GROUND-WATER RESOURCES

Of

McLEAN COUNTY, NORTH DAKOTA

by

ROBERT L. KLAUSING
U. S. Geological Survey
1974

COUNTY GROUND-WATER STUDIES 19 — PART III
North Dakota State Water Commission
Vernon Fahy, *State Engineer*

BULLETIN 60 — PART III
North Dakota Geological Survey
Edwin A. Noble, *State Geologist*

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

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Bismarck, North Dakota
1974

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GROUND-WATER RESOURCES OF MCLEAN COUNTY, NORTH DAKOTA

By Robert L. Klausing

ABSTRACT

Ground water in McLean County is obtainable from aquifers composed of sand and gravel in the glacial deposits and sandstone and lignite in the preglacial rocks.

The aquifers with greatest potential for development are those in the glacial deposits. Most are associated with buried valleys and melt-water channels. A large interconnected system of aquifers is associated with buried valleys in east-central McLean County. The aquifers, which are named Lake Nettie, Strawberry Lake, Turtle Lake, and Horse Shoe valley, contain about 940,000 acre-feet of ground water in available storage. Well yields of as much as 1,500 gallons per minute are possible from the Lake Nettie aquifer. Other aquifers having well yields of as much as 1,500 gallons per minute are the Fort Mandan and Painted Woods Lake, which are associated with melt-water channels adjacent to the Missouri River in southern McLean County. Well yields of as much as 1,000 gallons per minute should be obtainable from the White Shield aquifer, which occupies a former valley of the Missouri River in western McLean County. Several other aquifers in the glacial deposits in McLean County have potential well yields of as much as 1,000 gallons per minute. Water from the aquifers in the glacial deposits is predominantly a sodium bicarbonate or calcium bicarbonate type and is usually hard to very hard.

Wells tapping the Fort Union Group of Paleocene age generally yield from 5 to 75 gallons per minute; however, in places yields as great as 200 gallons per minute may be possible. The water is predominantly a sodium bicarbonate type. Wells tapping the Hell Creek and Fox Hills Formations yield from 10 to 50 gallons per minute. The water is predominantly a sodium bicarbonate type.

The rural population and most communities in McLean County are dependent on ground water as a source of supply. The use of ground water for irrigation is now of minor importance (only two wells), but will probably increase in the future.

INTRODUCTION

This investigation was made cooperatively by the U. S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, and the McLean County Board of Commissioners.

Purpose and Objectives

The purpose of the study was to determine the quantity and quality of ground water available for municipal, domestic, livestock, industrial, and irrigation uses. The main objectives were to: (1) determine the location, extent, and nature of the major aquifers; (2) estimate the quantities of water stored in the aquifers; (3) estimate the potential yields of wells tapping the different aquifers; and (4) determine the chemical quality of the ground water.

Location and Physical Geography

McLean County encompasses an area of 2,327 square miles in west-central North Dakota (fig. 1). All of the county is in the Great Plains physiographic province, except for a small area in the extreme northeastern part, which is in the Western Lake section of the Central Lowland province (Fenneman, 1931). Drainage in the Great Plains section is to the Gulf of Mexico by way of the Missouri River. Drainage in the Western Lake section is to Hudson Bay by way of the Sheyenne River. The principal tributaries of the Missouri River are Painted Woods Creek, Turtle Creek, Deep Water Creek, and the East, West, and Middle branches of Douglas Creek. All are intermittent streams. There are no significant tributaries to the Sheyenne River in McLean County.

Most of the area, although located in the drainage basins of the Missouri and Sheyenne Rivers, is internally drained. There are numerous sloughs, prairie potholes, and lakes, most of them intermittently wet and dry.

The maximum relief in the county is about 680 feet. The highest point is 2,290 feet above sea level in the SE¼NE¼ sec. 15, T. 150 N., R. 79 W. The lowest point, 1,610 feet above sea level, is in the NE cor. sec. 1, T. 150 N., R. 78 W.

The topography of the county is primarily the result of glacial erosion and deposition. Most of the present landforms were produced during the retreat and minor advances of the last ice sheet.

Climate

The weather of the area is variable. The winters are generally long and cold with temperatures as low as -40°F (Fahrenheit). The summers are usually warm with average daily temperatures ranging from 62° to 72°F. Occasional midday temperatures may exceed 100°F. The mean annual temperature is about 40°F.

The National Weather Service (1937-71) presently maintains precipitation and temperature stations at Garrison, Max, Raub, Riverdale, Turtle Lake, Underwood, Washburn, and Wilton. Data from these stations show that

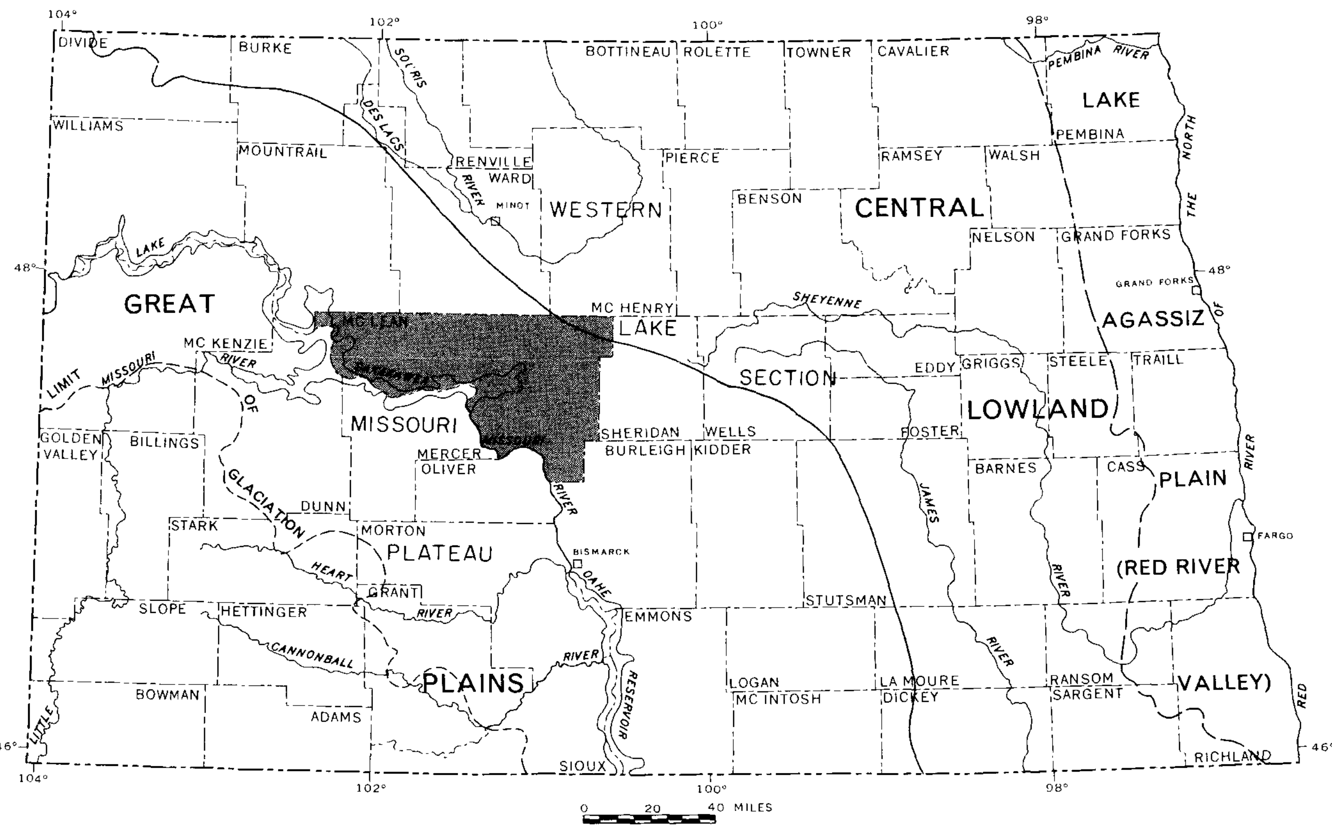


FIGURE 1.—Physiographic divisions in North Dakota and location of report area.

most of the annual precipitation occurs during the 6-month period extending from April through September. The data also show that the total annual precipitation may differ as much as 10 inches between stations. The wettest years were 1962 and 1970, when each station recorded more than 18 inches of precipitation. The driest year on record was 1936, when the four existing stations (Garrison, Max, Turtle Lake, and Washburn) each reported less than 10 inches.

Well-Numbering System

The wells, springs, and test holes mentioned in this report are numbered according to a system based on the public land classification of the U. S. Bureau of Land Management. The system is illustrated in figure 2. The first numeral denotes the township north of a base line, the second numeral the range west of the fifth principal meridian, and the third numeral indicates 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). For example, well 146-79-15DAA is in the NE¼NE¼SE¼ sec. 15, T. 146 N., R. 79 W. Consecutive terminal numbers are added if more than one well, spring, or test hole is recorded within a 10-acre tract.

Previous Investigations

Simpson (1929, p. 166-169) briefly described the occurrence of ground water in the glacial drift and the underlying bedrock. Logs of wells and chemical analyses of water from selected wells in McLean County were included in Simpon's report. A reconnaissance report by Greenman (1953) described the irrigation potential of aquifers along the Missouri River between Garrison Dam and Bismarck. Dingman and Gordon (1954) reported on the geology and ground-water resources of the Fort Berthold Indian Reservation. Their report contained a large number of well and test-hole logs and chemical analyses of water from different aquifers. Robinove, Langford, and Brookhart (1958, p.9-47) gave a general discussion of saline water in some of the aquifers in the county. General information on ground water in North Dakota has been summarized by Paulson (1962). Armstrong (1963) reported on the ground-water resources near Max, N. Dak. Logs of test holes and wells and chemical analyses of water collected during the study near Max are given in Part II of this series.

Bluemle (1971) described the geology of McLean County. His report served as a general framework for the present study. A basic-data report for McLean County was compiled by Klausing (1971). This report contained

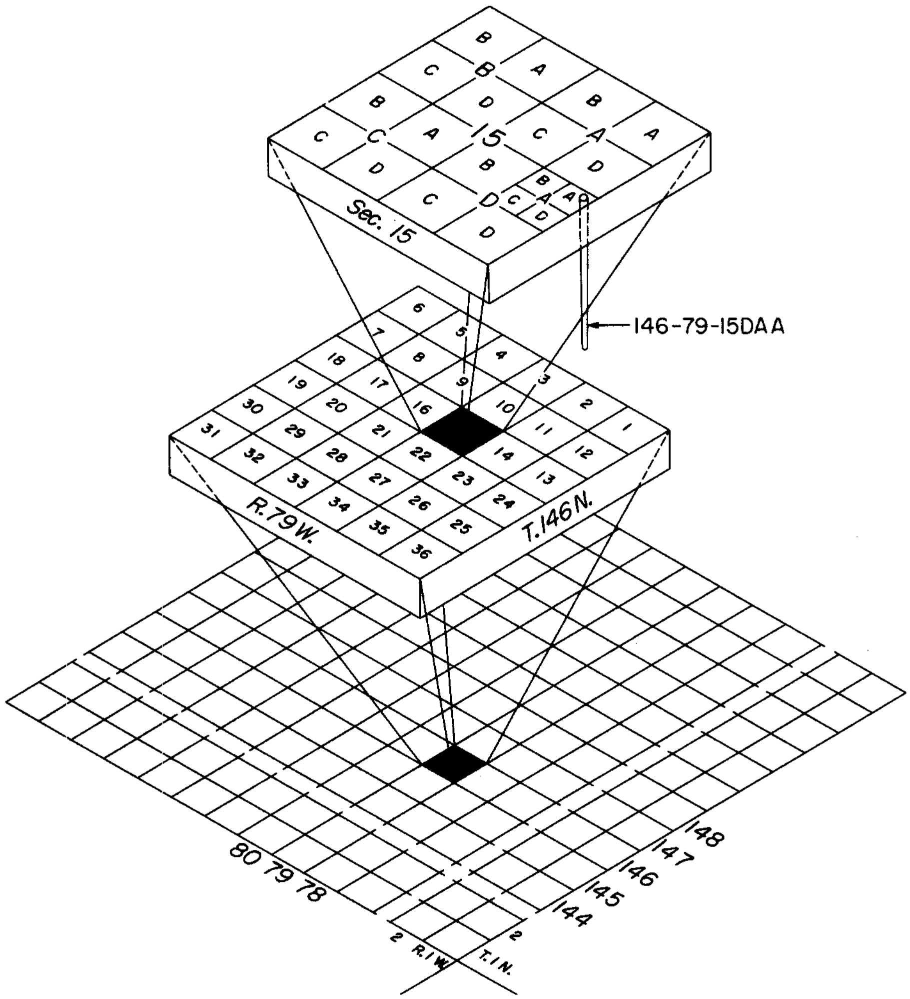


FIGURE 2.--System of numbering wells, springs, and test holes.

data on: (1) 1,750 wells and test holes; (2) 12 springs; (3) water-level measurements in 196 observation wells; (4) logs of 729 test holes and selected wells; and (5) chemical analyses of 329 water samples. All data referred to in the present report are from Klausing (1971), unless otherwise referenced.

Acknowledgements

The collection of data for this report was made possible by the cooperation of the County Commissioners and local residents of McLean County, the U. S. Corps of Engineers, the U. S. Bureau of Reclamation, and the U. S. Bureau of Indian Affairs. L. L. Froelich and C. E. Naplin of the North Dakota State Water Commission prepared lithologic logs and ran electric logs of most of the test holes. R. W. Schmid, also with the North Dakota State Water Commission, did much of the aquifer-test work.

GEOLOGIC SETTING

Preglacial Rocks

The preglacial sedimentary rocks underlying McLean County were deposited in a large, sporadically subsiding basin now known as the Williston basin. During Paleozoic time a Precambrian structural high located in Burleigh County (fig. 1) was subject to intermittent uplift (Ballard, 1963). Uplift of this structural feature resulted in thinning and nondeposition of some of the rocks of Paleozoic age. Following a period of erosion, deposition was renewed at the beginning of Mesozoic time and continued into the Cenozoic Era.

The sedimentary rocks deposited during Paleozoic time consist of limestone, dolomite, and lesser amounts of sandstone, shale, and evaporites. This sequence of sedimentary rocks ranges in thickness from about 4,000 feet in the eastern part of the county to about 8,000 feet in the western part (Bluemle, 1971, p. 8).

The sedimentary rocks deposited during Mesozoic time consist largely of shale; however, some well-developed sandstones are present in the Lower Cretaceous Dakota Group[1] and in the Upper Cretaceous Fox Hills and Hell Creek Formations. The rocks of Mesozoic age range in thickness from about 3,900 feet in northeastern McLean County to about 5,000 feet in the western part of the county (Bluemle, 1971, p. 11).

Geologic data from counties in the western part of the State indicate that deposition during Cenozoic time probably extended through the Miocene Epoch. There are, however, no Cenozoic rocks younger than Paleocene age

[1] The stratigraphic nomenclature used in this report is that of the North Dakota Geological Survey and does not necessarily follow the usage of the U.S. Geological Survey.

in McLean County. The rocks of Paleocene age consist of interbedded shale, siltstone, sandstone, and lignite. They range in thickness from 127 feet in the eastern part of the county to about 1,100 feet in the western part (Bluemle, 1971, p. 11). This sequence of sedimentary rocks forms the bedrock beneath the glacial deposits in McLean County and is generally referred to as the Fort Union Group.

BEDROCK TOPOGRAPHY

The generalized bedrock topography is shown on plate 1 (in pocket). Test-hole data, surficial geologic data (J. P. Bluemle, written commun., 1969), and topographic maps were used in constructing the map. The map indicates that glacial advances during the Pleistocene Epoch greatly altered the existing topography.

The most outstanding features shown on the map are the bedrock valleys. The valley that extends southeastward from the northwest corner of the county into Sheridan County northeast of Mercer is believed to be an interglacial diversion channel of the Missouri River. The width and depth of the main channel and the development of tributary valleys suggest that the diversion channel was a major drainage course for a substantial period of time. Another deep bedrock valley located about 6 miles east of Washburn is believed to be the preglacial Knife River valley.

Glacial Deposits

Glacial deposits of Pleistocene age cover almost all of McLean County and unconformably overlie sedimentary rocks of Paleocene age. The deposits range in thickness from 0 to 440 feet. They are unconsolidated and consist of fragments of older rock that has been eroded and transported by glaciers. In McLean County the glacial deposits may be divided into four principal types, based on lithology and inferred origin. The types are till, glaciofluvial deposits, ice-contact deposits, and lake deposits.

TILL

Till is a nonsorted, nonstratified sediment that usually consists of a mixture of clay, silt, sand, and gravel. Over a large area the percentages of the material in the till may vary considerably. Till is deposited from glacial ice by dumping, pushing, lodgement, and ablation. In places blocks of locally derived bedrock such as shale and sandstone are incorporated in the till.

GLACIOFLUVIAL DEPOSITS

Glaciofluvial deposits consist largely of sand and gravel that has been sorted and stratified by glacial melt water. The glaciofluvial deposits occur as (1) sediments in preglacial and interglacial stream valleys buried by till, (2) sediments in melt-water channels, (3) surficial-outwash sediments, and (4) isolated pockets surrounded by clay or till.

ICE-CONTACT DEPOSITS

Ice-contact deposits consisting largely of gravel, sand, and clay were deposited in contact with melting glacial ice. They are characterized by sharp changes in sorting, and by slumped or contorted bedding.

LAKE DEPOSITS

Lake deposits in McLean County, consisting of silt and clay deposited by glacial melt water, generally are only a few feet thick. However, considerable thicknesses of silt and clay have been penetrated in a few test holes. In some places the silt and clay seem to be associated with buried valleys; suggesting that deposition was caused by temporary damming of an existing stream.

Postglacial Deposits

ALLUVIUM

Alluvium, composed predominantly of clay, silt, and fine sand, is present in the postglacial flood plains of the Missouri River and its tributaries. Alluvium is also present in most of the melt-water channels, where it commonly overlies sand and gravel deposits of glacial origin. Locally the alluvium may be as much as 20 feet thick, but generally it is not differentiated from the glacial drift in this report.

EOLIAN DEPOSITS

Eolian deposits consisting predominantly of fine sand are present locally on the low hills and bluffs adjacent to the Missouri River southwest of Underwood (Bluemle, 1971, p. 37). These windblown deposits usually are thin, but in places they form relatively large dunes.

AVAILABILITY AND QUALITY OF GROUND WATER

General Concepts

Nearly all of the ground water in McLean County is derived from precipitation. After precipitation falls on the earth's surface, part is returned to the atmosphere by evaporation, part runs off into streams, and the remainder infiltrates into the ground. Some of the water that enters the soil is held by capillarity, to make up for the water that has evaporated or transpired by plants during the preceding dry period. After the soil and plant requirements have been satisfied, the excess water, if any, will infiltrate downward until it reaches the zone of saturation. After the excess water enters the zone of saturation it becomes available to wells.

Ground water moves under the influence of gravity from areas of recharge to areas of discharge. Ground-water movement is generally very slow; it may be only a few feet per year. The rate of movement is governed by the hydraulic conductivity of the material through which the water moves and by the hydraulic gradient. Gravel and well-sorted medium or coarse sand generally are highly conductive, and deposits of these materials commonly form aquifers. Fine-grained materials such as silt, clay, and shale usually have a low conductivity.

The water level in an aquifer fluctuates in response to recharge to and discharge from the aquifer. Aquifers exposed at land surface are recharged each spring and early summer by direct infiltration of precipitation. At the present time, recharge to these aquifers normally is sufficient to replace losses caused by natural processes and by pumping of wells, although long-term trends of several years may develop during which there are net gains or losses in storage. Aquifers that are confined by thick deposits of fine-grained materials such as clay or silt are recharged very slowly. Replenishment of these aquifers is by seepage from the fine-grained materials. The rate of recharge may increase as heads in the aquifers are reduced by pumping. However, head declines may continue for several years before sufficient recharge is induced to balance the rate of withdrawal. In some cases this balance may never be achieved without a curtailment of withdrawals.

In parts of McLean County, surface-water sources, such as the Missouri River, Lake Sakakawea, and smaller lakes and potholes, are in hydraulic connection with the aquifers. The aquifers either may receive recharge from these sources or may discharge into them, depending on head relationships, which generally vary both in time and space.

The ground water in McLean County contains dissolved mineral matter in varying degree. Rainfall begins to dissolve mineral matter as it falls, and continues to dissolve mineral matter as the water infiltrates through the soil. The amount and kind of dissolved mineral matter in water depends upon the solubility and types of rocks encountered, the length of time the water is in contact with the rocks, 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.

Further in this report numerous references are made to ground-water types, such as sodium bicarbonate type, calcium bicarbonate type, etc. These classifications are derived from inspection of the analyses and represent the predominant cation (sodium, calcium, or magnesium) and anion (bicarbonate, sulfate, or chloride) expressed in milliequivalents per liter.

The suitability of water for various uses is determined largely by the kind and amount of dissolved matter. The chemical constituents, physical properties, and indices most likely to be of concern are: iron, sulfate, nitrate, fluoride, dissolved solids, hardness, temperature, odor, taste, specific conductance, sodium-adsorption ratio, and percent sodium. The source of the major chemical constituents, their effects on usability, and the limits recommended by the U. S. Public Health Service are given in table 1. Additional information regarding drinking water standards may be found in "Drinking Water Standards" published by the U. S. Public Health Service (1962). Irrigation classifications in this report were derived by use of figure 3.

Aquifers In The Preglacial Rocks

The preglacial rocks in McLean County contain thick sequences of water-bearing rocks, but only those at relatively shallow depths are of economic importance as aquifers. These aquifers occur in the Fox Hills and Hell Creek Formations of Cretaceous age and the Fort Union Group of Paleocene age.

Information relating to the thickness of lithology of rocks older than Cretaceous is available only from oil-test logs. The rocks consist of several thousand feet of limestone, shale, dolomite, sandstone, and evaporites. Limestone is the predominant rock type. No chemical analyses are available to indicate the quality of water in these rocks underlying McLean County, but data from adjacent counties indicate that the water is a brine that has a dissolved-solids content in excess of 50,000 mg/l (milligrams per liter; Pettyjohn and Huchinson, 1971, p. 18-19). No data are available on the potential well yields.

FOX HILLS FORMATION

The Fox Hills Formation underlies the entire county. It consists of interbedded sandstone, shale, and siltstone and ranges in thickness from 233 to about 450 feet. The depth to the top of the formation ranges from about 540 feet in the eastern part of the county to about 1,200 feet in the western part.

The water in the Fox Hills Formation is under artesian pressure. The elevation of the potentiometric surface ranges from 1,971 feet above sea level at well 148-90-25BC to 1,901 feet above sea level at well 148-85-23CDC

TABLE 1. -- **Major chemical constituents in water -- their sources, effects upon usability, and recommended concentration limits**
(Concentrations are in milligrams per liter, except as noted)

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

Constituents	Major source	Effects upon usability	U.S. Public Health Service recommended limits for drinking water[1]
Silica (SiO_2)	Feldspars, ferromagnesian and clay minerals.	In presence of calcium and magnesium, silica forms a scale that retards heat transfer in boilers and on steam turbines.	
Iron (Fe)	Natural sources: Amphiboles, ferromagnesian minerals, ferrous and ferric sulfides, oxides, carbonates, and clay minerals. Manmade sources: well casings, pump parts, and storage tanks.	If more than 100 µg/l iron is present, it will precipitate when exposed to air; causing turbidity, staining plumbing fixtures, laundry and cooking utensils, and imparting tastes and colors to food and drinks. More than 200 µg/l is objectionable for most industrial uses.	300 µg/l
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, dolomite, and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment. Calcium and magnesium retard the suds-forming action of soap. High concentrations of magnesium have a laxative effect.	
Magnesium (Mg)	Amphilboles, olivine, pyroxenes, dolomite, magnesite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 mg/l sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	
Potassium (K)	Feldspars, feldspathoids, some micas, and clay minerals.		
Bicarbonate (HCO_3)	Limestone and dolomite.	Upon heating of water to the boiling point, bicarbonate is changed to steam, carbonate, and carbon dioxide. Carbonate combines with alkaline earths (principally calcium and magnesium) to form scale.	
Carbonate (CO_3)			
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation of sulfide minerals.	Combines with calcium to form scale. More than 500 mg/l tastes bitter and may be a laxative.	250
Chloride (Cl)	Halite and sylvite.	In excess of 250 mg/l may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 mg/l.	250
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth	Recommended limits depend on average of maximum daily temperatures. Limits range from 0.6 mg/l at 32°C to 1.7 mg/l at 10°C.
Nitrate (NO_3)	Nitrogenous fertilizers, animal excrement, legumes, and plant debris.	More than 100 mg/l may cause a bitter taste and may cause physiological distress. Concentrations greatly in excess of 45 mg/l have been reported to cause methemoglobinemia in infants.	45
Boron (B)	Tourmaline, biotite, and amphiboles.	Many plants are damaged by concentrations of 2,000 µg/l.	
Dissolved solids	Anything that is soluble.	More than 500 mg/l is not desirable if better water is available. Less than 300 mg/l is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500

1 U.S Public Health Service, 1962.

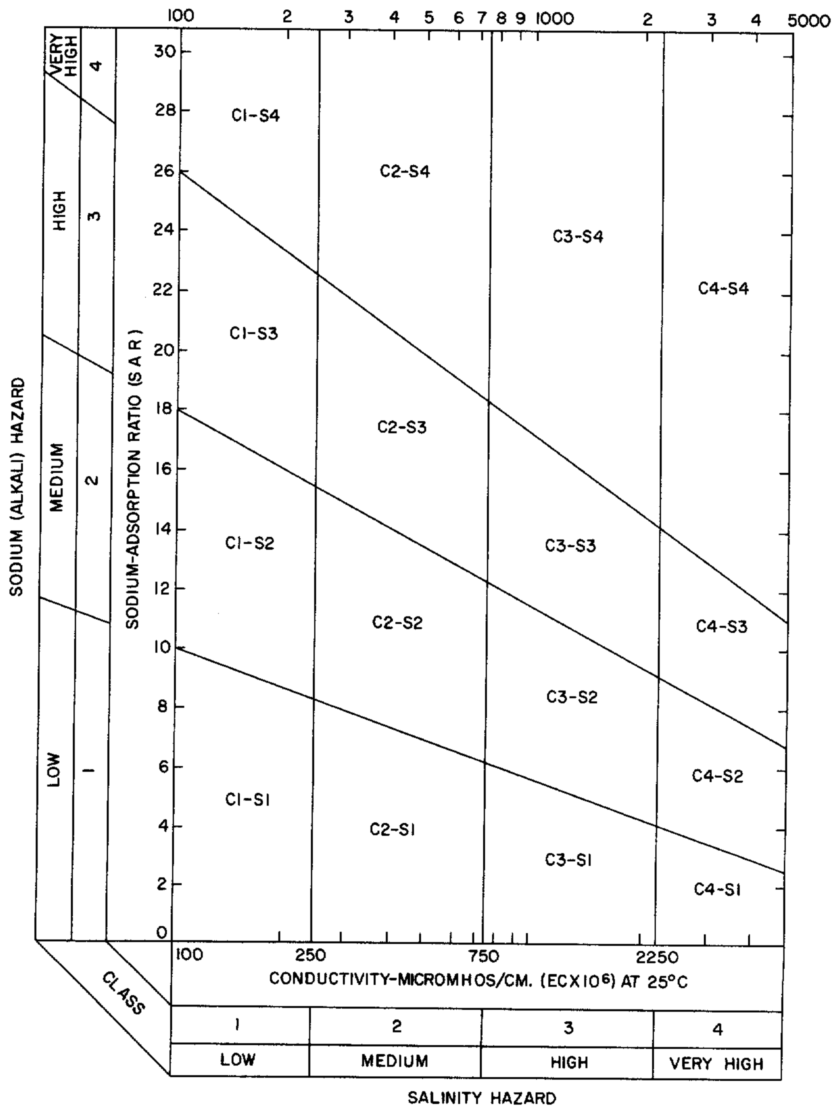


FIGURE 3.-- **Salinity and sodium hazard classification. (From U.S. Salinity Laboratory Staff, 1954).**

— indicating that the potentiometric gradient probably is toward the east.

Six water samples were collected from the Fox Hills Formation for chemical analyses. Examination of the analyses indicates that the water is soft and is a sodium bicarbonate type. The dissolved-solids content in the six samples ranged from 1,370 to 1,550 mg/l. Sulfate content was generally less than 10 mg/l. Iron content ranged from 70 to 820 μg/l (micrograms per liter), and chloride from 249 to 355 mg/l. The salinity and sodium hazard index was very high. The average residual sodium bicarbonate content was about 21 meq/l (milliequivalents per liter).

The potential yield of the water-bearing beds in the Fox Hills is unknown. Well yields of 10 gpm (gallons per minute) have been measured.

HELL CREEK FORMATION

The Hell Creek Formation, which conformably overlies the Fox Hills Formation, consists of interbedded silty shale and sandstone.

In the eastern part of the county the Hell Creek Formation was reached at a depth of 317 feet in test hole 146-79-34BBB, where it has a total thickness of 223 feet. The depth and thickness of the formation in the western part of the county is unknown.

Analyses of five water samples from the Hell Creek indicate that the water in the formation is soft and is a sodium bicarbonate type. The dissolved-solids content in the five samples ranged from 1,200 to 1,630 mg/l; iron from 80 to 660 μg/l. Sulfate content was generally less than 25 mg/l. The water has a very high salinity and sodium hazard index.

At the present time there are only a small number of domestic and stock wells tapping the formation. Prior to 1970 the city of Turtle Lake obtained water for municipal use from the Hell Creek Formation. Well 147-80-28CBC was reported to yield 50 gpm.

FORT UNION GROUP

The Fort Union Group of Paleocene age underlies the entire county. It is covered by glacial deposits, except locally where it crops out. The Fort Union Group ranges from a minimum known thickness of 127 feet in test hole 146-79-34BBB to about 1,100 feet in the western part of the county.

The Fort Union Group consists of interbedded silt, siltstone, clay, shale, sandstone, and lignite. The beds vary in thickness and generally are not continuous over a large area. The sandstone beds are the major water-bearing units and are predominantly very fine to fine grained. The beds range in thickness from a few feet to a maximum known thickness of 225 feet in test hole 146-82-32CDC. Locally, lignite beds serve as a source of water for domestic and livestock wells. The lignite beds range in thickness from 0.5 to 20 feet.

Garrison municipal well 148-84-7DDA was drilled to a depth of 260 feet and screened in a sandstone bed from 223 to 258 feet. During the development test, the well was reported to have been pumped at 75 gpm for an undetermined length of time with a drawdown of 20 feet.

Water levels in wells tapping the Fort Union Group are as much as 305 feet below land surface. However, the depth to water in most wells is less than 100 feet, and in some low-lying areas wells completed in the Fort Union Group flow.

Analyses of 65 water samples from aquifers in the Fort Union Group indicated that the water is predominantly a sodium bicarbonate type. About 60 percent of the analyses were classified as hard to very hard. The dissolved-solids content ranged from 206 to 3,550 mg/l. Iron concentrations ranged from 0 to 95,000 μg/l and sulfate from 3.2 to 2,000 mg/l. The concentration of chloride ranged from 0.2 to 423 mg/l and nitrate ranged from 0 to 350 mg/l. The irrigation classifications of the water samples from the Fort Union are as follows: (1) 48 percent were C4-S4; (2) 23 percent were C3-S2 to C3-S3; and (3) 29 percent were C2-S1. About two-thirds of the samples had residual sodium carbonate in excess of 2.5 meq/l.

Most of the water use is for domestic and livestock supplies; however, the cities of Garrison, Underwood, and Wilton use water from the Fort Union Group for their municipal supplies. Well yields generally range from 5 to 75 gpm, but properly constructed wells developed in the thick sandstone intervals may yield as much as 200 gpm.

Aquifers In The Glacial Deposits

Aquifers in the glacial deposits, particularly those of glaciofluvial origin, have the greatest potential for ground-water development in McLean County. The aquifers are classified into four main groups: (1) aquifers associated with buried valleys; (2) melt-water-channel aquifers; (3) surficial-outwash aquifers; and (4) undifferentiated sand and gravel aquifers. For convenience of discussion and identification in this report and for future reference, the individual aquifers are named, commonly after nearby prominent geographic features such as lakes, streams, or cities. The order of discussion is on the basis of economic importance — generally from most productive aquifers to least productive.

Where sufficient test-drilling and hydrologic data are available, an estimate of ground-water availability from storage is given for each aquifer. The estimates are given in acre-feet and are products of areal extent, saturated thickness, and specific yield. The storage estimates are provided for comparison purposes only and are based on static conditions. They do not take into account recharge, natural discharge by evapotranspiration or springs, or ground-water movement between adjacent aquifers. The quantitative evaluation of these factors is beyond the scope of the present reconnaissance-type study.

The potential yields of the aquifers to wells are shown on the ground-water availability map (pl. 2, in pocket). The yield values are based mainly on transmissivities and specific capacities that were estimated according to methods described by Keech (1964) and Meyer (1963, p. 339). The accuracies of the estimates were strengthened by data from pumping tests made at several locations in selected aquifers during the present study.

The aquifers generally are lenticular in cross section and the largest yields are obtainable usually from the central and therefore the thickest parts. Wells penetrating aquifers in narrow valleys generally have lower yields than wells tapping aquifers of comparable thickness but having large areal extent. Where several aquifers are superimposed, one upon another, the maximum yield indicated is obtainable only by tapping all aquifers.

The ground-water availability map should be used with the understanding that the estimated yields are for fully penetrating, properly screened and developed wells of adequate diameter. The map is intended as a general guide in the location of ground water and not as a map to locate specific wells. Few if any aquifers are so uniform in extent and physical properties that production wells may be drilled in them without preliminary test drilling.

AQUIFERS ASSOCIATED WITH BURIED VALLEYS

Most of the glacial aquifers in McLean County are contained within or overlie buried valleys that were formed prior to or during Pleistocene time. They are identified on plate 2 as the Lake Nettie aquifer system and the White Shield, Lost Lake, Snake Creek, Weller Slough, Wolf Creek, and Garrison aquifers.

Lake Nettie Aquifer System

The Lake Nettie aquifer system underlies an area of about 166 square miles in east-central McLean County (pl. 2). The aquifers in the system differ in mode and time of origin; however they all are interconnected and form a complex system that functions as a hydraulic unit or system. The individual aquifers in the system, which are named Lake Nettie, Strawberry Lake, Turtle Lake, and Horse Shoe valley, are discussed separately in the following sections.

Lake Nettie aquifer

Location and extent. – The Lake Nettie aquifer underlies an area of approximately 100 square miles in east-central McLean County. It ranges in width from 2 to 8 miles and extends southeastward from Lake Audubon (pl. 2) into Sheridan County about 2 miles northeast of the city of Mercer. The aquifer consists of an upper, middle, and lower unit. The clastic material of which the aquifer is comprised probably was deposited in a bedrock valley (pl. 1) during three major periods of deposition. The upper unit extends beyond the lateral boundaries of the middle and lower units.

Thickness and lithology. – The upper unit of the Lake Nettie aquifer ranges in thickness from 2 to 74 feet and is composed largely of mixed sand and gravel, but locally may consist either of sand or gravel. It is generally exposed at the surface, but locally is overlain by as much as 80 feet of glacial till (pl. 3, secs. A-A'-E-E', in pocket).

The middle unit is separated from the upper unit by as much as 10 feet of glacial till. It ranges in thickness from 0 to 97 feet (pl. 3, secs. C-C'-E-E') and consists of sand or gravel or a mixture of both.

The lower unit, which is separated from the middle unit by more than 30 feet of till, consists of one to four beds of interbedded and intermixed sand and gravel (pl. 3, secs. A-A'-E-E'). Individual beds range in thickness from about 7 to 102 feet and the aggregate thickness of all beds is as much as 132 feet.

Test hole 148-80-34DCC penetrated all three units. The aquifer at this location has an aggregate thickness of 207 feet. The average thickness of the aquifer is about 70 feet.

Hydrologic character. – Two aquifer tests were made — one on the upper unit and one on the lower unit — by the North Dakota State Water Commission (R. W. Schmid, written commun., 1971).

The first test was made using an irrigation well (148-80-33CBD) owned by Mr. Tom Boe. Pumping started November 4, 1970, and continued for 7,200 minutes (5 days) at a constant rate of 510 gpm. The well is cased with 17-inch inside-diameter concrete casing to a depth of 39 feet and screened from 39 to 51 feet. The water was discharged onto the ground about a quarter of a mile south of the pumping well. Water samples were collected at the pump after 25 minutes and 50, 75, 100, and 119 hours of pumping and analyzed for chemical content.

Observation wells spaced at distances of 60, 120, 185, 320, 575, 654, and 1,450 feet from the pumping well were used to measure the water-level decline during pumping and rise during recovery. There were no other wells pumping in the area during the test.

The aquifer-test data were analyzed according to methods described by Lohman (1972, p. 15-34). The analyses indicated a transmissivity of 8,600 ft^2day^{-1} and a storage coefficient of 0.14 (fig. 4). The drawdown in the production well after 7,200 minutes of pumping was 18.03 feet and the specific capacity was 29 gpm per foot of drawdown. The area of influence after 7,200 minutes of pumping is shown in figure 5.

The second test was made in the lower unit using a well (148-80-20CCD5) constructed by the State Water Commission on property owned by Mr. Arlo Beggs. Pumping started September 28, 1970, and continued for 7,200 minutes at a constant rate of 1,450 gpm. The well was cased with 16-inch steel casing to a depth of 162 feet and screened with 10-inch 50-slot screen from 162 to 190 feet. The water was discharged on the ground about 30 feet southwest of the production well and allowed to flow downslope into Crooked Lake, about 300 feet west of the production well. Water samples were collected after 13 minutes and 24, 48, 72, 96, and 119 hours of pumping and were analyzed for chemical content.

Twelve observation wells were drilled to monitor the effects of pumping. Seven of the wells were screened or perforated in the same interval as the production well in the lower unit. Two wells (148-81-20CCD3 and 20CDC2) were screened in the middle unit about 30 feet above the lower unit, and three wells (148-81-20CCD4, 20CDC3, and 29CAA) were screened in the upper unconfined unit. The location, depth, and screened or perforated interval of the wells are shown in figure 6. In addition to the 12 observation wells drilled for the test, water levels were monitored in 17 previously constructed observation wells.

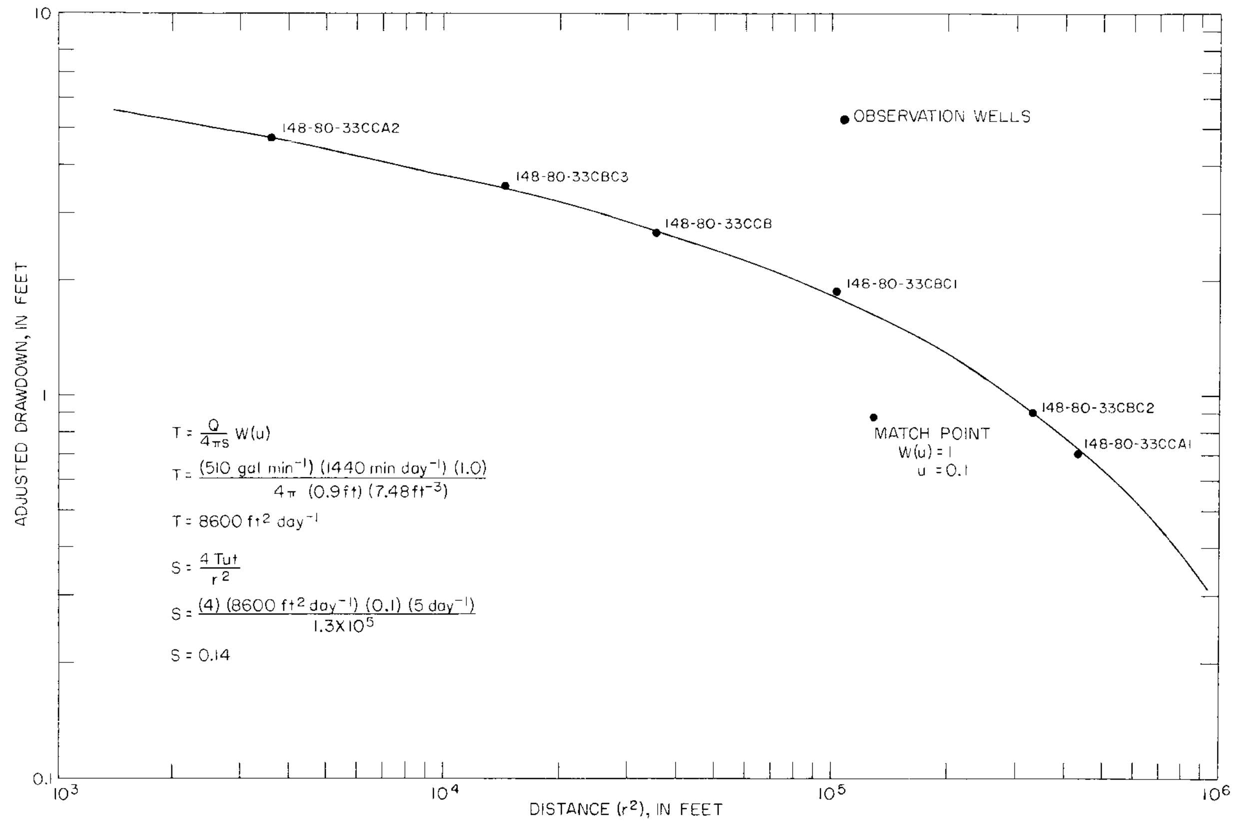


FIGURE 4.-- Logarithmic plot of distance (r^2) versus drawdown (s), upper unit of Lake Nettie aquifer.

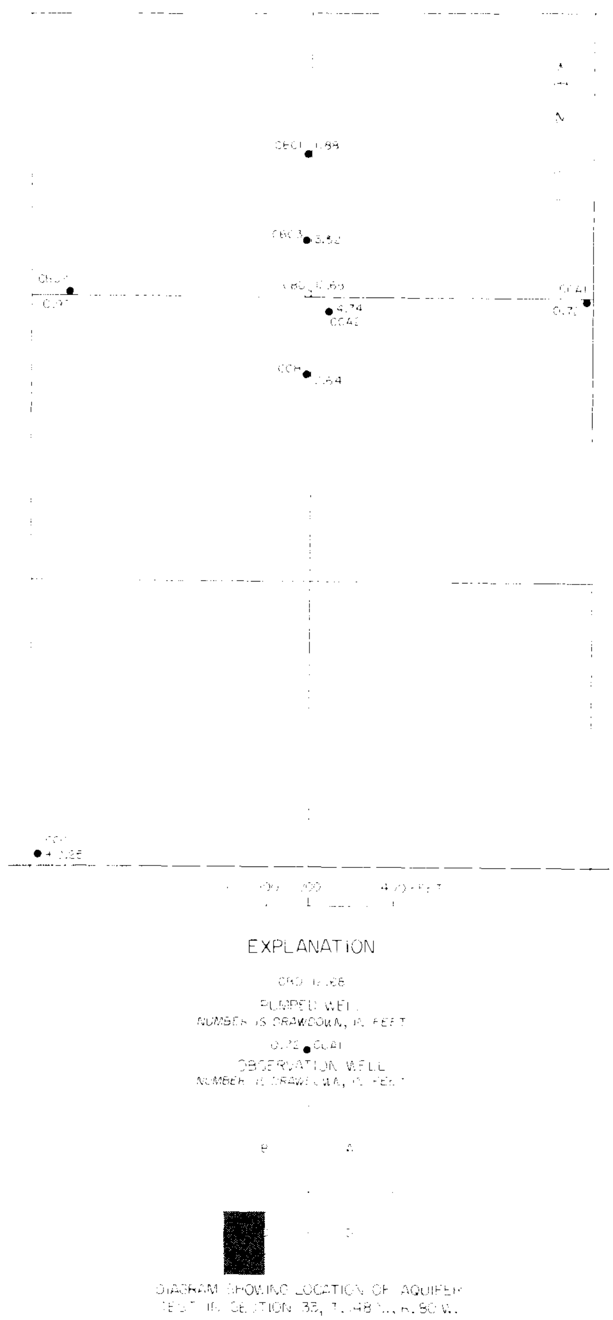
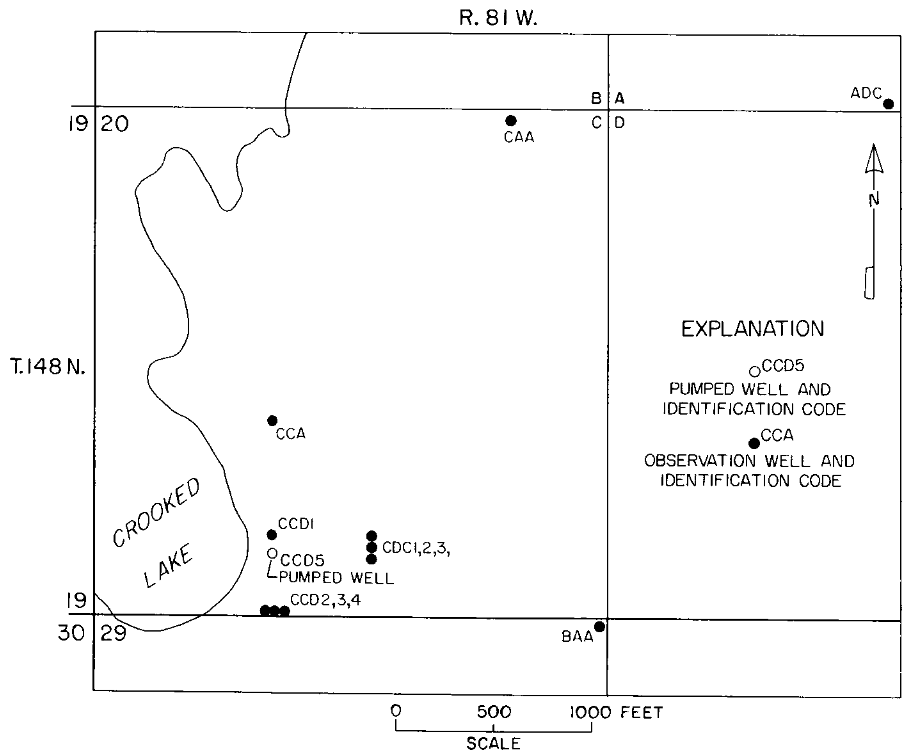


FIGURE 5.-- Location of wells, drawdown, and area of influence, upper unit of Lake Nettie aquifer.



WELL NUMBER	DEPTH (IN FEET BELOW LAND SURFACE)	SCREENED OR PERFORATED INTERVAL (IN FEET BELOW LAND SURFACE)
148-81-20ADC	178	138-178
148-81-20CAA	184	178-184
148-81-20CCA	155	149-155
148-81-20CCD1	175	169-175
148-81-20CCD2	185	179-185
148-81-20CCD3	105	99-105
148-81-20CCD4	55	49-55
148-81-20CCD5[1]	190	162-190
148-81-20CDC1	185	179-185
148-81-20CDC2	105	99-105
148-81-20CDC3	60	54-60
148-81-29BAA	178	158-178
148-81-29CAA[2]	49	39-49

[1] PUMPED WELL.
[2] NOT SHOWN ON LOCATION MAP.

FIGURE 6.-- Location, depth, and screened or perforated interval of wells in lower unit of Lake Nettie aquifer.

After the pump was shut off, the recovery of the water level in most of the observation wells was monitored for a period of about 11 days. There were no other wells pumping in the area during the test.

Analyses of the test data show that the transmissivity of the aquifer is 44,000 ft^2day^{-1} and the storage coefficient is 0.0002. The upward deviation of the data plot from the type curve shown in figure 7 suggests the presence of a hydrologic boundary of less permeable material. This is confirmed by test drilling, which indicates that the aquifer is confined by relatively impermeable valley walls (pl. 3, sec. C-C').

Drawdown in the pumped well after 7,200 minutes of pumping was about 32 feet and the specific capacity of the well was about 46 gpm. Drawdowns ranging from 1.3 to 1.5 feet were recorded in observation wells located 4 to 5 miles on either side of the production well.

The test data indicated leakage from the middle unit into the lower unit. The decline of the water level in the middle unit due to leakage was 2.3 feet in well 148-81-20CCD3 and 2.0 feet in well 20CDC2. The three observation wells in the upper unit showed no response to pumping, and thus, no leakage.

Storage. – Based on an areal extent of 100 square miles, an average thickness of 70 feet, and a specific yield of 15 percent, about 670,000 acre-feet of water is available from storage in the Lake Nettie aquifer.

Water-level fluctuations. – Water levels in the Lake Nettie aquifer range from about 2 feet above land surface to about 69 feet below land surface. The largest fluctuations occur in the upper unit (fig. 8, well 148-81-33CDD), which is readily recharged by infiltration of precipitation and snowmelt.

The hydrographs for wells 147-80-13CCC (middle unit) and 148-80-31AAA (lower unit) do not correlate well with the precipitation records nor with the hydrograph of well 148-81-33CDD. During the period of record, the highest water level in the middle unit generally preceded the highest water level in the lower unit.

Quality of water. – Analyses of 29 water samples from the upper unit of the aquifer indicate that the water is very hard and is predominantly a calcium bicarbonate type. The dissolved-solids content ranged from 287 to 2,880 mg/l. Sulfate content ranged from 23 to 983 mg/l and iron from 0 to 12,000 μg/l. The irrigation classification of the water ranged from C2-S1 to C4-S4 (fig. 3). About 90 percent of the samples contained residual sodium carbonate in excess of 2.5 meq/l.

Water samples taken at different times during the aquifer test on the upper unit indicated little change in chemical quality as the result of pumping (table 2).

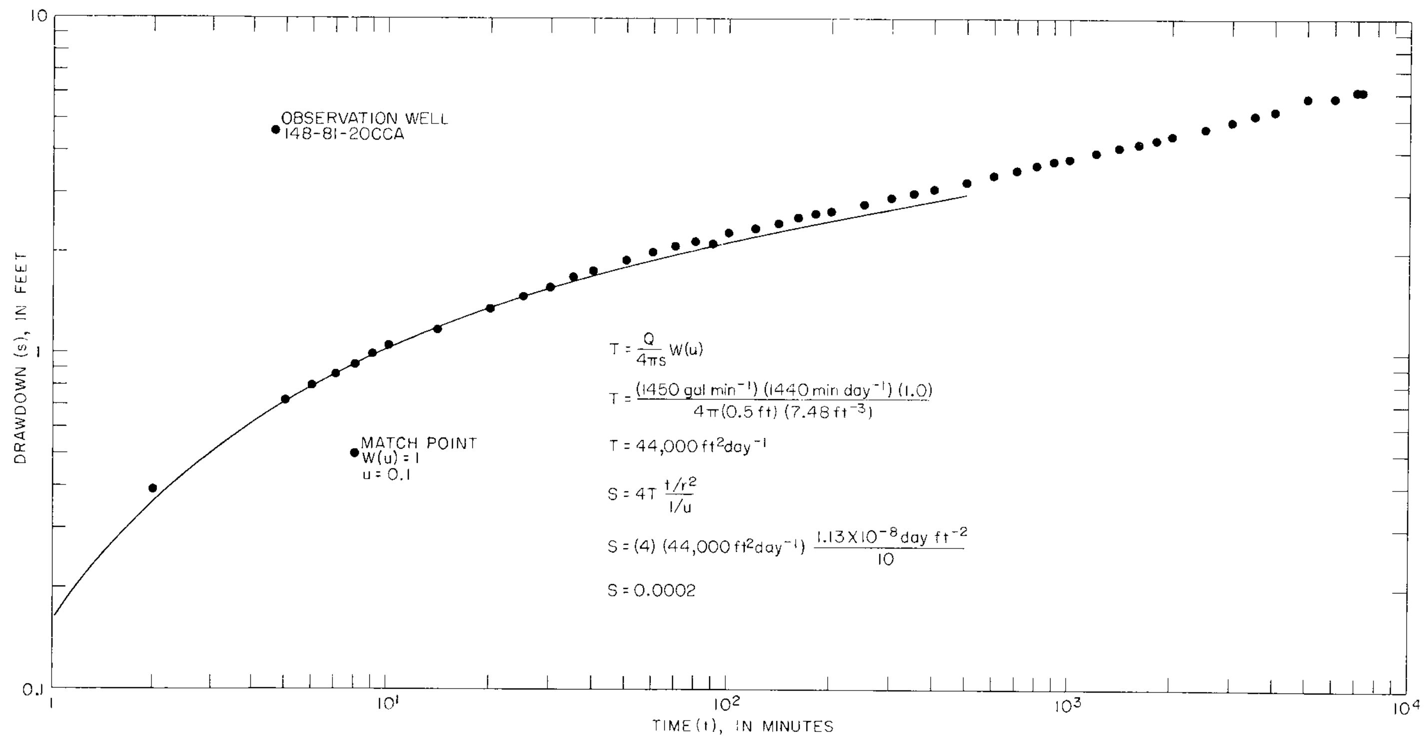


FIGURE 7.--Logarithmic plot of drawdown (s) versus time (t), lower unit of Lake Nettie aquifer.

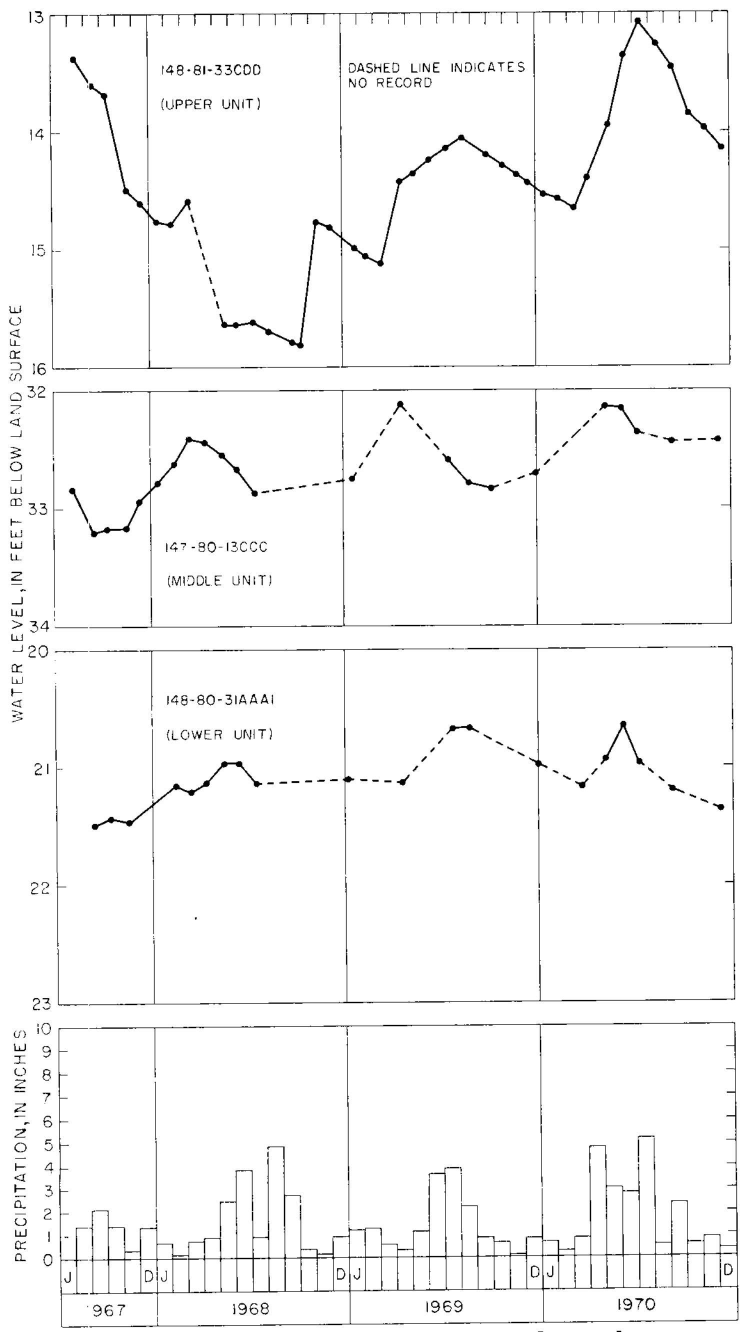


FIGURE 8.-- Water-level fluctuations in the Lake Nettie aquifer and precipitation at Turtle Lake.

Water samples from 13 wells tapping the middle aquifer unit indicate that the water is very hard and is predominantly a sodium bicarbonate type. Dissolved solids ranged from 520 to 1,810 mg/l. Sulfate content ranged from 175 to 609 mg/l and iron from 240 to 1,800 μg/l. The irrigation classification ranged from C3-S1 to C3-S2. The residual sodium carbonate content ranged from 0 to about 7 meq/l.

TABLE 2. — Chemical analysis of water samples taken during aquifer test on upper unit of Lake Nettie aquifer 148-80-33CBD

Constituents	Elapsed pumping time				
	25 minutes	50 hours	75 hours	100 hours	119 hours
	Concentrations in milligrams per liter				
Silica (SiO_2)	26	26	26	26	26
Iron (Fe)[1]	2,100	2,000	2,100	2,000	1,900
Calcium (Ca)	126	121	119	119	119
Magnesium (Mg)	41	38	32	35	36
Sodium (Na)	44	43	43	43	42
Potassium (K)	5.9	5.8	5.9	5.9	6.0
Bicarbonate (HCO_3)	512	492	488	488	489
Carbonate (CO_3)	0	0	0	0	0
Sulfate (SO_4)	136	133	133	134	134
Chloride (Cl)	5.2	5.2	5.2	3.0	5.5
Fluoride (F)	.5	.4	.1	.2	.2
Nitrate (NO_3)	.2	.4	.2	.2	.5
Boron (B)[1]	30	140	140	140	80
Dissolved solids	622	623	621	641	610
Hardness as $CaCO_3$	484	460	431	441	444
Specific conductance (micromhos per centimeter at 25°C)	988	963	955	951	951
pH (units)	7.6	7.5	7.5	7.5	7.5
Percent sodium	16	17	18	17	17
Sodium-adsorption ration	.9	.9	.9	.9	.9
Residual sodium carbonate	.16	.75	1.25	1.01	.95

[1] Iron (Fe) and boron (B) are given in micrograms per liter.

Water samples from 19 wells tapping the lower unit indicate that the water is hard and predominantly a sodium bicarbonate type. Dissolved-solids content ranged from 565 to 1,550 mg/l. Sulfate ranged from 117 to 576 mg/l and iron from 120 to 3,200 μg/l. The irrigation classification ranged from C3-S1 to C3-S3. Residual sodium carbonate content ranged from 0 to about 7 meq/l.

Water samples taken at different times during the aquifer test on the lower unit indicated little change in chemical quality except for iron, which varied considerably (table 3).

The concentrations of major constituents and hardness of water for selected samples from the Lake Nettie aquifer are shown in figure 9. The samples selected generally represent the high, low, and intermediate ranges of the constituents found in each of the three water-bearing units. The graph shows that there is not as much variation of the major chemical constituents in water from the lower unit as in the middle and upper units. Samples having low concentrations of chemical constituents are from wells that probably are located in areas of ground-water recharge. The relatively high concentration of constituents in the water from well 148-81-29CAA suggests that the aquifer may be receiving recharge from an alkali slough (not shown on pl. 2) that extends southeastward from Crooked Lake. The cause of the relatively high concentration of constituents in well 148-81-20CCD3 is now known.

Utilization and potential for future development. – At the present time a large number of livestock and domestic wells and one irrigation well are developed in the aquifer. Pumpage from these wells has produced no noticeable regional drawdown of the water level in the aquifer.

Depending on the local thickness and hydraulic conductivity of the material penetrated, properly constructed wells in the aquifer should yield from 50 to 1,500 gpm (pl. 2).

Strawberry Lake aquifer

The Strawberry Lake aquifer occupies a buried bedrock valley that extends northward from its junction with the Lake Nettie aquifer (pl. 2) into McHenry County at the northern edge of sec. 2, T. 150 N., R. 80 W. The aquifer has an areal extent of about 18 square miles.

Data from nine test holes show that the aquifer generally consists of several sand and gravel beds that range in thickness from 3 to 150 feet (pl. 3. sec. F-F'). The aggregate thickness of all beds ranges from 23 to 164 feet and averages about 65 feet.

Based on an areal extent of 18 square miles, an average thickness of 65 feet, and a specific yield of 15 percent, about 110,000 acre-feet of water should be available from storage in the Strawberry Lake aquifer.

The water level in the aquifer is generally between 16 and 59 feet below land surface (fig. 10). During the period extending from May to December 1970 the water level in observation well 150-80-35ABB rose about 1.3 feet. The rise in water level appears to be directly related to the increased precipitation in the area during 1970.

Analyses of five water samples from the aquifer indicate that the water is very hard and is predominantly a calcium bicarbonate type. The dissolved-

TABLE 3. — Chemical analysis of water samples taken during aquifer test on lower unit of Lake Nettie aquifer 148-80-20CCD5

Constituents	Elapsed pumping time					
	13 minutes	24 hours	48 hours	72 hours	96 hours	119 hours
	Concentrations in milligrams per liter					
Silica (SiO_2)	26	27	26	26	26	26
Iron (Fe)[1]	420	1,500	1,400	1,600	700	1,400
Calcium (Ca)	63	65	66	67	66	68
Magnesium (Mg)	27	28	28	30	29	31
Sodium (Na)	188	191	191	190	193	192
Potassium (K)	8.1	8.1	8.1	8.1	8.0	8.1
Bicarbonate (HCO_3)	600	611	614	618	621	623
Carbonate (CO_3)	0	0	0	0	0	0
Sulfate (SO_4)	176	183	186	190	193	196
Chloride (Cl)	5.4	3.7	4.3	3.5	6.1	3.8
Fluoride (F)	.5	.5	.4	.4	.4	.5
Nitrate (NO_3)	.4	1	1	1	1	1
Boron (B)[1]	350	380	380	490	380	380
Dissolved solids	796	819	809	814	778	841
Hardness as $CaCO_3$	270	278	280	289	284	296
Specific conductance (micromhos per centimeter at 25°C)	1,210	1,230	1,240	1,250	1,260	1,280
pH (units)	7.9	8.0	7.9	7.9	8.0	8.0
Percent sodium	59	59	59	58	59	58
Sodium-adsorption ratio	4.4	4.5	4.5	4.4	4.5	4.3
Residual sodium carbonate	6.7	6.7	6.7	6.6	6.8	6.6

[1] Iron (Fe) and boron (B) are given in micrograms per liter.

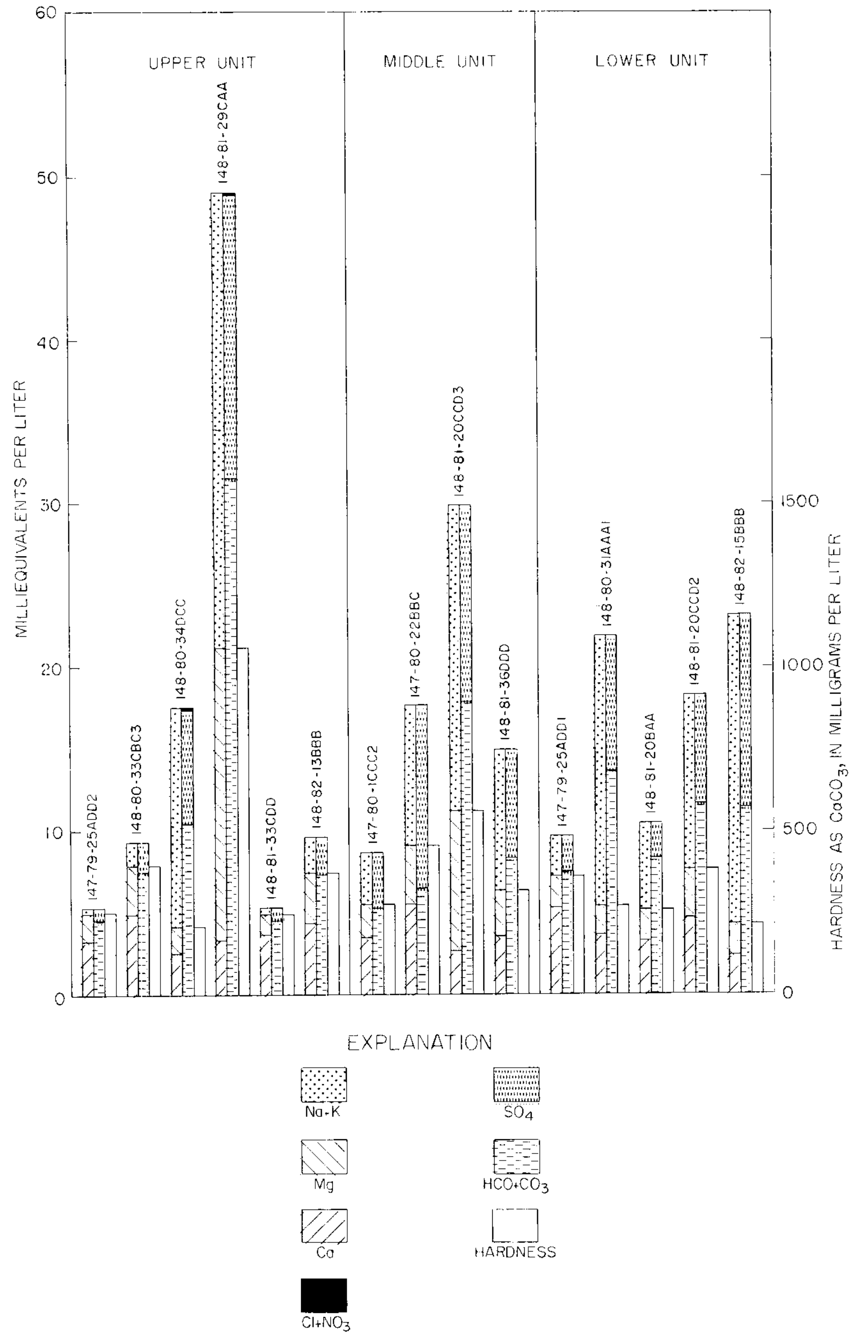


FIGURE 9.-- Concentration of major constituents and hardness of selected water samples from the Lake Nettie aquifer.

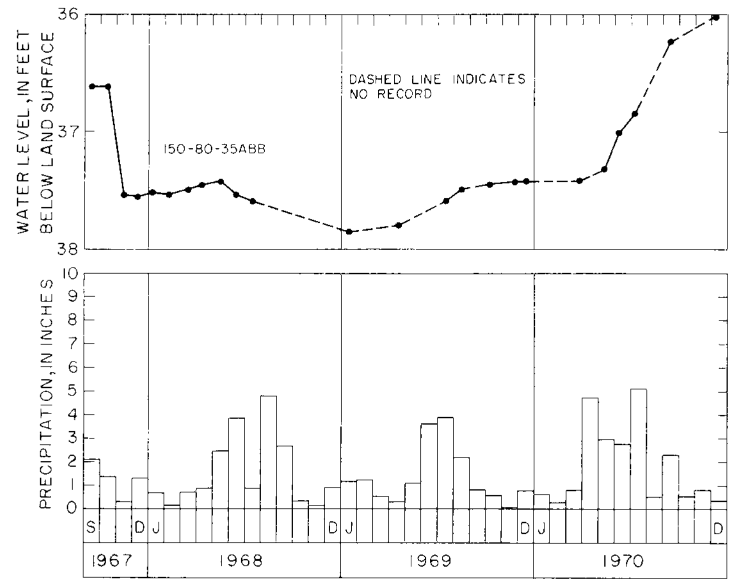


FIGURE 10.--Water-level fluctuations in the Strawberry Lake aquifer and precipitation at Turtle Lake.

solids content ranged from 352 to 1,080 mg/l, sulfate from 51 to 355 mg/l, and iron from 0 to 3,300 μg/l. The irrigation classification ranged from C2-S1 to C3-S2. All of the samples had residual sodium carbonate values of less than 1 meq/l, except for the sample from well 148-80-17CAB2, which had a value of 6 meq/l.

The range of the major constituents and the hardness of water from the Strawberry Lake aquifer are shown in figure 11. The relatively low concentrations of constituents in the samples from wells 150-80-25DCD and 35ABB suggest that locally the Strawberry Lake aquifer is being recharged by leakage from the Horse Shoe valley aquifer and possibly from Strawberry and Camp Lakes. A comparison of the bar graphs, except the one for well 150-80-2DCC, shows that the concentration of constituents in the water increases southward.

At the present time only a few small-capacity domestic and livestock wells tap the aquifer. It should be possible to construct wells in the aquifer

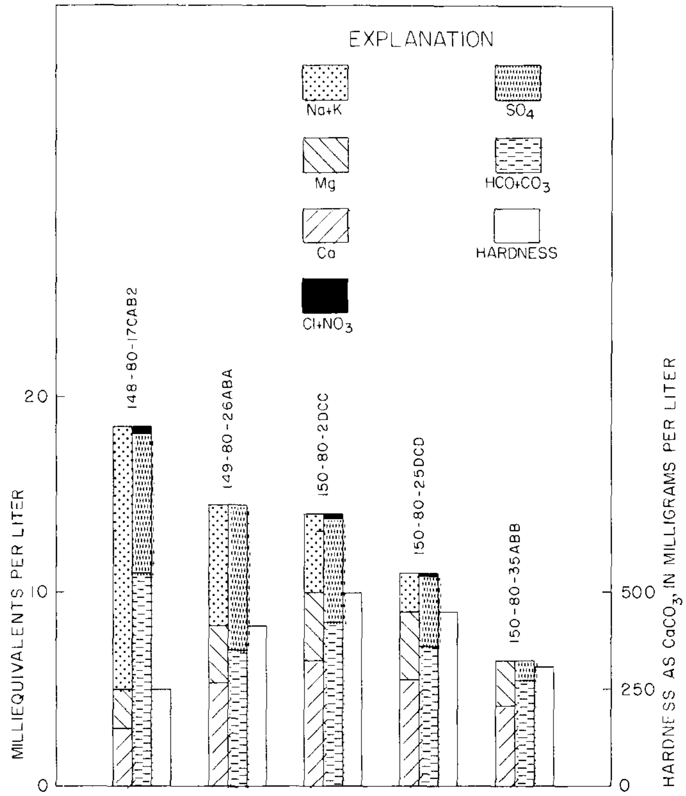


FIGURE 11.--Concentration of major constituents and hardness of water from the Strawberry Lake aquifer.

that would yield as much as 1,000 gpm for at least short periods (pl. 2). It is doubtful that large yields could be maintained for very long periods because the aquifer is relatively narrow. Any large-yield wells tapping the aquifer should be spaced far enough apart to avoid excessive interference effects.

Turtle Lake aquifer

Location and extent. – The Turtle Lake aquifer has an areal extent of about 26 square miles. The major aquifer unit underlies an area extending southeastward from the southeast arm of Lake Audubon to about half a mile east of State Highway 41 (pl. 2). Smaller segments of the aquifer extend into Coal Lake Coulee and Turtle Creek valley.

Thickness and lithology. – The top of the aquifer lies from 3 to 84 feet below land surface. The aggregate thickness ranges from 12 to 127 feet (pl. 3, sec. G-G'-J-J') and averages about 42 feet. The aquifer consists of very fine to very coarse sand that is interbedded and intermixed with fine to coarse gravel. Locally the aquifer may consist entirely of either gravel or sand.

Hydrologic character – In April 1968 the North Dakota State Water Commission (R. W. Schmid, written commun., 1968) made an aquifer test using a test well drilled for the city of Turtle Lake. The production well (147-80-19ADD3) was screened in sand and gravel from 40 to 54 feet. The well was pumped for 1,405 minutes at a rate of 88 gpm. The static water level was 8.4 feet below land surface. Drawdown at the end of the test was 17.8 feet and the specific capacity of the well was about 5 gpm per foot of drawdown.

Values of transmissivity derived from drawdown and recovery data from observation wells located at distances of 140 and 750 feet from the pumping well averaged about 1,500 ft^2 day^{-1}. The storage coefficient was 0.0002.

A municipal supply well (147-81-25DCB) drilled for the city of Turtle Lake in March 1969 penetrated 44 feet of fine to medium sandy gravel in the interval from 1 to 45 feet. The static water level was 3.9 feet. During development the well was pumped at a rate of 375 gpm for 600 minutes. Drawdown at the end of the test was about 14 feet (M. O. Lindvig, oral commun., 1970). The specific capacity of the well at the end of the test was about 27 gpm per foot of drawdown.

Storage – Based on an areal extent of 26 square miles, an average thickness of 42 feet, and a specific yield of 15 percent, about 100,000 acre-feet of water should be available from storage in the Turtle Lake aquifer.

Water-level fluctuations. – The water-level fluctuations shown in figure 12 reflect seasonal variations in storage, and show that the highest water levels generally occur between the first of March and the first of June.

Quality of water. – Analyses of 14 water samples from the aquifer indicate that the water is moderately hard to very hard. The water may be either a sodium bicarbonate or a calcium bicarbonate type. The dissolved solids ranged from 277 to 1,360 mg/l, sulfate from 37 to 447 mg/l, and iron from 0 to 5,000 μg/l. The irrigation classification of water from the Turtle Lake aquifer ranged from C2-S1 to C3-S4.

The concentrations of the major constituents and hardness of selected water samples are shown in figure 13. Those samples containing relatively large concentrations of sodium were collected from wells located near the edge of the aquifer, which is adjacent to topographically higher bedrock. Thus, it would appear that the relatively high sodium content of some of the water samples is caused by movement of water into the aquifer from adjacent bedrock.

Utilization and potential for future development. – The public supply well for the city of Turtle Lake is the only major ground-water development

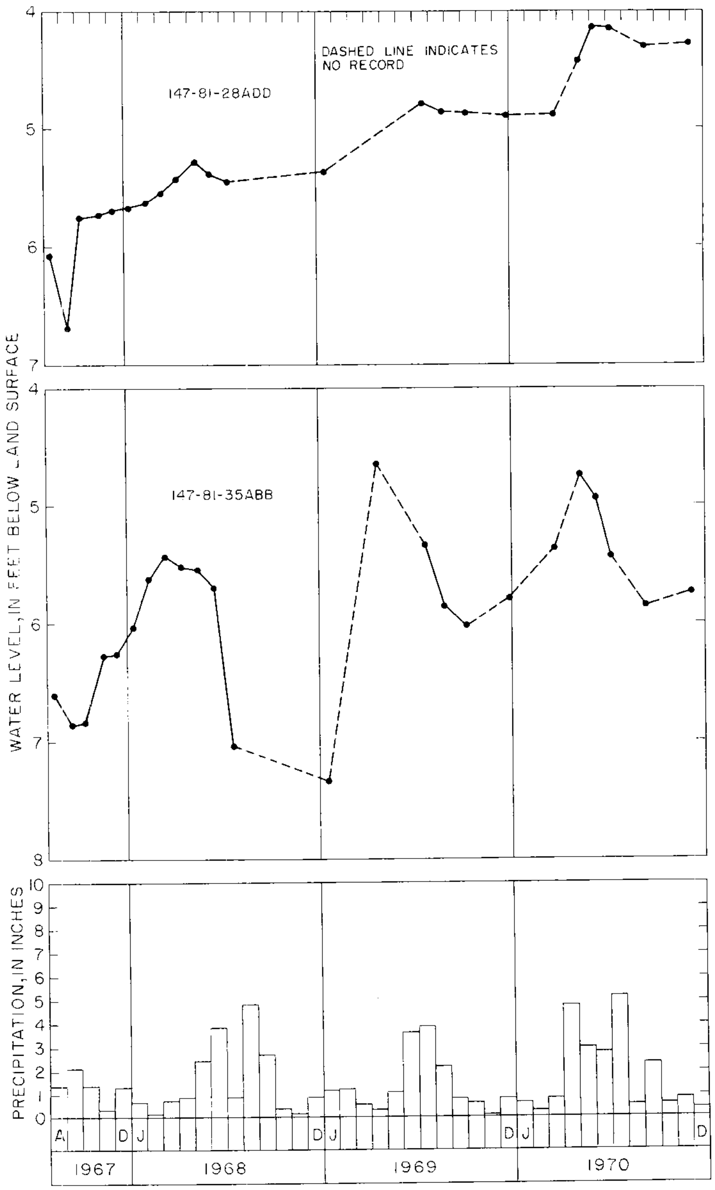


FIGURE 12.--Water-level fluctuations in the Turtle Lake aquifer and precipitation at Turtle Lake.

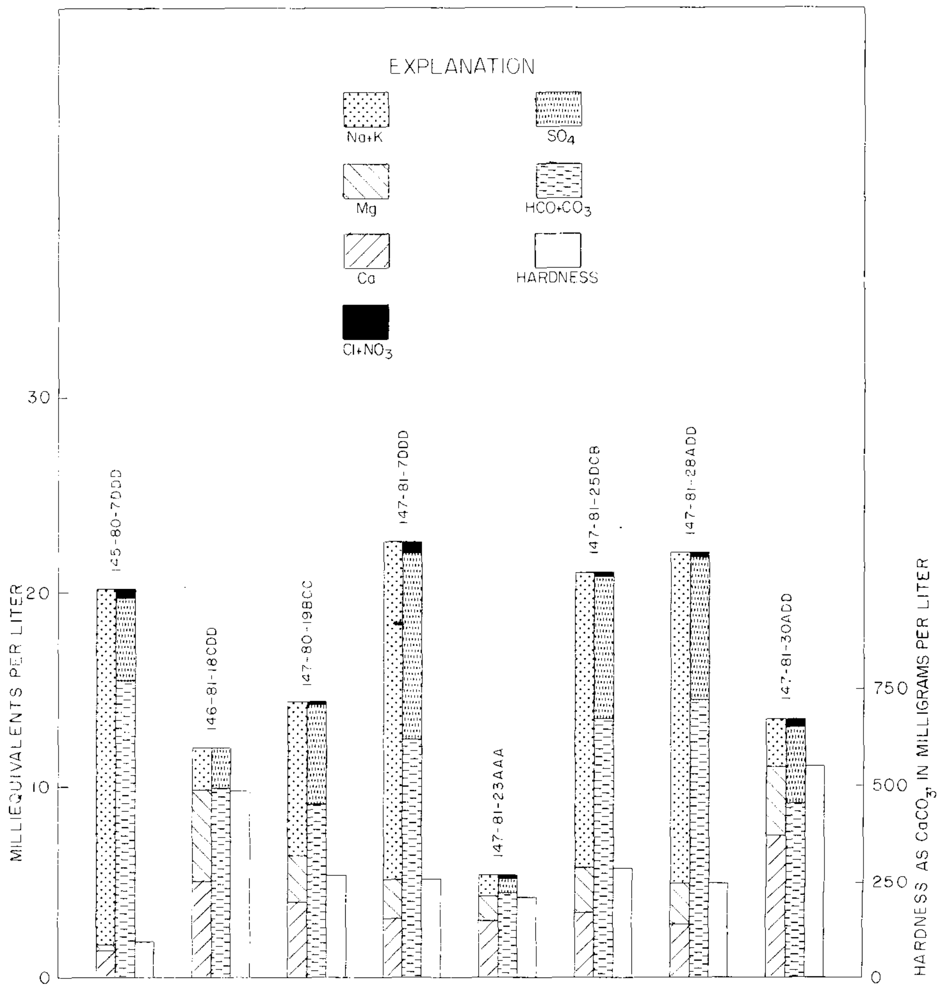


FIGURE 13.--Concentration of major constituents and hardness of selected water samples from the Turtle Lake aquifer.

in the aquifer. This well, located in 147-81-25DCB, has been in use since January 22, 1970. From January 22 to November 1, 1970, the well pumped about 13,140,000 gallons of water and it is estimated that total pumpage during 1970 was about 15,000,000 gallons. There are a few livestock and domestic wells tapping the aquifer, but the pumpage from these wells is only a small fraction of the Turtle Lake pumpage.

Because of its large areal extent and thickness, the aquifer should sustain considerable additional development in future years. Depending upon the local thickness and hydraulic conductivity of the material penetrated, properly constructed wells tapping the aquifer should yield from 50 to 1,000 gpm (pl. 2).

Horse Shoe valley aquifer

The Horse Shoe valley aquifer extends southward from the northern boundary of McLean County northwest of Ruso to its junction with the Lake Nettie aquifer about 2 miles south of the north line of T. 148 N., R. 81 W. (pl. 2). The aquifer lies in a glacial melt-water channel and underlies an area of about 21 square miles. Locally it overlies the Strawberry Lake aquifer (pl. 3, sec. F-F').

Test-hole data show that the aquifer ranges in thickness from 15 to about 44 feet and averages about 29 feet. It consists predominantly of fine to coarse sandy gravel.

Based on areal extent of 21 square miles, an average thickness of 29 feet, and a specific yield of 15 percent, about 60,000 acre-feet of water should be available from storage in the Horse Shoe valley aquifer.

Water levels in the aquifer are generally between 7 and 35 feet below land surface. Figure 14 shows seasonal water-level variations.

Chemical analyses of five water samples from the aquifer indicate that the water is a calcium bicarbonate type and is very hard. Dissolved-solids content ranged from 294 to 790 mg/l, sulfate from 45 to 267 mg/l, and iron from 0 to 2,100 μg/l. The irrigation classification of the water samples was either C2-S1 or C3-S1. All samples had residual sodium carbonate values of less than 1 meq/l.

Only a few domestic and livestock wells have been developed in the aquifer. Properly constructed wells developed in the aquifer should yield as much as 500 gpm (pl. 2).

White Shield Aquifer

Location and extent. – The White Shield aquifer underlies an area of about 40 square miles. It extends southeastward from the northwest corner of the county and intersects Lake Sakakawea about 11 miles southwest of Garrison. The aquifer extends eastward under Lake Sakakawea.

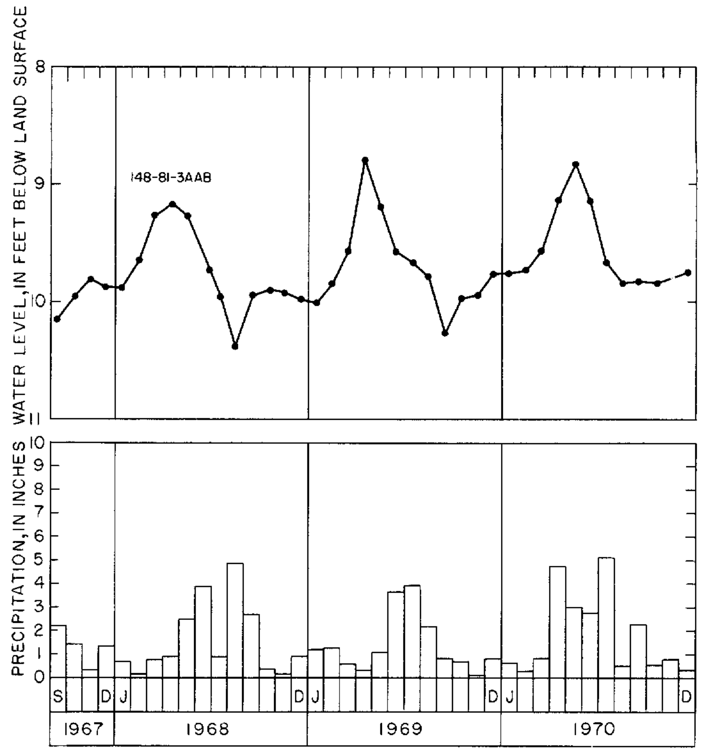


FIGURE 14.--Water-level fluctuations in the Horse Shoe valley aquifer and precipitation at Turtle Lake.

The aquifer generally occupies a buried bedrock valley (pl. 1) formed by an interglacial diversion of the Missouri River. In the vicinity of Raub the valley is entrenched in an older drift sheet (pl. 3, secs. K-K'-N-N').

Thickness and lithology. – The aggregate thickness of the White Shield aquifer ranges from 18 to 226 feet and averages about 100 feet. Individual beds range in thickness from 2 to about 200 feet and the thickest beds generally occur near the bottom of the aquifer. The aquifer consists of interbedded and intermixed silt, sand, and gravel. The thicker beds generally consist of fine to coarse gravel or very fine to coarse sand.

As shown in the geologic sections (pl. 3) the White Shield aquifer is generally overlain and confined by thick deposits of till.

Hydrologic character. – In 1965 the U.S. Bureau of Indian Affairs had a public supply well (148-88-2DDA) drilled at White Shield to augment the supply provided by the existing well (148-88-2DDB). The new well was 232 feet deep and penetrated 43 feet of sand and gravel in the interval from 191 to 234 feet. Completion data show that the well was pumped for 30 hours at a rate of 175 gpm. The specific capacity of the well after 30 hours of pumping was 16 gpm per foot of drawdown. The transmissivity of the aquifer in the vicinity of the well is about 5,300 ft^2day^{-1}. This value of transmissivity is not considered to be representative of the entire aquifer because the well is located near the edge where the water-bearing materials are relatively thin (pl. 3, sec. L-L'). It is estimated that the transmissivity in the vicinity of well 149-87-32CCC, where the aquifer is 214 feet thick, is about 21,000 ft^2day^{-1}. Because the transmissivity of the aquifer varies from place to place depending on the hydraulic conductivity and thickness, future development and testing of the aquifer may give values of transmissivity somewhat different from those stated above.

Storage. – Based on an areal extent of 40 square miles, an average thickness of 100 feet, and a specific yield of 15 percent, about 380,000 acre-feet of water should be available from storage in the White Shield aquifer.

Water-level fluctuations. – Water levels in the aquifer are generally between 50 and 150 feet below land surface.

The water-level fluctuations in observation well 148-87-7AAA2 and Lake Sakakawea are shown in figure 15. The high and low water levels in the well and in the lake occur at approximately the same time. The gradual water-level rise in the observation well is probably the combined result of recharge by infiltration of precipitation and an increasing head in the aquifer as the result of filling of the reservoir.

Quality of water. – Analyses of 20 water samples from the White Shield aquifer indicate that the water is very hard and may be either a sodium bicarbonate or sodium sulfate type. The dissolved-solids content ranged from 910 to 2,250 mg/l and sulfate from 128 to 1,040 mg/l. Iron content ranged from 0 to 10,000 μg/l. The samples had an irrigation classification of C3-S1 or C3-S2. Residual sodium carbonate values ranged from 1.24 to 9.42 meq/l.

Figure 16 shows the general range of concentrations of the major constituents and hardness of water in selected samples from the White Shield aquifer. The predominance of sodium in the water indicates that a considerable portion of the recharge to the aquifer may be derived from the bedrock.

Utilization and potential for development. – Numerous domestic and livestock well pump from the aquifer, but most of the water withdrawn is used to meet public supply demands at White Shield. Records show that approximately 3.4 million gallons of water was pumped from the two public supply wells (148-88-2DDA, 2DDB) at White Shield between October 15, 1967, and July 17, 1968. With subsequent construction of Indian housing units in the White Shield area, the pumpage from the aquifer probably

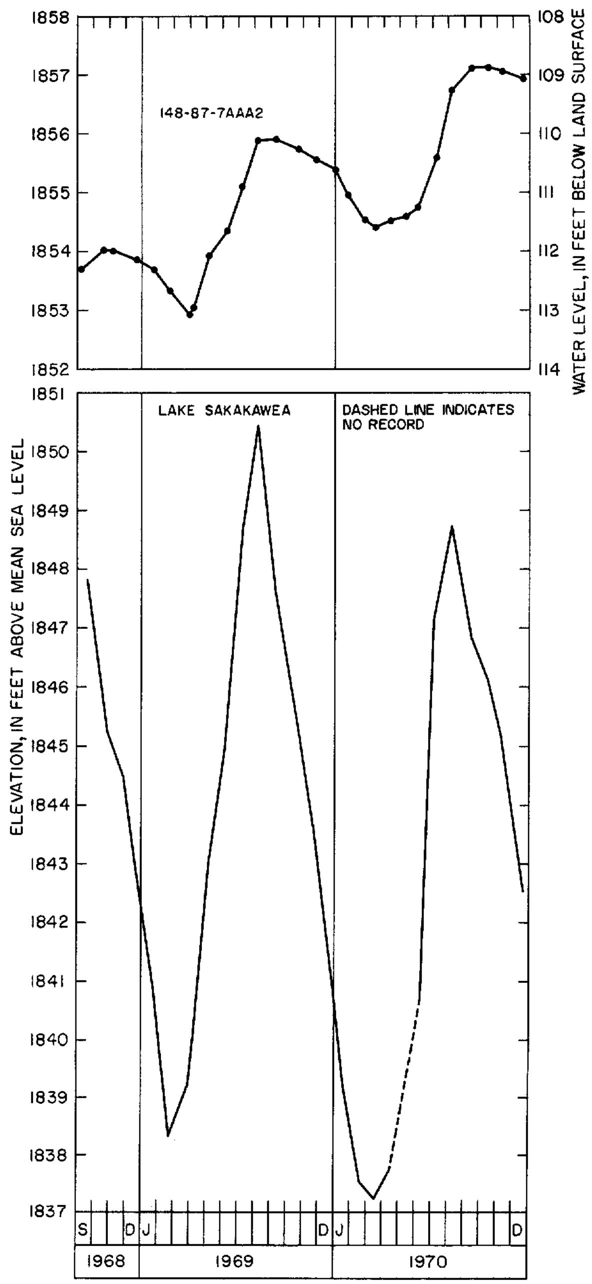


FIGURE 15.--Water-level fluctuations in the White Shield aquifer and fluctuations of Lake Sakakawea.

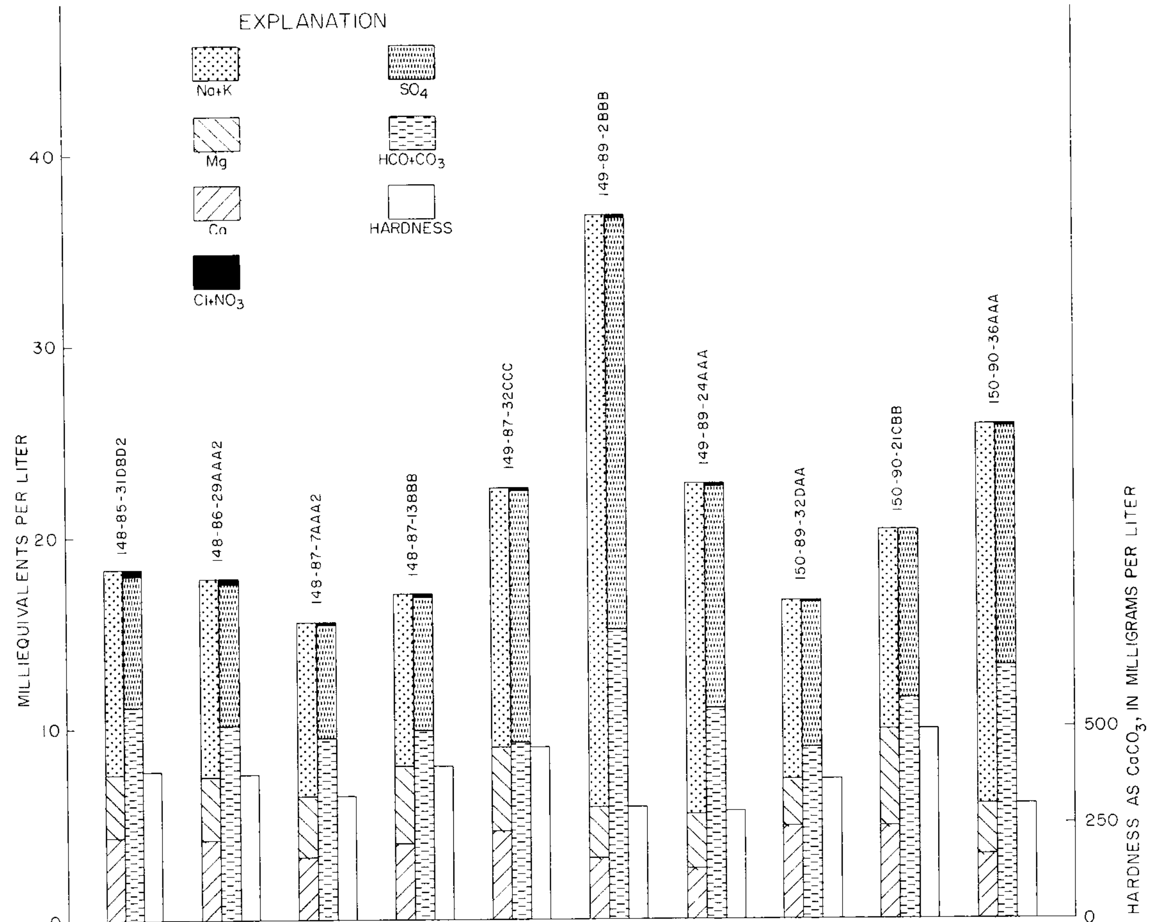


FIGURE 16.--Concentration of major constituents and hardness of selected water samples from the White Shield aquifer.

exceeds 6 million gallons annually. Withdrawal of this quantity of water has caused no regional declines in water levels.

Depending upon the local thickness and hydraulic conductivity of the material penetrated, several properly constructed wells capable of yielding as much as 1,000 gpm could be developed in the aquifer (pl. 2). Future wells should be spaced far enough apart to avoid large interference effects.

Lost Lake Aquifer

Location and extent. – The Lost Lake aquifer underlies an area of about 25 square miles east of the city of Washburn (pl. 2). The major aquifer unit lies in a buried valley that extends northeastward from the northeast edge of the Painted Woods Lake aquifer into Sheridan County in the SE cor. T. 146 N., R. 79 W. Smaller surficial segments of the aquifer extend into Painted Woods and Yanktonai Creeks.

The buried valley probably extends westward under the Painted Woods Lake aquifer to the Missouri River. From this point the valley probably underlies the Missouri River and extends upstream to near the present mouth of the Knife River in Mercer County. The available data suggest that the Lost Lake aquifer and the Painted Woods Lake aquifer are hydraulically connected.

Thickness and lithology. – The buried-valley unit has a maximum thickness of 251 feet and consists of sand and gravel that is interbedded and lensed with clay, silt, and glacial till (pl. 3, secs. Q-Q', R-R'). Individual beds and lenses range in thickness from 2 feet to as much as 123 feet. Logs of test holes drilled by the North Dakotda State Water Commission after the project fieldwork was completed show that north of T. 144 N., the aquifer consists chiefly of fine to coarse clayey sandy gravel (see appendix). Test holes penetrating the surficial glaciofluvial deposits in Painted Woods and Yanktonai Creeks show that the deposits range in thickness from 0 to about 33 feet, and consist largely of very fine to coarse sandy gravel. Locally the surficial glaciofluvial deposits are superimposed on the buried-valley unit. The average total thickness of the aquifer deposits is about 71 feet.

Storage. – Based on an areal extent of 25 square miles, an average thickness of 71 feet, and a specific yield of 15 percent, about 170,000 acre-feet of water should be available from storage in the Lost Lake aquifer.

Water-level fluctuations. – Water levels in the buried-valley unit range from about 1 foot above land surface to about 52 feet below land surface. Seasonal fluctuations range from 0.1 foot to about 1 foot. Water levels in the Painted Woods Creek and Yanktonai Creek segments range from about 3 to 5 feet below land surface, with the highest water levels generally occurring during the spring (fig. 17).

Quality of water. – Analyses of six water samples from the buried-valley unit and the Painted Woods Creek segment of the aquifer indicate that the water is a sodium bicarbonate type and is hard to very hard. The dissolved-solids content ranged from 367 to 1,550 mg/l, sulfate from 44 to 475 mg/l, and iron from 120 to 2,500 μg/l. Five of the water samples had an irrigation classification of C3-S4. The other sample (from well 143-81-2BCC2) was classified as C2-S1. All of the samples had residual sodium carbonate in excess of 2.5 meq/l except the one from well 143-81-2BCC2.

Analysis of one sample from the Yanktonai Creek segment of the aquifer indicates that the water is a sodium sulfate type and is very hard. The water contained 2,410 mg/l dissolved solids, 1,100 mg/l sulfate, and 1,000 μg/l iron. The irrigation classification was C4-S4 and the residual sodium carbonate content was about 9.0 meq/l.

Utilization and potential for future development. – Only a few livestock and domestic wells have been developed in the aquifer, and pumping from these wells has caused no regional decline in water levels. Properly constructed and spaced wells developed in the aquifer can be expected to yield from 50 to 1,000 gpm (pl. 2).

Snake Creek Aquifer

The Snake Creek aquifer extends northward from Lake Audubon into Ward County about 4 miles northwest of Benedict (pl. 2). The aquifer, which generally occupies a buried valley, underlies an area of about 19 square miles.

The aquifer materials consist of several sand and gravel beds separated by deposits of till. Locally the beds consist of either sand or gravel, but generally are a mixture of both. Individual beds range in thickness from 6 to 193 feet. The maximum aggregate thickness penetrated was 202 feet in test hole 150-82-15DDD and the average thickness is about 60 feet.

Based on an areal extent of 19 square miles, an average thickness of 60 feet, and a specific yield of 15 percent, about 110,000 acre-feet of water should be available from storage in the Snake Creek aquifer.

The water level in the aquifer ranges from about 142 feet below land surface in the northern part to about 2 feet above land surface in the southern part.

Analyses of five water samples from the aquifer indicate that the water is hard to very hard and may be either a calcium magnesium bicarbonate, sodium calcium sulfate, or a sodium bicarbonate sulfate type. The dissolved-

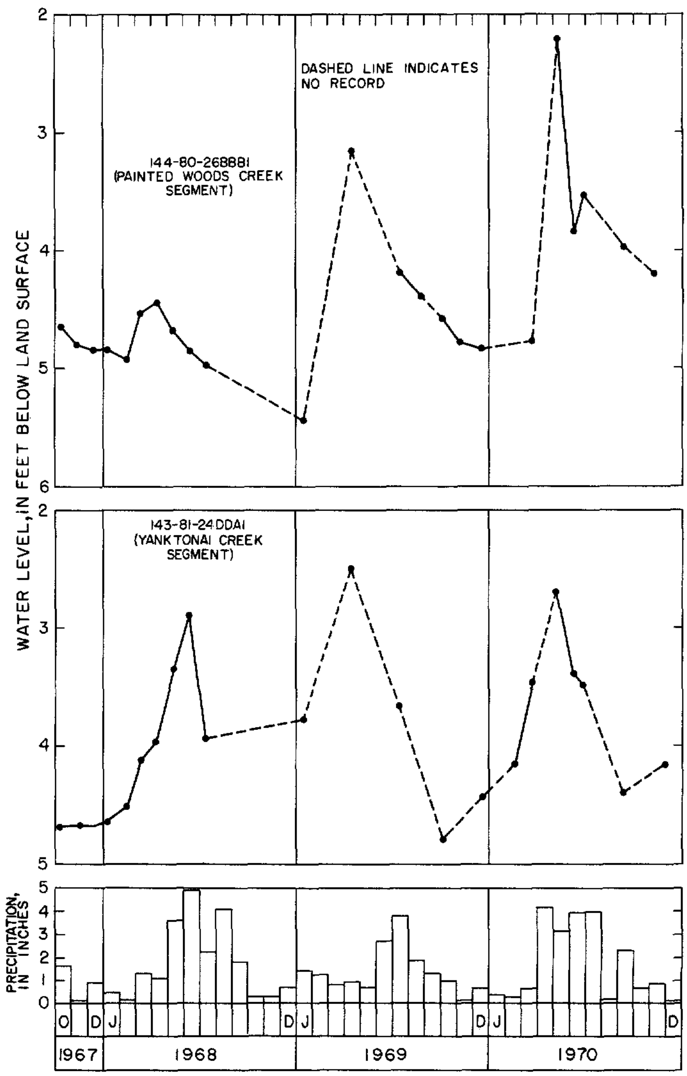


FIGURE 17.--Water-level fluctuations in the Painted Woods and Yanktonai Creek segments of the Lost Lake aquifer and precipitation at Wilton.

solids content ranged from 505 to 2,280 mg/l, sulfate from 153 to 1,040 mg/l, and iron from 560 to 5,300 μg/l. Three of the samples had irrigation classifications of C3-S1 and no residual sodium carbonate. The irrigation classifications of the remaining samples were C3-S3 and C4-S4, and the residual carbonate was 8.4 and 11 meq/l.

The concentrations of major constituents and hardness of water for the samples collected from the aquifer are shown in figure 18.

At the present time only a few domestic and livestock wells have been developed in the aquifer. It is believed that a few properly spaced and constructed wells would yield from 50 to 500 gpm (pl. 2).

Weller Slough Aquifer

The Weller Slough aquifer lies in a buried valley that extends northwestward from sec. 8, T. 145 N., R. 82 W., to its intersection with Lake Sakakawea about 2 miles west of Coleharbor (pl. 2). From this point the aquifer extends an unknown distance under the lake. The aquifer is about 14 miles long and varies in width from half a mile to a mile. It underlies an area of about 14 square miles.

Data from seven test holes indicate that the aquifer consists of beds and lenses of sand and gravel extending to depths of 300 feet. The major units consists of two beds near the bottom that are as much as 60 feet thick (pl. 3, sec. S-S'). The maximum aggregate thickness of aquifer penetrated was 90 feet in test hole 146-83-3AAA, but average thickness is about 40 feet.

Based on an areal extent of 14 square miles, an average thickness of 40 feet, and a specific yield of 15 percent, about 54,000 acre-feet of water should be available from storage in the Weller Slough aquifer.

Water levels in the aquifer range from about 57 feet below land surface in well 147-83-34ABB to about 101 feet in well 146-83-15CCC. The hydrograph for observation well 145-82-7DAA (fig. 19) shows that over a period of about 3 years the water level in the well has risen about 1.4 feet. The hydrograph for well 147-83-34ABB shows about a 0.8-foot rise in the water level since the well was drilled in 1969. The trend toward higher water levels is probably the combined result of recharge from precipitation and an increasing head in the aquifer as a result of increasing stages in Lake Sakakawea.

Analyses of three water samples from the aquifer indicate that the water is hard to very hard and is a sodium bicarbonate type. The dissolved-solids content ranged from 867 to 1,730 mg/l, sulfate from 188 to 561 mg/l, and iron from 80 to 4,200 μg/l. The irrigation classification ranged from C3-S1 to C4-S4 and the residual sodium carbonate content ranged from 3.7 meq/l in the sample from well 145-82-7DAA to 17.5 meq/l in the sample from well 146-83-15CCC.

At the present time the only wells developed in the aquifer are used for

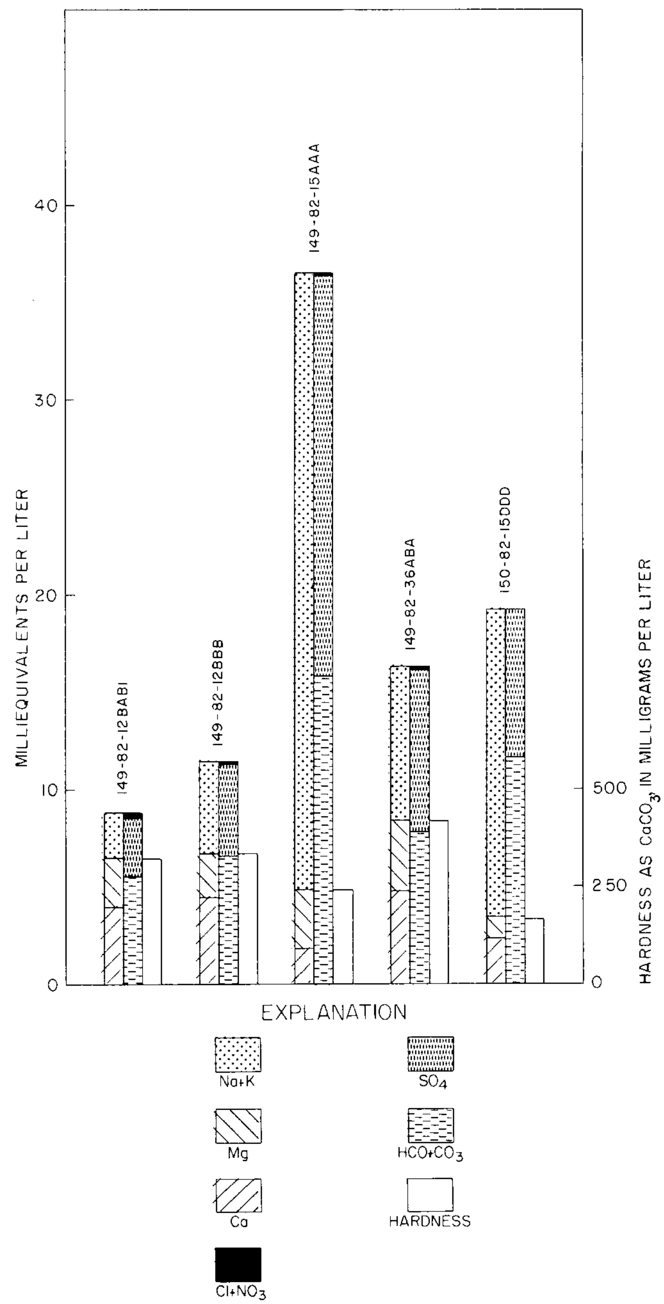


FIGURE 18.--Concentration of major constituents and hardness of water from the Snake Creek aquifer.

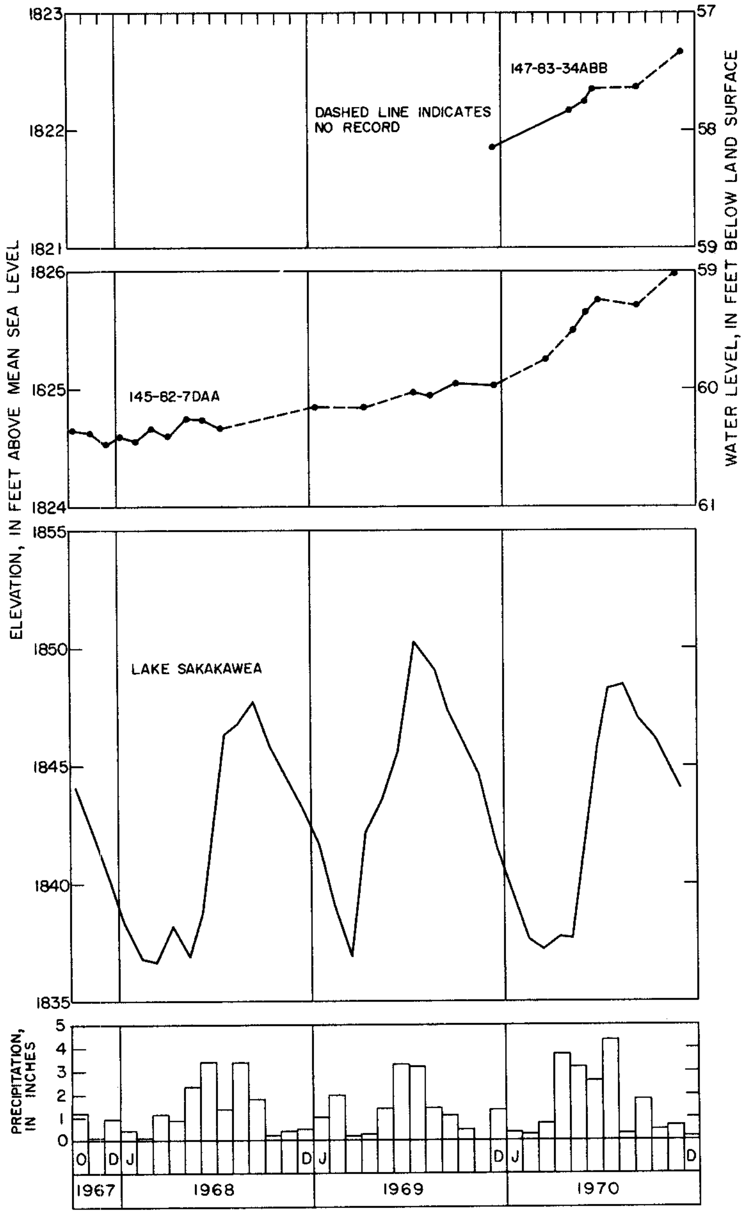


FIGURE 19.--Water-level fluctuations in the Weller Slough aquifer, fluctuations of Lake Sakakawea, and precipitation at Underwood.

domestic and livestock purposes. The amount of water withdrawn by these wells is relatively small in comparison to the amount of water stored in the aquifer.

Properly constructed wells can be expected to yield as much as 1,000 gpm from the central and thicker parts of the aquifer (pl. 2).

Wolf Creek Aquifer

The Wolf Creek aquifer underlies an area of about 5 square miles in the vicinity of Coleharbor (pl. 2). The major part of the aquifer, which is confined, lies north and west of Coleharbor and is hereafter referred to as the northern segment. A smaller segment of the aquifer, which is unconfined, extends into sec. 22, T. 147 N., R. 83 W., and is hereafter referred to as the southern segment. The aquifer boundaries are based on surface geology as well as test-hole and well data.

Test holes penetrating the northern segment show that it consists of an upper and lower unit. The upper unit, which is 30 to 42 feet below land surface, is predominantly a medium to coarse sand that ranges in thickness from 9 to 21 feet. The lower unit, which lies about 130 feet below land surface, is composed of fine to medium sand and gravel that ranges in thickness from 18 to 41 feet.

Data are insufficient to estimate the amount of water stored in the northern segment of the aquifer.

The water level in the lower unit is about 10 feet below land surface and in the upper unit about 14 feet below land surface.

Analysis of one water sample from the lower unit indicates that the water is very hard and is a sodium bicarbonate type. The water contained 1,560 mg/l dissolved solids, 583 mg/l sulfate, and 4,600 μg/l iron. The irrigation classification was C4-S4 and the residual sodium carbonate was about 11 meq/l.

No sample was obtained from the upper unit, but specific-conductance data obtained from private wells indicate that the water has less dissolved solids than water from the lower unit.

The southern segment of the aquifer has a maximum aggregate thickness of about 18 feet and consists of fine to coarse sand intermixed and interbedded with fine to coarse gravel. The depth to the top of the aquifer ranges from 2 to 10 feet below land surface.

Data are insufficient to estimate the amount of ground water available from storage in this segment of the aquifer. Water levels range from 2 to 10 feet below land surface.

Analyses of four water samples from the southern segment indicate that the water is very hard and is a calcium bicarbonate type. The average dissolved-solids content was about 480 mg/l. Iron content ranged from 90 to

190 μg/l, and sulfate from 66 to 161 mg/l. The irrigation classification of water ranged from C2-S1 to C3-S1 and the residual sodium carbonate was less than 1 meq/l.

Present development in the northern segment of the aquifer consists of a few small-capacity livestock and domestic wells. Depending upon the thickness and hydraulic conductivity of the material penetrated, a few properly constructed wells capable of yielding from 50 to 500 gpm (pl. 2) probably could be developed.

All of the water pumped from the southern segment of the aquifer is used to meet the municipal demands of Coleharbor. During development, the Coleharbor supply well (147-83-22DBC8) was reported to have been pumped at a rate of about 200 gpm (Tony Mann, oral commun., 1969). Present pumping rates are not known, but they probably do not exceed 25 gpm during periods of greatest demand. Wells requiring sustained yields of more than about 50 gpm probably would not be feasible because of the limited areal extent and relatively small storage capacity of this segment of the aquifer.

Garrison Aquifer

The Garrison aquifer consists of glaciofluvial deposits that occupy a narrow buried valley. The aquifer extends southeastward from the SE cor. sec. 30, T. 149 N., R. 84 W., to the north edge of Lake Sakakawea in secs. 22 and 23, T. 148 N., R. 84 W. (pl. 2). It underlies part of the city of Garrison in secs. 7 and 8, T. 148 N., R. 84 W., and has an areal extent of about 3 square miles.

In places the aquifer is rather lenticular (pl. 3, sec. T-T'). The lenses, which range in thickness from 2 to 78 feet, may consist entirely of sand or gravel, or a mixture of both. The maximum aggregate thickness penetrated in a test hole was 90 feet. Locally the aquifer may consist of a single thick bed (pl. 3, sec. V-V'). The average total thickness of the aquifer is about 31 feet.

An aquifer test was made during August 1971, using a newly constructed public supply well belonging to the city of Garrison and five observation wells. The production well was 118 feet deep and was located in the E½SW¼ sec. 6, T. 148 N., R. 84 W. The well was pumped for 50 hours at 250 gpm and allowed to recover for 50 hours after the pump was shut off.

Results of the test indicated a transmissivity of about 3,000 ft^2day^{-1} and a storage coefficient of 0.0001 (R. W. Schmid, written commun., 1971). The specific capacity of the production well after 3,000 minutes of pumping was about 10 gpm per foot of drawdown.

Based on an areal extent of 3 square miles, an average thickness of 31 feet, and a specific yield of 15 percent, about 9,000 acre-feet of water should be available from storage in the Garrison aquifer.

No long-term water-level records are available; however, water-level measurements made in six observation wells from July through December 1970 indicated water levels were generally between 50 and 80 feet below land surface. Fluctuations were less than 5 feet during this period. The lowest water levels occurred during the months of July, August, and September, probably as the result of increased pumpage by the city of Garrison.

Analyses of 19 water samples from the aquifer indicate that the water is predominantly a sodium bicarbonate type and is very hard. The dissolved-solids content ranged from 885 to 1,570 mg/l, sulfate from 160 to 517 mg/l, and iron from 400 to 10,000 μg/l. The irrigation classification of the water ranged from C3-S2 to C4-S4 and residual sodium carbonate was greater than 2.5 meq/l.

The general range of concentrations of the major constituents and hardness of the water in selected samples from the Garrison aquifer are shown in figure 20.

At the present time the city of Garrison has three public supply wells tapping the aquifer, and there are several livestock and domestic wells developed in the aquifer. The available data indicate that pumping from the aquifer has produced no permanent decline of the water level. Because the aquifer is small in areal extent, future development should include only a few large-capacity wells. Properly constructed and spaced wells tapping the aquifer can be expected to yield as much as 200 gpm (pl. 2).

MELT-WATER-CHANNEL AQUIFERS

The major melt-water-channel aquifers lie adjacent to the Missouri River. These aquifers consist largely of reworked deposits of glaciofluvial sand and gravel of Pleistocene age that are overlain by alluvium of undertermined thickness.

The melt-water-channel aquifers are, in order of decreasing size: Fort Mandan, Painted Woods Lake, Riverdale, and Buffalo Creek.

Fort Mandan Aquifer

The Fort Mandan aquifer, which includes the Hancock Flats unit of Greenman (1953, pl. 1), underlies an area of about 16 square miles adjacent to the Missouri River southwest and west of Falkirk (pl. 2). The aquifer is composed of glaciofluvial deposits that are generally overlain by undifferentiated glacial deposits and alluvium.

The depth to the top of the aquifer ranged from 11 to 53 feet in seven test holes drilled during this project. The thickness ranges from 31 to 61 feet (pl. 3, sec. W-W') and averages about 46 feet. The aquifer materials consist of fine to coarse sand that is interbedded and intermixed with medium to coarse gravel. The sand and gravel deposits are interspersed with clay lenses

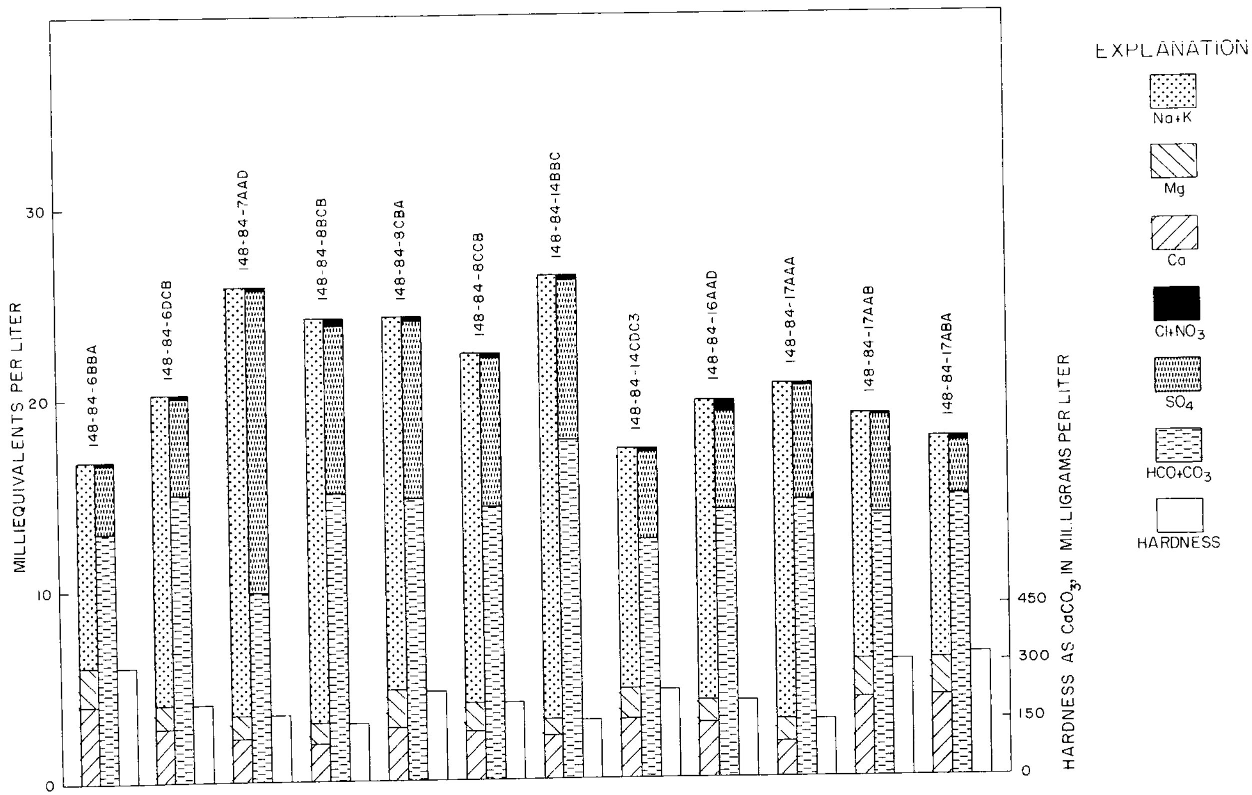


FIGURE 20.--Concentration of major constituents and hardness of selected water samples from the Garrison aquifer.

of varying thickness. Generally the bottom-most beds are composed of gravel, which may be as much as 50 feet thick.

Based on an areal extent of 16 square miles, an average thickness of 46 feet. and a specific yield of 15 percent, about 71,000 acre-feet of water should be available from storage in the Fort Mandan aquifer.

Water-levels in the Fort Mandan aquifer are related to seasonal variations in precipitation and to changes in stage of the Missouri River. They range from 11 to 13 feet below land surface in the southern part of the aquifer and 32 to 50 feet below land surface in the northern part.

Analyses of 11 water samples from the aquifer indicate that the water is predominantly a calcium magnesium bicarbonate type. However, water from two of the wells (144-84-24CBA and 145-84-15DDC) is a sodium bicarbonate type.

The calcium magnesium bicarbonate water was very hard and had a dissolved-solids content that ranged from 456 to 1,120 mg/l. Of the two sodium bicarbonate waters, the sample from well 144-84-24CBA was soft and the sample from well 145-84-15DDC was hard. The dissolved-solids contents were 1,130 and 1,530 mg/l, respectively. All of the samples except one (144-83-30ACB1) contained iron in excess of 300 μg/l.

The irrigation classification ranged from C3-S1 to C3-S3. The residual sodium carbonate content ranged from about 1 meq/l (145-84-14CDD) to about 22 meq/l (144-84-24CBA).

The range of major constituents and hardness of the water from the Fort Mandan aquifer are shown in figure 21.

At the present time the only withdrawals from the aquifer are for domestic and livestock purposes. The relatively small amount of water used for these purposes has not had any regional effect on the water levels in the aquifer. It should be possible to develop wells yielding as much as 1,500 gpm from the thicker parts of the aquifer (pl. 2). Large-yield wells pumping from the aquifer near the river could be expected to induce recharge from the river and possibly improve the quality of the ground water.

Painted Woods Lake Aquifer

Location and extent. – The Painted Woods Lake aquifer is composed of glaciofluvial deposits overlain by undifferentiated glacial deposits and alluvium. It underlies an area of about 9 square miles adjacent to the Missouri River south of Washburn (pl. 2).

Thickness and lithology. – The aquifer generally is confined by deposits of silty to sandy clay that are as much as 32 feet thick, but locally are absent. Depth to the top of the aquifer ranged from 9 to 32 feet in nine test holes drilled as part of this project. The thickness ranges from 0 to 124 feet and

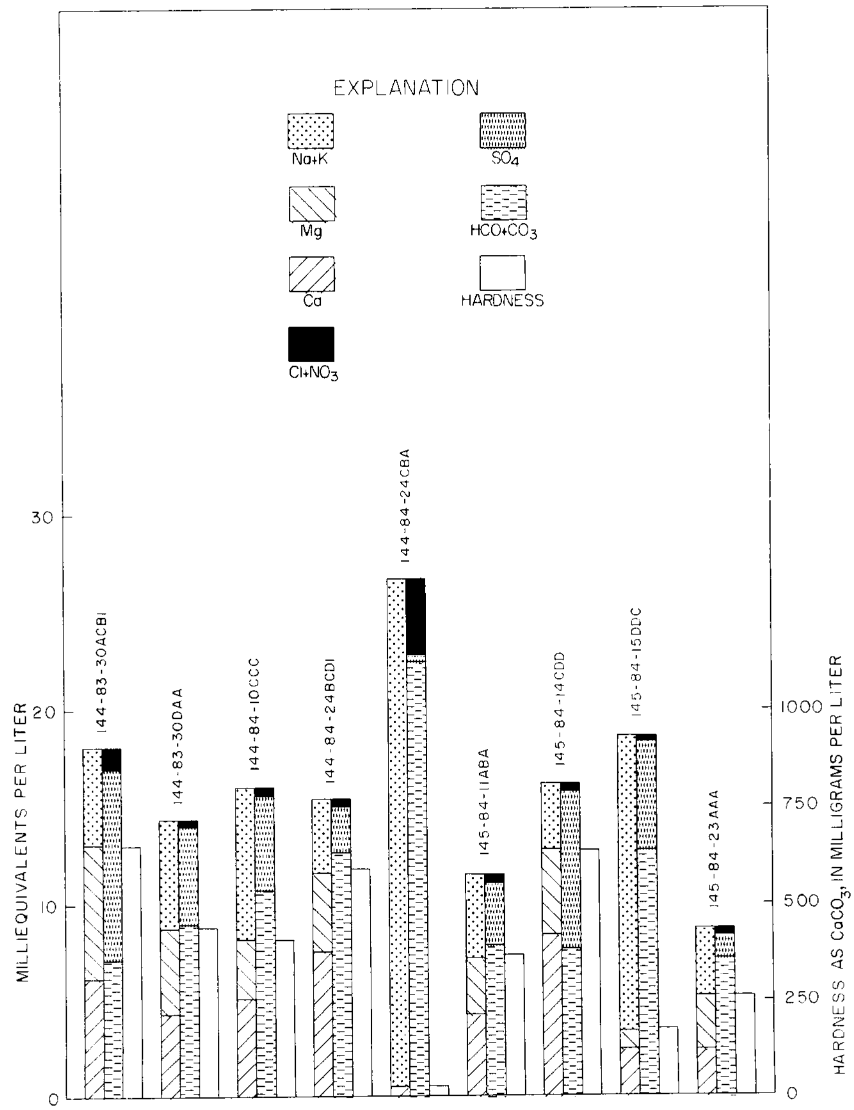


FIGURE 21.--Concentration of major constituents and hardness of water from the Fort Mandan aquifer.

averages about 70 feet. The thickest part appears to be associated with a buried channel near the eastern edge of the aquifer (fig. 22 and pl. 3, secs. X-X' and Z-Z'). Test-hole data show that the aquifer is composed predominantly of very fine to very coarse sand interbedded and intermixed with gravel. Numerous clay lenses of varying thickness and extent are scattered throughout the aquifer.

Hydrologic character. – An aquifer test was made using an irrigation well (143-81-29BBB1) owned by the South McLean Mutual Aid Association. The well is cased with 12-inch concrete casing to 82 feet and screened from 82 to 107 feet. Five observation wells were installed (fig. 23). Four of the wells (143-81-29BBA3, BBD, BBA2, and BBB2) were screened in the lower part of the aquifer at about the same depth as the production well, and the other well (143-81-20CCB) was screened in the upper part of the aquifer. Pumping started October 3, 1967, and continued for 6,000 minutes (4.2 days). A constant discharge of 1,180 gpm was maintained throughout the test. Water levels were measured in all wells during the pumping and for about 2,800 minutes after the pump was shut off. No other wells were pumping in the area during the test.

Water samples were taken prior to the test and after 24 minutes, 5.5, 24, 73, and 99.4 hours of pumping.

Data for well 143-81-29BBA2 were not available owing to malfunction of equipment during the early part of the test. Data from well 143-81-20CCB were not used because there was no significant amount of drawdown during the early part of the test.

The time-drawdown data plot for well 143-81-29BBA3 is shown in figure 24, in which the field data were superimposed on a family of leaky artesian type curves. The early data fit the type curve but after about 20 minutes of pumping the data plot fell below the type curve onto one of the leaky artesian curves. After about 300 minutes the data plot deviated upward from the leaky artesian curve indicating the presence of a barrier boundary. Therefore, it is believed that the aquifer is a leaky artesian system that is affected by one or more barrier boundaries.

The results of the aquifer test indicate a transmissivity of 26,200 $ft^2 day^{-1}$ and a storage coefficient of 0.00045. The drawdown in the pumped well at 6,000 minutes was 11.1 feet and the specific capacity of the well was 106 gpm per foot of drawdown. Greenman (1953, p. 21-42) obtained similar results from aquifer tests made in secs. 17 and 20, T. 143 N., R. 81 W.

Storage. – Based on an areal extent of 9 square miles, an average thickness of 70 feet, and a specific yield of 15 percent, about 63,000 acre-feet of water should be available from storage in the Painted Woods Lake aquifer.

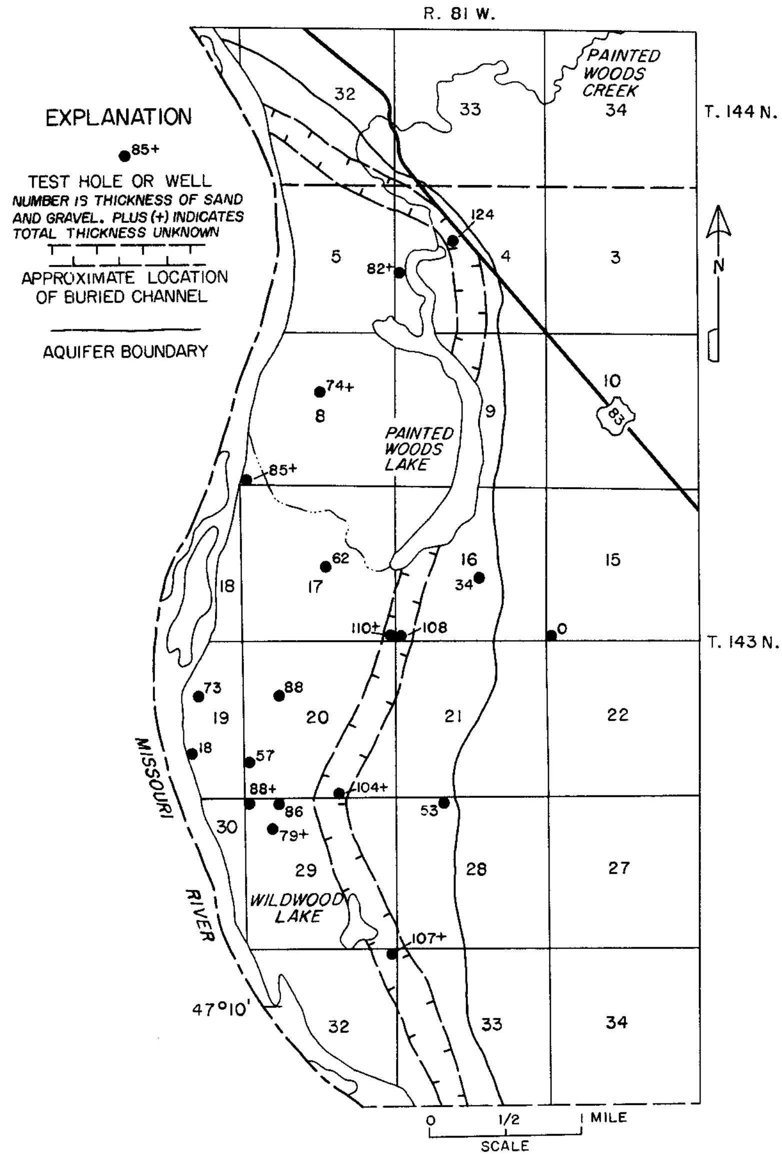


FIGURE 22.--Location of test holes and buried channel in the Painted Woods Lake aquifer.

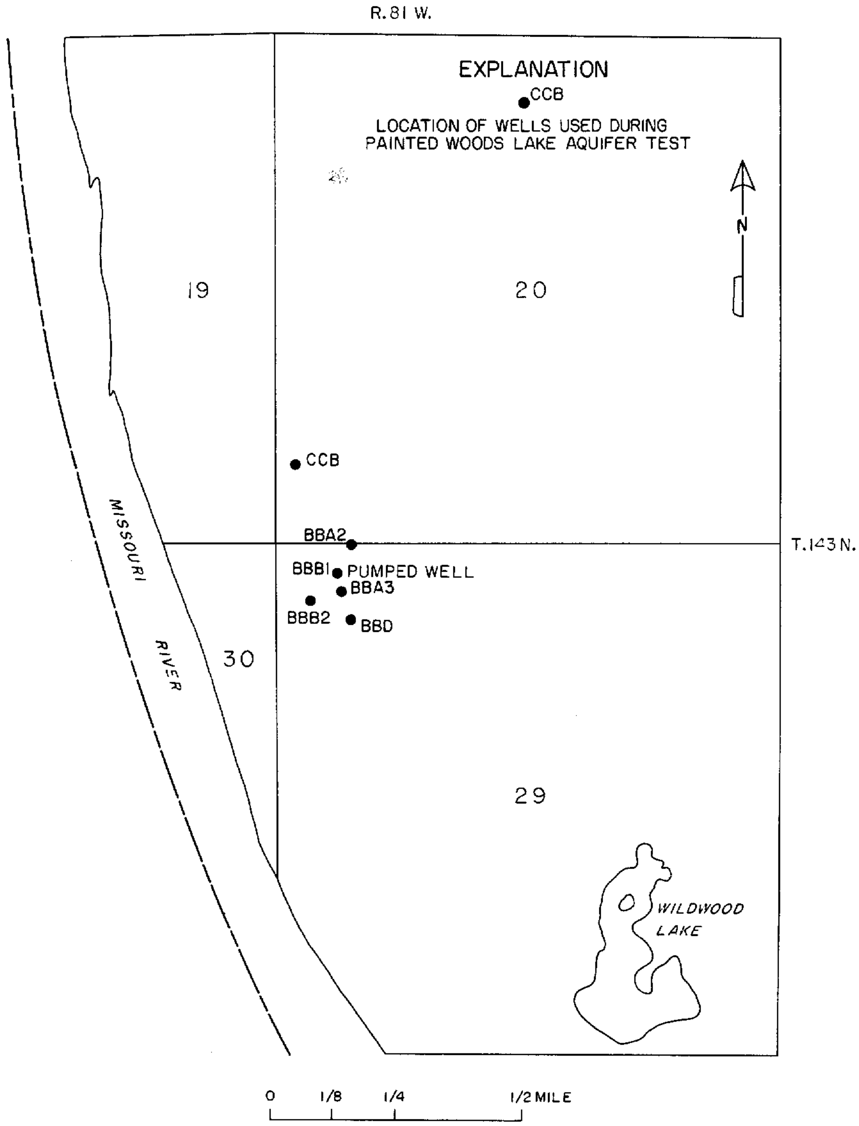


FIGURE 23.-- Location of aquifer-test observation wells, Painted Woods Lake aquifer.

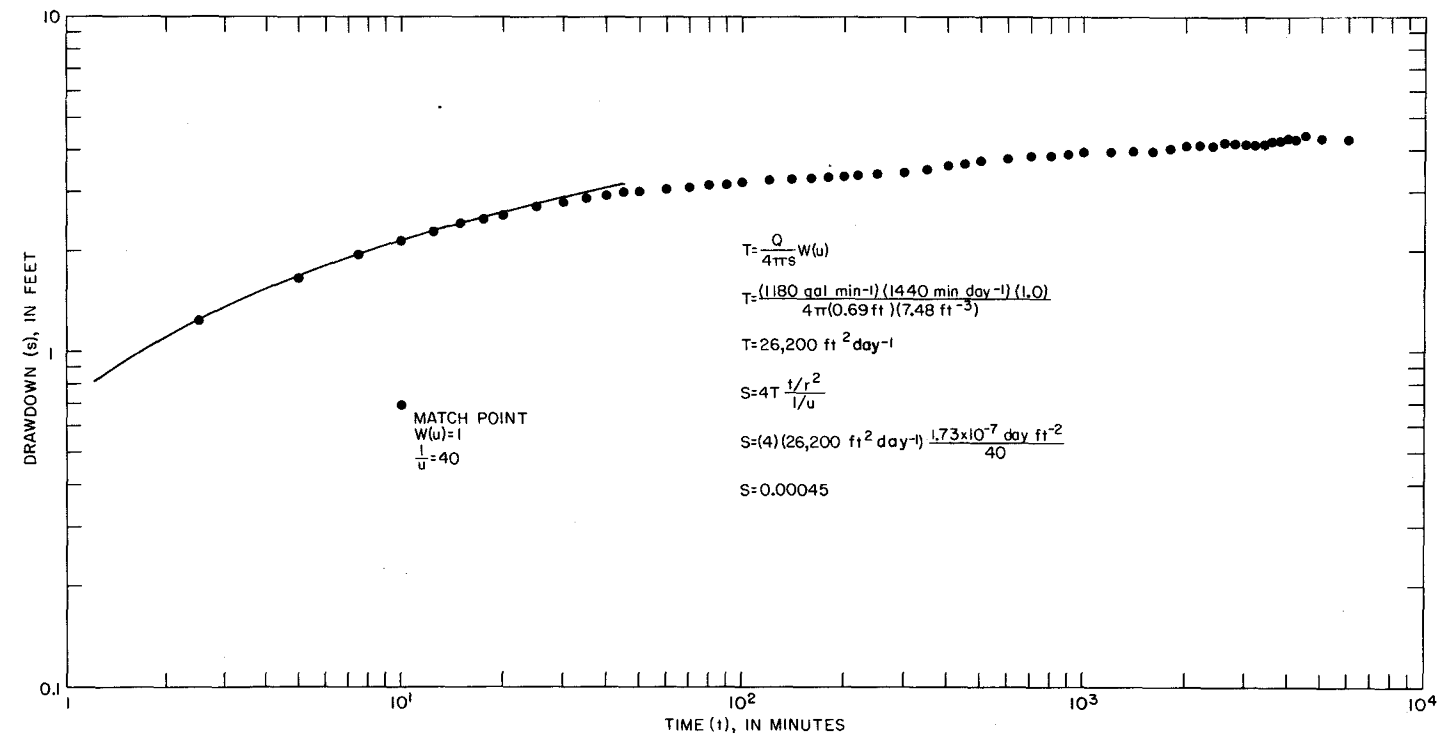


FIGURE 24.-- **Logarithmic plot of drawdown (s) versus time (t) for observation well 143-81-29BBA3, Painted Woods Lake aquifer.**

Water-level fluctuations. – Water levels in the aquifer range from 6 to about 12 feet below land surface and are affected by infiltration of precipitation and stage changes in the Missouri River.

Quality of water. – Analyses of nine water samples indicate that the water is very hard and is predominantly a sodium bicarbonate type. The dissolved solids ranged from 503 to 1,240 mg/l, sulfate from 117 to 370 mg/l, and iron from 0 to 5,100 μg/l. Most of the samples had either a C3-S1 or C3-S2 irrigation classification and a residual sodium carbonate content was greater than 2.5 meq/l.

Analyses of water samples taken during the aquifer test are listed in table 4, and indicate only minor changes in water quality during the test.

Utilization and potential for future development. – At the present time there are only a few domestic wells and one irrigation well tapping the aquifer. Pumpage from these wells has not had any regional effect on the water levels in the aquifer.

Depending on the thickness and hydraulic conductivity of the material penetrated, properly constructed wells tapping the Painted Woods Lake aquifer should yield as much as 1,500 gpm (pl. 2).

Riverdale Aquifer

The Riverdale aquifer underlies an area of about 4 square miles adjacent to the Missouri River south of Riverdale (pl. 2).

The aquifer consists of an upper and lower unit. The upper unit consists largely of very fine to coarse sand, whereas the lower unit is predominantly gravel. The total thickness of the aquifer ranges from about 28 feet in test hole 146-84-8DBD to 94 feet in test hole 146-84-17DAA. However, the test holes were drilled near the eastern edge of the aquifer and the thicknesses may not be representative of the aquifer farther west.

Data are inadequate to estimate the quantity of water available from storage in the Riverdale aquifer.

The water level in observation well 146-84-8DBD, which is screened in the upper unit, ranges from 8 to 11 feet below land surface. The water level in observation well 146-84-17DAA, which is screened in the lower unit, ranges from 31 to 32 feet below land surface.

The chemical analyses shown in table 5 indicate that the water may be either a sodium sulfate or a calcium sulfate type. The water from well 146-84-8DBD had a C4-S3 irrigation classification and water from well 146-84-17DAA had a C4-S2 classification. Residual sodium carbonate in water from well 146-84-8DBD was 4.3 meq/l and it was less than 1 meq/l in well 146-84-17DAA.

TABLE 4. -- Chemical analysis of water samples taken during the Painted Woods aquifer test

Constituents	Elapsed pumping time				
	24 minutes	5.5 hours	24 hours	73 hours	99.4 hours
	Concentrations, in milligrams per liter				
Silica (SiO_2)	23	--	--	24	24
Iron (Fe)[1]	1,500	1,900	2,000	3,300	2,600
Calcium (Ca)	73	82	84	42	82
Magnesium (Mg)	48	40	43	42	41
Sodium (Na)	231	233	226	223	231
Potassium (K)	7.1	7.1	7.0	6.8	7.1
Bicarbonate (HCO_3)	662	664	694	563	672
Carbonate (CO_3)	0	0	0	0	0
Sulfate (SO_4)	279	279	282	279	285
Chloride (Cl)	20	20	20	20	19
Fluoride (F)	.7	--	--	.1	.7
Nitrate (NO_3)	2.9	4.6	3.7	3.1	3.9
Boron (B)[1]	240	--	--	200	150
Dissolved solids	992	--	--	812	1,000
Hardness as $CaCO_3$	378	371	387	279	375
Specific conductance (micromhos per centimeter at 25°C)	1,610	1,620	1,540	1,390	1,610
pH (units)	7.8	7.9	7.9	8.2	7.9
Percent sodium	56	57	55	63	57
Sodium-adsorption ratio	5.2	5.3	5.0	5.8	5.2
Residual sodium carbonate	5.8	6.0	6.2	5.8	6.1

[1] Iron (Fe) and boron (B) are given in micrograms per liter.

TABLE 5. -- Chemical analysis of water samples from the Riverdale aquifer

Location:	146-84-8DBD	146-84-17DAA
Constituents (in milligrams per liter)		
Silica (SiO_2)	17	21
Iron (Fe)[1]	5,100	10,000
Calcium (Ca)	34	514
Magnesium (Mg)	56	157
Sodium (Na)	406	394
Potassium (K)	7.3	17
Bicarbonate (HCO_3)	584	474
Carbonate (CO_3)	0	0
Sulfate (SO_4)	633	2,310
Chloride (Cl)	55	12
Fluoride (F)	0	0
Nitrate (NO_3)	2.5	0
Boron (B)[1]	1,100	740
Dissolved solids	1,470	3,780
Hardness as $CaCO_3$	316	1,930
Specific conductance (micromhos per centimeter at 25°C)	2,170	3,990
pH (units)	8.2	7.7
Percent sodium	73	31
Sodium-adsorption ratio	9.9	3.9
Residual sodium carbonate	4.3	.9

[1] Iron (Fe) and boron (B) are given in micrograms per liter.

At the present time there are no wells developed in the aquifer. Properly constructed and located wells could be expected to yield as much as 1,000 gpm (pl. 2).

Buffalo Creek Aquifer

The Buffalo Creek aquifer underlies an area of about 3 square miles adjacent to the Missouri River west of Washburn (pl. 2). The aquifer was penetrated by one test hole (144-82-17AAD), which penetrated sand from 6 to 34 feet and gravel from 34 to 42 feet.

Data are inadequate to estimate the quantity of water available from storage in the Buffalo Creek aquifer. Water levels fluctuate from about 2 to 7 feet below land surface.

Analysis of one sample indicates that the water is hard and is a sodium bicarbonate type. Dissolved-solids content was 1,760 mg/l, sulfate was 602 mg/l, and iron was 2,700 μg/l. The water had a irrigation classification of C4-S4 and a residual sodium carbonate value of 10.7 meq/l.

At the present time there are no known wells tapping the aquifer. Properly developed wells could yield as much as 1,000 gpm (pl. 2). The salinity of the water could possibly be reduced as the result of induced recharge from the Missouri River by pumping.

SURFICIAL-OUTWASH AQUIFER

Surficial-outwash deposits consisting largely of sand and gravel underlie a small area southeast of the city of Mercer. These deposits comprise the Mercer aquifer.

Mercer Aquifer

The Mercer aquifer underlies an area of about 8 square miles and extends southwestward from the west edge of sec. 12, T. 146 N., R. 79 W., into sec. 2, T. 145 N., R. 80 W. (pl. 2).

The aquifer, which was penetrated by two test holes and two auger holes, has a thickness ranging from 18 to 28 feet. It consists generally of medium to very coarse sand intermixed and interbedded with gravel, but locally may consist of fine to coarse sandy gravel.

Data are insufficient to estimate the amount of water available from storage in the aquifer. Water levels range from about 6 feet below land surface in the northeastern part of the aquifer to about 16 feet below land surface in the southwestern part.

Analyses of three water samples indicate the water may be either a calcium bicarbonate sulfate or a calcium bicarbonate type and is very hard. The dissolved-solids content ranged from 341 to 622 mg/l and iron ranged from 260 to 1,800 μg/l. Sulfate content ranged from 57 to 233 mg/l. The irrigation classification of the water ranged from C2-S1 to C3-S1. Residual sodium carbonate content was less than 1 meq/l.

Only a few domestic and livestock wells have been developed in the aquifer. Properly spaced and constructed wells developed in the thicker parts of the aquifer should yield as much as 200 gpm (pl. 2).

UNDIFFERENTIATED SAND AND GRAVEL AQUIFERS

Undifferentiated sand and gravel deposits that were laid down in a glaciofluvial environment are distributed randomly throughout the glacial deposits in McLean County. Test holes and wells commonly penetrated one or more beds of sand and (or) gravel at depths from 1 to more than 300 feet below land surface. These deposits are known to be as much as 40 feet thick in places. Some of the sand and gravel deposits appear to be isolated pockets or lenses completely surrounded by glacial till.

Chemical analyses of water from some of the small sand and gravel aquifers are shown in table 6 and indicate a wide range in quality.

Most of the water pumped from the undifferentiated sand and gravel aquifers is used for domestic and livestock purposes; however, the city of Max has developed three wells in an undifferentiated sand and gravel aquifer.

Wells tapping the undifferentiated sand and gravel aquifers probably will yield from 1 to 50 gpm. The thickness and lithology of some of the deposits indicate that greater yields may be obtainable, but this cannot be verified without additional test drilling to determine the extent of the deposits. Any well development in these deposits should be preceded by test drilling and aquifer tests.

Pettyjohn and Hutchinson (1971, pl. 1) showed the Douglas aquifer entering McLean County along the northern edge of sec. 5, T. 150 N., R. 84 W., and the Hiddenwood Lake aquifer entering the county along the northwest edge of sec. 3, T. 150 N., R. 87 W. These aquifers were not located during this investigation. However, if they are present, they may provide sufficient water for livestock and domestic use.

UTILIZATION OF GROUND WATER

The rural population of McLean County is dependent upon ground water for its domestic and livestock needs. In addition, several communities obtain water for public supply use from wells. The use of ground water for irrigation is now of minor importance, but it will probably increase in the future.

Domestic and Livestock Use

Most of the wells that provide water for domestic and livestock use in in the county are drilled wells. They range in depth from about 10 feet to 1,200 feet and most yield less than 10 gpm. However, the yields are usually sufficient for most domestic uses and for small herds of livestock. Estimates of the quantity of water pumped daily from domestic and livestock wells in McLean County are listed in the following table.

TABLE 6. -- Chemical analysis of water samples from undifferentiated sand and gravel aquifers

Constituents	Location						
	Surficial deposits			Buried deposits			
	145-80-29DCD	149-80-6CBC	150-83-16ABB	143-80-8AAA	145-80-10ABA	145-82-28ABB	150-83-9DDA
	Concentrations, in milligrams per liter						
Silica (SiO_2)	19	12	20	25	27	24	17
Iron (Fe)[1]	3,600	520	80	1,000	360	0	2,000
Calcium (Ca)	48	49	164	194	21	66	124
Magnesium (Mg)	25	43	100	49	11	21	81
Sodium (Na)	266	21	56	209	561	487	380
Potassium (K)	1.8	9.6	12	7.6	4.5	4.3	13
Bicarbonate (HCO_3)	610	445	443	432	1,250	683	875
Carbonate (CO_3)	0	0	0	0	18	2.7	0
Sulfate (SO_4)	297	103	564	787	249	746	760
Chloride (Cl)	3.2	.5	15	7.7	7.4	0	7.1
Fluoride (F)	.4	.2	.3	.2	.9	.7	.1
Nitrate (NO_3)	3.1	0	2	.6	.5	1	11
Boron (B)[1]	260	0	100	300	0	0	290
Dissolved solids	947	495	1,220	1,500	1,400	1,640	1,840
Hardness as $CaCO_3$	224	426	821	688	96	250	643
Specific conductance (micromhos per centimeter at 25°C)	1,450	805	1,540	1,950	2,330	2,430	2,460
pH (units)	8.1	7.8	7.9	7.8	8.4	8.3	6.5
Percent sodium	72	9	13	39	92	81	56
Sodium-adsorption ratio	7.7	.4	.9	3.5	25	13	6.5
Residual sodium carbonate	7.8	3	0	0	23	8.7	5.0

[1] Iron (Fe) and boron (B) are given in micrograms per liter

Use	Individual requirements[1] (gallons per day)	Population or number	Total pumpage (gallons per day)
Domestic (not including communities having municipal water supplies)	100	[2] 1,937	193,700
Cattle	15	[3] 60,000	900,000
Milk cows	35	[3] 4,600	161,000
Sheep	1.5	[3] 6,000	9,000
Chickens	.10	[3] 32,000	3,200
Hogs	5	[3] 268	1,340
	Total pumpage		1,268,000 (rounded)

[1] Murray, 1965.
[2] U.S. Bureau of the Census, 1971.
[3] North Dakota State University, 1968.

Public Supply

Eight communities in McLean County rely on ground water for their municipal supplies.

COLEHARBOR

The city of Coleharbor obtains its municipal water supply from a well tapping sand and gravel deposits in the southern segment of the Wolf Creek aquifer. This well, which is about 18 feet deep, produces about 2.8 million gallons annually.

The water is a calcium bicarbonate type and is very hard. The dissolved-solids content of the water is about 423 mg/l.

GARRISON

The city of Garrison obtains its water supply from three wells tapping the Garrison aquifer and from a standby well completed in the Fort Union Group. The wells tapping the Garrison aquifer range in depth from 151 to 200 feet. The well in the Fort Union is 258 feet deep. From 1957 to 1968 these wells produced about 30 million gallons of water. Most of this was pumped from the Garrison aquifer.

The water from the three wells completed in the Garrison aquifer is a sodium bicarbonate type. It is very hard and the dissolved-solids content ranges from 1,320 to 1,470 mg/l. The water from the well in the Fort Union is a sodium bicarbonate type. It is soft and the dissolved-solids content is about 1,820 mg/l.

MAX

The city of Max obtains its water supply from wells tapping buried and surficial undifferentiated sand and gravel aquifers. Well 150-83-9DDA, which is 130 feet deep, yields very hard sodium sulfate water containing objectionable amounts of iron. The dissolved-solids content of the water sample taken from this well was 1,840 mg/l. Well 150-83-16ABB is 23 feet deep and yields a very hard calcium magnesium sulfate water containing 1,220 mg/l dissolved solids. Well 150-83-9DBD, which is 122 feet deep, was unused at the time of inventory, but was later used to supplement the water supply from well 150-83-9DDA. During 1968 the two deep wells produced about 2.9 million gallons of water. The pumpage from the shallow well is unknown.

The buried and surficial aquifers are limited in areal extent and do not appear to be capable of sustaining any large development. Locally the Hell Creek and Fox Hills Formations do not appear to be capable of yielding any substantial amounts of water. Any development in this area requiring relatively large quantities of water should be preceded by test drilling.

MERCER

The city of Mercer has a well 585 feet deep that taps the Fox Hills Formation. The average annual yield from this well is about 1.5 million gallons. The water is soft and is a sodium bicarbonate type. It had a dissolved-solids content of 1,370 mg/l.

At the present time the existing well provides an adequate water supply for the city. Additional water supplies could be obtained from the Lake Nettie aquifer, which is about a mile north of Mercer.

TURTLE LAKE

Prior to January 22, 1970, the city of Turtle Lake obtained its municipal water supply from the Hell Creek (?) aquifer. Annual yield from this aquifer was about 16.4 million gallons.

In the latter part of 1969 a well (147-81-25DCB) was developed in the Turtle Lake aquifer. The water is piped about 2½ miles to the city of Turtle Lake. During the period from January 22 to November 1, 1970, the well produced about 13.1 million gallons of water.

The water from the well is very hard and is a sodium bicarbonate type containing 1,260 mg/l dissolved solids.

UNDERWOOD

The city of Underwood obtains its water supply from three wells that are completed in the sand and lignite beds of the Fort Union Group. The wells range in depth from about 82 to 95 feet and have an estimated annual yield of about 3.1 million gallons.

The water is very hard and is a calcium bicarbonate type. The dissolved-solids content ranged from 369 to 1,400 mg/l.

At the present time the existing wells provide adequate water for the city's needs. Additional water supplies probably could be obtained from the lower part of the Fort Union Group and the Hell Creek and Fox Hills aquifers.

WHITE SHIELD

White Shield, located in western McLean County, is a U.S. Bureau of Indian Affairs' school and housing development. The community is located on the south edge of the White Shield aquifer and has two wells tapping the aquifer. These wells produce about 5.8 million gallons annually. The water is very hard and is a sodium bicarbonate type containing about 900 mg/l dissolved solids. Any increase in demand can be met by expansion of the existing well field.

WILTON

The city of Wilton, located in southeastern McLean County, obtains its water supply from three wells tapping very fine grained sandstone in the Fort Union Group. These wells, which range from 85 to 100 feet in depth, yield about 12.1 million gallons of water annually.

The water is very hard and is a calcium bicarbonate type with a dissolved-solids content ranging from 291 to 401 mg/l.

At the present time the water supply appears to be adequate for the city's use. Additional water supplies probably could be obtained from the Hell Creek and Fox Hills aquifers.

Irrigation

At the present time there are only two irrigation wells in the county. One of the wells taps the Painted Woods Lake aquifer. This well (143-81-29BBB1) yields more than 1,000 gpm of high-salinity, high-sodium type water with a residual sodium carbonate content of more than 2.5 meq/l.

The other irrigation well (148-80-33CBD) taps the upper unit of the Lake Nettie aquifer and yields more than 500 gpm of high-salinity, low-sodium type water having a residual sodium carbonate content of less than 1 meq/l.

In 1969 a combined total of about 330 acre-feet of ground water was withdrawn to irrigate 217 acres of cropland (Gordon Baesler, oral commun., 1971).

SUMMARY

Ground water in McLean County is obtained mainly from sandstone and lignite aquifers in the preglacial rocks and from sand and gravel aquifers in the glacial deposits. The preglacial aquifers of economic importance in McClean County are the Fox Hills and Hell Creek Formations and the Fort Union Group.

Water from the Fox Hills and Hell Creek Formations is soft and is a sodium bicarbonate type. The dissolved-solids content measured in the water sampled ranged from 1,200 to 1,630 mg/l. The potential yields from these formations are unknown. Yields of 10 gpm have been measured in wells tapping the Fox Hills and 50 gpm in wells tapping the Hell Creek.

Water from the Fort Union Group is predominantly a sodium bicarbonate type and about 60 percent of the water sampled was hard to very hard. Yields generally range from 5 to 75 gpm but potentially may be as high as 200 gpm. The cities of Garrison, Underwood, and Wilton obtain water for their municipal supplies from the Fort Union Group.

The aquifers with the greatest potential for development are those in the glacial deposits and are generally associated with buried valleys and melt-water channels. The buried-valley aquifers are the largest in areal extent and contain the greatest amounts of water in storage. The melt-water-channel aquifers are narrower, but because of large thicknesses, contain significant amounts of water in storage.

In east-central McLean County the Lake Nettie, Strawberry Lake, Turtle Lake, and Horse Shoe valley aquifers form a complex interconnected system called the Lake Nettie aquifer system. This system has an areal extent of about 166 square miles and contains an estimated 940,000 acre-feet of water available in storage.

Hydrologic data for the aquifers in the glacial deposits are summarized in table 7.

The rural population of McLean County is dependent upon ground water for its domestic and livestock needs. In addition, the communities of Coleharbor, Garrison, Max, Mercer, Turtle Lake, Underwood, White Shield, and Wilton obtain public water supplies from wells. The use of ground water for irrigation is now of minor importance (only two wells), but will probably increase in the future.

TABLE 7. — Summary of data for aquifers in the glacial deposits

Aquifer	Areal extent (square miles)	Average saturated thickness (feet)	Water available from storage (acre-feet)	General water type	General irrigation classification
Lake Nettie	100	70	670,000	Sodium bicarbonate to calcium bicarbonate	C2-S1 to C4-S4
Strawberry Lake	18	65	110,000	Calcium bicarbonate	C2-S1 to C3-S2
Turtle Lake	26	42	100,000	Sodium bicarbonate to calcium bicarbonate	C2-S1 to C3-S4
Horse Shoe valley	21	29	60,000	Calcium bicarbonate	C2-S1 to C3-S1
White Shield	40	100	380,000	Sodium bicarbonate to sodium sulfate	C3-S1 to C3-S2
Lost Lake	25	71	170,000	Sodium bicarbonate	C2-S1 to C3-S4
Snake Creek	19	60	110,000	Calcium magnesium bicarbonate to sodium bicarbonate sulfate	C3-S1 to C4-S4
Weller Slough	14	40	54,000	Sodium bicarbonate	C3-S1 to C4-S4
Wolf Creek	5	--	--	Calcium bicarbonate to sodium bicarbonate	C2-S1 to C4-S4
Garrison	3	31	9,000	Sodium bicarbonate	C3-S2 to C4-S4
Fort Mandan	16	46	71,000	Calcium magnesium bicarbonate to sodium bicarbonate	C3-S1 to C3-S3
Painted Woods Lake	9	70	63,000	Sodium bicarbonate	C3-S1 to C3-S2
Riverdale	4	--	--	Calcium sulfate to sodium sulfate	C4-S2 to C4-S3
Buffalo Creek	3	--	--	Sodium bicarbonate	C4-S4
Mercer	8	--	--	Calcium bicarbonate sulfate to calcium bicarbonate	C2-S1 to C3-S1

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GLOSSARY OF SELECTED TERMS

Aquifer – a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Area of influence – the area underlain by the cone of depression caused by a discharging well.

Artesian – artesian is synonymous with confined. Artesian water and artesian water body are equivalent, respectively, to confined ground water and confined water body. An artesian well obtains its water from an artesian or confined water body. The water level in an artesian well stands above the top of the artesian water body it taps.

Bedrock – consolidated rock underlying glacial and alluvial deposits of Pleistocene and (or) Holocene age.

Cone of depression – the conical low produced in a water table or potentiometric surface by a discharging well.

Confined – as used in this report the term confined refers to an aquifer in which the water is under artesian pressure. See artesian.

Drawdown – decline of the water level in a well or aquifer caused by pumping or artesian flow.

Evapotranspiration – the process by which water is returned to the atmosphere through direct evaporation from water or land surfaces and by transpiration of vegetation.

Fluvial deposits – sediments deposited by streams.

Ground water – water in the zone of saturation.

Hydraulic conductivity – the capacity of a rock to transmit water — usually described as the rate of flow in cubic feet per day through 1 square foot of the aquifer under unit hydraulic gradient, at existing kinematic viscosity.

Hydraulic gradient – the change in head per unit of distance in a given direction.

Hydrologic system – a series of interconnected aquifers, lakes, and streams.

Infiltration – the movement of water from the land surface toward the water table.

Inflow – movement of ground water into an area in response to the hydraulic gradient.

Lacustrine deposits – sediments formed in a lake environment.

Percolation – movement of water through the interstices of a rock or soil.

Potentiometric surface – as related to an aquifer, it is defined by the levels to which water will rise in tightly cased wells. The potentiometric surface is reported in feet above mean sea level.

Recharge – the addition of water to the zone of saturation.

Residual sodium carbonate (RSC) – residual sodium carbonate is twice the amount of carbonate or bicarbonate a water would contain after subtracting an amount equivalent to the calcium plus the magnesium. The U.S. Department of Agriculture Salinity Laboratory (1954, p. 81) proposed that water containing more than 2.5 meq/l of residual sodium carbonate is not suitable for irrigation, that containing 1.25-2.5 meq/l is marginal, and that containing less than 1.25 meq/l is safe.

Sodium-adsorption ratio (SAR) – the sodium-adsorption ratio of water is defined as

$$SAR = \frac{(Na+)}{\sqrt{\frac{(Ca+^2) + (Mg+^2)}{2}}}$$

where ion concentrations are expressed in milliequivalents per liter. Experiments citied by the U.S. Department of Agriculture Salinity Laboratory (1954) show that SAR predicts reasonably well the degree to which irrigation water tends to enter into cation-exchange reactions in soil. High values for SAR imply a hazard of a sodium replacing adsorbed calcium and magnesium. This replacement is damaging to soil structure.

Specific capacity – the rate of discharge of water from a well divided by the drawdown of the water level within the well.

Specific conductance – electrical conductance, or conductivity is the ability of a substance to conduct an electric current. The electrical conductivity of water is related to the concentration of ions in the water. Distilled water normally will have a conductance of about 1.0 micromhos per centimeter, whereas sea water may have a conductance of about 50,000 micromhos per centimeter. Standard laboratory measurements report the conductivity of water in micromhos per centimeter at 25°Celsius.

Specific yield – the ratio of volume of water which a rock or soil, after being saturated, will yield by gravity to the volume of the rock or soil. Generally expressed as a percentage or decimal fraction.

Stage – the height of a water surface above an established datum plane. Stage is often used interchangeably with the term "gage height."

Storage coefficient – the volume of water an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in head.

Surface runoff – that part of the runoff which travels over the soil surface to to the nearest stream channel.

Transmissivity – the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths.

Unconfined – as used in this report the term unconfined refers to an aquifer in which the water is under atmospheric pressure. See water table.

Underflow – the downstream movement of ground water through the permeable deposits beneath a stream.

Water table – surface in an unconfined water body at which the pressure is atmospheric. Defined by the levels at which water stands in wells that penetrate the water body far enough to hold standing water.

Zone, saturated – that part of the water-bearing material in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric.

APPENDIX

145-79-9BBB
NDSWC test hole 5918

Elevation: 1,850 feet

Geologic source	Material	Thickness (feet)	Depth (feet)
Glacial deposits:			
	Topsoil, silty, clayey, brownish-black	1	1
	Clay (till), silty, sandy, pebbly, moderate-yellowish-brown	31	32
	Clay (till), silty, sandy, pebbly, olive-gray	21	53
	Gravel, fine to medium, sandy, angular to subrounded	3	56
	Clay (till), silty, sandy, pebbly, olive-gray	57	113
	Clay, silty, plastic, olive-gray to medium-dark-gray	71	184
	Clay (till), silty, sandy, gravelly, olive-gray	14	198
	Clay, silty, sandy, laminated, olive-gray	31	229
	Gravel, fine to coarse, sandy, clayey, angular to well-rounded	33	262
	Clay, silty, plastic, olive-gray	10	272
	Gravel, fine to medium, clayey, sandy, angular to subrounded	22	294
	Clay, silty, sandy, plastic, olive-gray	22	316
	Gravel, fine to coarse, clayey, sandy, angular to subrounded	24	340
	Clay (till), silty, sandy, gravelly, olive-gray to medium-dark-gray	97	437
	Gravel, coarse, angular; numerous cobbles and boulders	3	440
Hell Creek Formation (?):			
	Shale, sandy, clayey, noncalcareous, brownish-gray; numerous small dark-brown concretions	10	450

145-80-25BAA
NDSWC test hole 5917

Elevation: 1,850 feet

Geologic source	Material	Thickness (feet)	Depth (feet)
Glacial deposits:			
	Topsoil, silty, clayey, brownish-black	1	1
	Clay (till), silty, sandy, pebbly, yellowish-brown; scattered pebbles	43	44
	Clay (till), silty, sandy, pebbly, olive-gray	14	58
	Clay (till), silty, pebbly, olive-gray to grayish-olive-green	17	75
	Clay, silty, sandy, olive-gray; scattered sand lenses	47	122
	Clay (till), sandy, silty, olive-gray	18	140
	Silt, clayey, olive-gray	22	162
	Clay (till), silty, sandy, pebbly, olive-gray; numerous thin gravel lenses	23	185
	Clay (till), silty, sandy, pebbly, dark-olive-gray	37	222
	Gravel, fine to coarse, sandy, clayey, subangular to rounded	5	227
	Clay (till), sandy, silty, pebbly, dark-olive-gray	6	233
	Gravel, fine to coarse, sandy, clayey, angular to subrounded	3	236
	Clay (till), silty, sandy, pebbly, olive-gray	7	243
	Gravel, fine to coarse, clayey, sandy, angular to subrounded	30	273
	Clay, silty, sandy, brownish-gray to olive-gray	22	295
	Gravel, fine to medium, clayey, sandy, subangular	11	306
	Clay (till), silty, sandy, gravelly, olive-gray	107	413
	Gravel, fine to coarse, angular to rounded; numerous cobbles and boulders	7	420
Hell Creek Formation (?):			
	Shale, sandy, clayey, noncalcareous, dark-greenish-gray to brownish-gray	10	430