North Dakota Geological Survey

WILSON M. LAIRD, *State Geologist*

BULLETIN 45

North Dakota State
Water Conservation Commission

MILO W. HOISVEEN, *State Engineer*

COUNTY GROUND WATER STUDIES 6

GEOLOGY AND GROUND WATER RESOURCES

DIVIDE COUNTY, NORTH DAKOTA

PART III

GROUND WATER RESOURCES

By
C. A. Armstrong
Geological Survey
United States Department of the Interior

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

GRAND FORKS, NORTH DAKOTA
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CONTENTS

Illustrations

Page

Tables

GEOLOGY AND GROUND WATER RESOURCES of Divide County, North Dakota

Part III - Ground Water Resources

by C. A. Armstrong

ABSTRACT

Ground water in Divide County, North Dakota is obtained from aquifers in glacial drift and in the Tongue River Formation of Paleocene age. The most productive aquifers consist of buried sand and gravel deposits in the ancestral Yellowstone River channel that extends northeastward across the county near the central part. Test drilling and other data indicate that individual well yields of more than 500 gallons per minute are obtainable in places from these deposits. Yields of more than 500 gallons per minute also are obtainable from surficial and buried outwash deposits in parts of Tps. 162 and 163 N., R. 103 W. in northwestern Divide County, and in a small area in T. 160 N., R. 97 W. in the southeastern part. Yields of 50 to 500 gallons per minute are obtainable from buried sand and gravel deposits in the ancestral Missouri River channel in the western part of the county, the less permeable deposits in the ancestral Yellowstone channel, and the less permeable parts of the surficial and buried outwash deposits in the southeastern part of the county.

The water from the glacial drift aquifers ranges greatly in quality. Generally it is very hard and of a calcium bicarbonate type. Water in the Tongue River Formation consists of two types: a soft, sodium bicarbonate water, and a hard, sodium sulfate water. Generally it is too saline for human consumption or irrigation.

INTRODUCTION

Divide County, an area of approximately 1,300 square miles, is in the extreme northwestern part of North Dakota (fig. 1). It is bounded on the west by Montana, on the north by Saskatchewan, and on the east and south by Burke and Williams Counties, respectively.

The study of the geological and ground-water resources of Divide County was a cooperative investigation made by the U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and the Divide County Board of Commissioners. The nomenclature used in this report is that of the North Dakota Geological Survey and, in some instances, differs from that of the U.S. Geological Survey. The North Dakota Geological Survey mapped the geology of the county and will publish the results in a report entitled "Geology and Ground Water Resources of Divide County, North Dakota, Part 1, Geology" by D. E. Hansen and T. F. Freers. The basic data were published in a report entitled "Geology and Ground Water Resources of Divide County, North Dakota, Part II, Ground Water Basic Data" by C. A. Armstrong (1965).

Purpose and Scope

The purpose of the investigation was to evaluate the quantity and quality of ground water in Divide County. The principal objective was to locate ground water that could be used to irrigate part of the approximately 400,000 acres of arable land. Other objectives were to locate dependable ground-water supplies that could be used for industrial, public, private, domestic, and stock supplies.

The field work consisted of inventorying wells and springs to obtain information about existing water supplies from water users in the county. Test holes were drilled to supplement the information gathered during the inventory. Water levels were measured periodically in selected wells in order to evaluate recharge to and discharge from the aquifers. Two aquifer tests were made in the Skjermo Lake and West Wildrose aquifers in order to determine the coefficients of storage and transmissibility, and to establish a basis for estimating coefficients of transmissibility in other areas. Water samples were obtained from 95 selected wells to determine the chemical characteristics of water from selected aquifers in the county.

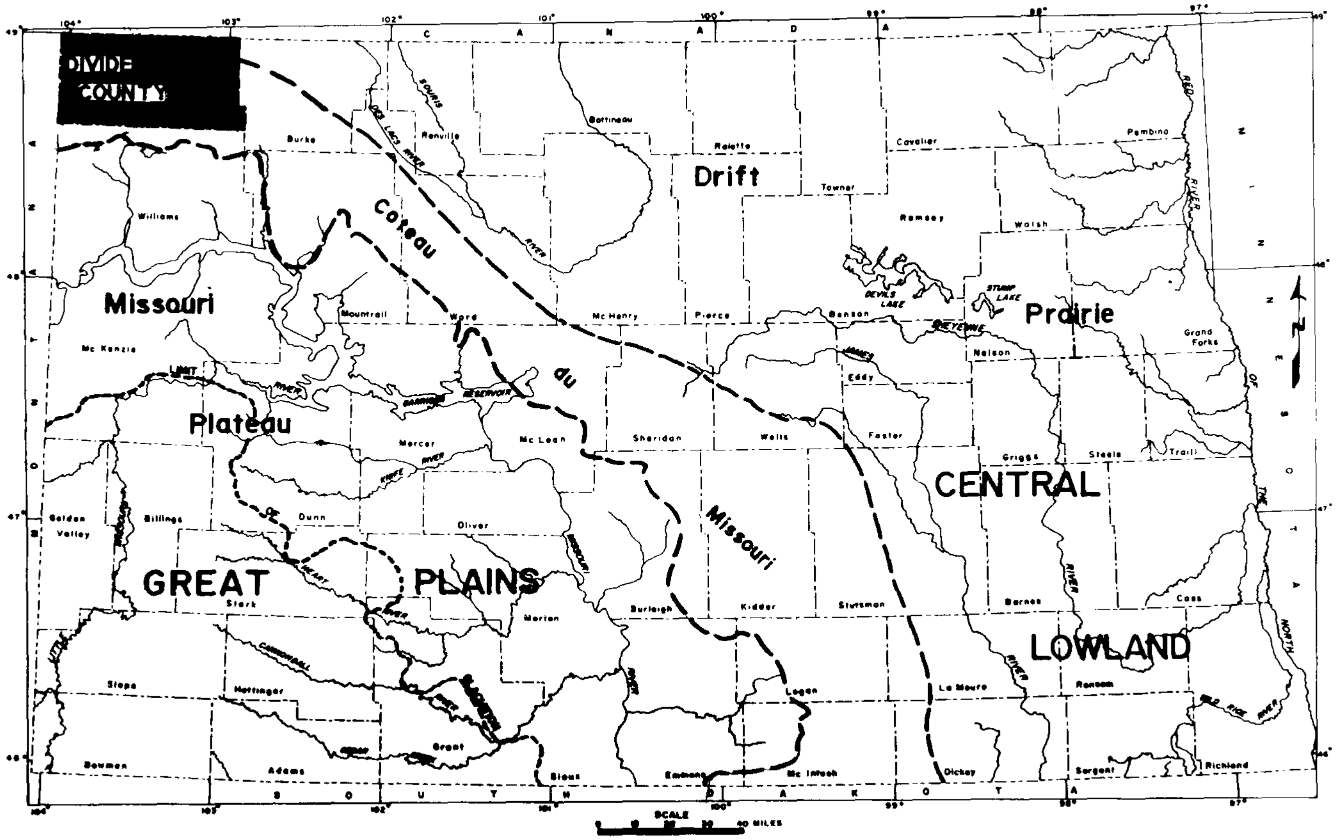

Figure 1. Location of physiographic provinces and Divide County.

Well-Numbering System

The well-numbering system used in this report (fig. 2) is based on the federal system of rectangular surveys of the public lands. The first numeral denotes the township, the second denotes the range, and the third denotes the section in which the well, spring, or test hole is located. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). Thus, well 160-95-15daa would be located in the NE 1/4 NE 1/4 SE 1/4 sec. 15, T. 160 N., R. 95 W. This numbering system also is used in this report for the location of small areas.

Previous Investigations

Divide County ground-water data were included by Simpson (1929) in a report on the ground-water resources of North Dakota. Several North Dakota Geological Survey reports contain detailed information concerning the ground water in Divide County (Simpson, 1932, 1935, 1937; Abbott and Voedisch, 1938). Water resources in approximately four townships in the southwestern part of the county were described in an investigation by Vorhis (1949). Witkind (1959), in his report "Quaternary Geology of the Smoke Creek - Medicine Lake - Grenora Area, Montana and North Dakota," included a brief section on water resources. LaRocque, Swenson, and Greenman (1963a and b) investigated the ground-water resources of the northeast quarter of the county. Several geologic and special mineral investigations include at least part of Divide County. Additional references can be found in Part I of this Bulletin.

Acknowledgments

Appreciation is expressed to the Divide County Commissioners, other county officials, and the Divide County Journal for aid and publicity which made it possible to complete the field work without unnecessary delays. Particular recognition is due M. O. Lindvig, of the North Dakota State Water Commission, for his aid during aquifer tests, and to Messrs. Axel Palm, Oscar Weber, Charles Hansen, and Marinus Jensen, well drillers who furnished sample logs. Recognition is also due the Skelly Oil Co. and the California Co. for contributing sample

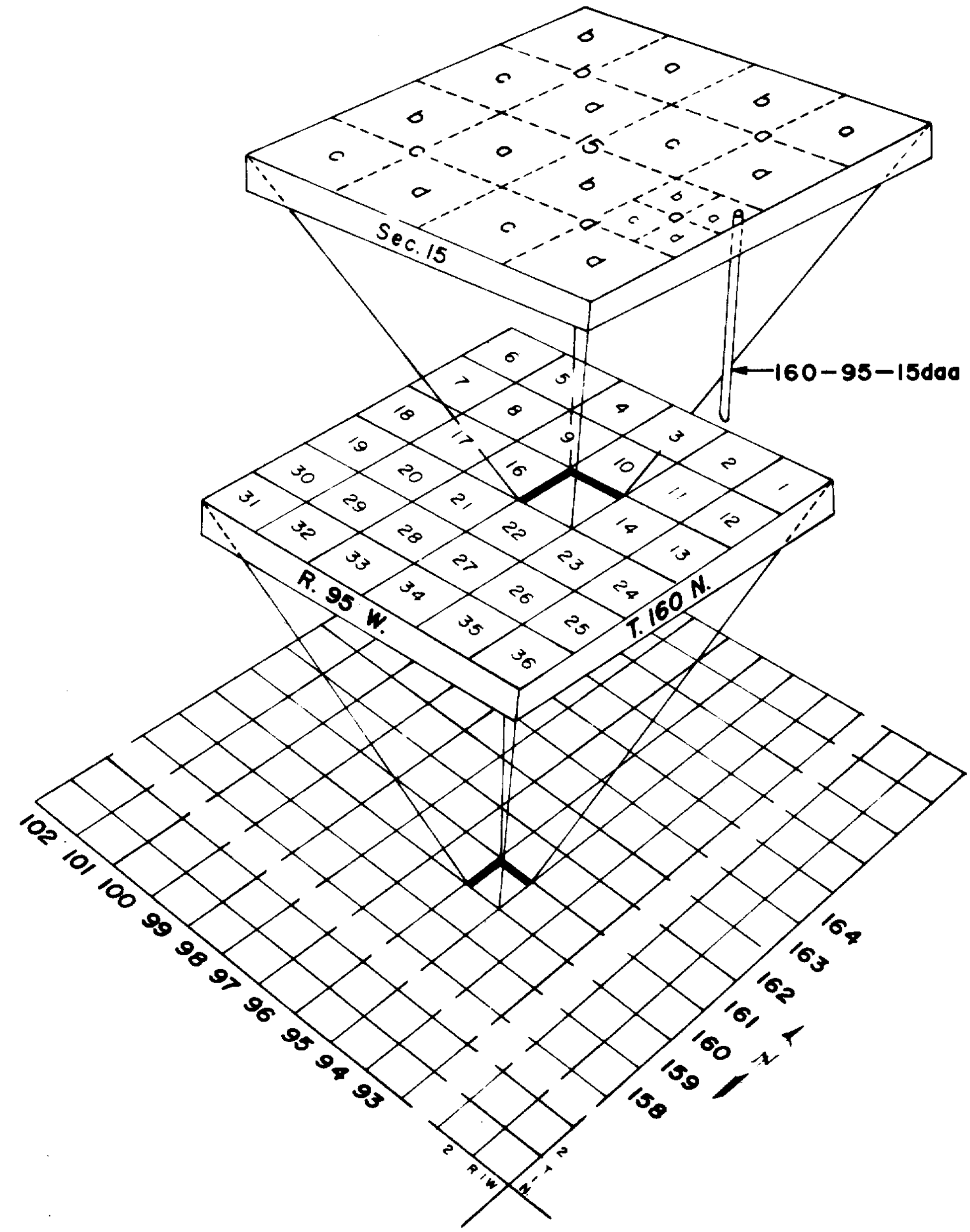

Figure 2. System of numbering wells, springs, and test holes.

logs of seismograph holes. Mr. Marlyn Brorby, Superintendent of Noonan water works, and Mr. Kenneth Haugland, City Engineer of Crosby, furnished information pertaining to the respective public supplies. Appreciation also is expressed to the farmers and ranchers in Divide County for giving free access to their lands and records of wells.

Population and Economy

The population of Divide County in 1960 was 5,566 (U.S. Bureau of Census, 1960), and Crosby, the county seat and largest city, had a population of 1,759. Other communities include Noonan, Ambrose, and Fortuna with populations of 625, 220, and 185, respectively. Other villages are Alkabo, Colgan, and Westby.

The economy of the county is based largely on agriculture. Small grains and flax are the principal crops. Dairy cattle and sheep are other important sources of farm income.

Climate

The climate of Divide County is semiarid. Figure 3 shows the monthly precipitation at the U.S. Weather Bureau station in Crosby. The average annual precipitation is 13.36 inches at Crosby and 13.83 inches at Wildrose (Williams County). About 75 percent of the precipitation falls during the growing season (average 110 days) from May through September. Most of the summer precipitation is extremely variable from month to month and place to place within the county. It is not uncommon for a part of the county to receive an inch of rain or more during a thunderstorm while another part receives very little or none. Over a period of years precipitation in one area within the county is probably similar to that of an adjacent area, but within any one growing season there can be an appreciable difference. For example; during the period May through September 1962, Crosby received 10.35 inches of rain, but during the same period the Ambrose station, about 10 miles away, received only 7.43 inches of rain.

Temperatures of below 0° F are common during January and February. The minimum temperature at Crosby since 1949 was -41° F on January 20, 1954. The summers usually are warm with maximum daily temperatures generally ranging from 78° to 84° F. However, temperatures exceeding 90° F are not uncommon. The maximum temperature since 1949 was 107° F on August 8, 1949.

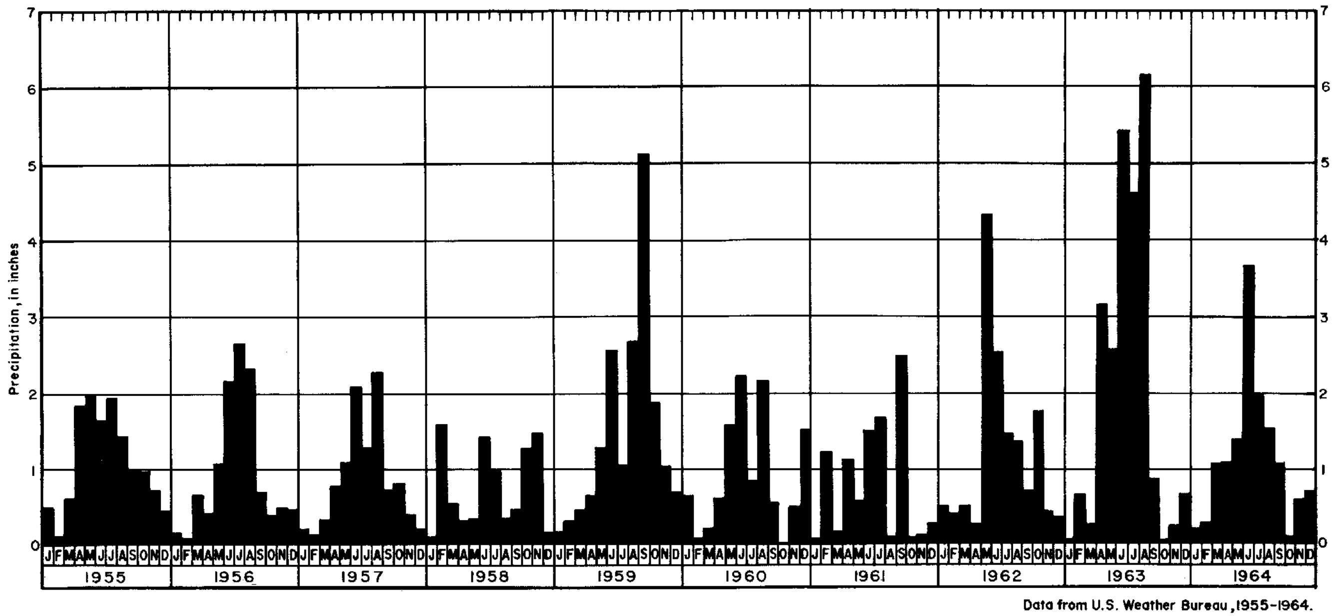

Figure 3. Monthly precipitation from 1955 through 1964 at Crosby.

Physiography and Drainage

Divide County lies within two physiographic provinces (fig. 1). The larger part, about 1,000 square miles in the southern and western parts of the county, lies within the glaciated area of the Missouri Plateau section of the Great Plains province. It contains large tracts of steep-sided hills and depressions and was referred to as the Coteau du Missouri (Hills of the Missouri) by early explorers.

The northeastern part of the county lies within the Drift Prairie section of the Central Lowland physiographic province. This part of the county is characterized by a northeastward sloping plain with a few low hills and shallow depressions.

Two large reentrants extend southwestward from the Central Lowlands into the Great Plains for as much as 15 miles. The reentrants, which are dominating features in the topography, mark the buried valleys of the ancient Yellowstone and Missouri Rivers that formerly flowed northeastward across the county prior to their being blocked by glacial debris.

Maximum topographic relief in the area exceeds 550 feet. The highest altitude is more than 2,400 feet on the summit of a hill at 161-102-12ddd, and the lowest is about 1,840 feet in the Long Creek channel where it leaves Divide County north of Noonan. Local relief, however, rarely exceeds 250 feet, being greatest in the Alkabo moraine area.

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

Drainage in the Drift Prairie generally is toward Long Creek, the largest waterway in the county. However, a few undrained depressions have not been integrated into Long Creek.

During the period of record from 1944 through 1963, the median yearly mean discharge of Long Creek was 15.6 cfs (cubic feet per second), or 11,290 acre-feet per year. The greatest flow usually occurs during March, April or May, although it may occur as early as February or as late as June. Periods of no flow are common from August through February, but the stream may be dry during any month.

PRINCIPLES OF GROUND-WATER OCCURRENCE

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

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

Permeability is the capacity of rocks to transmit water. The degree of permeability is determined by the size and shape of the pore spaces in the rock and extent of their interconnections. Gravel, well-sorted medium or coarse sand, and fractured lignite beds generally are highly permeable. Well-cemented sandstone or gravel and fine-grained materials such as silt, clay, and shale usually have low permeability, and may act as barriers, impeding the movement of water into or out of more permeable rocks.

Beds of sand, gravel, and fractured coal serve not only as conduits through which ground water moves, but also as reservoirs in which water is stored. The coefficient of transmissibility is a measure of capacity of an aquifer (water-bearing rocks) to act as a conduit. It is expressed as the number of gallons of water that will move in 1 day under a unit hydraulic gradient (one foot per foot) through a vertical strip of the aquifer 1-foot wide extending the full saturated height of the aquifer at a temperature of 60° F.

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

The coefficient of storage is the volume of water released from or taken into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface. Under water-table conditions the coefficient of storage is practically equal to the specific yield, which is the volume of water released by gravity drainage divided by the volume of the material drained.

The upper surface of the zone of saturation is called the water table. Water-table conditions refer to ground water that is not confined by overlying impermeable beds. As the water is subject only to atmospheric pressure, it does not rise in wells above the level at which it is encountered. If an aquifer is overlain by relatively impermeable beds, the water is confined and is under pressure exerted by water at higher elevations. It will rise above the level at which it is first encountered; wells supplied from this type of aquifer are said to be artesian. The piezometric surface is that level to which artesian water would rise in an open column.

The water level in a well fluctuates in response to changes in recharge to, and discharge from, the aquifer, including the effect of pumping from other wells. Atmospheric pressure changes and land surface loadings also cause minor water-level fluctuations in artesian aquifers. The static level is the level at which water stands in a well when it is not being pumped. When water is withdrawn from a well, the water level in and around the well is lowered, and the piezometric surface resembles an inverted cone with the well at its center. The slope produces a hydraulic gradient toward the well, and the inverted cone is called the cone of depression. The amount of water-level drawdown, or the difference between the static level and the pumping level, is determined by the capacity of the aquifer, the physical characteristics of the well, and the rate and duration of pumping. During constant and uniform discharge from a well, the water level declines rapidly at first and then continues to lower at a decreasing rate as the cone of depression slowly broadens.

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

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

Under natural conditions, over a long period of time, the rate of discharge from an aquifer approximately equals the rate of recharge. When equilibrium exists, the amount of water in storage remains essentially the same. However, some water-level fluctuations may occur when periods of peak recharge and discharge are at different times.

Withdrawal of water from an aquifer causes one or a combination of the following: (1) a decrease in the rate of natural discharge, (2) an increase in the rate of recharge, or (3) a reduction in the volume of water in storage. If ground-water withdrawal plus natural discharge does not exceed recharge to an aquifer, the water level will approach equilibrium. If they exceed recharge, the excess will be withdrawn from storage. When water is taken from storage, the water level continues to decline as long as water is discharged.

The maximum rate of ground-water withdrawal that can be maintained indefinitely is related directly to the rate of recharge. However, recharge is regulated largely by climate and geologic controls and is impossible to evaluate quantitatively without large amounts of data.

QUALITY OF WATER

All natural water contains some dissolved solids. As precipitation, it begins to dissolve mineral matter as it falls to the earth and continues to dissolve minerals as it infiltrates through the earth. The amount and kind of mineral matter dissolved depends upon the solubility and types of rocks 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 recovered near the recharge area. Ground water usually contains more dissolved minerals than surface water.

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

The suitability of water for various uses is determined largely by the kind and amount of dissolved mineral matter. The various constituents of water in Divide County were listed by Armstrong (tables 4 and 5, 1965). The data in these tables are summarized in the discussion of each of the major aquifers described in the section of this report dealing with the rock units and their water-bearing properties.

Table 1 was modified from Durfor and Becker (1964, table 2). It shows the major constituents in water, their major sources in Divide County, and their effects upon usability. Most of the minerals, rocks, and mineral substances shown in the major source column are present in the glacial drift or the Tongue River Formation in Divide County.

The chemical properties and constituents most likely to be of concern to residents of Divide County are: (1) dissolved solids and the related specific conductance, (2) sodium-adsorption ratio, (3) hardness, (4) iron, (5) sulfate, (6) nitrate, and (7) fluoride. The relative importance of the above properties and constituents

Constituents	Major source	Effects upon usability	U. S. Public Health Dept. recommended limits for drinking water 1/
Silica (SiO_2)	Feldspars, feromagnesium and clay minerals.	In presence of calcium and magnesium silica forms a scale in boilers and on steam turbines that retards heat.	
Iron (Fe)	Natural sources: Amphiboles, feromagnesium minerals, ferrous and ferric sulfides, oxides and carbonates, and clay minerals. Man-made sources: well casing, pump parts, storage tanks.	More than 0.1 ppm precipitates when exposed to air; causes turbidity, stains plumbing fixtures, laundry and cooking utensils, and imparts tastes and colors to food and drinks.	0.3 ppm
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, dolomite, clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate and silica, to form scale in heating equipment. Calcium and magnesium retard the suds forming action of soap. High concentrations of magnesium have a laxative effect.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, clay minerals.		
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, clay minerals.		
Boron (B)	Tourmaline, biotite, amphiboles	Many plants are damaged by concentrations of 2.0 ppm.	

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

Constituents	Major source	Effects upon usability	U. S. Public Health Dept. recommended limits for drinking water 1/
Bicarbonate (HCO_3)	Limestone, dolomite	Upon heating bicarbonate is changed to steam, carbonate and carbon dioxide. Carbonate combines with alkaline earth (principally calcium and magnesium) to form scale.	
Carbonate (CO_3)			
Sulfate (SO_4)	Gypsum, anhydrite 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, mica.	Optimum concentrations 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 control limits depend on average of maximum daily temperature. 0.9 to 1.7 ppm at 50° to 53.7° F.
Nitrate (NO_3)	Nitrogeneous fertilizers, animal excrement, legumes, plant debris.	More than 100 ppm may cause a bitter taste and may cause physiological distress. Water containing more than 45 ppm has 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).

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 a water undesirable for use in a commercial laundry. Additional information may be found in "Drinking Water Standards" published by the U.S. Public Health Service (1962).

Dissolved Solids and Specific Conductance

The concentration of dissolved solids is a measure of the total mineralization of water. It 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 have ranged as high as 2,000 ppm have consumed the water with no noticeable ill effects. Stock have been known to survive on water containing 10,000 ppm. However, growth and reproduction of stock may be affected by water containing more than 3,000 ppm of dissolved solids.

The specific conductance, in micromhos, of water is a measure of its ability to conduct an electrical current; it is a function of the amount and kind of dissolved mineral matter. An estimate of the total dissolved solids in parts per million can be obtained by multiplying specific conductance by 0.65; however, the conversion factor may range from 0.55 to 0.75, depending upon the type and amount of dissolved minerals. For Example: The water from 160-97-32ddb1 has a specific conductance of 700 micromhos; the analysis shows that there are 435 ppm dissolved solids. which is a factor of 0.62.

Irrigation Indices

Two indices used to show the suitability of water for irrigation in this report 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 the indices increase. Figure 4 shows the SAR versus the specific conductance of analyzed water from Divide County. The analyses are plotted to show the general range of sodium and salinity hazards of water from a surface stream and from ground water in the glacial drift and Tongue River Formation. The figure indicates that water from the Tongue River Formation and some of the glacial drift in Divide County should not be used for irrigation. For example: C4-S4 water should not be used for irrigation. It also indicates that much of the water from the glacial drift is of marginal quality for irrigation,

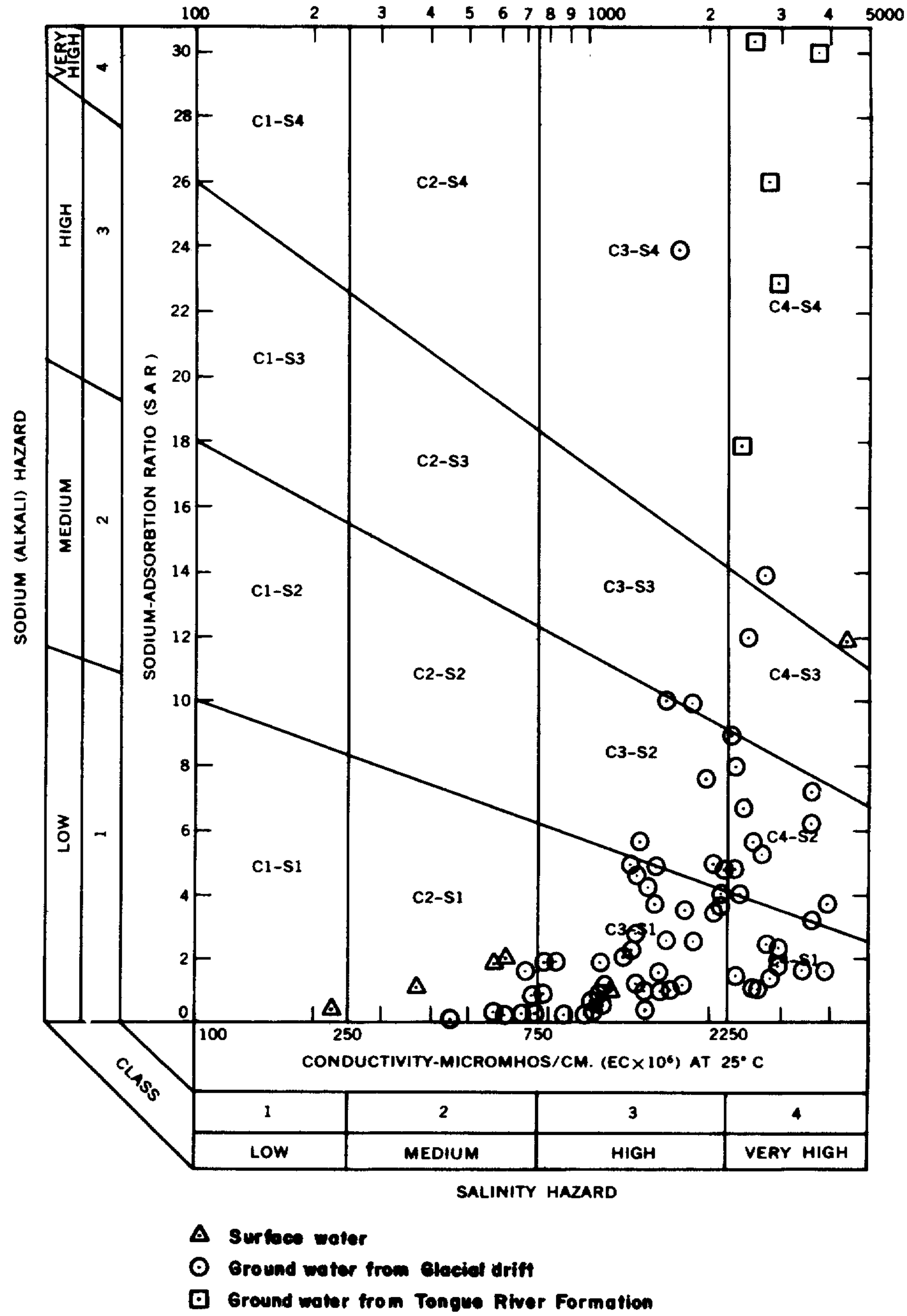

Figure 4. Salinity and sodium hazard classification of selected water samples.

but might be used for irrigation if good management practices are followed.

Another index used to rate irrigation water is the RSC (residual sodium carbonate). This quantity is determined by subtracting the equivalents per million of calcium and magnesium from the sum of equivalents per million of bicarbonate and carbonate. If the RSC is between 1.25 and 2.5 epm, the water is marginal for irrigation. An RSC of more than 2.5 epm indicates that the water is not suitable for irrigation purposes. Generally the water in Divide County has an RSC index of less than 2.5 epm, if there is sufficient water for irrigation purposes.

High sodium and high salinity hazard waters can be used successfully with ideal soil conditions and drainage in conjunction with proper water management. Good management practices and the proper use of amendments might make it possible to use successfully some of the marginal RSC water for irrigation. For further information the reader is referred to "Diagnosis and Improvement of Saline and Alkali Soils." (U.S. Salinity Laboratory Staff, 1954).

Hardness

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

THE ROCKS AND THEIR WATER-BEARING PROPERTIES

The sedimentary rocks of Divide County that contain aquifers are divided into the following units: (1) rocks of pre-Cretaceous age, (2) basal Cretaceous sandstone, (3) Fox Hills and Hell Creek Formations, (4) Fort Union Group, and (5) glacial drift. The Fort Union Group, chiefly the Tongue River Formation, and the glacial drift contain the only aquifers that are presently of economic importance. Consequently, they are described in the greatest detail.

In western North Dakota, pre-Pleistocene sedimentary rocks were deposited in a large, sporadically sinking basin now known as the Williston Basin. Divide County is located on the northwestern flank of this basin; consequently, the rocks generally dip to the southeast in the western part of the county. The eastern part of the county overlies the western flank of the Nesson anticline, a fold within the basin, hence the beds dip westward in this part of the county. The total structural effect is a somewhat asymmetrical troughlike structure that dips southward. The axis of this trough extends through the central part of the county.

The sediments in the deepest part of the trough in Divide County are as much as 13,600 feet thick. They are probably less than 13,000 feet thick in the northeast and northwest corners of the county.

The meager data concerning the pre-Fort Union Group rocks, as used in this paper, are based on information obtained from petroleum exploration.

Rocks of Pre-Cretaceous Age

Rocks of pre-Cretaceous age generally lie more than 5,000 feet beneath the land surface in Divide County; they are composed principally of limestone and dolomite with lesser amounts of sandstone, shale, and evaporites. The sandstones generally are reported to be either fine or very fine grained. Most of the sandstones probably would yield a small, dependable supply of water, but the water probably is more highly mineralized than water from the shallower basal Cretaceous rocks. The limestone in places is porous, and occasional reports of lost circulation during oil tests indicate that some of the limestones are cavernous. These rocks probably would yield very large supplies of very highly mineralized water. The following table shows examples of the dissolved solids content of water from rocks of pre-Cretaceous age. Some of the shallower pre-Cretaceous rocks probably contain water of much better quality than that shown in the table; nevertheless, the water probably would not be suitable for most purposes.

Well number	Depth	Dissolved solids
162-95-20ca	7,026-7,032	a/ 328,800
163-95-9bc	6,695-6,725	a/ 205,100
163-95-29a	7,064	b/ 298,823

a/ Analysis from the files of the North Dakota Geological Survey, Grand Forks, North Dakota.

b/ Analysis by Yapuncich, Sanderson and Brown Laboratories, Billings, Montana.

Cretaceous System

BASAL CRETACEOUS SANDSTONE

The basal Cretaceous sandstone in the Divide County area is believed to be equivalent to the Fall River and Lakota Formations undifferentiated. It generally is composed of fine-grained sandstone and gray shale. The thickness ranges from 302 to 390 feet and averages about 346 feet. The depth below land surface to the top of the basal Cretaceous sandstone ranges from 3,938 feet at oil test 163-95-3db to 4,887 at oil test 160-97-11da (Hansen, written communication). Approximately 300 feet of the difference in depth is because of differences in the surface elevation of the two test sites, but the other 650 feet is due to 160-97-11da being down dip from 163-95-3db and therefore in a deeper part of the Williston Basin.

Very little is known about the ground-water potential of the basal Cretaceous sandstone in Divide County; however, in many areas of North Dakota it is a highly productive aquifer. The thickness of the unit in the report area suggests that it would yield large quantities of water.

The water in the basal Cretaceous sandstone in the report area is apparently of poor quality. One sample taken from depths of 4,715 to 4,725 feet in an oil test at 163-95-29a (analysis by Yapuncich, Sanderson and Brown Laboratory, Billings, Montana) contained 3,294 ppm sodium, 3,666 ppm chloride, and 8,331 ppm total dissolved solids. Samples of water from the same rocks in western Burke County (well 161-92-3) contained 12,300 ppm total dissolved solids, and another from Williams County (well 155-96-1b) contained 9,539 ppm total dissolved solids.

The Cretaceous rocks between the basal Cretaceous sandstone and the Fox Hills Formation are not aquifers because they are generally fine grained. They are composed principally of clay, silt, shaley limestone, and shaley sandstone. The permeabilities of these rocks are very low.

FOX HILLS AND HELL CREEK FORMATIONS

The Fox Hills and Hell Creek Formations may yield small quantities of ground water in Divide County. An electric log of an oil test at 163-102-7ab (Carter Oil Co., D. Moore No. 1), indicates some lignite and sandy or silty beds in these two formations. Lignite and shale were the only rock types mentioned in the lithologic description of the samples and the character of the electric log curves does not indicate good aquifers. However, some of these beds probably would yield enough water to supply small-capacity wells.

The quality of the water in these formations has not been determined, but the electric log of oil test 163-102-7ab indicates that it is of poorer quality than that in the shallower Tongue River Formation.

Tertiary System

FORT UNION GROUP

The Fort Union Group, of Paleocene age, crops out in a few small areas and underlies the glacial drift in most of Divide County. The group has been subdivided into three formations in some parts of North Dakota: The marine Cannonball Formation; the continental Ludlow Formation, which is a lateral equivalent to the Cannonball; and the continental Tongue River Formation.

Figure 5 shows the topographic surface that was cut by preglacial erosion on the Fort Union Group as it would appear if the glacial drift were removed. The ancient Yellowstone and Missouri River valleys, which are the major valleys, and some of their larger tributaries are shown. Many small tributaries probably exist but are not shown because of lack of data.

This preglacial topography of Divide County apparently was similar to that of the present badlands areas of the Little Missouri River in Billings and McKenzie Counties, North Dakota.

Probably the highest altitude of the Fort Union Group (more than 2,200 feet) is in the eastern part of T. 161 N., R. 102 W. in the southwest part of the county. The lowest altitude probably is about 1,450 feet in the buried channel of the ancient Yellowstone River where it crossed the northern boundary of the county.

Cannonball and Ludlow Formations Undifferentiated

The Cannonball and Ludlow Formations are not differentiated or treated separately in Divide County because of the sparsity of information. These rocks do not crop out anywhere in the report area, and apparently they directly underlie the glacial drift only in the deeper parts of the buried Missouri River valley near Fortuna. Test hole 163-101-35cbb penetrated 27 feet of very calcareous silt and limestone between 638 and 665 feet that may represent Cannonball Formation, but definite identification was not possible. The electric log of the oil test at 163-102-7ab indicates a fine-grained rock, possibly silt or very fine clayey sand, at depths of 380 to 550 feet. This formation possibly would yield a dependable water supply to small capacity wells.

No samples of water were obtained from the Cannonball and Ludlow Formations in Divide County. However, a 635 foot well, 163-101-26bcc, (Armstrong, 1965, table 1), near the northeastern part of Fortuna was drilled to a somewhat deeper horizon than was penetrated in test hole 163-101-35cbb. The well was abandoned because the water was too salty for domestic use. This information, coupled with the reported average of 3,640 ppm dissolved solids (LaRocque and others, 1963a, p. 39) for water from the Cannonball in the eastern part of the Crosby-Mohall area, suggests that water from these formations in Divide County is unsuitable for most purposes.

Tongue River Formation

The Tongue River Formation, the youngest bedrock formation in Divide County, is composed of a series of nearly horizontal, lenticular beds of lignite, clay, silt, and very fine sand. Some coarser sand and possible gravel lenses have been reported in a few wells near Ambrose and in well 163-102-36acb. These lenses are usually not more than a few feet thick. Outcrops and exploration holes drilled by mining companies indicate that some lignite beds have an areal extent of at least a few square miles, but lenses of the other sediments have not been traced for more than a few hundred yards. This lack of correlation may be the result of the scarcity of outcrops and well logs as well as the lenticular nature of the sediments. the thickness of individual sand lenses is variable, but is usually less than 5 feet. However, thicker lenses do exist, for example, 49 feet of very fine sand was penetrated in test hole 160-95-22aad.

The most widespread aquifer believed to be in the Tongue River Formation occurs along the west side of the buried Yellowstone River channel and underlies the glacial deposits in the buried channel. The deposits that form the aquifer may be associated with the buried Yellowstone channel and may be younger than the Tongue River Formation. However, they do not appear to be glacial in origin. The aquifer is about 2 to 3 miles wide and extends from the central part of the county north to at least well 163-97-6ccd (Armstrong, 1965, fig. 3). It is generally composed of interbedded deposits of sand and clay that are hydraulically interconnected.

Another extensive Tongue River aquifer extends from about 2 miles east of Ambrose to about a mile west. It is more than a mile wide at the village. Wells in this aquifer flow if they are located at altitudes of less than 1,995 feet.

Yield

The Tongue River Formation is composed predominantly of fine-grained sediments. Consequently, it has a low coefficient of permeability and generally will yield only small quantities of water to wells. The quantity of water that can be developed, however, depends to a great extent on the thickness, sorting, and grain size of the sand that is screened in the well. Because most of the sand lenses in the formation are very fine to fine-grained and thin, the coefficients of permeability and transmissibility are usually low and well yields are also low. Only two wells in the county are known to have produced as much as 50 gpm (gallons per minute) for more than a few hours. Properly constructed wells completed in the Tongue River Formation along the west side of the buried Yellowstone valley and some of the flowing wells in the Ambrose area possibly could be pumped at rates exceeding 50 gpm.

It is estimated that the coefficients of permeability of typical sand lenses in the Fort Union Group are about 110 gpd per square foot (gallons per day per square foot), but they may be as high as about 300 gpd per square foot; thus, the coefficient of transmissibility of a lens of sand 5 feet thick could be about 500 gpd per foot, or possibly as high as 1,500.

The method of estimating transmissibility from specific capacities was derived from a chart (Meyer, 1963) which shows that a well in an aquifer with a transmissibility of 2,000 gpd per foot will have a specific capacity of 1 gpm per foot of drawdown. Thus, the specific capacity of a well can be multiplied by 2,000 to obtain an approximate coefficient of transmissibility. This method assumes that a well is 100 percent efficient, fully penetrates an aquifer, and that the specific capacity is calculated at the end of 1 day of pumping. Specific capacities calculated on less than a day's pumping will result in estimated transmissibility coefficients that are too high. The specific capacities listed in the following table were based on only a few hours pumping so the transmissibility coefficients as calculated are probably high.

Well number	Specific capacity 1/	Transmissibility
162-95-2bbc	.17 gpm per foot x 2,000	340 gpd per foot
162-95-3daa	.5 gpm per foot x 2,000	1,000 gpd per foot
163-102-36acb	1.25 gpm per foot x 2,000	2,500 gpd per foot

1/ Specific capacity based on drillers bailing tests.

The higher than normal specific capacity of well 163-102-36acb is due to sand lenses that are coarser and thicker than usual (Armstrong, 1965, table 3). The estimated figures of transmissibility based on grain size compare favorably with those estimated by multiplying the specific capacities of wells by 2,000 as shown above.

Lignite beds in the Tongue River Formation also will yield water. The quantity of water that can be obtained depends upon the amount of fracturing, the size and extent of the fractures in the lignite, and the transmissibility of the overlying or underlying rocks. Yields from lignite beds are variable from place to place but commonly they are at least a few gallons per minute.

Most farm wells that pump from the Tongue River Formation are completed in the uppermost saturated sand lens. The wells are equipped with cylinder pumps with capacities of only a few gallons per minute. Some of the lenses are only a foot or two thick and not capable of yielding more than the capacity of the pumps. Wells in thinner lenses are usually deep, but even so, the water levels draw down to or near the cylinder when pumping. Most wells completed in lignite seams apparently have higher specific capacities than those finished in sand.

The municipal supply for the city of Noonan is obtained chiefly from two wells in the Tongue River. One well, 162-95-4add3, 365 feet deep, is pumped at the rate of 50 gpm; the other well, 162-95-4acd, 390 feet deep (Armstrong, 1965, table 1) is pumped at the rate of 25 gpm. The static water level is 100 feet below land surface in 162-95-4add3, and 119 feet below land surface in 162-95-4acd. Pumping levels were not measured in either well but the reported withdrawal rates can be maintained only if the specific capacities of the wells are not lower than 0.1 and 0.2 gpm per foot drawdown, respectively.

Recharge and Water-level Fluctuations

Recharge to the Tongue River Formation is apparently from the high stagnation and end moraines (fig. 8) that extend across much of the county. The piezometric surface follows the general surface slope rather than the dip of the beds in the underlying Tongue River Formation. Locally, however, water levels may be higher beneath a slough than beneath an adjacent hill. Figure 6 shows the generalized configuration of the piezometric surface in the Tongue River Formation and the glacial drift. Water-level fluctuations during 1960 to 1964 were assumed to have been small and would not make a significant difference in the shape and location of the contour lines on figure 6. Most water levels in wells in the Tongue River aquifers are at nearly the same altitude as water levels in glacial drift wells, and thus indicate a similar source of recharge. The quantity of recharge to the Tongue River is probably small, because in the area of recharge the overlying glacial drift is usually more than 100 feet thick, and in most places it has a very low permeability.

The quantity of recharge to the Tongue River Formation that occurs in the areas of low-relief ground moraine is not known, but probably it is small even though the ground moraine deposits are rather thin. East of the buried Yellowstone River channel (fig. 5), the low wet areas are underlain by nearly impermeable glacial till that restricts downward percolation. In most other areas drainage has developed sufficiently for surface water to run off before much can infiltrate downward. Some recharge probably occurs in small areas of sand and gravel exposed on the surface of the drift.

Hydrographs (fig. 7) show fluctuations of water levels in the Tongue River Formation. Well 162-95-1bbb, 25 feet deep, shows fluctuations due to seasonal precipitation. The sharp rises shown began within a few days after heavy rainfalls and the spring thaw (the first rise of more than a foot in 1964). Although fluctuations exceeded 2 feet, the net decline was less than a foot, and even this decline was probably due to the differences in the annual precipitation during 1963 and 1964.

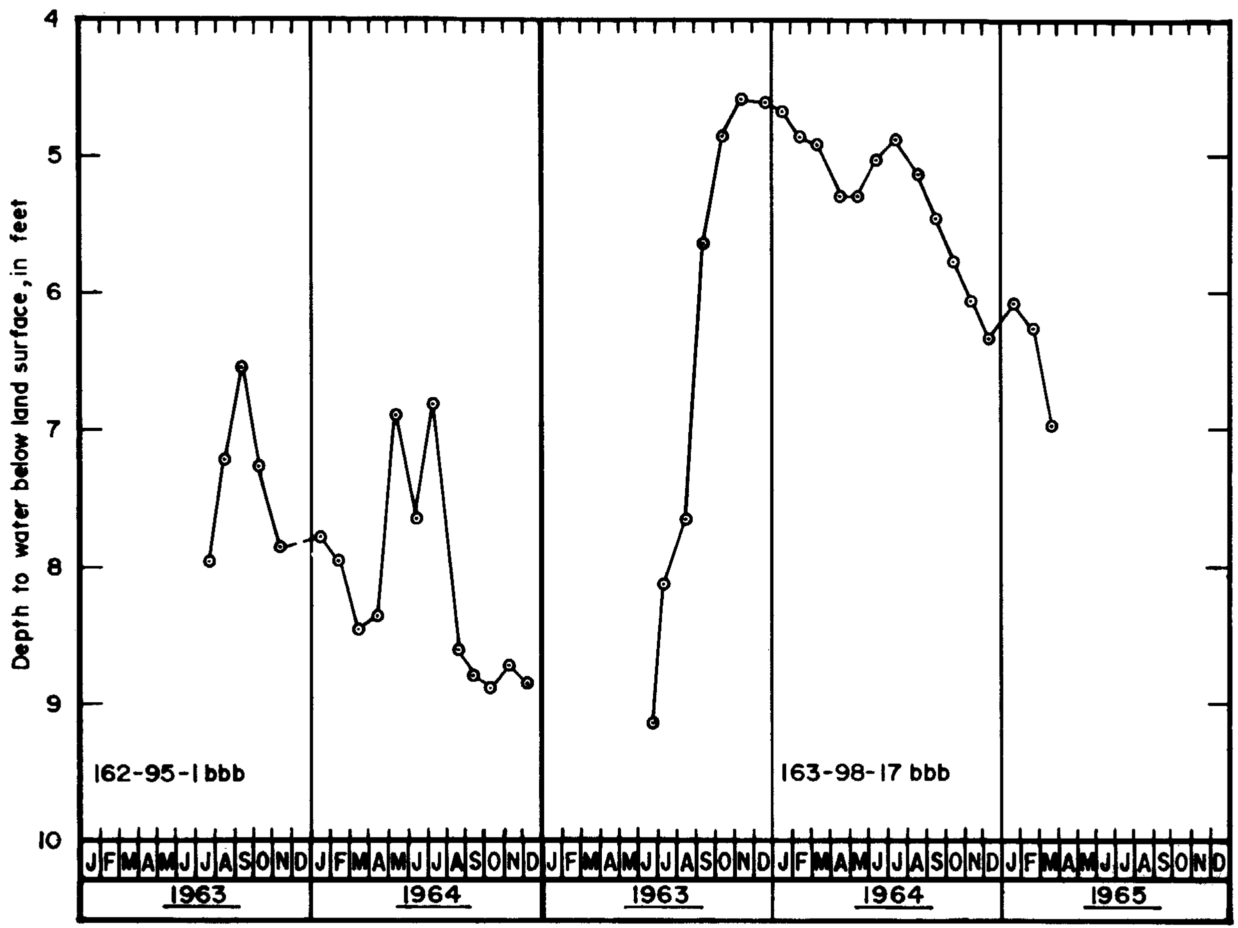

Figure 7. Water-level fluctuations in wells 162-95-1bbb and 163-98-17bbb.

Well 163-98-17bbb, 183 feet deep, also reflects precipitation, but the effect of precipitation on water levels is slow. In 1963, the heavy precipitation occurred during June, July, and August, but water levels were still rising in November.

Quality of Water

Ground water in the Tongue River Formation is generally high in sodium, bicarbonate, and total dissolved solids; and low in calcium and magnesium. Nearly complete chemical analyses (Armstrong, 1965, table 5) were made of water from 18 wells that tap the Tongue River Formation. Dissolved solids in these samples ranged from 1,250 ppm to 6,680 ppm. The sodium concentration was: 1,000 ppm or more in 4 samples, between 500 and 1,000 ppm in 12 samples, and less than 500 ppm in 2 samples. The bicarbonate ion concentration exceeded 700 ppm in all of the samples and exceeded 1,000 ppm in 14 samples. Calcium and magnesium combined were less than 100 ppm in 17 samples, and less than 50 ppm in 12 samples. The percent sodium and SAR for 16 samples exceeded 80 and 15, respectively.

Sulfates in water samples from the Tongue River Formation ranged from a trace to 3,150 ppm. Five samples contained less than 250 ppm, 6 contained from 250 to 900 ppm, and 7 contained more than 900 ppm. There is no recognizable sulfate distribution pattern in the county, but 3 of the 6 samples containing more than 900 ppm were from wells in lignite. The records for the other three wells did not indicate the lithology of the aquifer.

Five samples were from wells having depths that normally would have reached the Tongue River; however, there is some doubt concerning the identity of the aquifer because the water was similar in quality to water from the glacial drift. These samples may represent a mixture of the two types.

Water from the Tongue River, although high in total dissolved solids, is commonly soft. Eight of the 18 samples were soft (less than 60 ppm hardness as CaCO), 4 were moderately hard, 2 were hard, and 4 were very hard. The 4 samples that were very hard also contained more than 1,000 ppm sulfates.

Water from the Tongue River Formation generally is satisfactory for stock water, but is not recommended for human consumption if better water can be obtained. The water also has a high to very high sodium and salinity hazard for irrigation.

Quaternary System

GLACIAL DRIFT

Divide County is covered by glacial drift that in places is more than 500 feet thick. The various types of drift deposits were mapped and described in detail by Hansen and Freers (written communication). Figure 8 is a generalized geologic map of the county based on their work. The areas shown as stagnation and end moraines and collapsed outwash are the principal areas of recharge. Some recharge also occurs in the outwash areas. However, the piezometric surface is locally higher than some of the outwash in the northeastern part of the county. In these areas some discharge may occur.

The outwash and collapsed outwash deposits generally contain some water that can be obtained from wells or springs.

Most of the glacial drift is composed of till, a relatively impermeable mixture of clay, silt, sand, and gravel that yields little or no water. However, some drift consists of stratified glaciofluvial deposits of sand and gravel. The ability of these deposits to yield large quantities of water depends on their transmissibility, size, and on the amount of recharge they receive. If the sand or gravel deposit is enclosed by till, it receives recharge slowly; consequently, such deposits, particularly small ones, will not yield large quantities of water for sustained periods.

Vorhis (1949, p. 11) suggested that there are three permeable zones within the drift in his area of study; one near the base of the drift, one at medium depth, and a shallow zone. The presence of three widespread permeable zones was disputed by Witkind (1959, p. 76) and their existance was not substantiated by this investigation. Possibly the deeply buried sand and gravel deposits in the ancestral Yellowstone and Missouri River channels could be interpreted as the deep zone, but these are mainly restricted to the pre-Wisconsin drainageways and should not be construed as being widespread. The middle part of the drift contains many glaciofluvial deposits of sand and gravel, but these are local and should not be considered as an areally extensive permeable zone. Many of the deeper wells in the county have been drilled to or nearly to bedrock without encountering any sand or gravel in the middle part of the drift. The available records do not indicate the existance of a widespread shallow permeable zone.

Figure 9, which shows the availability and chemical quality of water from glacial drift aquifers in Divide County, is based primarily on test drilling records and on information about private wells. The bedrock topography map (fig. 5) and geologic map (fig. 8) also aided in determining the extent of the various aquifers. The 0 to 50 gpm area covers most of the county and indicates where saturated glaciofluvial deposits are of very limited extent or nonexistent. If sufficient water for stock or domestic purposes cannot be obtained from the glaciofluvial deposits in the drift in this area, a well finished in the underlying Tongue River Formation probably will provide a sufficient supply.

The 50 to 500 gpm areas generally are underlain by the buried Yellowstone channel, the Grenora, the Wildrose, and parts of the West Wildrose and Skjermo Lake aquifers. Test drilling has shown that these aquifers are irregular in distribution and thicknesses. Locally only a few gallons per minute can be obtained, but at other localities several hundred gallons per minute can be obtained.

The areas that can provide more than 500 gpm are underlain by the southern

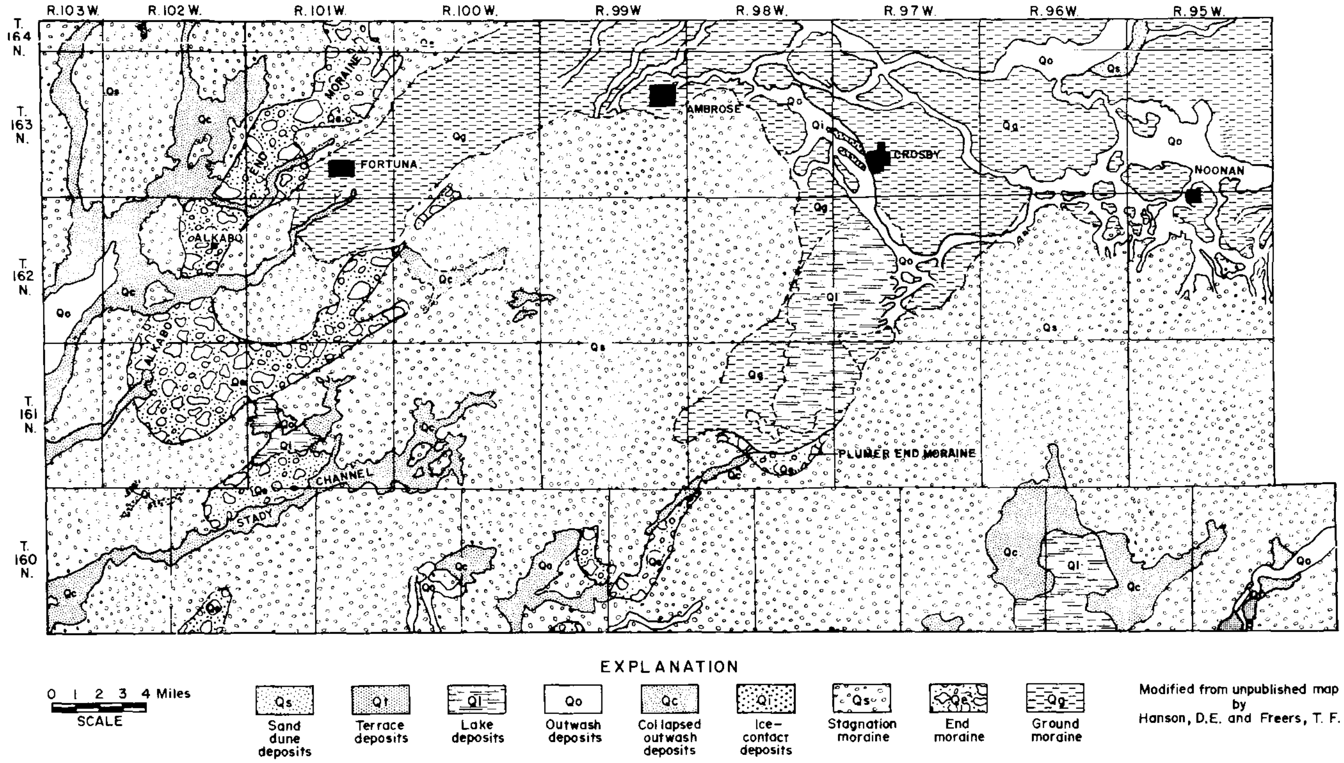

Figure 8. Generalized surface geology.

unit of the buried Yellowstone channel, the Skjermo Lake, and the West Wildrose aquifers.

Aquifers in the Buried Yellowstone Channel

The buried Yellowstone channel, as used in this report, refers to a valley that was eroded by the ancient Yellowstone River and subsequently buried by glacial dirft. Originally the river flowed northward near Williston, N. Dak., past Crosby, and north of Estevan, Saskatchewan, from where it took a more easterly course toward the Hudson Bay area. The bedrock topographic map (fig. 5) shows the course of the buried channel through Divide County.

There were at least two major periods of erosion in this valley. A wide valley was established by downcutting during an early period of erosion, which probably occurred prior to the Wisconsin Glaciation. A relatively narrow inner valley was eroded during the last period of erosion, which probably ended with one of the Wisconsin glacial advances. The deposits filling the ancient valley are principally drift or interglacial and proglacial fluvial and lacustrine deposits, but some terrace material probably is included.

The buried Yellowstone channel (fig. 9) in Divide County is divided into three areal hydrogeologic units based on characteristics of the deposits in each area. The boundaries between the three units are poorly defined. The southern unit extends southward from the distal edge of the Plumer end moraine in the southern part of T. 161 N., R. 98 W. to the upper reaches of the Little Muddy River in Williams County. The central unit extends from the Plumer end moraine northward to about the north end of the lake plain shown on figure 8. The northern unit extends from the lake plain northward into Canada. Each of the units widen and thicken wherever tributaries entered the ancient Yellowstone River valley. The southern unit is characterized by fluvial deposits of sand and gravel; the central unit by lake deposits of bedded silt, well-sorted sand (usually fine), and clay; and the northern unit by a combination of the two types of deposits.

Southern Unit

The southern unit consists of gravel, sand, silt, and till. Apparently most of the sand and gravel deposits are buried outwash, although some of the deeper deposits may be buried terrace and river channel deposits of the preglacial Yellowstone River. The log of test hole 160-99-3bbb (figs. 9 and 16), which penetrated the greatest conbined thickness of the deposits (560 feet) in the buried channel, indicates the presence of several aquifers at that location (Armstrong, 1965, table 2). An upper aquifer, A, from 97 to 152 feet below land surface, is composed of fine to coarse sand and probably extends more than 4 miles eastward from the test hole. This aquifer is overlain by 97 feet of fine-grained sediments and underlain by 93 feet of till and silt, which probably function as effective confining beds.

Aquifer B, from 250 to 277 feet, contains two sand and gravel deposits, 7 and 9 feet thick, which are separated by silt and very fine sand. Even though each gravel deposit is an aquifer, the separating silt zones are somewhat permeable and the entire interval can be considered a hydrologic unit. This aquifer probably is not extensive.

Aquifer C, from 308 to 397 feet, consists mainly of gravel and coarse sand. This aquifer may be buried outwash that extends southward into Williams County. It may be continuous with the aquifer that underlies much of the Little Muddy River valley in Williams County.

The samples from 397 to 449 feet were too poor to estimate accurately the water-yielding characteristics.

Aquifer D, from 449 to 496, consists mainly of gravel and coarse sand. This aquifer may be formed in terrace deposits of the ancient Yellowstone River. If so, the aquifer is probably long and narrow, and perhaps discontinuous.

Yield.--The transmissibilities and yields from the various aquifers in the southern unit of the buried Yellowstone channel were estimated from the grain size and thicknesses of the deposits. Ground-water barriers are certain to exist, thus the estimated values for transmissibilities and yields are probably high. However, they are useful guides for evaluating future development.

The transmissibility coefficient would be about 55,000 if the fine to coarse sand of aquifer A has an average permeability coefficient of 1,000 gpd per square foot. The estimated capacity of a properly constructed well in this aquifer would be about 27 gpm per foot of drawdown. Theoretically, more than 250 gpm could be obtained with only 10 feet of drawdown.

Aquifer B probably has a wide range in permeability. The coefficient of permeability of the sand and gravel is estimated to be as high as 1,500 gpd per square foot; with the silt included, the estimated coefficient of transmissibility could exceed 22,000 gpd per foot. The specific capacity is estimated to be about 10 gpm per foot drawdown. Inasmuch as no wells have been completed in this aquifer, no development information is available to check the accuracy of the estimates.

Aquifer C is the thickest known and probably the most extensive aquifer in the buried Yellowstone channel deposits. The aquifer has a total thickness of 89 feet. Assuming an average coefficient of permeability of 3,000 gpd per square foot for the gravel, the coefficient of transmissibility may be as much as 250,000 gpd per foot. The specific capacity of a properly constructed well in this aquifer may be as much as 125 gpd per foot drawdown, and the aquifer should yield more than 500 gpm to properly constructed wells in the area indicated on the water availability map (fig. 9).

Aquifer D is a fairly thick aquifer, but it probably is of limited extent and variable thickness. The aquifer is as thick as 47 feet. Assuming an average coefficient of permeability of 2,000 gpd per square foot for the aquifer, the coefficient of transmissibility may be as high as 90,000 gpd per foot. The specific capacity of a properly constructed well in this aquifer may be as high as 45 gpd per foot

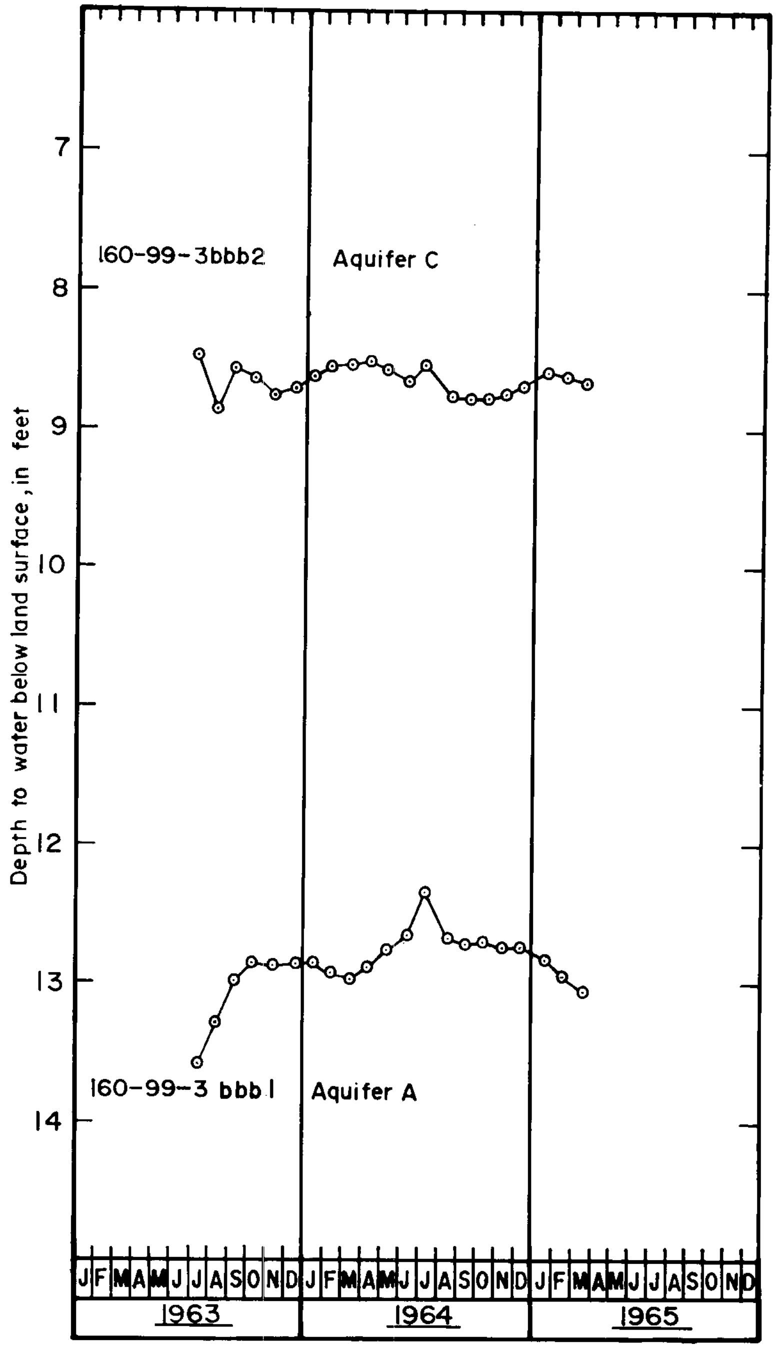

Figure 10. Water-level fluctuations in aquifers A and C in wells 160-99-3bbb1 and 160-99-3bbb2.

of drawdown, and the aquifer should yield more than 500 gpm to wells.

The total quantity of water in storage in the southern unit of the buried Yellowstone channel has not been determined. Aquifer C, however, probably contains more than 300,000 acre-feet of water.

Recharge and water-level fluctuations.--The contour map of the piezometric surface (fig. 6) indicates that recharge to the aquifers in the southern unit is from the higher areas to the east and west of the Bright Water Lake area, a short distance south of the ground-water divide (fig. 9). Bright Water Lake also may contribute some recharge to the upper aquifer. The hydrographs of water levels in aquifer A and aquifer C (fig. 10) show that the water levels are essentially at equilibrium in the two wells that were completed in test hole 160-99-3bbb.

The water level in aquifer C is approximately 4 to 5 feet higher than the water level in aquifer A. Aquifer C is apparently much more extensive than aquifer A and the regional piezometric surface is probably represented by the head in aquifer C.

Quality of water.--A water sample (160-99-3bbb1) from aquifer A contained a sodium sulfate type water with 6,520 ppm dissolved solids, 1,465 ppm sodium, 4,375 ppm sulfates, 1,810 ppm hardness, and had an SAR of 15. Both the salinity and sodium hazards are very high. The classification for irrigation is C4-S4.

A water sample (160-99-3bbb2) from aquifer C contained a calcium sodium sulfate type water with 1,378 ppm dissolved solids, 170 ppm calcium, 250 ppm sodium, 580 ppm sulfate, 576 ppm hardness, and had an SAR of 4.6. The salinity hazard is somewhat high, but the sodium hazard is low. The classification of the water for irrigation is C3-S1. Water from aquifer C probably could be used successfully for irrigation on sandy soils.

Central Unit

The central unit of the buried Yellowstone channel is overlain by lake deposits and ground moraine (fig. 8). The youngest lake deposits apparently were laid down in a proglacial lake formed as the last glacier receded northeastward. Data from logs and test holes drilled in the central unit suggest that there have been several glacial cycles with intervening pondings as each glacier retreated.

The deposits in the central unit consist of sand, silt, till, and some gravel. The ratio of till and silt to sand and gravel is much higher than in the southern unit. Also, the sand and gravel deposits generally are finer grained in the central unit than in the southern unit. Logs of a few test holes, such as 162-97-19ccc3 and 162-98-25ddc, indicate more than 20 feet of saturated coarse-grained sediments. However, other logs and information from private wells indicate that the coarse-grained sediments are not extensive.

Yield.--Individual wells in the central unit produce only a few gallons per minute. The low yields are generally due to the small capacity of the pumps, but a few wells are completed in very limited aquifers and are producing to capacity. The more than 20 feet of sand and gravel that is locally present in the central unit indicates that much more than 50 gpm and possibly as much as 500 gpm probably could be obtained from properly constructed wells completed in aquifers in this unit.

Test drilling shows that the deposits of silt, sand, and gravel in the central unit range in total thickness from 2 feet in well 162-98-23aaa to 146 feet in 162-98-25ddd (the upper 30 feet of silt in the latter well is not saturated and not included in the total); the average thickness is about 47 feet. If the specific yield of these materials is as much as 15 percent, the deposits should yield about 200,000 acre-feet of water to properly constructed wells. Pumping tests should be made on each well to determine the rates at which the water could be produced at reasonably sustained pumping levels.

Recharge and water-level fluctuations.--Recharge to the central unit is probably from three sources: (1) precipitation that infiltrates directly through the silty and sandy soils, (2) underflow from adjacent morainal deposits, and (3) underflow from adjacent Tongue River sediments. The quantity of recharge from the various sources has not been determined, but it is apparently enough to replace most of the water presently being discharged from the aquifer.

Quality of water.--The water in the central unit of the buried Yellowstone channel is similar to that in the glacial drift aquifers elsewhere in Divide County. Generally the water is a calcium bicarbonate type, but locally sodium or sulfate predominate. The SAR commonly is less than 5. However, the high specific conductance (Armstrong, 1965, tables 4 and 5) of the water from some of the wells in this unit suggests that an SAR of more than 5 would not be unusual. The specific conductance ranges from 780 micromhos in well 161-98-20bbb2 to 3,410 micromhos in well 162-97-6dab.

Northern Unit

The northern unit of the buried Yellowstone channel is overlain by ground moraine and outwash deposits. Few data are available concerning the extent, thickness, and permeability of the aquifers in the northern unit. However, the proportion of sand and gravel to the finer-grained materials appears to be somewhat higher than in the central unit.

The city of Crosby has three wells (163-97-34aac, 34ada, and 35bca) that tap two separate aquifers in the northern unit. The upper aquifer is tapped by wells 163-97-34aac (city well 1) and 35bca (city well 3), which are 296 and 310 feet deep, respectively. Well 163-97-34aac has 12 feet of screen and well 163-97-35bca has 20 feet of screen. Probably the aquifers are at least as thick as the length of the screens. Well yields, screen lengths, and the specific capacities of the wells suggest that the aquifer is thicker at well 163-97-35bca than at 34aac. The third well at 163-97-34ada (well 2) penetrates the lower aquifer. The log of the well indicates the aquifer is as least 20 feet thick (Armstrong, 1965, table 2). Little is known concerning the areal extent of these aquifers.

Another aquifer in the northern unit was penetrated between 384 and 457 feet in test hole 163-97-13cc (Armstrong, 1965, table 2). This aquifer, which consists of sand and gravel, may be more extensive than other aquifers in the northern unit because it is at the confluence of the main buried channel and a fairly large buried tributary channel (fig. 5). The greater than usual thickness may be attributed to the confluence of the two streams.

Yield.--Most of the wells in the northern unit are producing only a few gallons per minute or less. However, this is due primarily to the limiting capacity of the pumps or to the low heads in the case of flowing wells.

Maximum yields from the various aquifers in the northern unit have not been determined. The shallower aquifer at Crosby (approximately 296-310 feet deep) has been pumped at 290 gpm for several hours and could be pumped at a somewhat higher rate for at least several days. Well 163-97-35bca, which was pumped at 290 gpm, has a specific capacity of about 6 gpm per foot of drawdown. This specific capacity is based on only 4 to 6 hours of pumping, and the specific capacity of the well for longer periods of pumping is unknown. The specific capacity of well 163-97-34aac, also determined from a few hours pumping, is approximately 1 gpm per foot drawdown. These specific capacities indicate coefficients of transmissibility of less than 12,000 gpd per foot at well 163-97-35bca and less than 2,000 gpd per foot at well 163-97-34aac. The low yields indicate that the aquifer either is composed principally of fine-grained material or is of very limited extent. The pumping rate and specific capacity of well 163-97-34ada, in the deeper aquifer at Crosby, have not been determined, and very little is known of possible yields from this aquifer. The report of 20 feet of coarse sand suggests that the coefficient of transmissibility probably is about 30,000 gpd per foot.

Yields from the aquifer penetrated between 384 and 457 feet in test hole 163-97-13cc (Armstrong, 1965, table 2) have not been determined, but the thickness and permeability of the sand and gravel would suggest a coefficient of transmissibility of at least 55,000 gpd per foot and possibly as much as 100,000 gpd per foot. The probable high transmissibility and larger areal extent of this aquifer indicate more than 500 gpm may be obtainable from it.

Recharge and water-level fluctuations.--Recharge to aquifers in the northern unit is from three sources: (1) underflow from the adjacent Tongue River sediments, (2) precipitation that infiltrates directly through the drift, and (3) underflow from the adjacent morainal deposits. It is not known which source supplies the most recharge.

Several wells in the northern unit of the buried Yellowstone channel either have lower heads, or flow at a lower rate than they did during the study of the Crosby-Mohall area (LaRocque and others, 1963). Most of the indicated decline in water levels and rates is apparently due to: (1) deterioration of the wells, (2) increase in withdrawal, or (3) a combination of the two causes. The water level in well 162-97-21bbc, 50 feet deep, averaged approximately 1 foot higher during the

1963-64 period of measurement than it did during the 1945-47 period of measurement. This indicates more recharge was received during 1963-64 than during the earlier period.

The decline of head in the area of the Crosby well field (163-97-34a and 35b) is caused principally by interference from pumping city wells 1 and 3. Gage readings at Crosby well 3 indicate that the pressure head rises to a level of nearly 20 feet above land surface when the pumps have been off for several hours, indicating that there has been little if any natural decline in the static head. The shut-in pressure head at Crosby well 3 is approximately the same as the altitude of the 1948 water level in 163-97-35babl. Hence, recharge probably equals or nearly equals discharge.

The logs of test holes show that the combined thicknesses of the aquifers in the northern unit range considerably, but average about 50 feet. If the specific yield is as much as 15 percent, about 300,000 acre-feet of water should be available to properly designed and constructed wells.

Quality of water.--The water in the northern unit of the buried Yellowstone channel is similar to that in the glacial drift aquifers elsewhere in Divide County. Generally the water is a calcium bicarbonate type, but locally sodium or sulfate predominate. The SAR ranges from 1.0 in 163-97-29ddb to 10 in 163-97-34ada; the specific conductance ranges from 1,260 micromhos in well 163-97-35babl to 3,710 micromhos in well 162-97-14cdd2.

The analyses of water samples from wells in the buried Yellowstone channel indicate that the quality of water varies both laterally and vertically and distribution patterns cannot be determined with the available data.

Skjermo Lake Aquifer

The Skjermo Lake aquifer is in northwestern Divide County; it mainly underlies the western part of T. 162 N. and the southeastern part of T. 163 N., R. 102 W. (fig. 9). The aquifer is composed of an upper part formed in surficial and buried outwash deposits of sand and gravel, and a basal part formed in buried terrace deposits of sand and gravel. The aquifer is less than a mile wide north of Skjermo Lake, but widens southward to a width of more than 3 miles. It may grade into and overlap the Grenora aquifer. However, the part of the aquifer that will yield the most water is about 2 miles wide near State Highway 5, but narrows to about a mile in width near Miller Lake.

The saturated sand and gravel in the Skjermo Lake aquifer ranges in thickness from 38 feet in test hole 162-102-7ccc to 106 feet in test hole 163-102-13aad. The thickness of the basal gravel in these two test holes is 2 feet and 26 feet, respectively.

The Skjermo Lake aquifer is under water-table conditions from the north end to at least as far south as a pond at 163-102-14d. In test hole 163-102-13aad, the northernmost test hole in the aquifer, the water table was at a depth of 4 feet.

In test hole 163-102-33cdd1, the upper part of the aquifer is 33 feet thick and is covered by 15 feet of silty till from 27 to 42 feet below the land surface. The basal gravel is 24 feet thick at this location. The till cover, which acts as a confining bed, extends at least as far south as Miller Lake. Some wells that have been drilled in topographic lows have flowed. Examples are wells 162-102-20aba and 163-102-33cdc1.

In places the collapsed outwash and outwash deposits are at relatively high topographic positions. In these places, the water table generally is deep and the Skjermo Lake aquifer is thin. For example, test hole 162-103-25bbb, which penetrated 100 feet of outwash sand and gravel, had only about 1 foot of aquifer at the base.

Yield

Three 24-hour aquifer tests were made at the site of test hole 163-102-33cdc1. The test hole was completed as a flowing well by cementing 27 feet of 3-inch pipe in the test hole. The end of the pipe is a few inches above the aquifer. This type of completion (without a screen or slotted pipe in the aquifer) does not allow for an efficient flow of water into the well and all of the aquifer test results should be considered minimal. Two observation wells at distances of 200 and 500 feet from the flowing well were completed near the bottom of the aquifer and equipped with automatic water-level recorders.

The rate of flow was 64 gpm during the first test and about 125 gpm during the second. During the third test the well was pumped at a rate that ranged from about 300 gpm for the first 120 minutes to 280 gpm for the remainder of the test. The results of the first test are plotted on figure 11, which shows the drawdown in the two observation wells in feet versus the logarithmic plot of time in minutes since the test started. The differences in the coefficients of transmissibility (110,000 gpd per foot in the near well and 140,000 gpd per foot in the far well) may be due to the effects of partial penetration of the wells. The effects of partial penetration decrease with increasing distance from the pumped well, and it is possible that the effects are negligible at 500 feet. If so, the coefficient of transmissibility of 140,000 gpd per foot may represent the aquifer transmissibility. As shown on figure 9, properly designed and constructed wells in this aquifer should yield more than 500 gpm. However, the amount of water stored in this aquifer is limited, and future developments should be based on adequate testing of each production well to determine pumping rates and adequate well spacing.

The specific yield may be as much as 20 percent. If so, and if the thickness averages 66 feet, as indicated by the logs of test holes 162-102-7ccc, 163-102-13aad, and 163-102-33cdd1 (Armstrong, 1965, p. 84, 99, and 100), there would be about 170,000 acre-feet of storage in the aquifer in the area shown as yielding more than 500 gpm.

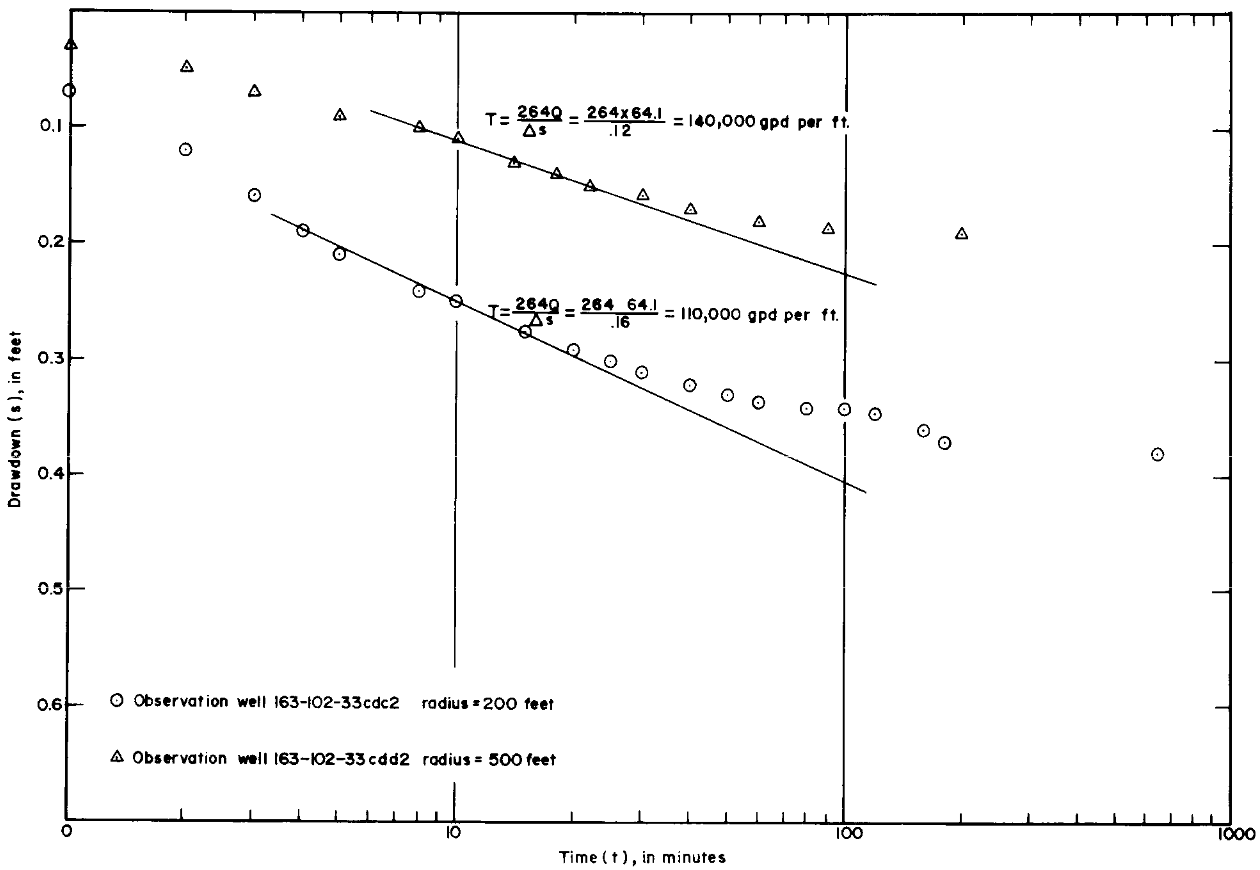

Figure 11. Drawdown (s) versus time (t) during an aquifer test on the Skjermo Lake aquifer.

Recharge and Water-level Fluctuations

The principal source of recharge to the Skjermo Lake aquifer is direct infiltration of precipitation into the sandy soils that overlie the aquifer and the lower west slope of the Alkabo end moraine. Some recharge also may percolate into the aquifer from the Tongue River Formation and from saline lakes to the west. Recharge from lakes probably is small because of the nearly impermeable bottoms and the small number and size of the lakes. There is no recharge from saline Miller and North Lakes, which overlie the aquifer, because the piezometric surface of the aquifer is higher than the lake surfaces.

The hydrographs of observation wells 162-102-7ccc, 163-102-33cdd1, and 33cdd2 (fig. 12) show that the Skjermo Lake aquifer is apparently at equilibrium.

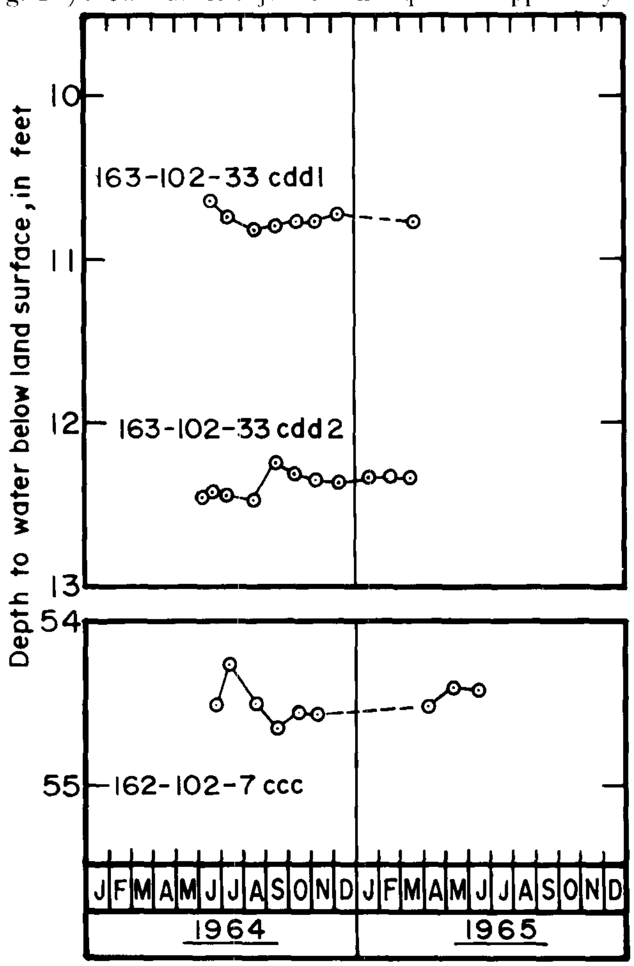

Figure 12. Water-level fluctuations in wells 162-102-7ccc, 163-102-33cdd1, and 33cdd2.

Water levels in the two observation wells rose only about 0.2 foot during the summer of 1964 and declined slightly during the remainder of the record period. However, the period of record is too short to show the long-term effects of droughts or above normal precipitation.

Quality of Water

The water in the Skjermo Lake aquifer generally is of better quality than that in most of the other glacial drift aquifers in Divide County. The water generally is very hard and is a calcium bicarbonate type. However, Skjermo Lake, which is hydraulically connected to the Skjermo Lake aquifer, contained a magnesium bicarbonate water when sampled on May 13, 1964. Perhaps magnesium was added by surface runoff.

The water from well 162-102-7ccc was appreciably higher in sodium, bicarbonates, and sulfates than water collected elsewhere in the aquifer. Apparently the poorer quality is caused by recharge from the west where there are several small lakes containing water high in sodium and sulfates. The SAR ranges from 1.2 in well 163-102-33cdcl to 7.1 in well 162-102-7ccc. The specific conductance ranges from 1,131 micromhos in well 163-102-33cdcl to 3,660 micromhos in observation well 162-102-7ccc. The water is suitable for irrigation of most crops except in the western part of the aquifer where it is marginal to unsuitable.

Only one sample of water was obtained from the basal gravel in the Skjermo Lake aquifer in Divide County (Armstrong, 1965, table 5). The analysis shows that the water is a sodium bicarbonate type with a total dissolved solids of 907 ppm. The water sample contained 0.42 ppm iron, the only ion present in concentration exceeding Public Health standards. The sodium percentage was 52 and the SAR number was 4.5. The water is classified as C3-S1, and probably could be used for irrigation on all but heavy soils.

Aquifers in the Buried Missouri Channel

The buried Missouri channel, which was formed prior to the advance of the earliest Wisconsin glacier, extends from the southwest corner of Divide County (fig. 5) to the vicinity of Miller Lake, thence northeasterly past the villages of Fortuna and Colgan and across the international boundary into Canada near Ambrose.

The water-bearing deposits in the buried Missouri channel in Divide County can be divided into two hydrogeologic units based on characteristics of the deposits in each area. These units are identified on figure 9 as the Grenora aquifer and the northeastern unit. The boundary between the two units is poorly defined but is approximately along the western side of the Alkabo end moraine near Miller Lake (figs. 8 and 9).

Grenora Aquifer

The Grenora aquifer is named after the city of Grenora, Williams County, North Dakota, which overlies part of the aquifer south of Divide County. For the first few miles south of Miller Lake the aquifer is composed of an upper part predominantly of silt and a few layers of coarse sand and fine gravel and a basal gravel. Southward, through T. 160 N., R. 103 W., the upper sand and gravel layers are more numerous and are thicker and more permeable. The total thickness of the sand and gravel in this aquifer ranges from 32 feet in test hole 160-103-5aaa to 87 feet in 160-103-16bbb. The silt in this aquifer ranges in thickness from 12 to 298 feet. This latter thickness includes considerable clayey silt.

Yield.--Wells in the Grenora aquifer generally yield only a few gallons per minute, although more than 500 gpm is locally available. In many places, especially in T. 161 N., Rs. 102 and 103 W., low yields are due to the thinness of the upper sand or gravel lenses in which the wells are finished. However, yields of more than 50 gpm probably could be obtained by the combined screening of several of the more sandy zones in the aquifer. In the western part of T. 161 N., R. 102 W. and the eastern part of T. 161 N., R. 103 W., where the basal gravel is thickest, the transmissibility is probably as much as 100,000 gpd per foot. Specific capacities as high as 50 gpm per foot of drawdown and yields of more than 500 gpm probably could be obtained from wells screened in all of the more permeable zones.

Data are not available to determine the quantity of water in storage in the Grenora aquifer. The areal extent of the aquifer suggests, however, that it contains more water than the northern unit of the buried Yellowstone channel.

Recharge.--Recharge to the Grenora aquifer is derived from four sources: (1) direct infiltration of precipitation, (2) ground-water underflow from the Skjermo Lake aquifer, (3) underflow from the adjacent Tongue River Formation, and (4) underflow from the adjacent moraine deposits. The quantity of recharge from these sources is not known, but the moraine deposits probably contribute the smallest quantity of water owing to their thinness in the vicinity of the Grenora aquifer.

Quality of water.--The water in the Grenora aquifer is similar to that found elsewhere in the glacial drift aquifers in Divide County. Generally the water is a hard calcium magnesium bicarbonate type, but locally sodium or sulfate predominate. The SAR, as determined from five samples, ranged from 1.1 in well 161-102-27cbb to 5.2 in well 160-103-5aad; it averaged 3.4. The specific conductance ranged from 1,444 micromhos in well 160-102-27cbb to 2,930 micromhos in well 160-103-27dcc.

Generally the water in the Grenora aquifer has a low sodium hazard but a high to very high salinity hazard for irrigation. Therefore, water in this aquifer should be considered marginal in quality for irrigation.

The chemical character of water from the basal gravel of this aquifer has not been determined.

Northeastern Unit

The northeastern unit of the buried Missouri channel contains several irregularly distributed deposits of water-bearing sand and gravel. These deposits are probably elongated, but all seem to be of small lateral extent and apparently are not interconnected; however, the channel extends northeastward from the Alkabo end moraine to the international boundary, and it is possible that some of the elongated sand and gravel aquifers do connect. It is also possible that larger aquifers do exist in places not penetrated by test drilling.

The irregular distribution and limited extent of the aquifers are inferred from the fact that several deep wells have been drilled in the northeastern unit and have not encountered any significant quantities of sand or gravel, whereas, sand or gravel has been penetrated nearby. For example, 45 feet of gravel was penetrated between 385 and 430 feet in test hole 163-100-31daa, but it was not encountered in either well 163-100-31aab, less than half a mile north or 163-100-32abb, about 0.7 mile northeast. Logs are not available for these wells, but the owners reported that sand or gravel was not encountered above the completion depth of the wells, which were 637 and 650 feet respectively. Another example is the gravel and sand that was encountered from 92 to 102 feet in test hole 163-99-18aaa was not encountered less than half a mile to the west when the farmer was drilling for a domestic supply.

Yield.--The yield of ground water from aquifers in the northeastern unit generally ranges from 1 to 30 gpm. The latter figure was obtained from a 1-hour pumping test on city well 4 in Fortuna. The logs (Armstrong, 1965, table 2) indicate aquifers from which larger quantities of water may be obtained. For example, 34 feet of sand and gravel was penetrated at a depth of 92 to 126 feet in test hole 162-101-31aaa. Based on an estimated permeability of 3,000 gpd per square foot, this aquifer probably would have a transmissibility of about 100,000 gpd per foot and may yield as much as 500 gpm. However, the probable narrowness of the deposit points to the likelihood that a high yield could be obtained for only a short period. Pumping tests of several days duration would be necessary before dependable yields could be determined.

Recharge and water-level fluctuations.--Recharge to the aquifers in the northeastern unit is primarily from sloughs, prairie potholes, and areas of surficial sand or gravel. Water from these sources slowly infiltrates through the underlying

Depth to water level below land surface, in feet

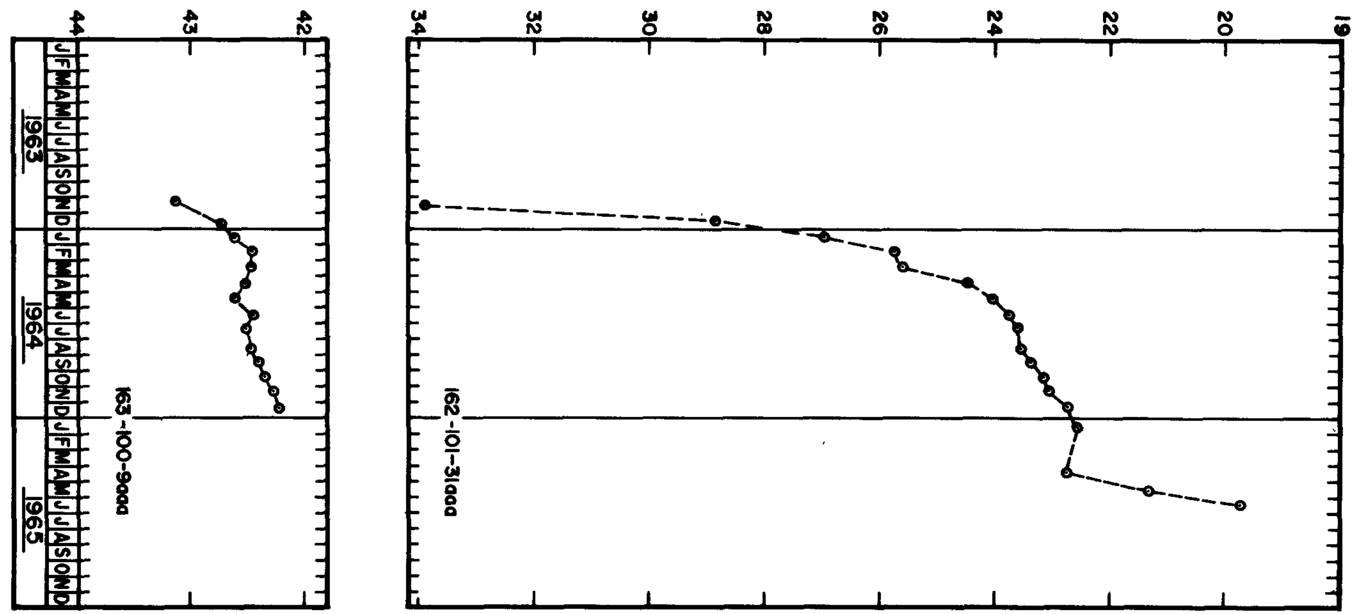

Figure 13. Water-level fluctuations in wells 162-101-31aaa and 163-100-9aaa.

glacial till and probably replaces most of the water presently being discharged. However, it is likely that the small aquifer currently developed by the village of Fortuna is being dewatered.

The Fortuna well field is located on a wide ridge about three quarters of a mile south of the village. The ridge is locally capped by gravel and receives some recharge, but the gravel areas are small, and recharge also is small. The wells probably are pumping more water than is being recharged, and the difference results in a decrease in storage.

Figure 13 shows the monthly water-level fluctuations in 2 observation wells, each of which tap aquifers in the northeastern unit. The hydrograph of 163-100-9aaa indicates that near equilibrium conditions exist in the aquifer. The hydrograph of 162-101-31aaa shows that for the period of record, recharge to the aquifer exceeded discharge from the aquifer. The unusually large rise in water level may be due to the greater than average precipitation of 1962 to 1964 that followed a period of below normal rainfall in 1960 and 1961.

Quality of water.--The quality of water in the aquifers of the northeastern unit is somewhat variable with total dissolved solids in 7 of 8 samples exceeding 1,250 ppm. The one exception was 242 ppm total dissolved solids in the sample taken from 162-101-3dba. The water in all of the samples was very hard, ranging from 200 ppm in well 162-101-3dba to 1,190 ppm in well 163-100-20dbc. The water has a low to high sodium hazard and a medium to very high salinity hazard (fig. 4).

Wildrose Aquifer

The Wildrose aquifer is named for the city of Wildrose, Williams County (159-97-2b, which is near the southern part of the area underlain by the aquifer. The boundaries of the aquifer are inferred largely from surficial geologic evidence (fig. 8). The surficial materials consist of lake deposits (predominantly silts) and collapsed deposits of outwash sand and gravel. In the subsurface, the aquifer generally consists of poorly sorted, fine sand to medium gravel in beds that range in thickness from 1 to 29 feet. These deposits seem to occur in interconnected channels. Silt beds also are common (see logs of test holes 160-96-26bbb, 160-97-13bbb, 160-97-36bcb, and 161-96-35ddd; Armstrong, 1965, table 2).

Yield

No large capacity wells have been constructed in the Wildrose aquifer, consequently, little is known concerning the aquifer's ability to yield water. The texture and thickness of the water-bearing materials indicate that production wells capable of 5 to 10 gpm per foot drawdown should be possible. Generally, there is less than 50 feet of water above the intake of well pumps in this aquifer so yields would be less than 500 gpm. However, in local areas where the aquifer is unusually thick, yields in excess of 500 gpm might be obtainable.

The city of Wildrose has a municipal well constructed in this aquifer that is reported to yield about 85 gpm. The specific capacity of the well when drilled (1952), based on a 24-hour pumping test at the rate of about 200 gpm, was between 6 and 7 gpm per foot of drawdown.

Based on surficial geologic evidence, logs of test holes, and an assumed specific yield of 15 percent, there appears to be a minimum of 100,000 acre-feet of water in storage in the Wildrose aquifer that is available to properly constructed wells. Water also is stored in the interbedded silt deposits and is available to replace water withdrawn from the sand and gravel, but the replenishment rate would be slow. Four test holes drilled in the Wildrose aquifer penetrated an average thickness of 24 feet of silt. If the specific yield is as high as 15 percent, approximately 90,000 acre-feet of water would be available from the interbedded silts. Therefore, approximately 190,000 acre-feet of water is available for future withdrawal.

Recharge and Water-level Fluctuations

Recharge to the Wildrose aquifer is mainly by direct infiltration of precipitation through the sandy soils of the outwash and lake sediments. Some recharge also may be derived from buried glaciofluvial sand and gravel deposits in the adjacent glacial drift. The quantity of recharge is not known, but it apparently is sufficient to replace the water presently being discharged by wells in the area. The hydrograph (fig. 14) of well 160-97-13bbb, which penetrates the Wildrose

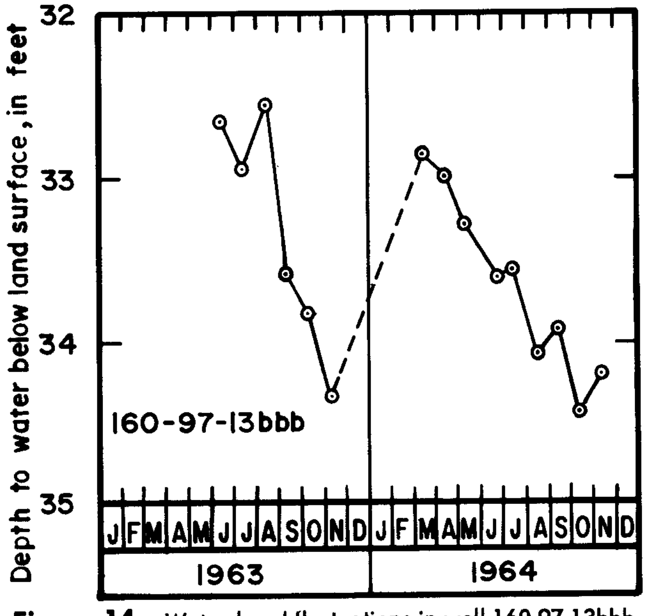

Figure 14. Water-level fluctuations in well 160-97-13bbb.

aquifer, shows an annual water-level fluctuation of nearly 2 feet. There are no nearby wells to cause interference, so the fluctuations probably are the result of seasonal changes in storage.

Quality of Water

Ground water in the Wildrose aquifer is rather variable in quality. Partial analyses of samples of water from four wells are shown in the following table.

	Analyses in parts per million							
Location	Ca	Na	HCO_3	SO_4	Dissolved solids	Hardness	Percent Na	SAR
160-96-4ccb	396	224	449	1,500	2,710	1,450	23	2.6
160-96-17cdb	81	13	227	67	391	304	8	.3
160-97-13bbb	60	9.6	298	43	291	260	7	.4
160-97-36bcb	102	195	537	525	1,316	610	40	3.5

The hardness and the high sulfate content of some of the water may limit the use of the water for some purposes. The water has a low sodium hazard and a medium to very high salinity hazard.

West Wildrose Aquifer

The West Wildrose aquifer boundaries are based on surficial geology, well and test-hole logs, and data obtained from a pumping test. The aquifer in Divide County has an areal extent of about 1.7 square miles and occupies most of section 32, the west half of section 33, and small parts of sections 29 and 31, T. 160 N., R. 97 W. (fig. 8). It trends from this area southwestward toward the Little Muddy River in Williams County. The south half of the area underlain by the aquifer is covered by collapsed outwash composed of from 1 to 14 feet of gravel, sand, and silt. The till underlying the outwash is generally more silty than that in other parts of the county. Logs (Armstrong, 1965, table 2) show that the principal aquifer consists of sand and gravel that ranges from 15 to 46 feet in thickness. The top of the aquifer ranges in depth from 88 feet in well 160-97-32aac to 125 feet in well 160-97-32dca.

Yield

One irrigation well, 160-97-32ddb1, has been constructed in the West Wildrose aquifer. It is 138 feet deep and penetrates the full thickness of sand and gravel from 121 to 138 feet. The well was completed with a 17-inch permeable concrete screen from 118 to 138 feet. The pump bowls were set at a depth of 100 feet. During a very short-term development test conducted by the driller, the well was reported to have yielded more than 1,100 gpm. However, during a subsequent 49-hour test, a rate of 750 gpm proved to be excessive.

The 49-hour pumping test was run September 27-29, 1962 using the irrigation well at 160-97-32ddb1 as the pumped well and wells 160-97-32daa, 160-97-32dac, and 160-97-32ddb2 as observation wells. The observation wells are 1,900, 575, and 350 feet, respectively, from the pumped well. During the test, water was pumped through irrigation pipe and distributed over about a quarter section of land by a sprinkler system. Discharge was determined by comparing the pressures at the sprinkler heads with a rating curve. By this method it was determined that the discharge averaged about 735 gpm during the first 1,400 minutes of the test and 750 gpm during the latter part of the test. Minor variations in pumping rate could not be determined. The drawdown test was terminated after 49 hours because of fluctuating water levels caused by turbulent flow of water as the drawdown neared the top of the pump bowls.

Figure 15 is the plot of drawdown in feet versus time in minutes since pumping started. The static water level, which was 57.83 feet below land surface in the pumped well, is not shown on the plot. The first 7 to 8 minutes of drawdown record show the effect of a reducing rate (which could not be determined) of discharge due to increasing back pressure as the irrigation pipe filled. The two departures from the curve between 27 and 53 minutes were the result of changes in pumping rate caused by reduced head while leaks were being fixed. The pumping rate was changed from 735 to 750 gpm when the location of distribution pipe was changed. The variations in pumping rate and imprecise method of determining the rate cast some doubt on the reliability of the test results. After the pumping was completed, a 24-hour recovery test was made by measuring the rate of rise of the water levels in the four wells. The results checked reasonably well with the drawdown test. The coefficient of transmissibility was about 78,000 gpd per foot during the early part of the test. The coefficient of transmissibility apparently reduced throughout the test to a final figure of about 10,000 gpd per foot. The apparent reduction of the value of the coefficient is due to the effects of the nearly impermeable barrier northeast of the aquifer rather than any impairment of the aquifer's capacity to transmit water. The formula upon which the calculations are based assumes ideal conditions. Any departure from the ideal conditions, either in the aquifer or the pumping test, may cause the results of the test to be questionable.

This aquifer, being composed principally of sand and gravel, probably would have a specific yield of about 20 percent. If the aquifer averages 26 feet in thickness, it would contain approximately 5,600 acre-feet of usable water in storage in Divide County.

Analyses of the test data lead to the following conclusions: (1) the aquifer will not produce a sustained yield of 750 gpm without a drawdown in excess of

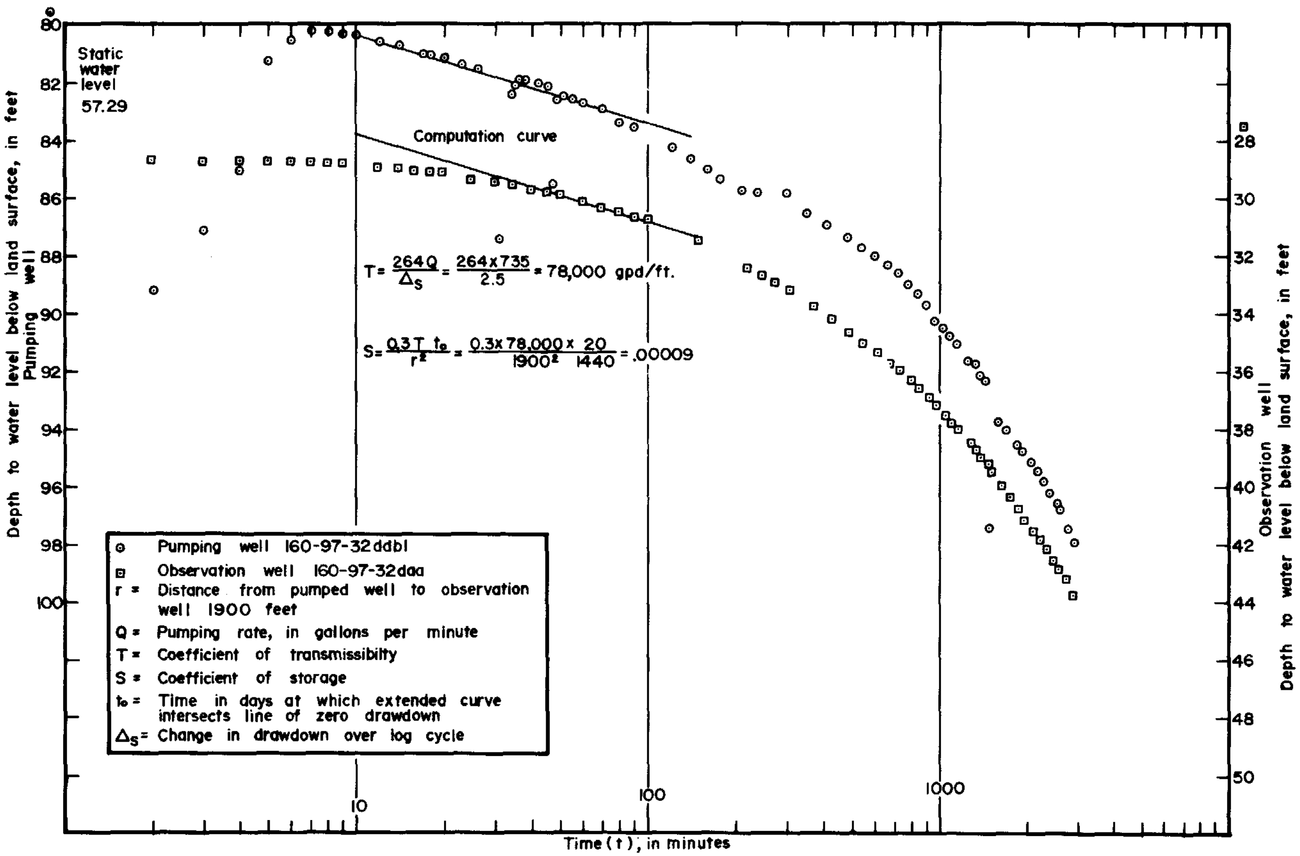

Figure 15. Drawdown (s) versus time (t) during a pumping test on the West Wildrose aquifer.

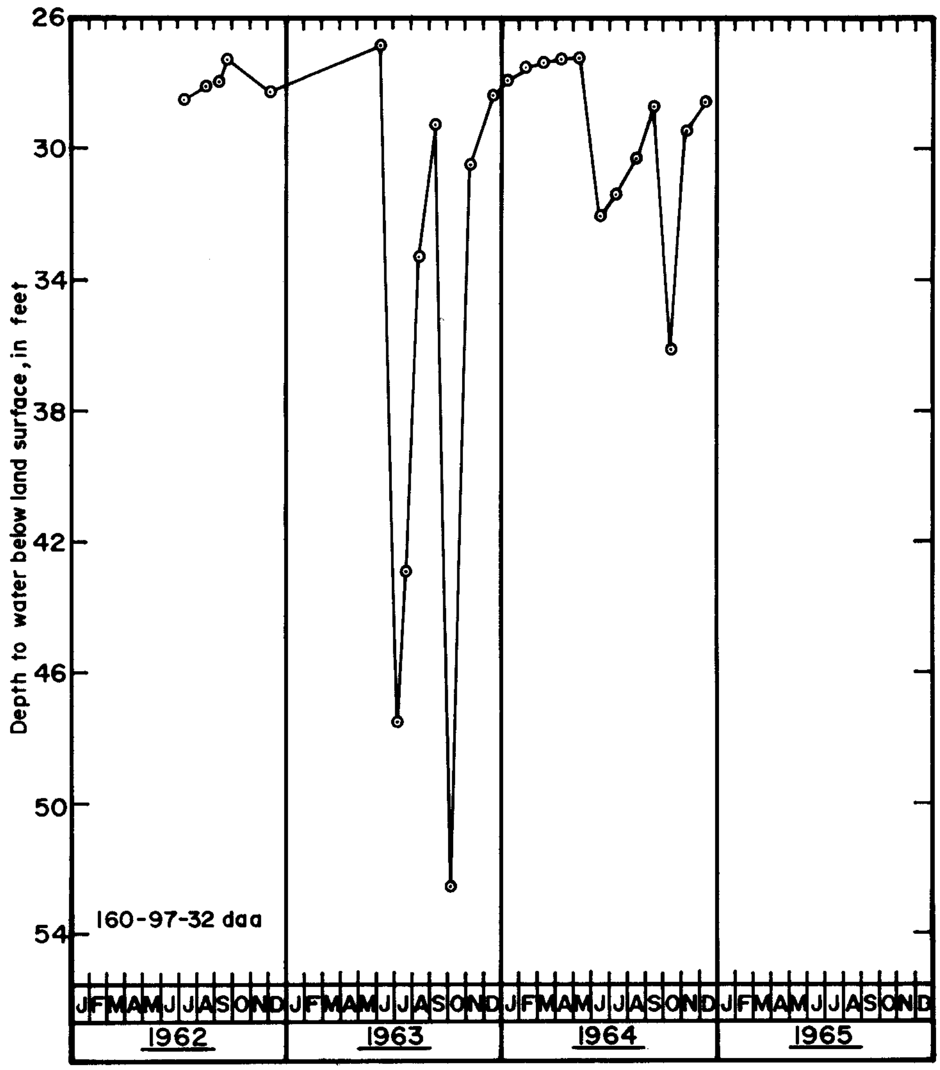

Figure 16. Water-level fluctuations in well 160-97-32daa.

40 feet in the vicinity of well 160-97-32ddb1, (2) a relatively impermeable barrier lies northeast of 160-97-32daa, and (3) the long-term specific capacity is less than the 19 gpm per foot of drawdown computed for the 49-hour period of pumping.

Subsequent to the test, the pump bowls were lowered and an additional column added so that the bottom of the suction pipe is drawing water from 123 feet below land surface. The sprinkler system was also changed so that approximately 680 gpm would be pumped. No additional pumping tests were run. However, on October 9, 1963, after well 160-97-32ddb1 had been pumping from 8 to 10 days, the water level in observation well 160-97-32daa was 52 feet below land surface. This level was 8.25 feet lower than the lowest level reached during the 49-hour pumping test.

Observations made during and after the pumping test suggest that the most efficient way to use the West Wildrose aquifer would be to pump water for several days, then discontinue pumping for a few days to allow the water levels to recover before pumping is repeated.

Recharge and Water-level Fluctuations

Recharge to the West Wildrose aquifer is by direct infiltration of rainfall and snowmelt through the sandy soils overlying the more permeable outwash, seepage from the prairie potholes, and possibly by underflow from the Wildrose aquifer. A hydrograph of observation well 160-97-32daa shows the effects of pumping the irrigation well (fig. 16). The observation well is 1,900 feet northeast of the irrigation well. The hydrograph shows that the 140 acre-feet of water that was pumped from the vicinity of 160-97-32ddb1 during the summer of 1963 was replaced by January 1964. During the summer of 1964, the pump was operated approximately 36 days and pumped an estimated 125 acre-feet of water. By December 1964, the water level in 160-97-32daa had recovered to about a foot below the preceding spring level.

Quality of Water

The water in much of the central part of the West Wildrose aquifer is probably similar to that obtained from the irrigation well, 160-97-32ddb1. This water was a very hard, calcium sodium bicarbonate water containing about 500 ppm dissolved solids (Armstrong, 1965, table 5). None of the constituents exceed the limits set by the U.S. Public Health standards. The sodium hazard is low, but the salinity hazard is high; the irrigation classification is C3-S1.

A sample of water taken from observation well 160-97-32daa, which is near the east side of the aquifer, had a specific conductance of 2,854 micromhos and a hardness of 1,030 ppm. This high specific conductance, coupled with slight increases in the specific conductances of a series of samples taken from the irrigation well during the pumping test, suggests that a small quantity of water migrated from near the edge of the aquifer to the well. This in turn suggests that the quality of water from the irrigation well will deteriorate as pumping continues. However, it may not be a serious problem if overpumping does not occur.

Outwash Channel Aquifers

The outwash channel and alluvial deposits in Divide County are not differentiated. In areas where the alluvial deposits can be differentiated they are generally thin and not significant as aquifers. The outwash channel deposits generally are water-bearing and yield enough water for domestic and stock supplies (fig. 8). However, they generally are too thin to form major aquifers.

The deposits are composed principally of sand and gravel with minor amounts of silt and clay. The known thickness ranges from 0 at the edges of the deposits to 104 feet in test hole 162-103-25bbb. However, it is generally less than 35 feet. The deposits are thicker and the material coarser near the center of the channels. Near the edges of these deposits, especially at topographically high positions, water may occur only in the bottom few inches of the sand and gravel. In places water sufficient for domestic or stock supplies can be obtained only from large-diameter wells, which function as collecting reservoirs, dug through the outwash deposits and into the underlying till. Well 161-100-31ddd is an example of this type (Armstrong, 1965, table 1). In 1962, there was nearly 4 feet of water in the 14-foot well.

The outwash deposits west of Crosby contain considerable quantities of water. At the present time (1965) the water is used only for domestic and stock supplies, but in the past it was a source of municipal supply for the city of Crosby. Before 1941, the city obtained between 50,000 and 100,000 gpd from two wells in these deposits, and probably can obtain a similar quantity at present. However, periods of drought, like that in the 1930's, will cause the water levels to decline and the yield of wells will decrease accordingly.

An outwash channel heads about a mile north of Fortuna and extends southwestward to join the more extensive deposits west of the Alkabo end moraine (fig. 8). The maximum thickness of the outwash is not known, but a small gravel pit at 163-101-22d on the northern side of a small ridge about a mile north of Fortuna shows that it is at least 10 feet thick. Apparently some of the precipitation that infiltrates these deposits percolates downward until it reaches the water table and then moves laterally to emerge as springs along the edge of the ridge. Well 163-101-22cdc, which flowed 3 gpm in 1963, was developed at the site of one of the larger springs. The spring was converted into a 10-foot diameter well to increase the yield.

Vorhis (1949, p. 14) stated "the largest ground-water reservoirs in the area are the principal glacial-outwash channels." Stady channel was included in his principal channels (fig. 8). Three test holes, 161-101-35add, 160-102-18ccc, and 160-103-20dcd, were drilled into the channel during this investigation to explore the possibilities of a large water supply. The test holes penetrated only 10 feet, 6 feet, and 8 feet of outwash material, respectively. The sand and gravel are not saturated through the full thickness, so the ground-water potential of this channel is very small. The records of domestic and stock wells in the channel also show that the deposits are thin throughout the Stady channel.

The other outwash channel deposits in the county also are thin and will not yield more than a few gallons of water per minute per well.

Recharge to the outwash aquifers is principally from precipitation that percolates rapidly to the water table. Recharge to these aquifers is greater per unit area than elsewhere in the county, but the total quantity of recharge is small because of the small areal extent of the outwash deposits.

Quality of Water

Water in the outwash deposits probably is of better quality than in most other glacioaqueous deposits. The analysis of water from well 163-101-22cdc indicates a calcium bicarbonate type with only 439 ppm dissolved solids. It probably is similar to much of the water in other outwash deposits in the county.

Undifferentiated Drift Aquifers

Numerous small glaciofluvial deposits of sand and gravel are interspersed within the till throughout much of Divide County. Where they lie within the zone of saturation, they form aquifers of varying importance depending on their volume, permeability, and accessibility to recharge. For the most part the deposits were formed in long narrow channels. Some, however, are also short.

The irregular distribution and limited extent of these aquifers are illustrated on figure 17, which was constructed mainly from test hole data. For example, the gravel penetrated at 194 feet in test hole 161-96-35ddd was not penetrated 0.6 mile east in well 160-96-4aad (Armstrong, 1965, table 1). Some farmers have reported drilling as many as five test holes within a small area of the farm before enough sand was penetrated to yield a sufficient supply of water for domestic purposes. Others failed to discover any drift aquifers of significance and, consequently, must haul water for several miles.

Yield

The small size of most of the undifferentiated drift aquifers severely restricts their capacity to yield water to wells. Yields from these aquifers generally range from 90 gpd to 20 gpm. However, yields of more than 10 gpm are unusual and probably most could not be sustained for more than a few days.

Recharge and Water-level Fluctuations

Recharge to the undifferentiated drift aquifers is principally from sloughs, prairie potholes, areas of surficial sand or gravel, and adjacent deposits of glacial till. Most of the sloughs and prairie potholes contain water during the spring and early summer months. Even though these areas are underlain with materials having very low permeabilities, the water is available for a long enough period that some recharge probably does occur. The quantity of recharge from any one slough of prairie pothole probably is small, but the total is significant and probably sufficient to replace most of the water presently being discharged.

Figure 18 shows the monthly water-level fluctuations in two observation wells, each of which taps a small, undifferentiated drift aquifer.

The hydrographs of wells 162-95-15bbb and 162-98-33cbb indicate near equilibrium conditions in the aquifers. Well 162-95-15bbb taps a shallow aquifer, and the water level appears to reflect the seasonal variations of rainfall and pumping. (See Armstrong, 1965, tables 1 and 3.)

Quality of Water

Ground waters in the undifferentiated drift aquifers are variable in quality, as would be expected. The total dissolved solids in the samples obtained range from 386 ppm in well 160-95-27aad2 (25 feet deep) to 3,690 ppm in well 161-102-25ddc (152 feet deep). Hardness ranged from 198 ppm in well 162-96-33bab (291 feet deep) to 2,500 ppm in well 161-101-13cbd (87 feet deep). Sulfates ranged from less than 50 ppm in several wells to 2,300 ppm in well 161-102-25ddc. In general, water with more than 1.000 ppm hardness also has more than 700 ppm sulfate. The percent sodium is usually less than 70. The water generally has a low to medium sodium hazard and a medium to very high salinity hazard (fig. 4).

PUBLIC WATER SUPPLIES

Crosby

Prior to 1941, the city of Crosby obtained its water supply from two wells in the outwash channel deposits west of town. The two wells were pumped alternately until the water level declined to the pump intake. Apparently the well that was pumped nearly dry would recover by the time the other well was dewatered. Accurate pumpage records are not available, but it has been reported that approximately 50,000 to 100,000 gpd were pumped in this manner.

In 1941 Crosby drilled a deep well into the buried Yellowstone channel at 163-

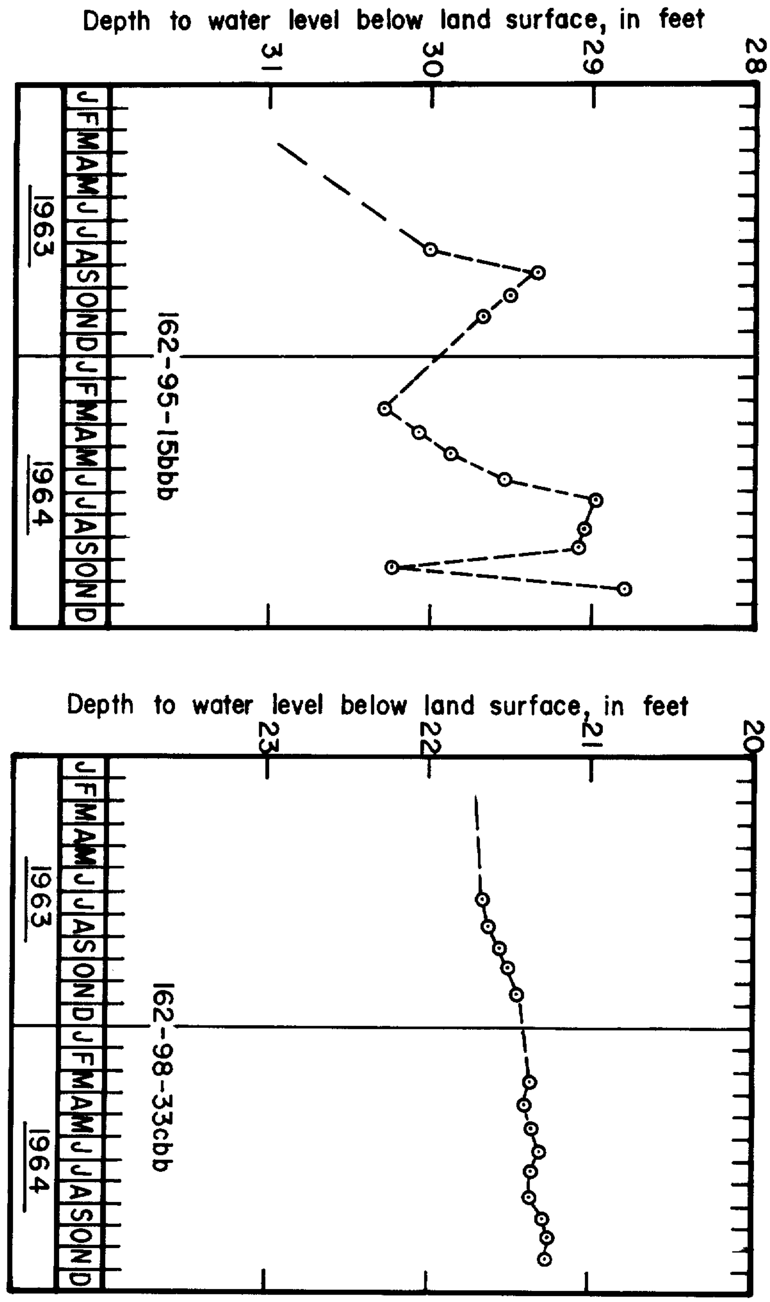

Figure 18. Water-level fluctuations in wells 162-95-15bbb and 162-98-33cbb.

97-34acc (well 1). This well is reported to yield 74 gpm; however, it is usually pumped at this rate for only a few hours.

In 1949 the city drilled a second deep well at 163-97-34ada (well 2). It was drilled to a deeper zone and does not yield as much water as well 1. Well 2 was used as a standby supply until 1964 when its use was discontinued.

In 1957 the city drilled well 163-97-35bca (well 3), which has proven to be the best producer of the three deep wells. It is pumped at 290 gpm and is presently the principal source of supply; well 1 is on standby basis.

The city engineer reports that well 3 supplies about 70-80 percent of the total city supply. A partial daily record of pumping from well 3 for the years 1962 and 1963 indicates that the maximum daily pumpage occurred during July 28 and 29, 1962, when 315,500 gallons of water were used. The maximum monthly pumpage occurred August 1962, when 6,230,000 gallons were pumped. The average monthly pumpage for the 2-year period was 3,600,000 gallons. If this figure represents 75 percent of the total supply, then the average city use would be about 4,800,000 gallons monthly, or about 160,000 gallons per day. If the population remained the same as when the 1960 census was taken, the daily per capita use would have been 91 gallons.

Prior to 1964, the city also had a large-diameter well, 163-97-29ddb, which is 38 feet deep. It was equipped with a hand pump and furnished drinking water to those who did not like the taste of the regular city supply. This well was shut down in 1964 because of excessive nitrates in the water.

The quality of the municipal water supply varies with the wells in production. The water from wells 1 and 3 is a sodium bicarbonate type with about 900 ppm dissolved solids. Iron is the only constituent that is present in quantities greater than the limits recommended by the U.S. Public Health Service. Water from well 2 is also a sodium bicarbonate type, but it has a higher iron content and about 1,200 ppm dissolved solids. The SAR is 10 in well 2, whereas it is approximately 5 in wells 1 and 3.

Noonan

The city of Noonan obtains its water supply from three wells, 162-95-4add2, 162-95-4add3, and 162-95-4acd; these are wells 1, 2, and 3, respectively. Well 1 obtains water from the glacial drift; wells 2 and 3 obtain water from the Tongue River Formation. The city's distribution system is supplied by water from wells 2 and 3. The combined usage from the wells ranges from 15,000 to 25,000 gallons daily, of which approximately 75 percent is obtained from well 2. Well 1 is equipped with a hand pump and is not part of the regular distribution system. However, the well furnishes much of the city drinking water.

Well 1 contains very hard calcium magnesium bicarbonate sulfate water with about 621 ppm dissolved solids. Well 3 contains soft, sodium bicarbonate water with about 1,958 ppm dissolved solids. Water from well 2 is similar to that from well 3, but it contains less sodium and sulfate. Iron is the only constituent that exceeds the limits recommended by the U.S. Public Health Service.

Ambrose

The city of Ambrose obtains its water supply from four wells, but there is no distribution system. Two flowing wells, 163-99-12cac1 and 12cac2, supply water that is used principally for cleaning and sanitation purposes. The wells flow at a combined rate of 10 gpm; much of the discharge is wasted.

The city's drinking water supply is hauled from wells 163-98-18cdc1 and 18cdc2 about 2 miles from the city. These wells furnish only a few thousand gallons per week.

The water from the flowing wells is a soft, sodium bicarbonate type having about 2,140 ppm dissolved solids. Iron and sulfate are both in excess of the quantities recommended by the U.S. Public Health Service. Water from well 163-98-18cdc1 and probably from well 163-98-18cdc2 is a very hard, calcium magnesium bicarbonate type containing 431 ppm dissolved solids. No constituents are in excess of the recommended Public Health standards.

Fortuna

The Fortuna water supply is obtained from four wells in 163-101-35c. Two (163-101-35cac1 and 161-101-35cca) are shallow, large-diameter wells that are used when water levels are high, usually only in late spring. The other two wells, 163-101-35cac3 and 163-101-35ccb2, are 91 and 106 feet deep, respectively, and are used throughout the year. (See Armstrong, 1965, table 1.) These wells supply from 60,000 to 100,000 gallons per month. The greatest usage of water generally is when school is in session.

The analysis of water from the deeper wells shows that the water is a very hard, sodium calcium sulfate type, containing about 1,493 ppm dissolved solids. (See North Dakota State Dept. of Health, 1964, p. 8.) The sulfate ion exceeds that recommended by the U.S. Public Health Service.

When Fortuna develops a need for an additional water supply, the best areas to prospect for it are to the south-southwest of their present supply, or in the outwash channel deposits about a mile north of the village (fig. 8). The outwash deposits will not supply as large a quantity of water as the aquifer to the south-southwest, but the quality of the water will be much better.

Other Public Supplies

The villages of Colgan and Alkabo have shallow, large-diameter wells equipped with hand pumps. They do not have distribution systems.

The water at Colgan is a very hard, calcium magnesium sulfate type having a dissolved solids content of 1,760 ppm. The sulfate ion exceeds that recommended by the U.S. Public Health Service. Iron is slightly in excess of the recommended quantity.

A sample of water from the well at Alkabo shows that the water is a very hard, magnesium calcium bicarbonate type containing 534 ppm dissolved solids.

SUMMARY AND CONCLUSIONS

Ground water is present in practically all of Divide County in glacial drift aquifers or in the underlying Tongue River Formation of the Fort Union Group. Five major drift aquifers have been identified and described. In addition, a large number of small drift aquifers are scattered throughout the county. Where glacial drift aquifers are not present, water adequate for at least stock-watering purposes can usually be obtained from the underlying Tongue River Formation; however, it is unlikely that large supplies of water can be obtained in these areas.

The aquifers with the greatest potential for ground-water development for irrigation or light industry, in order of importance are: The buried Yellowstone channel, Skjermo Lake, Grenora (the principal aquifer in the buried Missouri channel), Wildrose, and West Wildrose aquifers. The buried Yellowstone channel deposits were divided into three hydrogeologic units: (1) southern, (2) central, and (3) northern. Specific capacities of wells in the southern unit may be as high as 125 gpm per foot of drawdown, and locally, yields greater than 500 gpm can be expected from it. Yields from wells in the northern unit of the buried Yellowstone channel deposits likely will range from 100 to 400 gpm with about 100 feet of drawdown. Locally, however, yields may exceed 500 gpm. Yields in the central unit probably would be somewhat less than in the northern unit; locally yields may be only a few gallons per minute. Large dependable supplies of water probably could be obtained from a field of several wells in either the northern or central units, which contain about 50,000 acre-feet of water. The quality of water in the aquifers of the buried Yellowstone channel is variable so an analysis of the water at a particular site would be necessary to determine the usability of the water. Much of the water in these aquifers is considered to be marginal for irrigation, but could be used on light soils or with the use of proper additives.

The Skjermo Lake aquifer, in the western part of Divide County, has a good potential for large-scale ground-water development. Yields in excess of 500 gpm probably could be obtained from much of this aquifer. The water in much of the aquifer is considered to be good to marginal for irrigation and could be used on most of the soils overlying the aquifer.

The Grenora aquifer is a fairly extensive aquifer that may yield as much as 500 gpm if all sand and gravel lenses are developed. Sufficient quantities to meet irrigation or industrial needs could be developed in the southern part of this aquifer. Except locally, the northern part of the aquifer will not support large-scale ground-water development. The water is generally considered to be of marginal quality for irrigation.

The Wildrose aquifer in the southeastern part of the county has a potential for small to moderate ground-water development. Yields probably would be less than 500 gpm to individual wells. The water, although variable in quality, is generally considered to be good to marginal for irrigation purposes.

The West Wildrose aquifer, located a few miles west of the Wildrose aquifer, has a very limited potential for further development in Divide County. Some of the aquifer is capable of yielding more than 500 gpm to wells, but the small areal extent of the aquifer combined with interference due to pumpage from several large-production wells would cause a rapid decline in the pumping rates. The water in this aquifer is generally suitable for irrigation.

The chemical quality of the water in the Tongue River Formation in Divide County is generally too poor to be recommended for human consumption or agricultural uses. In most places, however, it is suitable for livestock. Analyses show two types of water: a soft, sodium bicarbonate water, and a hard, sodium sulfate water.

The water in the glacial drift aquifers is generally very hard and has a wide range of dissolved solids. Water containing low total dissolved solids usually is a calcium bicarbonate type. Water containing high total dissolved solids usually is a sodium sulfate type.

Most of the water in Divide County may be marginal to unsuitable for irrigation purposes. However, the Skjermo Lake aquifer and the West Wildrose aquifer contain water that probably could be used for irrigation of tolerant crops on all but heavy types of soil. Water from the Grenora aquifer and aquifer C in the southern unit of the buried Yellowstone channel deposits possibly could be used for irrigation on adequately drained soils or if proper amendments are added.

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