 1 foot per mile. The quantity of underflow northwestward from the divide in 155-82-33 into the adjacent Minot aquifer is probably about 1 mgd (million gallons per day).

The water level in the aquifer ranges from 10 to 40 feet below land surface. Hydrographs of water-level fluctuations in the aquifer are shown in figure 19. The greatest fluctuations were in the vicinity of Minot where the aquifer is heavily pumped. Southeastward from the Bison Generating Plant, only minor seasonal changes in ground-water storage are indicated by the water-level fluctuations; water levels are highest in July or August and lowest in February, March, or April.

An aquifer test was conducted on the Lower Souris aquifer on October 11-16, 1965, using Northern States Power Company's Bison Generating Plant well (154-82-3cdb3). The well is 92 feet deep, and apparently completely penetrates the aquifer. It has a 10-inch-diameter steel well casing and 20 feet of gravel-packed screen at the bottom. The turbine pump is powered by a 30-horsepower electric motor. During the test, the water was discharged through a 4-inch-diameter pipe into the Souris River. The discharge, which was measured by a flowmeter coupled to a chart recorder, was maintained at a constant rate of 420 gpm by using an inline valve. The well was pumped 4,200 minutes and recovery was measured for 3,000 minutes.

Four observation wells were drilled at distances of 150 feet (observation well 1), 300 feet (observation well 2), 600 feet (observation well 3), and 1,200 feet (observation well 4) from the pumped well (fig. 20). Observation well 1 (154-82-3cdb1) is 80 feet deep and the lower 10 feet of the 3-inch pipe is slotted and gravel packed. Thirty feet of gravel was penetrated at this well. An additional 25 feet of fine to coarse sand above the main body of the aquifer may also be hydraulically connected. Observation well 2 (154-82-3cdb2) is 80 feet deep and the 1½-inch pipe is coupled to a 2-foot sand point. The aquifer contains 61 feet of sand in its upper part and at least 20 feet of coarse gravel in the lower part, but was not completely penetrated. Observation well 3 (154-82-3cac) was drilled to a depth of 170 feet, but only 82 feet of 1½-inch pipe and a 2-foot sand point were installed in the hole. The well was gravel packed. Sand and gravel extends from 65 to 88 feet and fine to medium sand with an abundance of lignite extends from 88 to at least 170 feet below land surface. Observation well 4 (154-82-3cba) is 96 feet deep, including a sand

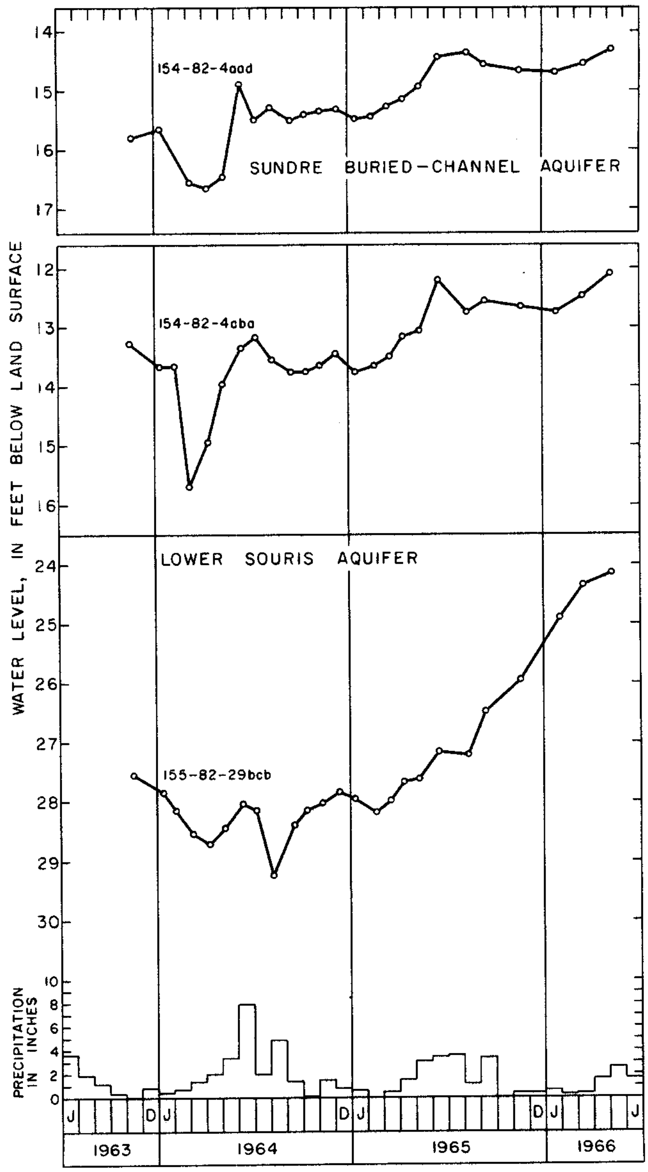


FIGURE 19. Water-level fluctuations in the Lower Souris and Sundre Buried-Channel aquifers. Precipitation at Minot Airport.

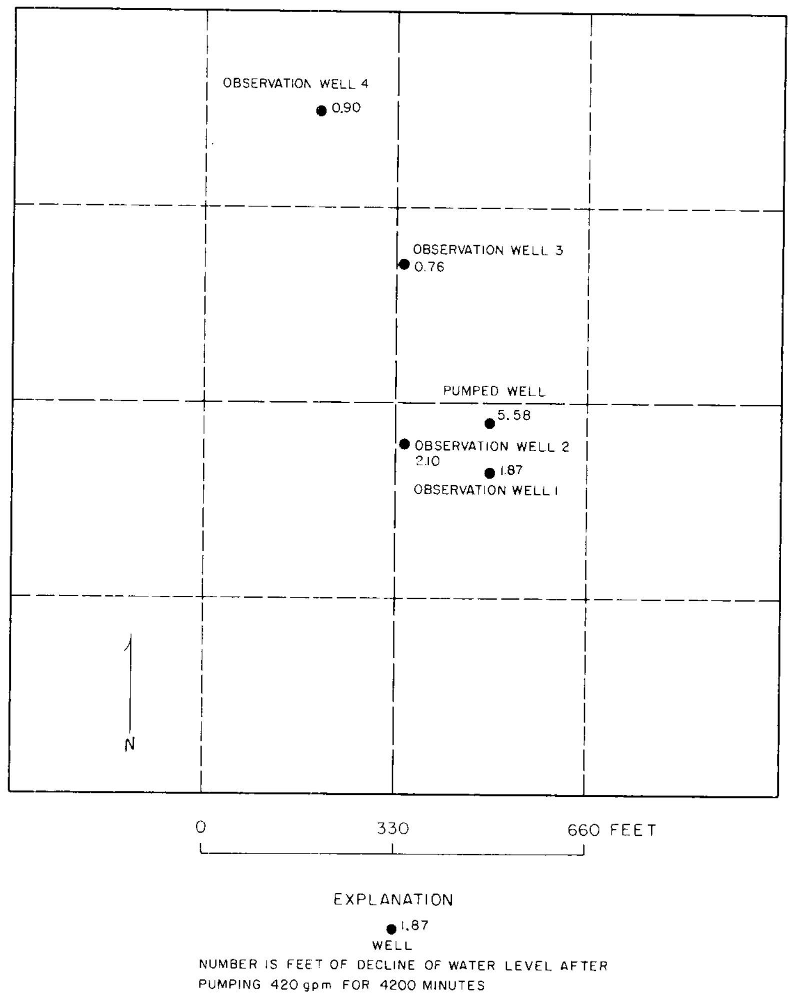


FIGURE 20. Location of wells for the Lower Souris aquifer test (154-82-3).

point. This well was also gravel packed. A total of 34 feet of sand, separated by layers of clay, extends from 12 to 61 feet. Fine to coarse sand and gravel was penetrated from 66 to 103 feet.

The drawdown and recovery of the water level in the pumped well were measured with a steel tape. The observation wells were equipped with automatic water-level recorders with electric water-level sensing devices that produced a continuous record.

Semilog plots of drawdown and recovery versus time, and logarithmic plots of drawdown versus r^2/t were prepared for the pumped well and observation wells 1-4. The drawdown curve for observation well 1 is shown in figure 21. The values of the coefficients of transmissibility and storage were determined from the early part of the drawdown and recovery curves before the appearance of boundaries.

The results of the Lower Souris aquifer test are summarized in table 5. The analyses gave values of the coefficient of transmissibility from 140,000 to 520,000 gpd per foot and the storage coefficient ranges from 0.00009 to 0.0009. Variations in the values of transmissibility and storage coefficient are due to differences in aquifer hydraulic characteristics, to changes in aquifer thickness, and to well development. The high values of transmissibility in observation well 3 reflect the greater thickness of the aquifer in that area. The specific capacity of the pumped well after 24 hours of pumping was 79 gpm per foot of drawdown.

The test on the Lower Souris aquifer shows that it has a large potential for future ground-water development. As of 1967, the only high-capacity well tapping the aquifer was at the Bison Generating Plant, but it was seldom used. Properly constructed and fully penetrating wells locally could produce as much as 1,000 gpm with a drawdown ranging between 6 and 13 feet. However, lenses of less permeable material such as silt and clay, where present, will restrict the yield of a well.

Water from the Lower Souris aquifer is suitable for most domestic and industrial uses. The water is a hard sodium bicarbonate type. The iron will stain clothes and fixtures, but the concentrations of other chemical components are generally much lower than in parts of the Minot aquifer (Pettyjohn and Hills, 1965). The water is in the C3-S1 and C3-S2 classifications for irrigation and should be suitable for irrigation wherever there is adequate drainage (fig. 22).

Minot aquifer

The Minot aquifer consists of sand and gravel outwash deposits that apparently were emplaced during several minor advances and retreats of glacial ice. The aquifer, although hydraulically connected to

TABLE 5.–Results of Lower Souris aquifer test

Well	Distance from pumped well "r" (feet)	Coefficient of transmissibility "T", gpd per foot			Storage coefficient "S"
		Semilog solution		Theis type-curve solution	
		Drawdown	Recovery	Drawdown	
Bison Plant	...	240,000	210,000	...	0.0002
1	150	198,000	250,000	190,000	.0004
2	300	140,000	160,000	140,000	.0001
3	600	380,000	430,000	520,000	.00009
4	1,200	240,000	220,000	270,000	.0009

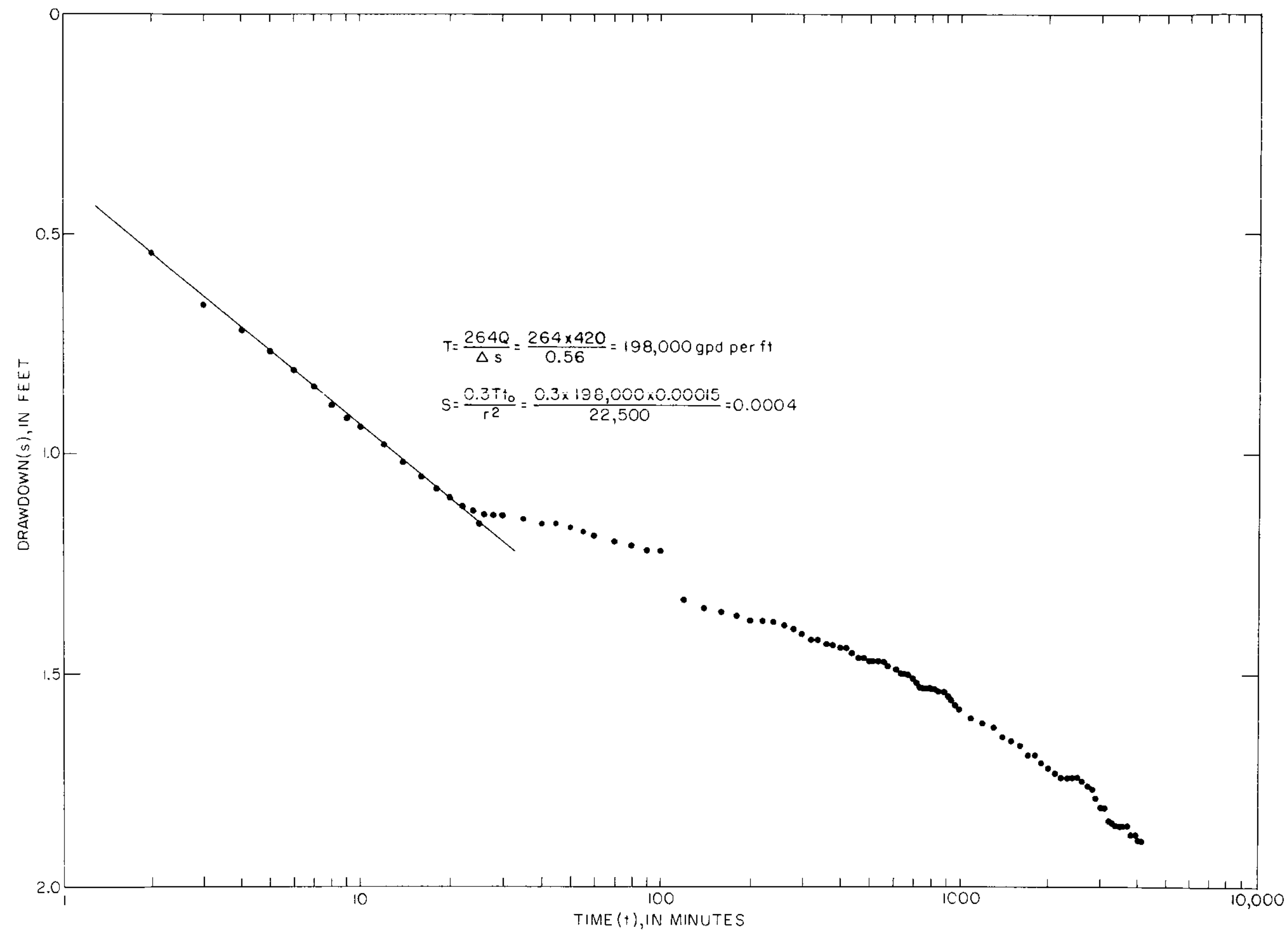


FIGURE 21. Lower Souris aquifer test drawdown-test data for observation well 1.

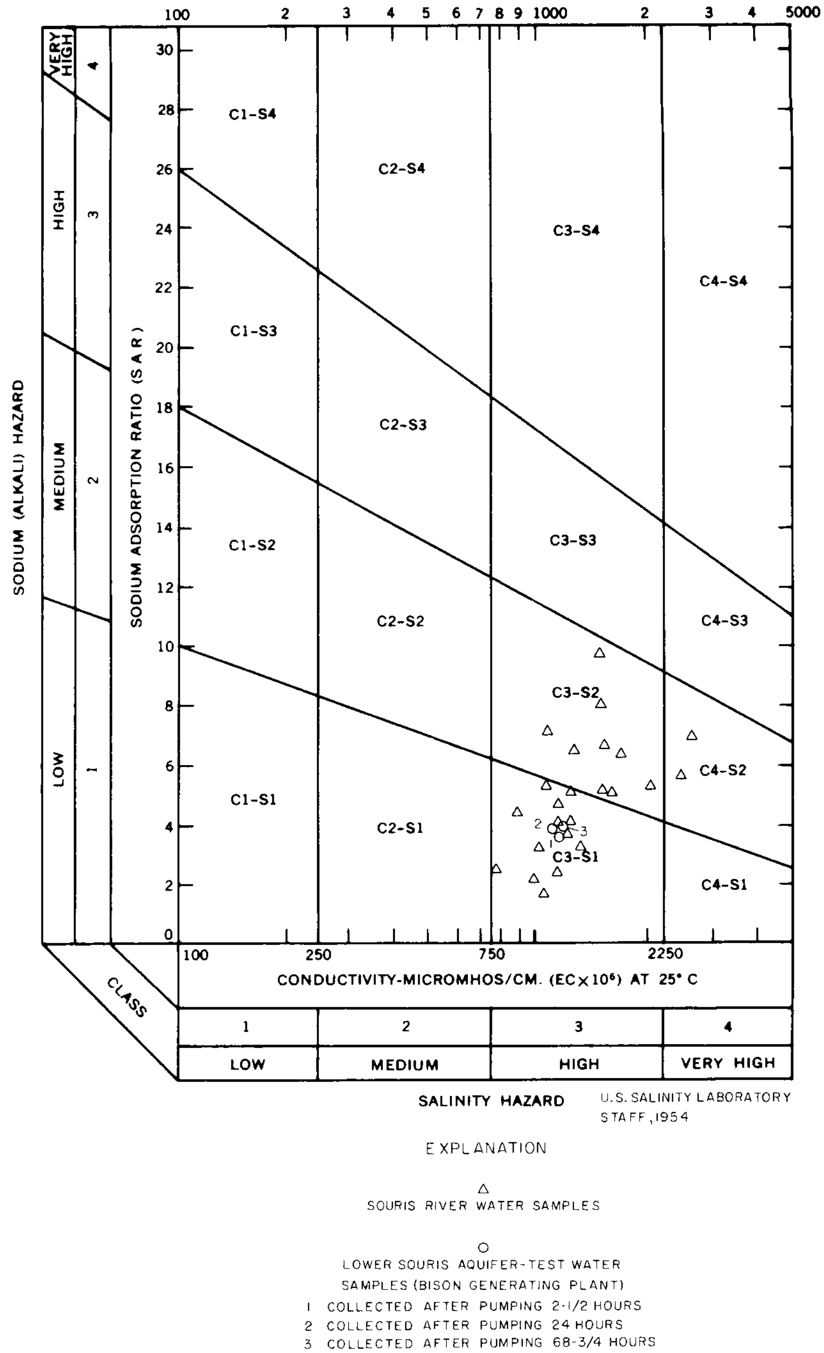


FIGURE 22. Classification for irrigation use of selected water samples from the Lower Souris aquifer and from the Souris River between Burlington and Sawyer.

aquifers both upstream and downstream, is considered in this report to be confined to the Souris River valley in the vicinity of Minot (pl. 1).

The aquifer consists, in many places, of very coarse sandy gravel containing an abundance of boulders. The deposits vary considerably in thickness, but commonly are 30 to 50 feet thick. In most places, sand overlies the gravel and may be as much as 85 feet thick. Where the sand is thick, the gravel is generally thin. The coarse gravel is exposed in the extreme western part of Minot. In the eastern part of Minot, the gravel and sand are overlain by more than 80 feet of clay (Pettyjohn, 1967a, p. 21-22).

Ground water occurs under both water-table and artesian conditions in the Minot aquifer. Water-table conditions exist in areas where there is no upper confining bed and in areas where the potentiometric surface has been lowered below the overlying confining bed. Elsewhere, artesian conditions exist.

Natural recharge takes place in the Minot aquifer by: (1) direct infiltration of precipitation, (2) inflow from adjacent bedrock and glacial-drift deposits, and (3) seepage from the Souris River.

Natural recharge to the Minot aquifer is apparently about 3 mgd, of which about 2 mgd is derived from the Northwest Buried-Channel and Lower Souris aquifers; about 0.5 mgd is seepage from the Souris River; and about 0.5 mgd is released from bedrock sources, adjacent glacial till, and infiltration of precipitation.

Recharge from the bedrock has probably increased with the decline in water level in the Minot aquifer, but the quantity has not been sufficient to make noticeable changes in water quality.

The relation between precipitation at Minot, discharge of the Souris River, and the water levels in the central part of the Minot aquifer is shown in figure 23. The data indicate a general relationship between the discharge of the river and the water level in the aquifer.

In 1965, the city of Minot constructed an artificial recharge facility in an attempt to halt the rapid water-level decline in the aquifer (Pettyjohn, 1968b). The facility consists of a settling basin connected to a Y-shaped canal system. Along the centerline of the canals are gravel-filled bored holes, called hydraulic connectors, that perforate the poorly permeable material that overlies the Minot aquifer. The hydraulic connectors range in diameter from 30 to 72 inches and from 28 to 34 feet in depth. The lower part of the hydraulic connectors taps sand and gravel in the dewatered upper part of the Minot aquifer.

Two pumps lift water from the river at a rate of about 4 mgd. The river water is pumped through two 10-inch-diameter cast-iron mains for about 1,000 feet and discharges into the settling basin. When the water level in the basin is sufficiently high, water flows down the canals and

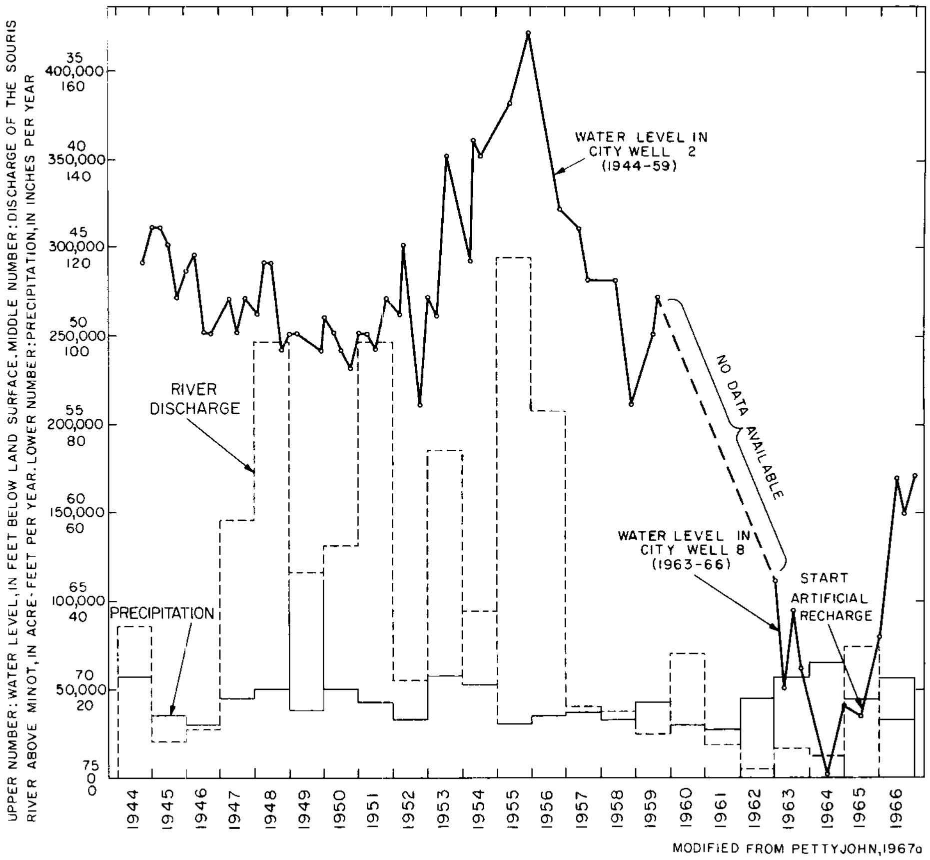


FIGURE 23. Precipitation at Minot, discharge of the Souris River, and water levels in the central part of the Minot aquifer, 1944-66.

thence into the hydraulic connectors where it filters downward into the aquifer. During optimum conditions, the recharge rate is about 2 mgd.

The raw water pumped from the river contains a large amount of sediment. Within a few weeks of artificial recharging, sediment begins to clog the sand and gravel in the bottom and along the sides of the sediment basin and in the hydraulic connectors, causing the recharge rate to diminish. The facility is cleaned each 3 to 5 months when the recharge rate decreases to about 1 mgd.

Full-scale use of the artificial recharge facility began in October 1965. The quantity recharged from October to December 31, 1965, was 245,880,000 gallons; from January 1, 1966, to December 31, 1966, was 478,344,250 gallons; and from January 1, 1967, to April 7, 1967, was 51,589,000 gallons, for a total of three-quarters of a billion gallons during the 18-month period of operation.

The water recharged resulted in a substantial water-level rise throughout the aquifer, but particularly in the vicinity of the recharge system where the rise was more than 15 feet (figs. 24 and 25).

During 1966, approximately a billion gallons was added to the Minot aquifer by natural recharge and 500 million gallons by artificial recharge. Approximately 850 million gallons was withdrawn from the aquifer by municipal pumping. Thus, the net increase in ground-water storage was nearly 650 million gallons.

Ground water is principally discharged from the Minot aquifer by pumping wells. Water loss by evapotranspiration from the aquifer is negligible. The aquifer probably does not discharge ground water to streams under present conditions.

Pumpage for municipal water supplies at Minot from 1944 to 1966 is shown in figure 26. The annual pumpage rate has more than quadrupled since 1944. In general, the greatest pumpage from the well field is during June, July, and August. During this period in 1963, the average pumpage from municipal wells was nearly 5 mgd, but it exceeded 7 mgd during short intervals. The least pumpage is during January, February, and March; in 1964 it averaged about 3.3 mgd during this period (Pettyjohn,1967a, p. 36-38).

Water levels in the Minot aquifer reportedly declined rapidly at the close of 1961 following the construction and subsequent heavy pumping from city wells 11-18. A general trend toward equilibrium is indicated on hydrographs from the early winter of 1963 through the spring of 1965 (fig. 24). This trend is probably the result of decreased pumping during fall and winter and of the large municipal withdrawals directly from the Souris River. The rapid rise of the water level starting in May 1965 is the result of artificial recharge.

City wells 5 and 6 are in the deeper eastern part of the aquifer, and even though they have been heavily pumped for nearly 20 years, the water level has declined less than in wells in the western part of the city. This is probably because of their nearness to large sources of natural recharge.

The available data indicate that under natural conditions the Minot aquifer can supply about 3.0 mgd without a substantial decline of water level.

Transmissibilities of the Minot aquifer are shown in table 6. The data from Akin (1947) were the most accurately determined, but they do not reflect the conditions in 1966 because the water level in the aquifer has declined nearly 20 feet since the tests were run in 1946. Transmissibilities determined by development- and production-test data

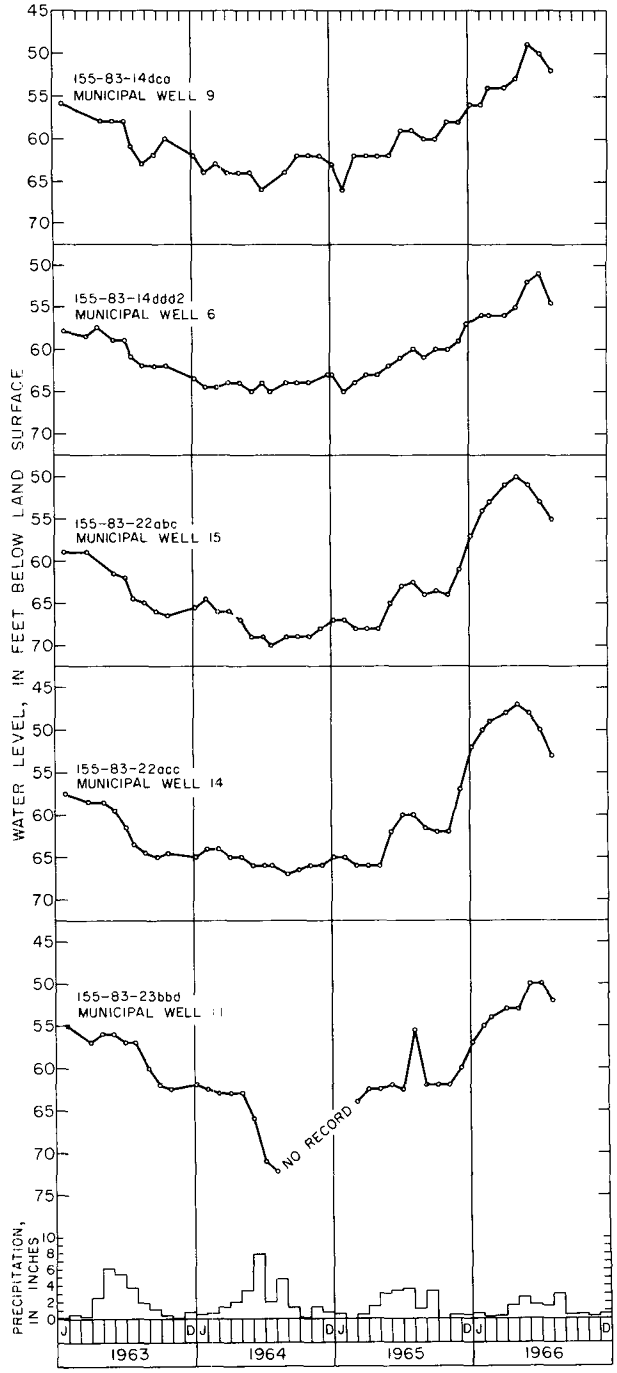
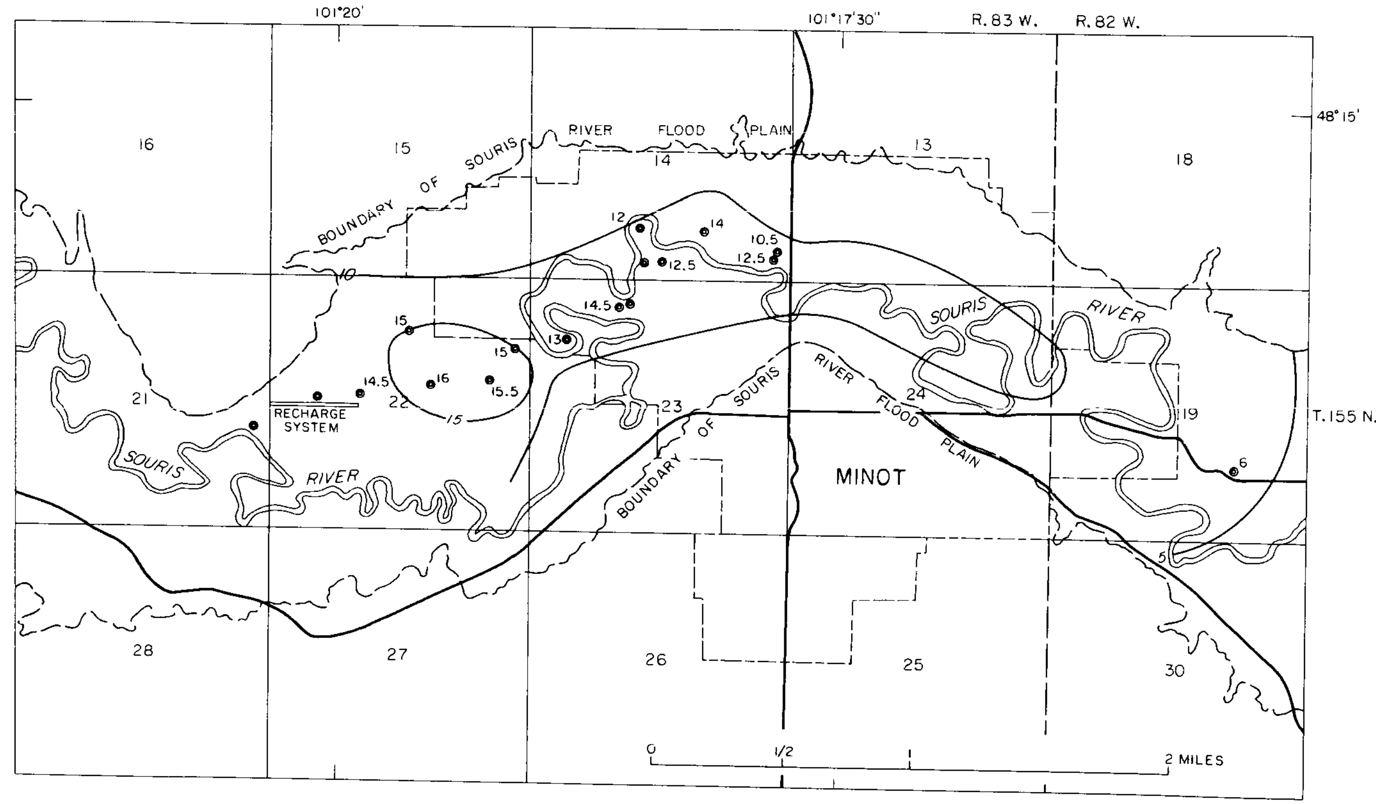


FIGURE 24. Water-level fluctuations in the Minot aquifer and precipitation at Minot Airport.



EXPLANATION

15

MUNICIPAL WELL. NUMBER IS AMOUNT OF WATER-LEVEL RISE, IN FEET

10

LINE OF EQUAL WATER-LEVEL RISE. INTERVAL 5 FEET

FIGURE 25. Water-level rise in part of the Minot aquifer from March 1964 to June 1966.

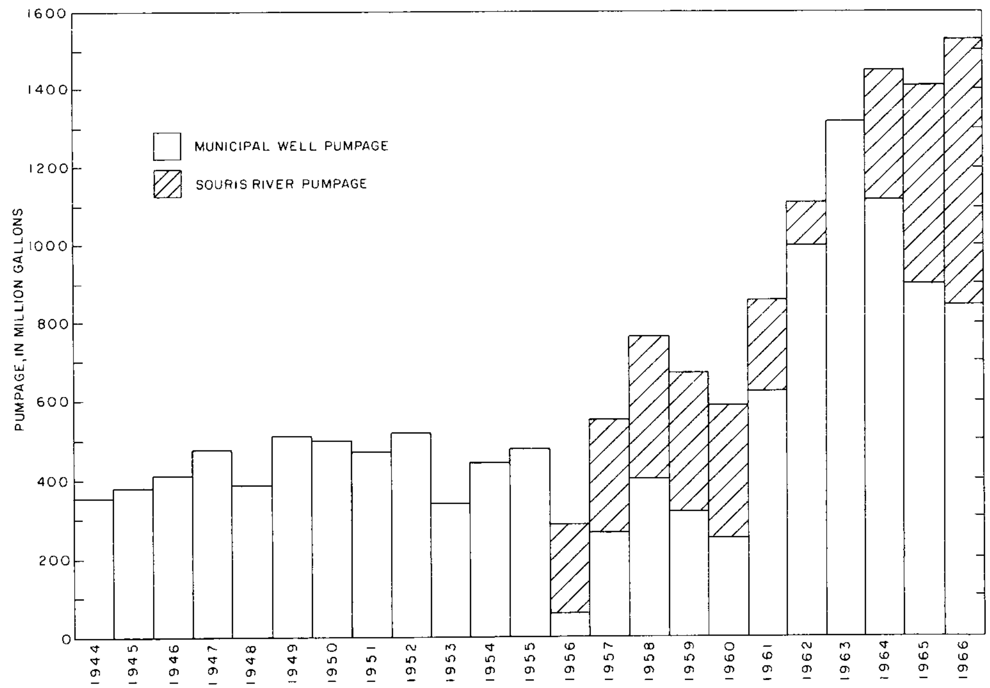


FIGURE 26. Pumpage by Minot, 1944-66.

TABLE 6.–Transmissibility of the Minot aquifer
(From Pettyjohn, 1967a, p. 41)

Well number or name	From Akin (1947)	Transmissibility (gpd per ft)				Remarks
		This study	Estimated[1/]			
			1964	1946-1961		
City test well 10 (1915)	259,000					
City well 1	259,000					
2	259,000					
3	264,000			12,000	1946	
4	163,000			42,000	1958	
5	216,000		312,000	354,000	1946	
				300,000	1946	Test hole T-1 adjacent to well 5.
6			350,000	270,000	1947	
7				142,000	1948	
8			312,000	94,000	1948	
9			28,000	124,000	1960	Corroded screen in 1964?
10		74,300	50,000	76,000	1960	Several boundary conditions noted. Corroded screen in 1964?
11		107,200	114,000	80,000	1961	Leaky artesian conditions. Several boundary conditions.

TABLE 6.–Transmissibility of the Minot aquifer, Continued

Well number or name	From Akin (1947)	Transmissibility (gpd per ft)				Remarks
		This study	1964	Estimated[1/] 1946-1961		
City well 12		151,000	240,000	178,000	1961	Multiple boundaries, water-table or leaky artesian conditions.
13		81,000?	114,000	50,000	1961	Multiple boundaries, water-table or leaky artesian conditions.
14		364,000	800,000	166,000	1961	Do.
15		294,000	400,000	400,000	1961	
16		350,000?	300,000	200,000	1961	Plot indicates two recharge boundaries.
17		254,000		228,000	1961	Probably water-table conditions.
18		150,000?		200,000	1961	Several boundary conditions. Artesian to water-table conditions in 1961.
Bison Electric Plant		227,000				Aquifer test in 1965.
Minot State College		5,000				
Minot Mill well	225,000					Aquifer test in 1946.

1/ Estimated by multiplying specific capacity by 2,000.

are less accurate due to short pumping periods (24 hours), lack of accurate drawdown measurements, and inadequate well development (Pettyjohn, 1967a, p. 41).

The storage coefficients for the Minot aquifer at selected well sites are shown in table 7. Data are not available for determining the storage coefficient in the western or water-table part of the aquifer. Limited information suggests, however, that the storage coefficient is about 0.10 in this area.

Specific capacities of selected wells in the vicinity of Minot are shown in table 8.

The variable characteristics of the Minot aquifer and the uneven pumpage distribution produce significant interference effects, particularly in the area of artesian conditions. Judging from drillers' logs, lengths of screens, and reported well depths, it appears that municipal wells only partially penetrate the aquifer. Consequently, the wells have more drawdown and interference than if they were fully penetrating.

Predicted drawdowns caused by pumping wells 5, 7, 8, and 15 at a rate of 700 gpm for selected periods are shown in figures 27 and 28. Wells 5, 7, and 8 are in the artesian part of the Minot aquifer; well 15 is in the water-table part of the aquifer. The plots were calculated from data obtained from aquifer tests in Minot in 1946 (Akin, 1947) and from production-test data for well 15 in 1961. The drawdown formulas are based on the assumption that the aquifer is infinite in areal extent, isotropic, homogeneous, and uniform in thickness.

In summary, large withdrawals from closely spaced wells in the artesian part of the Minot aquifer should be avoided. Either the discharge rates of these wells should be reduced and more wells used, or there should be greater withdrawals from the water-table part of the aquifer.

Calculations based on areal extent, thickness, and specific yield of certain rock types within an aquifer provide a rough estimate of available water in storage (Pettyjohn and Randich, 1966). The amount of available water in storage in the Minot aquifer from depths of 65 to 150 feet is about 56,000 acre-feet.

The amount of ground water available from the Minot aquifer is an estimate because the precise areal extent of the Minot aquifer is unknown. In addition, the amount of water that can be induced from the Northwest Buried-Channel aquifer, the Lower Souris aquifer, the Fort Union Group, and from the fine-grained parts of the aquifer was not considered. Additional water could also be induced from the Souris River.

The chemical quality of ground water differs considerably from place to place in the Minot aquifer (Pettyjohn and Hills, 1965, p. 88).

TABLE 7.–Storage coefficient for the Minot aquifer at

selected well sites

(From Pettyjohn, 1967a, p. 42)

Test site	Test method	Storage coefficient	Source
City test well 10	Drawdown	0.0007	Akin (1947)
	Recovery	.001	
City well 1	Drawdown	.00007	Do.
	Recovery	.0002	
City well 2	Drawdown	.00004	Do.
	Recovery	.0003	
City test well 4	Drawdown	.0004	Do.
U. S. Geological Survey test hole T-1	Drawdown	.00005	Do.
	Recovery	.0002	
Minot Mill well	Recovery	.0004	Do.
City well 15	Drawdown	.07	Data from routine 24-hour production test in 1961.

TABLE 8.–Specific capacities of selected wells in the vicinity of Minot
(From Pettyjohn, 1967a, p. 42)

Well number or name	Specific capacity (gpm per foot drawdown)		
	Estimated 1964[1]	Production tests[2]	Akin (1947)
Minot city well 4		13	21
Minot city well 5	156	177	150
Minot city well 6	175	135	
Minot city well 7		71	
Minot city well 8	156	47	
Minot city well 9	14	62	
Minot city well 10	25	38	
Minot city well 11	57	40	
Minot city well 12	120	89	
Minot city well 13	57	25	
Minot city well 14	400	533	
Minot city well 15	200	200	
Minot city well 16	150	100	
Minot city well 17		114	
Minot State College well	3.3		

1/ Data for Minot city wells estimated from airline gage under static conditions and after 13 hours pumping. Data for Minot State College from M. Williams.

2/ Calculations from routine 24-hour production pumping tests. Data from Minot City Engineer.

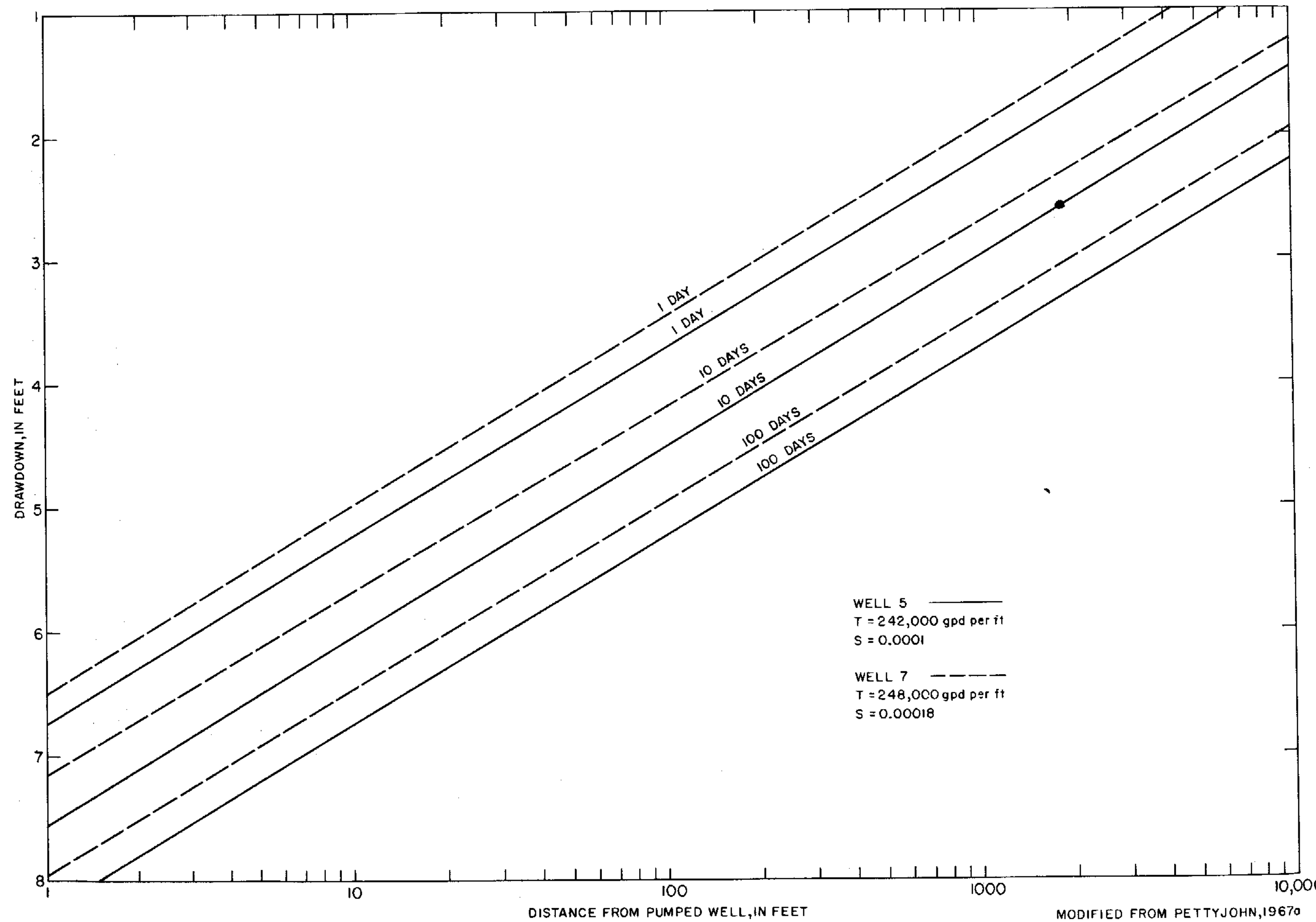


FIGURE 27. Predicted drawdowns in the vicinity of Minot wells 5 and 7, each discharging 700 gpm for selected periods.

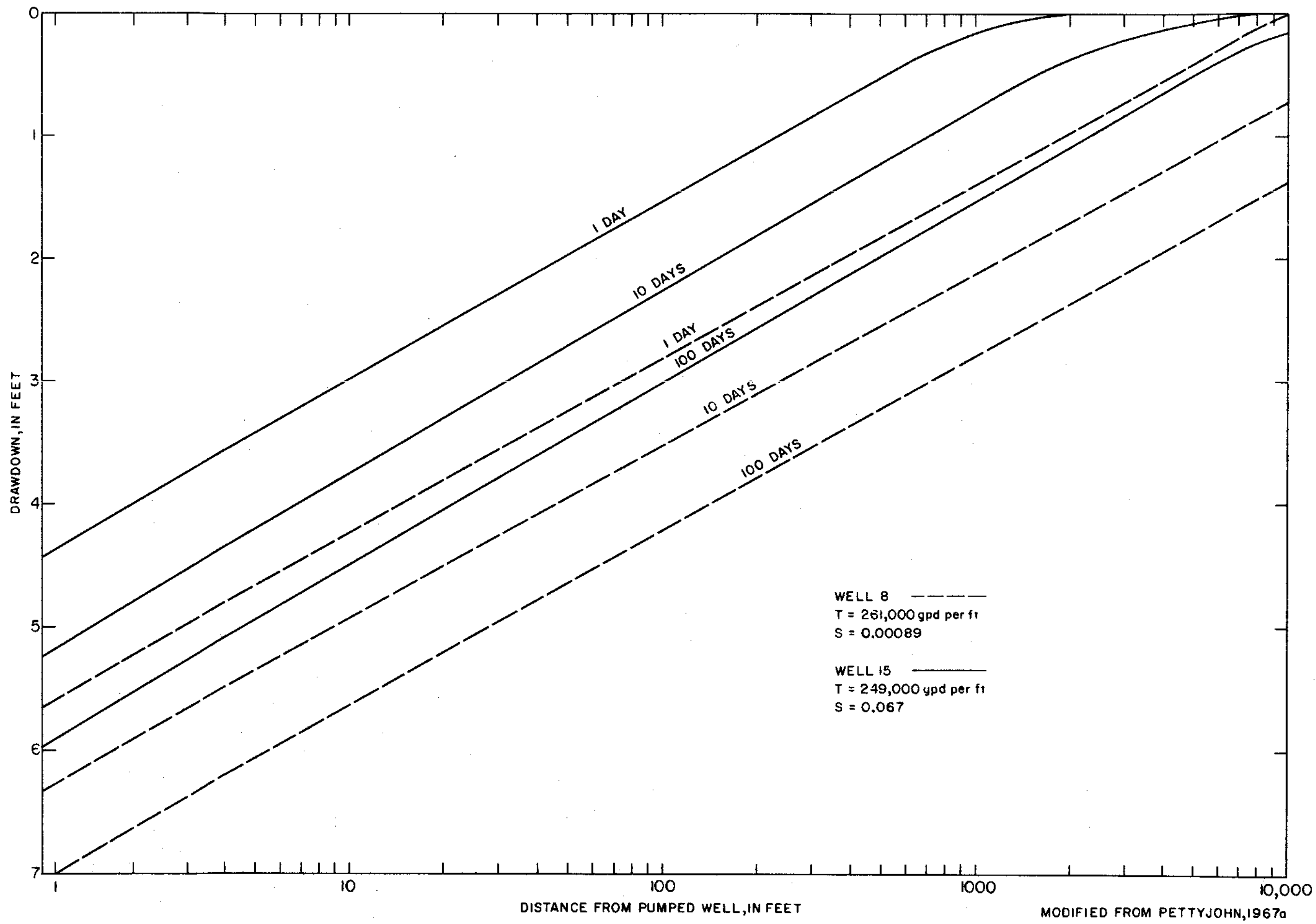


FIGURE 28. Predicted drawdowns in the vicinity of Minot wells 8 and 15, each discharging 700 gpm for selected periods.

The geochemistry is very complex because the aquifer consists of several interconnected beds that vary in composition and grain size. In addition, the interpretation of the water quality is made more complex by the mixing of waters of different chemical characteristics, base exchange, ion absorption, and changes in chemical equilibrium because of changes in hydrostatic pressure.

Generally, water from the Minot aquifer is a hard sodium bicarbonate type, but calcium or magnesium may be the dominant cation in some areas. Among the municipal wells, the hardness ranged from 44 to 590 ppm. The sulfate ranged from 26 to 225 ppm. The iron content in water from the Minot aquifer commonly was high, ranging from 0.13 to 3.6 ppm. The chloride content in city wells 5, 6, 9, 10, and the Minot State College well was relatively high; the concentrations ranged from 137 to 338 ppm. The concentration of dissolved solids in ground water in the Minot area ranged from 529 to 1,570 ppm (Pettyjohn and Hills, 1965, table 4).

The Minot aquifer can be subdivided into at least four parts that yield water of different chemical composition (fig. 29).

In area A, water has higher proportions of sodium plus potassium and bicarbonate than other municipal wells. In addition, the water is brown because of leaching of lignite in the aquifer and in the Fort Union Group.

In area B, the water also has a higher sodium plus potassium, bicarbonate, and chloride concentration than most of the other municipal wells. The wells are probably recharged predominantly from the south and southwest and from the underlying Fort Union. Lignite fragments in this part of the aquifer give a slight brownish color to the water.

Area C is in the western part of Minot where the aquifer is predominantly sand. The generally low dissolved-solids content of the water and other chemical characteristics of ground water from this area, when compared with surface-water analyses, suggest that recharge is from direct infiltration of precipitation and from the Souris River.

Water from area D contains more dissolved solids, chloride, magnesium, and sulfate but less sodium plus potassium and bicarbonate than the other areas. The chloride concentration is considerably greater than in water from the other municipal wells. Water of high chloride concentration moves southeastward from the Northwest Buried-Channel aquifer and recharges the Minot aquifer in the vicinity of wells 5, 6, 9, and 10. The low sodium plus potassium content of the water in area D indicates little or no recharge from the Fort Union Group.

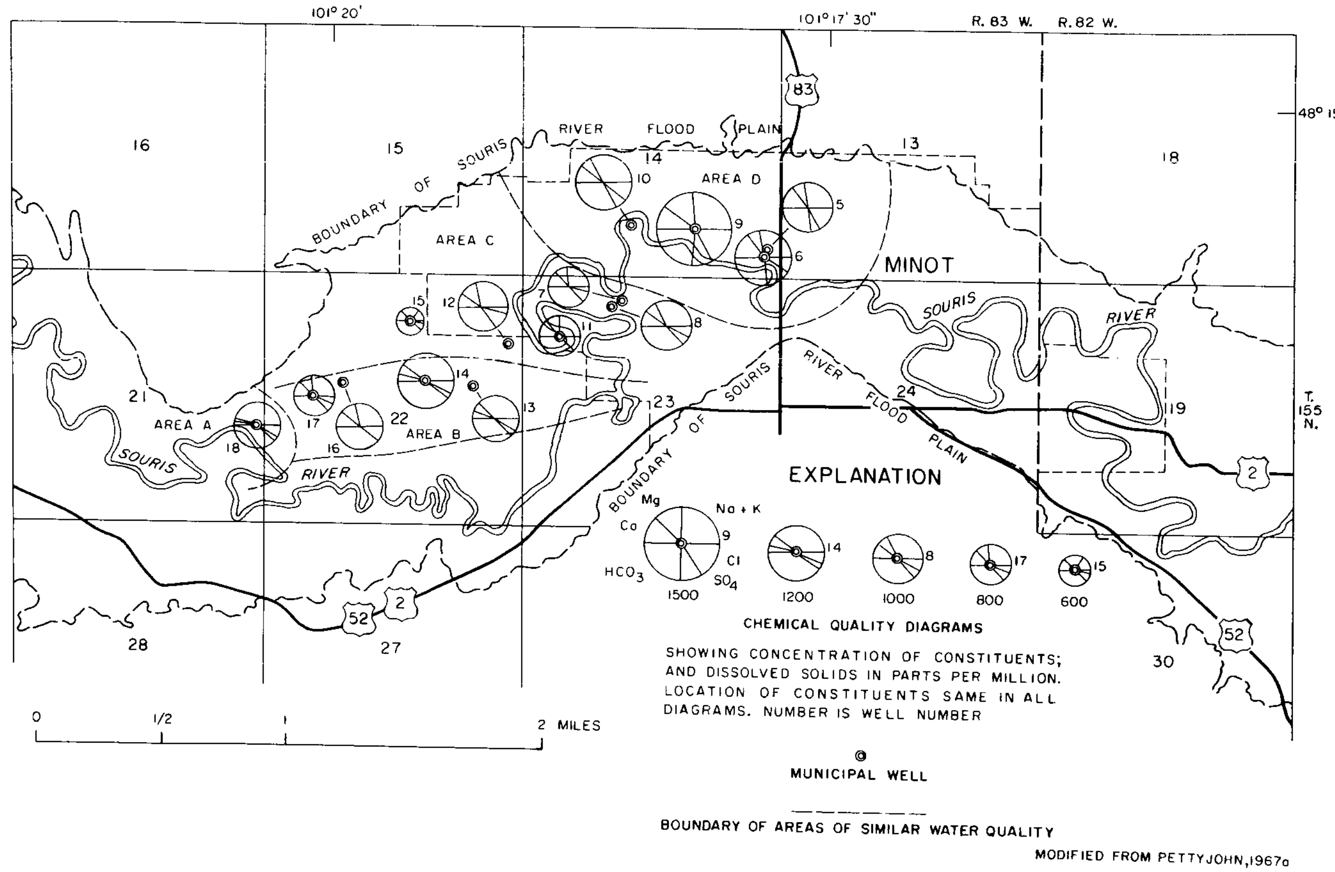


FIGURE 29. Chemical quality of water from the Minot aquifer.

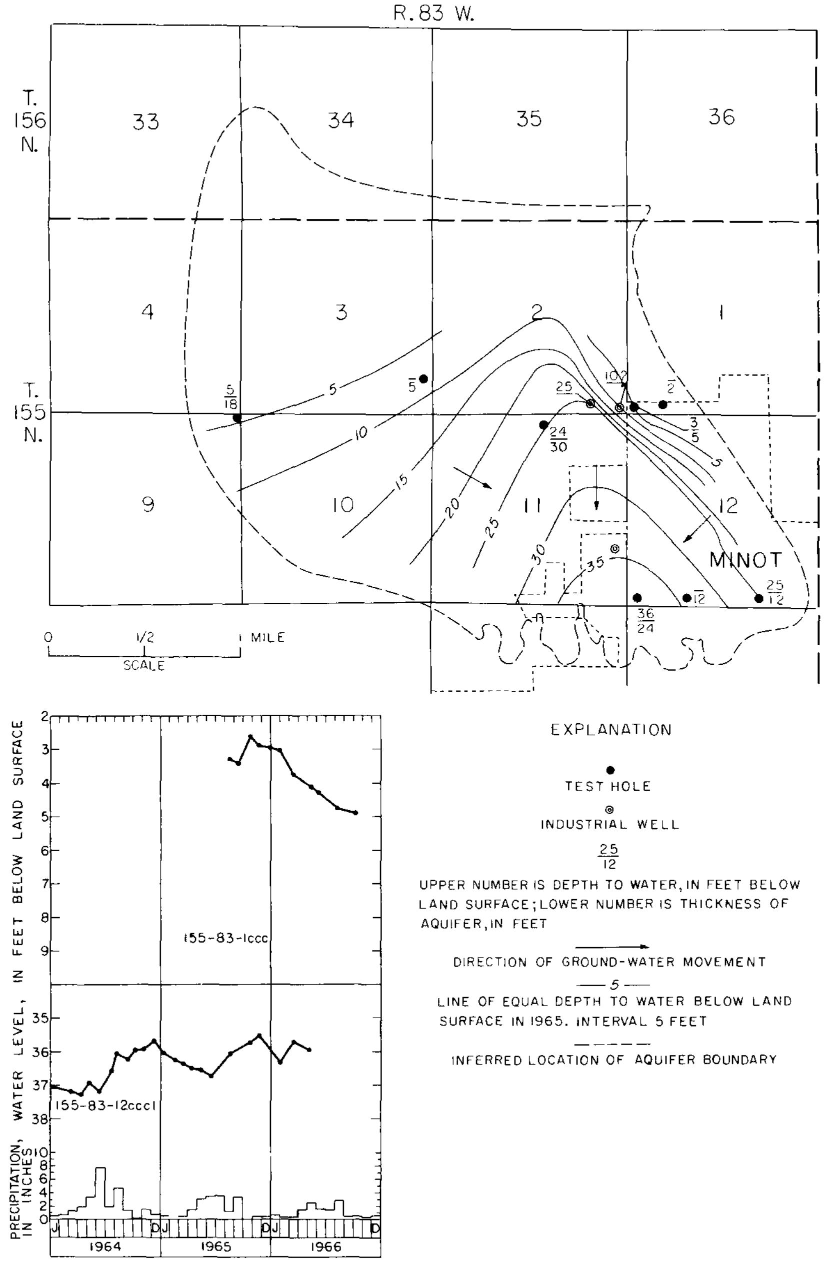


FIGURE 30. Location of the North Hill aquifer, and selected hydrologic data.

North Hill aquifer

The North Hill aquifer was described by Pettyjohn (1967a) as a shallow outwash deposit buried within glacial till in the uplands at the north end of Minot (pl. 1). The aquifer is artesian and underlies more than 5 square miles. It ranges in thickness from 2 to 30 feet (fig. 30), and the top of the aquifer ranges in depth from 26 to 66 feet below land surface. The aquifer consists of coarse sand and fine to medium gravel.

The potentiometric surface in the North Hill aquifer slopes toward the south and water from the aquifer is discharged in a zone of springs and seeps along the north wall of the Souris River valley. The water level ranges from 2 to 37 feet below land surface, as shown in the water-level map and in the hydrographs of test holes 155-83-1ccc and 155-83-12ccc1 (fig. 30).

The North Hill aquifer provides small quantities of water to six domestic and industrial wells. The deepest well (155-83-2ddc2) is reported to be 60 feet deep, and the shallowest well (155-83-2dad) is reported to be 32 feet deep (Pettyjohn and Hills, 1965, p. 12-13). The average depth of the wells is 47 feet.

Water from well 155-83-1ccc in the North Hill aquifer was a calcium sulfate type. It was high in dissolved solids (3,430 ppm), hardness (1,840 ppm), and sulfate (2,300 ppm).

Additional information is needed to determine the areal extent, thickness, and hydraulic characteristics of the North Hill aquifer. The high sulfate concentration in the water, the abrupt changes in thickness, and the small amount of natural recharge suggest that this aquifer does not have a large potential for future development.

Northwest Buried-Channel aquifer

The Northwest Buried-Channel aquifer consists of buried outwash sand and gravel that extends northwestward from the central part of Minot (pl. 1). The outline of the aquifer is not well known and may extend southward toward the South Hill aquifer. The channel may exceed 1½ miles in width, but is partly filled with clay and till. The aquifer, which is artesian, is probably less than a mile in width. There is no indication of this aquifer at the land surface.

Six test holes were drilled in the Northwest Buried-Channel aquifer north of Minot. One hundred and five feet of saturated sand and gravel was penetrated in test hole 155-83-12ccc from 220 to 325 feet (Pettyjohn and Hills, 1965, p. 29). Test hole 155-83-9aaa2 penetrated 27 feet of gravel from 235 to 262 feet. Test hole 155-83-4aaa penetrated 37 feet of sand, gravel, and boulders at the base of the glacial drift at depths of 393 to 430 feet. Only 10 feet of gravel was encountered in the lower part of the glacial drift in test hole 156-83-29ddd. Test holes 155-83-14dba and 155-83-14dbb (Pettyjohn and Hills, 1965, p. 34-35), on the campus of Minot State College, penetrated the Northwest Buried-Channel aquifer near its connection with the Minot aquifer.

The lithologic logs of the well and test holes on the college campus show considerable changes in lithology and thickness within short distances in the Northwest Buried-Channel aquifer. None of these wells were more than 400 feet apart.

Water levels range from 220 feet below land surface in the northern part of the aquifer to about 75 feet near the junction of the Northwest Buried-Channel aquifer and the Minot aquifer. The water level near the junction is influenced by pumping from the Minot aquifer.

Ground water moves southeastward through the aquifer, towards the adjacent Minot aquifer. The gradient between test holes 155-83-4aaa and 155-83-12ccc is approximately 7.3 feet per mile. The gradient between test holes 155-83-12ccc and 155-83-14dba (Pettyjohn and Hills, 1965, p. 14) is about 23 feet per mile.

Assuming the aquifer has an average width of 3,000 feet and an average thickness of 44 feet, approximately 5,300 acre-feet of water is in storage per linear mile of the channel. Approximately 4,000 acre-feet of this amount would be available to wells.

Water in the Northwest Buried-Channel aquifer generally is a hard sodium bicarbonate type; however, chloride and sulfate ions may total as much as 52 percent of the anions. The water was relatively high in chloride (as much as 381 ppm) and iron (as much as 0.84 ppm); according to Glen Berg, Superintendent of the Minot Water-Treatment Plant, this water is less expensive and easier to treat than water from other parts of Minot. The water generally has a high salinity hazard and a medium to high sodium hazard (C3-S2) for irrigation.

Additional information is required to determine the areal extent, thickness, and hydraulic characteristics of the Northwest Buried-Channel aquifer. The quality of the water is marginal for many purposes. Some wells in the aquifer produce more than 500 gpm and others as little as 15 gpm, indicating abrupt changes in thickness and permeability.

South Hill aquifer

The South Hill aquifer consists mostly of sand and gravel and trends nearly south near the south end of Minot (pl. 1). The aquifer lies in a buried valley that is about 1 mile wide and about 2 miles long. This artesian aquifer is 451 feet deep in test hole 155-83-35aaa1 (Pettyjohn and Hills, 1965, p. 75). The buried valley may represent a former preglacial channel that was blocked by drift during advances of glacial ice. The aquifer may be a continuation of the northwest buried channel and trend southeastward to the Sundre Buried-Channel aquifer.

Data from Pettyjohn and Hills (1965, p. 71-72, 75) show that the aquifer varies widely in thickness. In the lower part of test hole 155-83-25ddd, 67 feet of sand and gravel was penetrated (154-189 and 356-388 feet), whereas test hole 155-83-35aaa1 penetrated only 9 feet of sand and gravel (103-109 and 148-151 feet).

Eleven industrial and domestic wells produce small quantities of water from the South Hill aquifer. The deepest well is reported to be 338 feet (155-82-31baa) and the shallowest well has a reported depth of 170 feet (155-82-31dca) according to Pettyjohn and Hills (1965, p. 12). The average depth of wells is 259 feet and reported water-level depths are generally less than 230 feet below land surface (Pettyjohn, 1967a, p. 16).

Water from the South Hill aquifer is a sodium bicarbonate type and was high in dissolved solids (1,120 to 2,005 ppm), hardness (615 to 775 ppm), iron (0.8 to 5.2 ppm), and sulfate (285 to 620 ppm) (Pettyjohn, 1967a, p. 16). The water is in the C3-S1 and C3-S2 classifications for irrigation use.

Although additional information is required to determine the areal extent, thickness, and hydraulic characteristics of the South Hill aquifer, the poor quality of the water, the lateral variation in sand and gravel thickness, and deep water level may exclude the South Hill aquifer from extensive future development.

Sundre Buried-Channel aquifer

The Sundre Buried-Channel aquifer underlies the northeastern part of T. 154 N., R. 82 W., and is exposed in the Souris River valley between Minot and Logan. It consists of fine to coarse sand and fine to medium gravel with an abundance of lignite chips. Test hole 154-82-4aad penetrated 195 feet of saturated sand and gravel (Pettyjohn and Hills, 1965, p. 23) in a terrace along the north edge of the Souris River valley about 3½ miles southeast of Minot. The sand and gravel apparently was deposited in an ancient river valley, probably the same valley that contains the South Hill aquifer. The valley is buried by glacial drift in most places and is 233 feet deep at the test-hole site.

The Souris River flows across the Sundre Buried-Channel aquifer in the vicinity of test hole 154-82-4aad and probably provides recharge to the aquifer during high river stages. Conversely, the aquifer probably discharges into the river during low stages. Water-level fluctuations in observation well 154-82-4aad are shown in figure 19.

Apparently no wells are producing water from this aquifer, but it appears to have considerable potential. More information is needed concerning the extent, thickness, permeability, and quality of water in the aquifer before its full potential can be determined.

Water in the Sundre Buried-Channel aquifer is a sodium bicarbonate type (Pettyjohn and Hills, 1965, p. 88). The concentrations of individual chemical components, except iron, are within the limits recommended for drinking water by the U.S. Public Health Service (1962), although the water did contain as much as 800 ppm dissolved solids. Because the water has a high salinity hazard and a low sodium hazard (C3-S1), it can be used satisfactorily for irrigation on most soils.

Unnamed aquifers

Test hole 153-83-13bbb, about 9 miles south of Minot, penetrated a total of 17 feet of sand and gravel from 88 to 96 feet and 100 to 109 feet (pl. 1). The lower 9 feet contained a large percentage of lignite chips. The water level in the aquifer is nearly 60 feet below land surface. The water is a sodium bicarbonate sulfate type and had a dissolved solids content of 1,940 ppm. The high sodium content may be due to recharge from the Fort Union Group. Possibly the upper layer of sand and gravel has a more desirable quality water.

A total of 80 feet of saturated sand was penetrated in well 160-89-9aca. The water level was 8 to 10 feet below land surface. The quality of the water prohibited its use for irrigation in this area of heavy poorly drained soil. The specific conductance was 2,058 micromhos.

Central Recharge Area

The central recharge area includes the northern part of Ward County and most of Renville County (fig. 3). Local relief in the area is less than 25 feet, except along the valley of the Souris River and its few tributaries upstream from Burlington where the relief is greater. Generally the land surface slopes gently to the northeast.

With the exception of the Souris River valley, the entire region is a recharge area, as shown by the higher water level in shallow wells as compared to deeper wells. The Souris River valley is a long and narrow discharge area for the regional ground-water system.

A distinct part of the central recharge area is the Mohall gas-lift subarea that includes much of eastern Renville County east of the Souris River. Several flowing wells that contain an appreciable quantity of dissolved gas in the water are scattered throughout this gas-lift area. Most of the flowing wells are in bedrock, but a few tap sand and gravel deposits near the base of the glacial drift. Although the Fort Union Group is the most likely sequence of strata from which the gas originates, there is a possibility that the Hell Creek Formation, if present, or the Fox Hills Formation may also contribute gas.

The gas, mainly methane, is believed to accumulate in fractures and in places of increased porosity in lignite beds. Gas in an aquifer affects the height to which water will rise in a well and may provide the "lift" necessary to bring the water to the surface. When a well is drilled into a gaseous aquifer, the gas expands. As the gas expands, the specific gravity of the gas-water mixture decreases, and a lifting action is created. Because of this effect, probably several wells in the Mohall gas-lift subarea flow that otherwise would not.

The Souris River valley and several other ice-marginal channels in the central recharge area contain surficial sand and gravel aquifers (pl. 1). Several buried aquifers in the area appear to have a large ground-water development potential. In many cases, however, only one or two test holes penetrated these aquifers, and consequently little is known of their thickness, areal extent, or hydraulic properties.

The quality of the ground water in the central recharge area varies within wide limits. Water in surficial sand and gravel deposits, such as ice-marginal channels, generally is a calcium bicarbonate type in which the dissolved solids are less than 1,000 ppm. The water in buried aquifers, however, is considerably more mineralized and varies with increasing depth from a calcium sulfate to a sodium sulfate type. The most abundant chemical constituent is sulfate, which is commonly several thousand parts per million in water from shallow wells, but the concentration decreases with well depth. The depth to the top of buried aquifers and the generally expected concentration of sulfate are shown in the following table:

Depth to top of aquifer, in feet below land surface	Sulfate concentration, in parts per million
5-35	5,000+
35-70	1,500 to 5,000
70-200	1,000 to 1,500
200-400	500 to 1,000
More than 400	Less than 500

The higher concentration of sulfate in shallow wells presumably is due to soil leaching. Poor drainage does not permit the removal of sulfate and the soluble salts tend to accumulate. Even though glacial till has a very low permeability, there is enough infiltration of water to carry the sulfate to underlying sand and gravel aquifers.

Aquifers in the Souris River Valley Upstream from Burlington

Cross sections of the Souris River valley between Burlington and the international boundary show that the valley fill generally ranges from 70 to 125 feet in thickness (cross sections B-B', C-C', D-D', and E-E'). The valley fill consists mainly of till, but there are a few small deposits of sand and gravel.

Only a few domestic and stock wells tap the aquifer in the Souris River valley upstream from Burlington. Many of the wells are less than 20 feet deep and tap shallow deposits of sand and gravel. Several wells near the valley walls yield water from the Fort Union Group. Generally there are at least two wells at each homestead; a shallow well produces hard water for culinary purposes and a deeper Fort Union well produces soft water for other domestic uses. Both soft and hard water are used for stock.

Ground water from the Souris River valley aquifers is believed to be discharging into the stream. The quantity of water discharging from the aquifers is probably quite small, however, and from spring to fall most of it is lost to evapotranspiration.

Aquifers in Ice-Marginal Channel Deposits

Several ice-marginal channels in eastern Renville and northeastern Ward Counties contain sufficient thickness of saturated sand and gravel to be productive aquifers (pl. 1). The channels lie east of and roughly parallel to the Souris River, and some are more than 40 miles in length. In places, the larger channels spread out to widths of 1-3 miles, but are more commonly a quarter of a mile to half a mile in width.

The long, well-defined streams, such as Cut Bank and West Cut Bank Creeks, Spring Coulee, Egg Creek, and Little Deep Creek, have nearly uniform gradients over their total lengths. The average gradient of Little Deep Creek is nearly 5 feet per mile; the combined West Cut Bank-Spring Coulee channel, which is 49 miles long, has an average gradient of about 3.3 feet per mile.

Material in the ice-marginal channel deposits ranges in size from clay to boulders, but sand and fine to medium gravel predominate. The numerous gravel pits in these deposits provide good exposure of the aquifer materials. The sand and gravel generally ranges in thickness from 0 to 20 feet. Deposits in the larger channels are generally thicker and coarser near their mouths.

The present streams have cut narrow steep-walled channels into these deposits. Stream channels that have gently rounded cross sections commonly contain little sand and gravel, whereas channels that have relatively flat floors and gently sloping walls are generally underlain by sand and gravel.

Several stock, domestic, and municipal wells obtain water from the ice-marginal channel deposits. Apparently water from these deposits is preferred over other sources because of easy construction and shallowness of the wells and the superior quality of the water.

The city of Sherwood owns a well 1 mile north and 1½ miles east of the city (164-84-32cdd). The well is 24 feet deep and 22 inches in diameter, and produces water from ice-marginal channel deposits in the valley of Cut Bank Creek. The surficial sand and gravel in the vicinity of the well is 18 feet thick and approximately 8 feet is saturated. The well was reported to produce 80 gpm with only 2 feet of drawdown.

An aquifer test was conducted in December 1956 by pumping the Sherwood well for a period of 1,170 minutes at an average rate of 23.5 gpm. The drawdown and recovery was measured in an observation well 20.9 feet from the pumped well. A plot of the water-level recovery versus t/t' is shown in figure 31. Analysis of the aquifer test indicates that the transmissibility of the sand and gravel in the vicinity of the observation well is approximately 44,000 gpd per foot and the permeability is about 5,400 gpd per square foot.

Assuming an average water-level gradient of 2 feet per mile, an average saturated width of 4,200 feet, and an average transmissibility of 44,000 gpd per square foot, the underflow through a section across Cut Bank Creek would be about 68,000 gpd. Assuming a specific yield of 0.25 and disregarding natural recharge, the amount of water available for use from a 1-mile length of channel would be about 44 million gallons.

The village of Loraine obtains its water supply from a large-diameter dug well in an ice-marginal channel deposit that crosses the northeast corner of the village. The well is 20 feet deep and the water level is generally about 8 feet below land surface.

Test hole 162-84-8ddc, drilled in the center of West Cut Bank Creek about a mile west of Loraine, did not encounter surficial sand and gravel, although such deposits are present on the channel flanks. Domestic wells constructed in the West Cut Bank Creek valley reportedly provided water even during the drought of the 1930's when wells in adjacent areas went dry.

Glenburn obtains its water supply from a large-diameter well 32 feet deep dug in a narrow ice-marginal channel at the northern edge of the city. The water level in the well averages about 8 feet below land surface. Although the aquifer is only about a quarter of a mile wide in places, it contains as much as 20 feet of saturated sand and gravel. Well and test-hole data indicate that part of the aquifer is buried by as much as 30 feet of poorly permeable material.

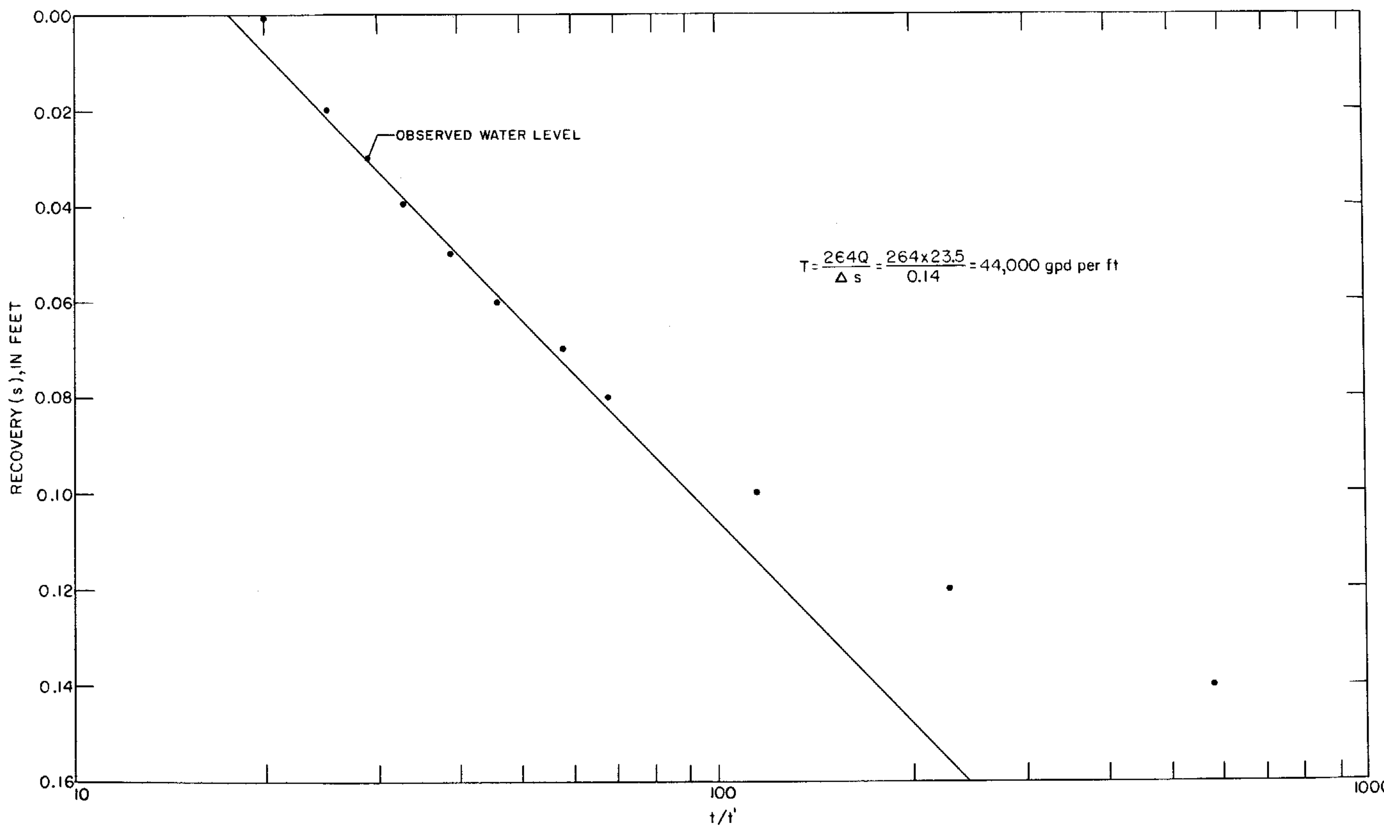


FIGURE 31. Recovery data obtained during aquifer test on the city of Sherwood well (164-84-32cdd).

Test hole 158-81-36bbb penetrated 13 feet of fine to medium gravel in a narrow channel south of Spring Coulee. About 6 feet of the deposit is saturated with water.

The thickest and most extensive ice-marginal channel deposits in Renville and Ward Counties are probably in Little Deep Creek. Sand and gravel in these deposits probably exceeds 20 feet in thickness, as shown by the several large gravel pits in the central part of the channel. Small lakes are common in several of the gravel pits during spring and early summer, indicating the shallow depth of the water table.

Near the middle of Livingston Creek channel, test holes 156-83-25bbc1 and bbc2 penetrated 10 and 13 feet, respectively, of surficial gravel. The water level is about 4 feet below land surface. Southeast in the same channel (155-82-8c), several large abandoned gravel pits contain an abundance of coarse gravel and boulders. Operation of these gravel pits was stopped because the water table was reached.

There are several stock and domestic wells in the diverging branches of the ice-marginal channel deposits north and northeast of Surrey (pl. 1). Only a few of these deposits, however, contain a sufficient thickness of saturated sand and gravel to be considered an aquifer.

Froelich (1964, p. 23) reported that a preliminary aquifer test was conducted in these deposits using stock well 155-81-7ddd3. The well is 18 inches in diameter and 21 feet deep. The lower 5 feet of the well casing consists of perforated steel culvert. The well was pumped continuously for 8 hours at a rate of 60 gpm. After 5 hours of pumping, there was 0.09 foot of drawdown in an observation well located 142 feet from the pumped well. The transmissibility computed from the above data is approximately 18,000 gpd per foot.

The water level in the channel deposits in the Surrey area ranges from 1 to at least 15 feet below land surface. The wells range in depth from 8 to 36 feet.

Recharge to the ice-marginal channel deposits is entirely dependent upon infiltration of precipitation and seepage from lakes, reservoirs, and streams. Although the channels are narrow, their length and permeability permit the infiltration of large amounts of water.

Discharge from aquifers in the ice-marginal channels takes place by underflow, evapotranspiration, seepage to deeper aquifers, and pumping from wells. Pumpage, in most places, is insignificant when compared to the large quantity of water in storage. Pumping from these aquifers would lower the water level and salvage part of the water lost to evapotranspiration and underflow.

The quality of the water in the ice-marginal deposits varies within wide limits. The water generally is a hard calcium bicarbonate type. The specific conductance of samples tested ranged between 200 and 900 micromhos. In most cases the concentration of iron was sufficient to cause staining. The sulfate concentration in many places exceeded 250 ppm. In addition, the nitrate content, in places, was greater than 45 ppm. Most of the water has a high to very high salinity hazard but a low sodium hazard. It is classified as C3-S1 and C4-S1 for irrigation use.

Unnamed Aquifers

A total of 117 feet of saturated sand, gravel, and boulders was penetrated in several layers down to a depth of 420 feet in test hole 161-88-11bbb (pl. 1). An observation well was installed in medium to very coarse sand and fine to medium gravel from 105 to 156 feet. The water level is about 26 feet below land surface. The water was a sodium sulfate type containing high concentrations of sulfate (1,440 ppm) and dissolved solids (2,530 ppm). It has a high sodium hazard and a very high salinity hazard for irrigation. Possibly deeper layers of sand and gravel in this test hole would yield water of a more desirable quality. The extent of this aquifer is unknown.

An observation well was installed in 19 feet of sand and gravel from 171 to 190 feet in test hole 160-87-17ddd. The water level is about 33 feet below land surface. This aquifer contains a sodium calcium sulfate type water. The sulfate (1,270 ppm) and dissolved solids (2,210 ppm) exceeded U.S. Public Health Service (1962) standards for drinking water. The water has a medium sodium hazard and a high salinity hazard (C3-S2), but possibly could be used for irrigation on well-drained soil with low cation exchange capacity. The areal extent of this aquifer is unknown.

Test hole 162-87-2ddd penetrated 28 feet of sand and gravel and encountered bedrock at 111 feet. Other test holes in the same township penetrated sand and gravel at about the same depth, but the correlation is uncertain.

An aquifer of unknown areal extent was found in test hole 162-87-22aaa. The test hole penetrated 49 feet of sand and gravel from 300 to 349 feet below land surface. The upper 27 feet consisted of gravelly medium to very coarse sand, while the lower 22 feet consisted of fine to coarse gravel containing boulders. The water level was about 36 feet below land surface. The water was a sodium sulfate type that exceeded U.S. Public Health Service recommended limits with respect to sulfate (527 ppm) and dissolved solids (1,320 ppm). It was classified C3-S2 for irrigation use. Other test holes drilled in the township did not penetrate the aquifer.

Ninety feet of gravelly medium to coarse sand was penetrated from 565 to 655 feet in test hole 162-87-27baa2. Two thinner layers of fine sand were encountered from 380 to 390 feet and 505 to 520 feet.

Although a water sample from this aquifer was not obtained, experience in this area suggests that water from so deep an aquifer probably contains a large concentration of chloride. The aquifer appears to lie in a deeply buried ancient river valley and could be a continuation of the Kenmare aquifer.

Seven miles north of Carpio, test hole 158-86-1aaa penetrated 24 feet of sand and gravel with a few thin layers of clay between 39 and 63 feet below land surface. The water level is about 13 feet below land surface. The water is a sodium sulfate type and contained large concentrations of sulfate (4,640 ppm), sodium (1,400 ppm), and dissolved solids (6,640 ppm). The water is too highly mineralized for domestic and stock use or irrigation.

About a mile northwest of Glenburn, observation well 158-82-10aad2 was completed near the bottom of a sand and gravel deposit from 184 to 240 feet below land surface. The water level in the well is about 15 feet below land surface. The water is a sodium magnesium sulfate type. It contained excessive quantities of sulfate (1,240 ppm), dissolved solids (2,460 ppm), and fluoride (1.8 ppm) for use as drinking water. The water is within the C4-S2 (very high salinity and medium sodium hazard) classifications for irrigation use.

Test hole 158-82-34ccd penetrated fine to coarse gravel between 154 and 171 feet. The water level is about 32 feet below land surface. The water is a sodium sulfate bicarbonate type and contained excessive amounts of sodium (652 ppm), sulfate (820 ppm), and total solids (2,120 ppm) for use as drinking water. The water has a high salinity and very high sodium hazard (C3-S4), and is too mineralized to be used for irrigation.

On the north margin of Little Deep Creek, test hole 158-82-26ccc penetrated 32 feet of very fine to coarse sand (11-43 feet below land surface). The water level is about 5 feet below land surface. The water is a sodium magnesium sulfate type and was high in sodium (924 ppm), sulfate (5,100 ppm), and dissolved solids (8,160 ppm). It is too highly mineralized for irrigation or domestic and livestock use without treatment. The same aquifer was penetrated in test hole 158-82-27aaa where the sand is 30 feet thick. In addition, 24 feet of boulders was encountered between 165 and 189 feet; the hole was abandoned because of the difficult drilling conditions.

USE OF GROUND WATER

The rural population of Renville and Ward Counties depends mainly upon ground water for its domestic and stock requirements. In many places, however, the ground-water supply is supplemented by the use of dugouts or collection galleries. Eight communities obtain their water supplies from wells, but only seven of these have water distribution systems. Ten villages have no public water-supply systems. At present, ground water is not used for large-scale irrigation and the heavy, poorly drained soil and the high mineral content of much of the water preclude irrigation throughout most of Renville and Ward Counties.

Domestic and Stock Use

Most farms and ranches use two or more wells, generally one shallow and one deep. The shallow wells generally provide hard calcium water that is desirable for culinary uses and the deeper wells generally provide soft sodium water that is used for laundry purposes as well as for livestock. A few wells are large diameter and hand dug; however, most are small-diameter drilled wells ranging in depth from 50 to 1,000 feet. Generally the wells have only short screens or open-ended casing, and consequently yield only a few gallons per minute.

Public Supply

Eight communities in Renville and Ward Counties have municipal water supplies: Berthold, Glenburn, Kenmare, Loraine, Minot, Mohall, Ryder, and Sherwood. Loraine has no water distribution system and Mohall obtains its water supply from wells in Bottineau County. All of the municipalities have adequate water supplies, but the water is of poor quality at Berthold and Ryder. Residents of other communities are dependent upon privately owned wells or must haul water from the nearest available source.

Berthold

The municipal supply for Berthold is pumped from a well 570 feet deep that taps the Fort Union Group. The well pumps water at an average rate of about 15,000 gpd, which has been adequate for the 398 people (1970 census). The well has a specific capacity of only 0.3 gpm per foot according to Randich (1963). The raw water is pumped directly into the distribution lines.

Glenburn

The city of Glenburn owns two wells. A 300-foot well capable of yielding 30 gpm from the Fort Union Group supplies water for fire protection. A 10- by 20-foot dug well, 32 feet deep, is used for most of the municipal requirements. The well produces from the sand and gravel outwash that partly fills an ice-marginal channel.

A few yards downstream from the dug well, the gravel was removed across the width of the stream channel and a clay dam was installed. The dam provides a control on the underflow. In addition, during high stages of the creek, particularly during the spring runoff period, excess surface water is diverted into an unused gravel pit upstream from the clay dam. The water in the gravel pit moves downward to replenish the ground-water reservoir. The annual quantity of water added by artificial recharge per year is unknown, but since installation of the recharge system, the city has had an adequate water supply. The city requires an average of about 35,000 gpd for the 381 inhabitants.

Kenmare

The water supply for Kenmare is pumped from a well 340 feet deep that taps outwash sand and gravel. The average daily pumpage is about 150,000 gallons, which is considerably less than the Kenmare aquifer will provide. Although accurate records are not available, the water level probably has declined less than 40 feet in the last 60 years, and probably about 10 feet since 1956. There are no water-treatment facilities at Kenmare.

Loraine

The east-central Renville County community of Loraine has a shallow large-diameter well in an ice-marginal channel occupied by a creek at the east edge of the village. The well, which was dug in 1959, is a 12-foot diameter concrete caisson that is 20 feet deep. The pump is powered with a 2-horsepower electric motor. No production or water-level data are available, but the water level will fluctuate with the stage and quantity of underflow in the creek. In addition, the quality of the water probably varies with the seasons. There are no water-treatment facilities at the well site.

Minot

The Minot well field consists of 18 wells, of which only 13 are used. The first municipal well was drilled in 1916 and additional wells were drilled as the need for water increased or wells failed. Originally ground water was used to augment municipal withdrawals from the Souris River, but later, surface water augmented ground-water pumping. During the early part of the summer of 1964, the city pumped 60 percent of its water requirements from the Minot aquifer and 40 percent from the Souris River. Since 1965, river water has also been used for artificial recharge of the aquifer. The combined use of surface water and ground water is carried on whenever river water is available.

Annual pumpage from municipal wells from 1944 to 1966 is shown in figure 26. Exceptionally heavy withdrawals from the Minot aquifer in 1961, 1962, and 1963 were a result of: (1) drought, (2) decrease and temporary termination of pumping directly from the Souris River, (3) increased city population, and (4) needs of the Minot Air Force Base.

The city resumed pumping from the Souris River on May 28, 1964, and has continued with only short interruptions. Pumping from municipal wells is decreased during the periods of river withdrawal. The city requires water at an average rate of about 4½ mgd.

Ryder

Water for municipal purposes is pumped from surficial sand and gravel of the Ryder aquifer about half a mile north of Ryder. The large-diameter well is 18 feet deep and the raw water is pumped directly into the distribution system. Although records are not available, Ryder reportedly pumps about 10,000 gpd for the 211 inhabitants. The water is hard and high in dissolved solids, sulfate, and iron.

Sherwood

The Sherwood water supply is pumped from a well 24 feet deep in an ice-marginal channel deposit of sand and gravel in Cut Bank Creek, nearly 2 miles northeast of the city. Sherwood uses an average of 50,000 gpd. The raw water is pumped directly into the distribution lines without treatment. The chemical quality of the water is good. The dissolved solids generally ranged between 500 and 600 ppm. The quality probably changes, however, from season to season owing to the variable discharge and underflow in the creek.

SUMMARY AND CONCLUSIONS

The Souris and Des Lacs Rivers and thousands of potholes contain substantial quantities of water; however, the chemical quality varies within wide limits. The water in many of the potholes is briny. The dissolved solids in the streams ranged from about 400 ppm during the spring to as much as 1,300 ppm during the winter.

Locally large sources of ground water are available for use in Renville and Ward Counties.

Two types of aquifers occur in the area--those in the semiconsolidated and consolidated bedrock formations and those in the unconsolidated glacial deposits. The Fort Union Group contains the most productive bedrock aquifers in Renville and Ward Counties.

Generally water from the Fort Union is a sodium bicarbonate type, a sodium chloride type, or a mixture. The water is unsuitable for irrigation and in many places is undesirable for domestic use.

Deposits of Quaternary age comprise the major aquifers in Renville and Ward Counties. In a few places, these aquifers will yield more than 500 gpm of good quality water. In other places, the aquifers are too thin, are of small areal extent, or the rate of natural recharge is too slow to provide sustained yields of more than a few gallons per minute.

Several extensive deposits of surficial sand and gravel underlie the Coteau du Missouri. The Douglas, Tolgen, and Vang aquifers contain large quantities of water of good chemical quality suitable for irrigation. However, the saturated thickness of these aquifers varies within wide limits and any particular area should be studied in detail before a large-scale ground-water development is undertaken.

Several poorly defined water-bearing zones are buried in the glacial drift. With the exception of those in river valleys, the buried deposits commonly contain water of undesirable chemical quality, with objectionable concentrations of iron, sulfate, and dissolved solids. Most of the buried water-bearing deposits are not of great extent and will supply only small quantities of ground water to wells.

The most productive aquifers are in the valleys of the Souris and Des Lacs Rivers. Well yields of more than 500 gpm should be available from the Kenmare aquifer and locally from aquifers in the Souris River valley between Minot and Logan. Northwest of Minot and between Logan and Sawyer, yields of 50 to 500 gpm can be expected.

Much of the water in the valley aquifers is suitable for domestic, municipal, and industrial uses, but it may be of marginal value for irrigation, particularly in the Des Lacs River valley.

Substantial quantities of ground water are stored in surficial sand and gravel deposits in ice-marginal channels. In most places, the water had a specific conductance that is less than 1,000 micromhos. In a few places, these deposits could provide enough water for small-scale irrigation projects, especially during years of above-normal precipitation.

Additional test drilling is necessary to define the extent of many of the aquifers, and to delimit areas of maximum permeability and saturated thickness within each aquifer. Accurate long-term data, especially water-level measurements, pumpage, and water quality determinations, are essential for proper management of the ground-water resources that are now in use as well as for those which may be developed in the future.

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