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COUNTY GROUND WATER STUDIES 8

GEOLOGY and GROUND WATER RESOURCES of CASS COUNTY, NORTH DAKOTA

PART III

HYDROLOGY

By

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Prepared by the United States Geological Survey in co-operation with the North Dakota State Water Commission, North Dakota Geological Survey, and Cass County Board of Commissioners.

GRAND FORKS, NORTH DAKOTA
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This is one of a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. The reports are in three parts; Part I describes the geology, Part II represents ground water basic data, and Part III describes the ground water resources.

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GEOLOGY AND GROUND WATER RESOURCES
of Cass County, North Dakota

Part III - Ground Water Resources

By
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ABSTRACT

Ground water in Cass County is obtainable from sand and gravel deposits associated with the glacial drift and from sand and (or) sandstone beds in the Dakota Sandstone.

Six major drift aquifers are identified and described. These are, the Fargo, West Fargo, Page, Tower City, Bantel, and Sheyenne Delta aquifers. The West Fargo aquifer is the most permeable and productive and will yield as much as 1,300 gallons per minute to individual wells. Heavy pumping from the West Fargo aquifer has caused the water levels to decline as much as 85 feet since 1938. During 1965, water levels declined more than 2.5 feet at West Fargo and more than 0.5 foot in areas 20 miles away. The declines will continue as long as withdrawals exceed recharge.

Potentially important sources of water are the Sheyenne Delta aquifer in the southern part of the county and the Page aquifer in the northwestern part. Neither of these is extensively developed.

Water from the glacial drift aquifers generally contains less than 1,500 parts per million dissolved solids, whereas water from the Dakota Sandstone contains more than 2,500 parts per million dissolved solids.

INTRODUCTION

Purpose and Scope

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

The primary purpose of the study was to determine the occurrence, availability, and quality of ground water in Cass County. This report describes the location and extent of the various sources of ground water in the county, discusses the chemical quality of the water available from each source, and evaluates the potential of each ground-water source for future dvelopment.

Much of the basic data on which this interpretive report is based has been tabulated in an earlier report entitled "Geology and Ground Water Resources of Cass County, North Dakota, Part II, Ground Water Basic Data." However, 43 well logs that were collected since publication of the basic data report are included as an appendix to this report. Another report—"Geology and Ground Water Resources of Cass County, North Dakota, Part I, Geology"—describes the geology of the county and provides a framework for evaluating the ground-water resources. The three reports are meant to complement each other, and the usefulness of any of them will be greatly enchanced by having all three available for reference.

Location and Physiography

Cass County (fig. 1) is in southeastern North Dakota and encompasses an area of 1,749 square miles. The county is in the Central Lowland physiographic province of Fenneman (1938, p. 559), and occupies parts of the Drift Prairie and Red River Valley areas as defined by Simpson (1929, p. 4-7). The entire county is in the drainage basin of the Red River of the North (fig. 2).

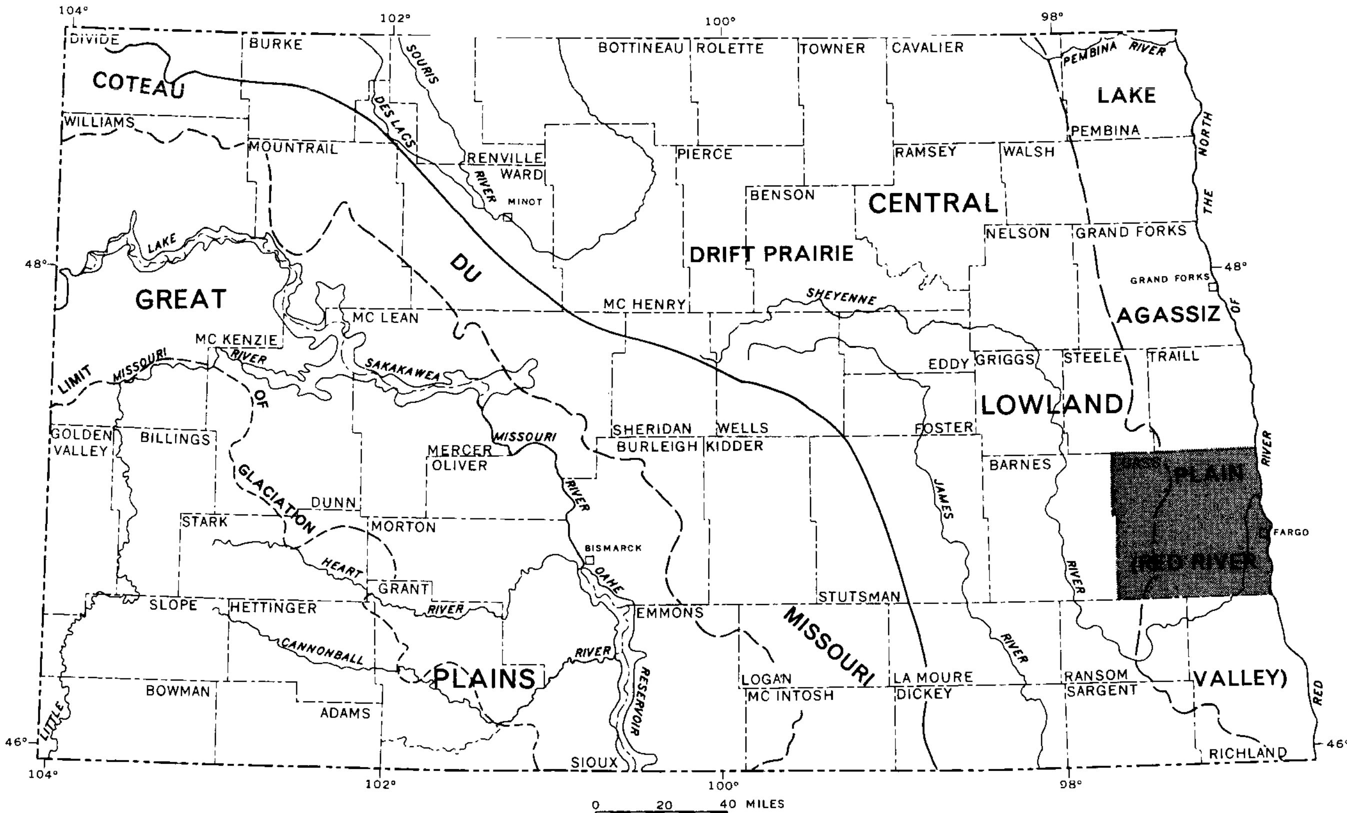


FIGURE 1. Physiographic divisions in North Dakota and location of report area.

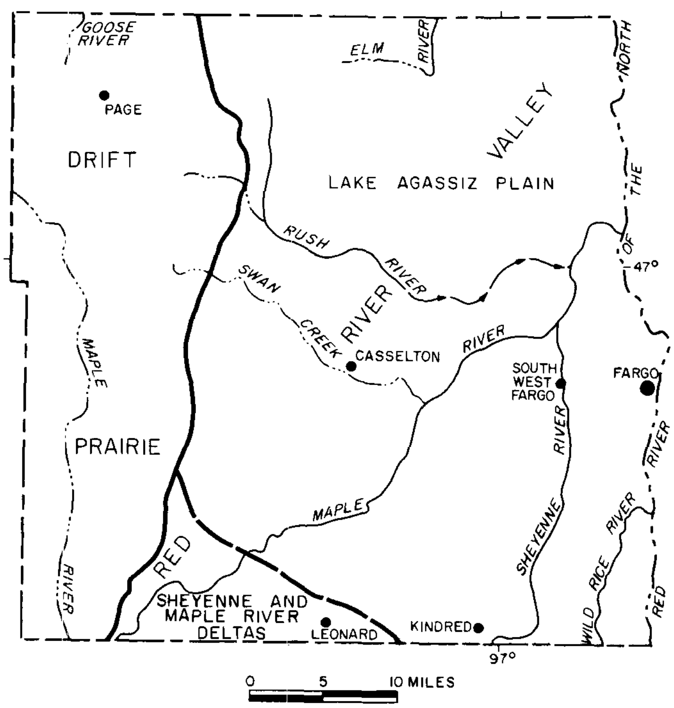


FIGURE 2. Major geomorphic units and drainage.

Climate

The climate of the area is variable. The winters are generally long and cold with temperatures occasionally falling to as much as 40° below zero. The summers usually are hot with midday temperatures occasionally rising to 100°. The average annual temperature is 39.9°.

Most of the annual precipitation is in the form of rain, which falls during the spring and summer. Precipitation in the Fargo area during the period 1930 to 1965 ranged from about 9 to 30 inches per year and averaged 18.65 inches. Precipitation in the vicinity of Amenia during the period 1934 to 1965 ranged from about 9 to 27 inches and averaged 19.46 inches. Precipitation data for the stations at Fargo and Amenia are shown graphically on figure 3.

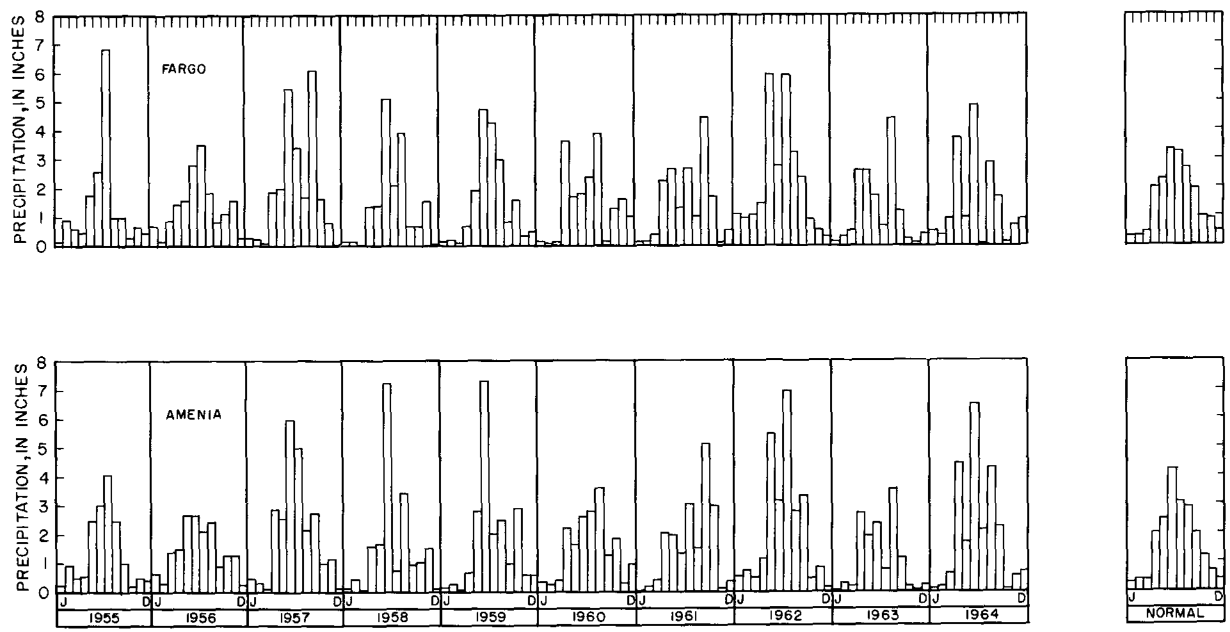


FIGURE 3. Monthly precipitation recorded at Fargo and Amenia, 1955-64.

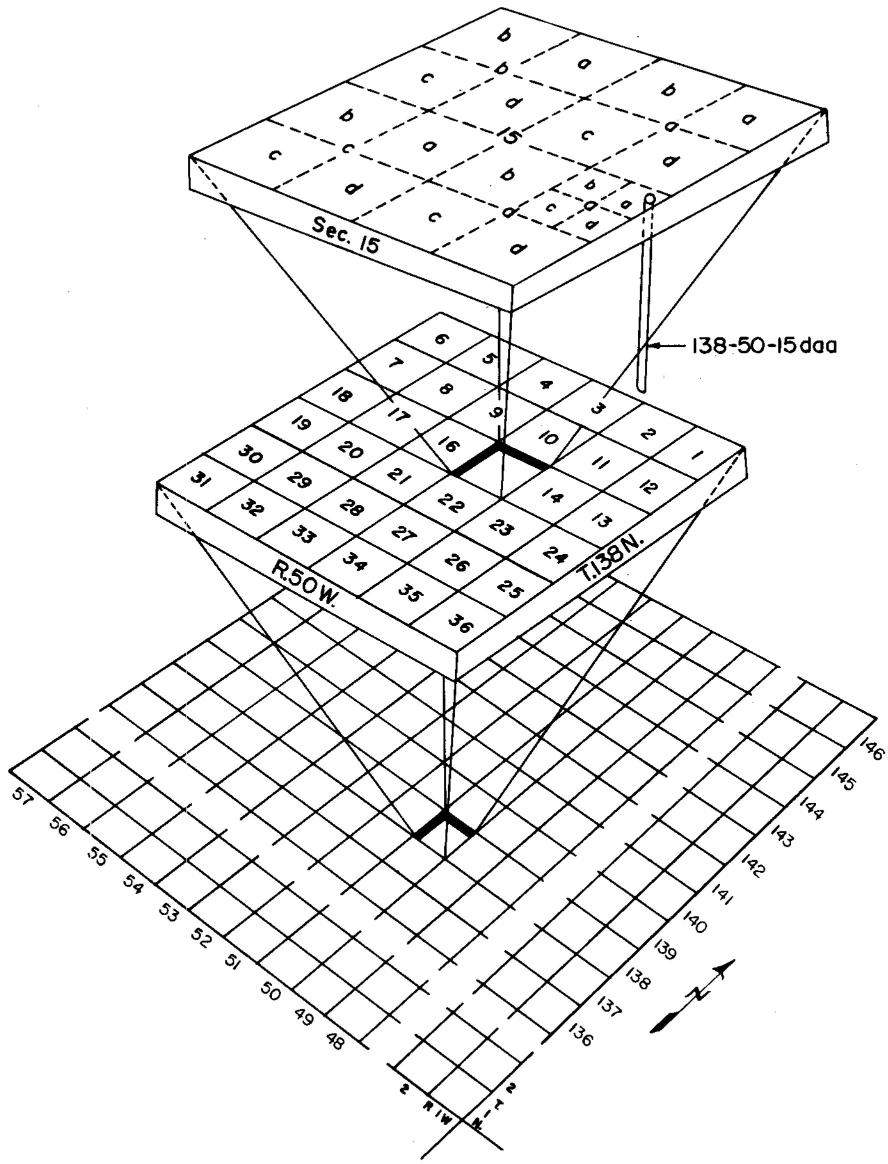


FIGURE 4. System of numbering wells, springs, and test holes.

Well-Numbering System

The wells 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 4. The first numeral denotes the township north of the base line, the second numeral the range west of the fifth principal meridian, and the third indicates the section in which the well or test hole is located. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarter sections, quarter-quarter sections, and quarter-quarter-quarter sections (10-acre tracts). For example, well 138-50-15daa is in the NE¼-NE¼SE¼ sec. 15, T. 138 N., R. 50 W. Consecutive terminal numbers are added if more than one well is recorded within a 10-acre tract.

Previous Investigation

The geology and ground-water resources of the southern half of the county were described by Hall and Willard (1905) and by Willard (1909). Simpson (1929, p. 97-108) gave a brief summary of the geology and ground-water resources of the county. Byers and others (1946) discussed ground-water conditions in the Fargo-Moorhead area, North Dakota and Minnesota. Dennis and others (1949) reported on the results of a ground-water investigation in parts of Cass and Clay Counties, North Dakota and Minnesota. This report contains an excellent summary of the history of ground-water development in the Fargo-Moorhead area. Dennis and others (1950) described the ground-water resources in the vicinity of Kindred. Brookhart and Powell (1961) reported on the results of test drilling in the vicinity of Hunter, and Froelich (1964) made a ground-water survey in the Amenia area.

Acknowledgments

The author is grateful to all the residents of Cass County who provided information during the study. Messrs. R. Fuller, K. R. Lehman of South West Fargo, and M. O. Gunderson of Fargo deserve special mention for their cooperation. The writer gratefully acknowledges the sample logs furnished by Frederickson's Inc., Fargo, and Lako Drilling Co., Arthur.

GEOLOGIC SETTING
Glacial Deposits

All of Cass County is covered with glacial drift, which ranges in thickness from 80 to 470 feet. Four major surface units, based on lithology, landform, and mode of deposition, are recognized. They are: ground moraine, lake plain, shore, and deltaic deposits (Klausing, 1968).

Ground-moraine deposits believed to have formed at the base of the glacier occupy an area of about 450 square miles in the western part of the county. The ground moraine is characterized by a nearly flat to gently rolling surface, and local relief generally does not exceed 20 feet. The ground-moraine deposits are composed chiefly of till, heterogeneous mixture of clay, silt, sand, gravel, and boulders with clay and silt predominating.

Isolated deposits of sand and gravel occur at numerous places on the ground-moraine surface. These are referred to as ice-contact and outwash deposits. The ice-contact deposits, characterized by sharp changes in sorting and bedding, are closely associated with the till and are believed to have formed within or along the edges of the glacial ice. These deposits commonly form low ridges and hills and are called, respectively, eskers and kames. The outwash deposits that were laid down on or in front of the glacier consist for the most part of poorly sorted to moderately well-sorted silt, sand, and gravel. The outwash deposits underlie nearly flat plains, terraces, and channels.

The lake-plain deposits occupy approximately the eastern three-fourths of the county and consist chiefly of silt and clay that were laid down in glacial Lake Agassiz (Upham, 1895). The lake plain is characterized by its unusually flat and nearly featureless surface. Dennis and others (1949, p. 18) divided the lake deposits into two units: a silt unit that comprises the surficial deposits and a lower clay unit. The contact between the two units is disconformable and in places is marked by dessication and vegetal remnant zones. The silt unit has known thicknesses ranging from 10-50 feet. The clay unit ranges from 0 to about 80 feet in thickness.

The deposits bordering the lake plain on the west consist of sorted and stratified deposits of clay, silt, sand, and gravel. The deposits were derived from the till by wave action along the lake shore, and range in thickness from 0 to about 15 feet.

Deltaic deposits, which consist of silt and fine to medium sand, were formed in the southern part of the county where the sediment-laden waters of the Sheyenne and Maple Rivers discharged into glacial Lake Agassiz. The deltaic deposits range in thickness from 0 to about 120 feet.

Throughout most of the county, the glacial drift unconformably overlies sedimentary rocks of Cretaceous age; however, in the extreme eastern part, the Cretaceous shale has been eroded away and the drift rests on Precambrian crystalline rocks.

Bedrock Units

The three Cretaceous bedrock units known to underlie the area are the Greenhorn Formation, Graneros Shale, and the Dakota Sandstone (Klausing, 1968). Much of the Greenhorn Formation was eroded away during the period following the cessation of Cretaceous deposition and the beginning of Pleistocene glaciation, and now it underlies the glacial deposits only in the western part of the area. The Greenhorn Formation is a black, calcareous shale characterized by the presence of numerous white specks. It lies 200 to 420 feet below land surface. The thickness of this unit is unknown.

The Graneros Shale is a black, silty, noncalcareous shale containing thin beds and lenses of fine white sand. In places it contains lignitic and other organic material. Where the Graneros Shale is not overlain by the Greenhorn Formation, it has a deeply eroded surface and ranges in thickness from 10 to about 100 feet. In the western and central parts of the area, it is generally underlain by the Dakota Sandstone, but in the eastern part it rests on Precambrian crystalline rocks.

The Dakota Sandstone consists chiefly of interbedded black shale and fine to coarse sand. Although absent in the eastern and southeastern parts of the area, it underlies the rest of the county at depths ranging from about 300 to more than 650 feet. The total thickness of the Dakota Sandstone in Cass County is unknown.

The Precambrian crystalline rocks form the basement rock in the area. The upper part of the Precambrian rocks is weathered in many places, and consists mostly of red and green clay that appears to have been derived from granite. In some places the weathered material has been removed by glacial erosion and fresh unaltered rock underlies the glacial drift. The depth to the Precambrian below land surfaces ranges from about 160 feet in the eastern part of the area to more than 900 feet in the western part.

GROUND-WATER RESOURCES

Principles of Ground-Water Occurrence

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

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

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

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

The coefficient of transmissibility is a measure of the rate of flow through porous material. It is expressed as the number of gallons of water that will move in 1 day under a unit hydraulic gradient (1 foot per foot) through a vertical strip of the aquifer 1-foot wide extending the full saturated height of the aquifer at a temperature of 60°F.

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

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

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

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

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

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

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

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

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

Quality of Water

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

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

The suitability of water for various uses is determined largely by the kind and amount of dissolved mineral matter. The various constituents of water in Cass County were listed by Klausinig (1966, table 3). The data are summarized in the discussion of each of the major aquifers described in the section of this report dealing with the rock units and their water-bearing properties.

Table 1 shows the major constituents in water, their major sources in Cass County, and their effects upon usuability. Most of the minerals, rocks, and mineral substances shown in the major source column are present in the rock formations underlying Cass County.

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

TABLE 1.—Major chemical constituents in water—their sources, concentrations, and effects upon usability (Concentrations are in parts per million)

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

Constituents	Major source	Effects upon usability	U.S. Public Health Service recommended limits for drinking water1/
Silica (SiO_2)	Feldspars, ferromagnesium, and clay minerals.	In presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat.	
Iron (Fe)	Natural sources: Amphiboles, ferromagnesium minerals, ferrous and ferric sulfides, oxides, and carbonates, and clay minerals. Manmade sources: well casings, pump parts, storage tanks.	If more than 0.1 ppm iron is present, it will precipitate when exposed to air; causing turbidity, staining plumbing fixtures, laundry and cooking utensils, and imparting tastes and colors to food and drinks. More than 0.2 ppm is objectionable for most industrial uses.	0.3 ppm
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, dolomite, and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment. Calcium and magnesium retard the suds-forming action of soap. High concentrations of magnesium have a laxative effect.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, and clay minerals.		
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 ppm sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	
Potassium (K)	Feldspars, feldspathoids, some micas, and clay minerals.		
Boron (B)	Tourmaline, biotite, and amphiboles.	Many plants are damaged by concentrations of 2.0 ppm.	
Bicarbonate (HCO_3)	Limestone and dolomite.	Upon heating, bicarbonate is changed to steam, carbonate, and carbon dioxide. Carbonate combines with alkaline earth (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 ppm tastes bitter and may be a laxative.	250 ppm
Chloride (Cl)	Halite and sylvite.	In excess of 250 ppm may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 ppm.	250 ppm
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Recommended limits depend on average of maximum daily temperature. Limits range from 0.6 ppm at 90.5°F to 1.7 ppm at 50°F.
Nitrate (NO_3)	Nitrogenous fertilizers, animal excrement, legumes, and plant debris.	More than 100 ppm may cause a bitter taste and may cause physiological distress. Concentrations greatly in excess of 45 ppm have been reported to cause methemoglobinemia in infants.	45 ppm
Dissolved solids	Anything that is soluble.	More than 500 ppm is not desirable if better water is available. Less than 300 ppm is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500 ppm

1/ U.S. Public Health Service, 1962.

Dissolved Solids and Specific Conductance

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

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

Irrigation Indices

Two indices used to show the suitability of water for irrigation in this report are SAR and specific conductance. SAR is related to the sodium hazard; the specific conductance is related to the salinity hazard. The hazards increase as the numerical values of the indices increase. Figure 5 shows the SAR versus the specific conductance of analyzed water from Cass County. The analyses are plotted to show the general range of sodium and salinity hazards of water from the major glacial drift aquifers. Most of the samples fall within the C3-S1 and C3-S2 ranges. This type of water can be used for irrigation of plants with good salt tolerance (corn, wheat, rye, and flax) provided there is adequate drainage and the soil salinity is controlled.

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

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

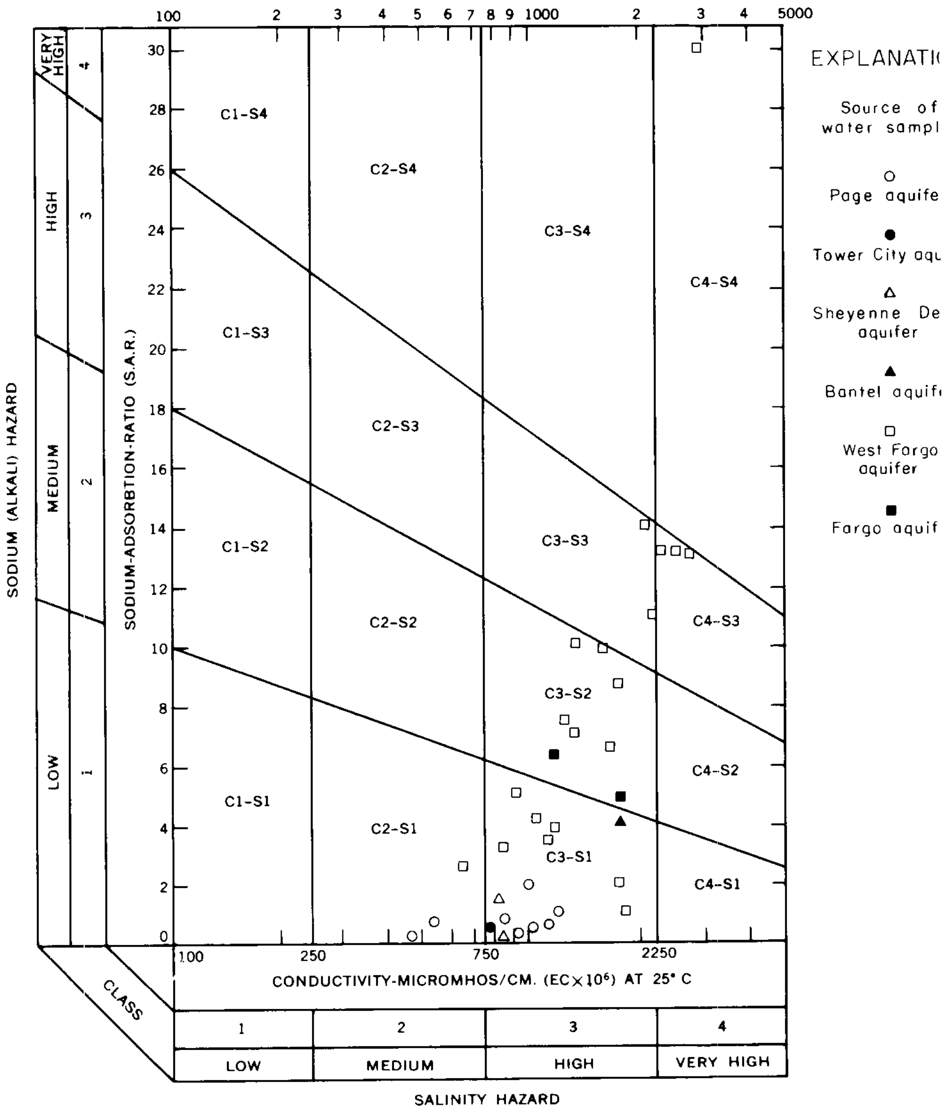


FIGURE 5. Classification of water samples for irrigation purposes.

Hardness

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

Aquifers in the Glacial Drift

Deposits of sand and gravel of glaciofluvial or glaciolacustine origin are the most important sources of ground water in Cass County. The potential yields from these aquifers, shown on the ground-water availability map (pl. 1, in pocket), were determined from the thickness and estimated permeability of the water-bearing deposits logged at each test hole and well. The logs were examined in detail and the materials were divided into units on the basis of assigned permeabilities according to a method given by Keech (1964, p. 17). The permeabilities of the units were estimated from the grain size, apparent sorting, and drilling characteristics of the materials, and by comparison with available pumping-test data. The test holes were drilled by hydraulic rotary rigs, which on drilling sand and gravel beds commonly produce samples having less silt and clay than is actually the case. In assigning of the permeabilities, some allowances were made for this discrepancy.

The areas shown as yielding more than 250 gpm (gallons per minute) have the greatest potential for the development of industrial, municipal, and irrigation wells. The aquifers generally are lenticular in cross section; that is, they are thinnest along their lateral boundaries. Consequently, the largest yields generally are obtained from the central parts of the aquifers. Also, wells penetrating water-bearing deposits in a narrow channel may be expected to have lower sustained yields than wells tapping deposits of comparable thickness that have a large areal extent. The 250-750 gpm area east of Page is underlain by two sand and gravel zones superimposed in the drift. The maximum yields in this area are obtainable only by tapping both the upper and lower zones.

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

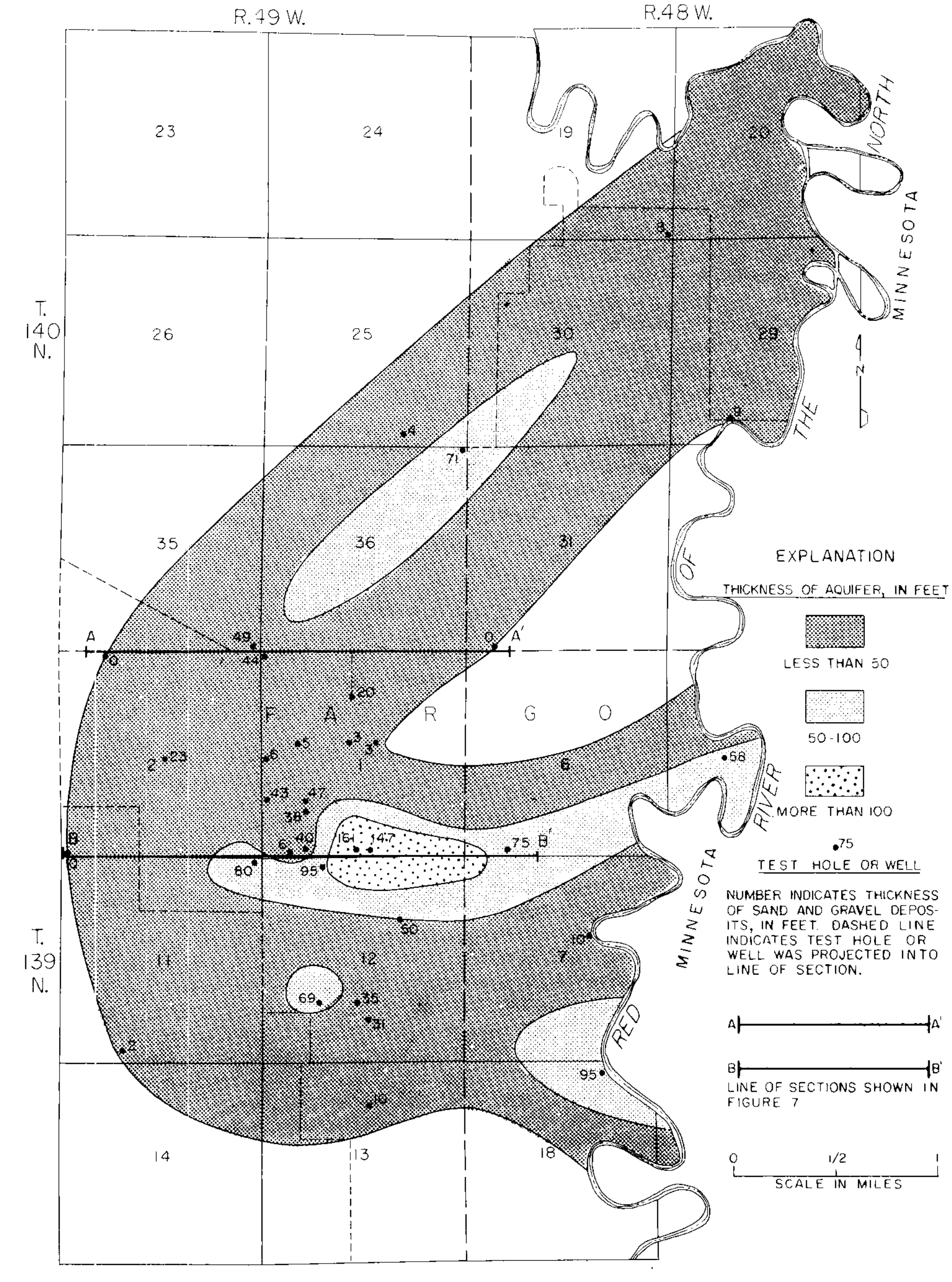


FIGURE 6. Location and thickness of Fargo aquifer, eastern Cass County.

Fargo Aquifer

Location and extent.—The Fargo aquifer is a buried glaciofluvial deposit that underlies an area of at least 10 square miles, mostly within the city limits of Fargo. As shown in figure 6, the aquifer probably extends into Minnesota.

About 25 test holes and wells are known to have penetrated the aquifer. Most of these were drilled prior to 1950 (Dennis and others, 1949, p. 137-150). Four test holes were drilled during the course of the present investigation to delineate the northern part of the aquifer. One test hole in the

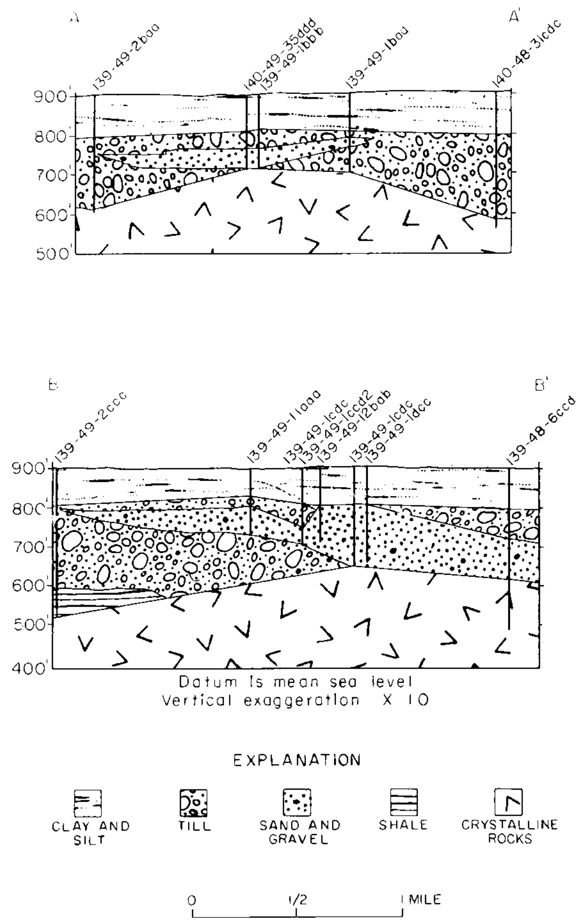


FIGURE 7. Geologic sections in Fargo aquifer.

NE cor. sec. 36, T. 140 N., R. 49 W., penetrated 71 feet of sand and gravel from 157 to 228 feet. Test holes drilled in adjacent sections did not penetrate water-bearing deposits at comparable depths.

Thickness and lithology.—The aquifer ranges in thickness from 0 to about 160 feet and averages about 45 feet. The thickest part is near the south line of sec. 1, T. 139 N., R. 49 W. The aquifer consists of fine to coarse sand interbedded and intermixed with gravel (fig. 7). Boulders were reported in well 139-49-1cdd (Dennis and others, 1949, p. 150).

Reservoir characteristics.—The Fargo aquifer is an artesian system confined at the top by deposits of glacial till and lake clay. The average aggregate thickness of the top confining beds is about 130 feet. The basal confining units may consist either of till or crystalline rock.

Byers and others (1946, p. 35-39) estimated the average coefficient of permeability of the aquifer in the vicinity of well 139-49-1cbd2 (fig. 8) to be 720 gpd (gallons per day) per square foot. Thus for an aquifer 100 feet thick, the coefficient of transmissibility would be 72,000 gpd per foot. However, computations made by Dennis and others (1949, p. 85-86) indicate that the coefficient of transmissibility of the aquifer in the vicinity of wells 139-48-6ccd and 139-49-1cbd2 ranged from a low of 1,190 gpd per foot to a high of 6,180 gpd per foot and averaged 3,700 gpd per foot.

In 1956, a well was developed in the aquifer for industrial use by the Cass-Clay Creamery (139-49-1cdb). Data from the well-development test indicate that the well was pumped for a period of 14 hours at a discharge rate of 400 to 596 gpm and with a drawdown ranging from 68 to 78 feet. The average pumping rate was 478 gpm and the average drawdown was 72 feet.

Because the greater part of the total drawdown in a well pumping from an artesian aquifer occurs during the first few hours of the pumping period, the drawdown data from acceptance and development tests can be used to obtain an estimate of the drawdown in a well at the end of a 24-hour period. These data are useful in estimating the coefficient of transmissibility. As mentioned previously, the average drawdown in well 139-49-1cdb after 14 hours of pumping was 72 feet. Assuming that pumping had continued for an additional 10 hours and that the water level in the well would not have declined more than 4 feet, the drawdown at the end of 24 hours would have been about 76 feet. The pumping rate divided by the drawdown gives a specific capacity of about 6 gallons per foot of drawdown. Using a graph relating specific capacity to transmissibility (Meyer, 1963, p. 338), the estimated coefficient of transmissibility in the vicinity of well 139-49-1cdb is about 10,000 gallons per day per foot.

According to Dennis and others (1949, p. 89), the coefficient of storage ranged from 7.5×10^{-5} to 8.3×10^{-4} and averaged 5.8×10^{-4}.

Recharge, discharge, and movement.—The aquifer could be recharged by lateral movement of water through the till and by downward percolation of water through the overlying sediments. At the present time water levels in the aquifer are well above the top of the till and it seems unlikely

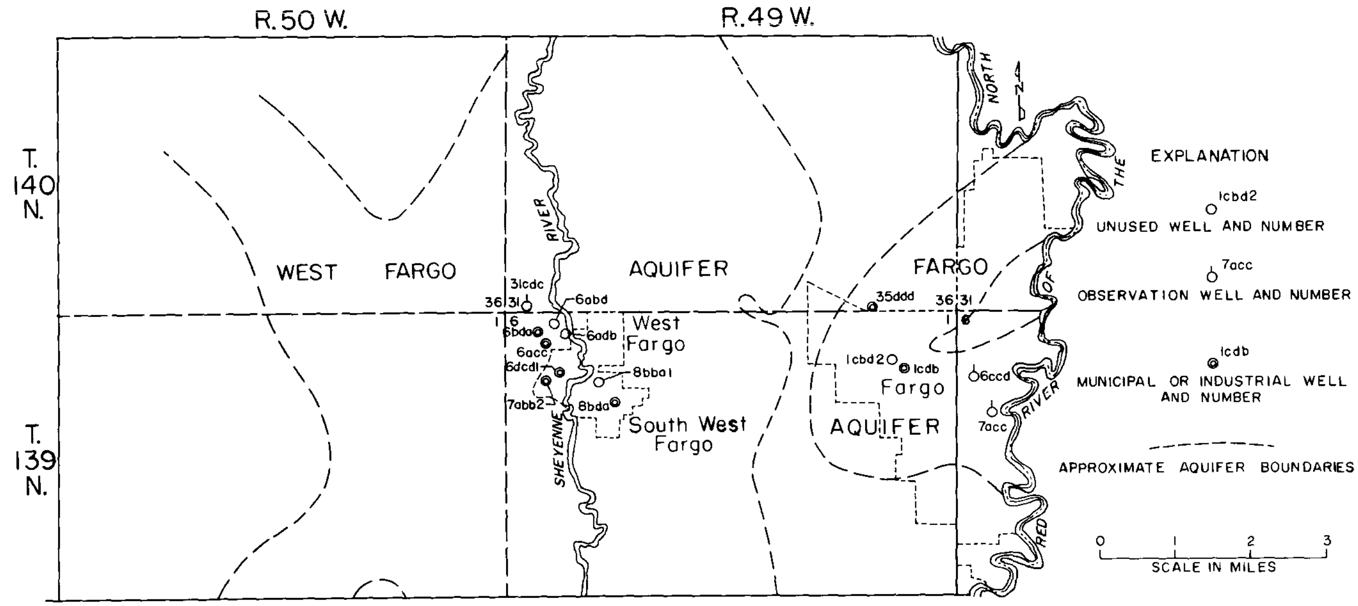


FIGURE 8. Location of key wells in the Fargo and West Fargo aquifers, eastern Cass County.

that the aquifer is receiving significant amounts of recharge from the till. Recharge by downward percolation of water through the overlying materials probably will not take place until water levels in the aquifer are lowered below the base of the lake deposits. The amount of recharge reaching the aquifer by downward percolation of water probably will be insignificant owing to the very low permeability of the overlying sediments and the small areal extent of the aquifer.

Because water levels are 50 feet or more above the top of the aquifer, it seems likely that some water is being discharged into the adjacent deposits. Annual discharge by pumping is estimated to be about 20.5 million gallons. Probably more water is discharged from the aquifer by pumping than by natural means.

According to Dennis and others (1949, p. 73), the hydraulic gradient in the Fargo aquifer in 1937 sloped to the southeast. Excluding temporary reversals of the gradient caused by intermittent pumping of Fargo supply well 139-49-1cbd2 between July 1940 and October 1952, the southeasterly gradient persisted until June 1957, when the hydraulic gradient was reversed. The reversal of the gradient from southeast to northwest was caused by pumping from Cass-Clay Creamery well 139-49-1cdb, which was put into operation June 1, 1956.

Storage.—Assuming an average thickness of 45 feet and a porosity of 30 percent, it is estimated that there is 86,000 acre-feet of water in transient storage; however, the total yield of the aquifer would be much less (see principles of occurrence, p. 9). Pumpage records indicate that at least 1,100 acre-feet of water was withdrawn from storage between July 1938 and October 1952.

Water-level fluctuations.—Dennis and others (1949, p. 73) reported that water levels in the Fargo aquifer had declined 16 to 23 feet between 1910 and 1937. They attributed the decline to pumping from a municipal supply well in Moorhead, Minnesota.

From July 1940 to October 1952, the water level in well 139-48-6ccd declined about 7.5 feet. The decline and the fluctuations of the water level in this well (pl. 2, in pocket) were caused by pumping from Fargo supply well 139-49-1cbd2.

The Fargo supply well was shut down October 7, 1952 and there was no significant amount of pumpage from the aquifer until June 1956. During this period, the water level in well 139-48-6ccd should have recovered to near the 1940 level; however, it did not rise significantly. It is therefore concluded that the water pumped from the aquifer by the Fargo supply well was withdrawn from storage and that the aquifer is receiving little or no recharge.

On June 1, 1956, the Cass-Clay Creamery well, 139-49-1cdb, was put into operation. The water level in well 139-48-6ccd began to decline almost immediately as indicated in plate 2. As of June 1965, the total water-level decline in well 139-48-6ccd caused by pumping of the creamery well was 15.5 feet. The sharp declines of the water level in well 139-48-6ccd during the summers of 1960, 1961, 1963, and 1964 were caused by pumping.

The water-level fluctuations in well 139-48-7acc (pl. 2) are similar to the flucutations in well 139-48-6ccd, but on a smaller scale. The water level in well 139-48-7acc is affected by flood waters in the Red River (Dennis and others, 1949, p. 63). The additional weight of the water in the channel compresses the aquifer and the sediments overlying it, causing a marked rise of the water level. This loading effect is not noticeable in wells farther from the river. The most notable fluctuations of the water level due to loading occurred in April 1947 and May 1962.

The cause of the water-level decline in well 139-48-7acc starting June 1, 1964 is unknown.

Quality of water.—Chemical analyses of two water samples from the aquifer indicate that the water is a hard, sodium bicarbonate type. The total dissolved solids ranged from 750 ppm in the sample taken from Western Fruit Express Co. well 140-49-35ddd, to 1,129 ppm in the sample taken from test hole 140-49-36aaa. The dissolved solids in both samples exceeded the 500 ppm recommended for drinking water by the U.S. Public Health Service. Also, the sample from test hole 140-49-36aaa contained 120 ppm more sulfate than is recommended for drinking water by the U.S. Public Health Service.

A comparison of the following chemical analyses indicates that there has been no significant change of the quality of the water in the aquifer between 1949 and 1964.

Owner:	City of Fargo	Western Fruit Express Co.
Location:	139-49-1cbdl	140-49-35ddd
Date of analysis:	Prior to 1949 (Dennis and others, 1949, p. 112a)	August 19, 1964

Constituents (parts per million)

Silica (SiO_2)	22	18
Iron (Fe)	.43	.35
Calcium (Ca)	45	49
Magnesium (Mg)	15	15
Sodium (Na) and potassium (K)	206	206

Bicarbonate (HOC_3)	324	315
Sulfate (SO_4)	161	162
Chloride (Cl)	132	143
Fluoride (F)	.6	.7
Nitrate (NO_3)	3	1
Hardness as $CaCO_3$	178	185
Total dissolved solids	746	750

Plots of SAR versus specific conductance (fig. 5) show that the two samples have a C3-S2 irrigation classification.

Utilization and potential for future development.—Prior to June 1956, the water pumped from the aquifer was used to supplement the Fargo municipal supply from the Red River in summers when the flow in the river was inadequate or when water demands were unusually high. The pumpage from well 139-49-1cbd2 since its completion in 1938 is given below. Years for which no pumpage is given were wet years in which the flow of the Red River was adequate and the well was not operated.

Year	Months	Gallons pumped
1938	July, August, September, October	22,994,000
1939	July, August, September	18,137,000
1940	July, August, September	14,219,000
1941	June, July, August, September	53,979,000
1942	July, August	9,850,000
1943	April	2,577,000
1944	—	—
1945	—	—
1946	August, September	9,284,000
1947	July, August	13,852,000
1948	June, July, August, September, October	19,037,000
1949	August, September, October	10,700,000
1950	July, August	6,131,000
1951	May, July, August, September	8,650,000
1952	June, August, September	1,285,000
	Total gallons	190,695,000

The Fargo supply well was abandoned on October 7, 1952 and no significant amount of water is known to have been pumped from the aquifer until Cass-Clay Creamery well 139-49-1cdb was placed in operation June 1, 1956. The water from this well is used for cooling and washing purposes. The volume of waste water discharged into the Fargo sewer system indicates that the creamery well pumps about 19.9 million gallons annually.

In November 1960, a well was drilled in the SE cor. sec. 35, T. 140 N., R. 49 W. for the Western Fruit Express Co. The water pumped from this well is used to wash railroad refrigerator cars. Estimated annual pumpage amounts to about 600,000 gallons.

The amount of water withdrawn from the Fargo aquifer between July 1938 and June 1965 is estimated to be about 372.5 million gallons.

The water-bearing properties of the aquifer indicate that wells will yield as much as 1,000 gpm. Dennis and others (1949, p. 105) list data indicating that the maximum seasonal drawdown in well 139-49-1cbd2 was 106.73 feet while pumping at the rate of 850 gpm. A development test for Cass-Clay Creamery well 139-49-1cdb indicated respective drawdowns of 70 and 78 feet when the well was pumped at rates of 400 and 600 gpm. The magnitude and extent of the drawdown cone demonstrate the necessity for locating new developments as far from the creamery well as possible to avoid interference. Because of the shape and limited extent of the aquifer, it is doubtful that any new developments requiring very large quantities of water could be made without producing interference.

At the present time, water levels are well above the top of the aquifer and drainage of the aquifer materials and of the till has not yet begun, even after extended periods of pumping.

West Fargo Aquifer

Location and extent.—The West Fargo aquifer is a buried glaciofluvial deposit that extends in a north-south direction and underlies parts of Tps. 137-140 N., Rs. 49-50 W. The aquifer ranges in width from about 2½ miles in T. 137 N., R. 49 W., to about 8 miles in T. 140 N, R. 49 W. As presently defined, the aquifer underlies an area of about 110 square miles (fig. 9).

Thickness and lithology.—The West Fargo aquifer ranges in thickness from 0 to as much as 140 feet in the northwestern part of T. 139 N. R. 49 W. The average is about 60 feet. The data shown in figures 9 and 10 are from Dennis and others (1949), Klausing (1966), and logs given in the appendix of this report. The orientation of the thick (greater than 90 feet) aquifer segments extending southward from West Fargo suggests that these segments may be buried channel deposits, which probably converge into a single channel about 2 miles north of Horace. This channel may extend southward from Horace; however, additional test drilling would be necessary to verify this assumption.

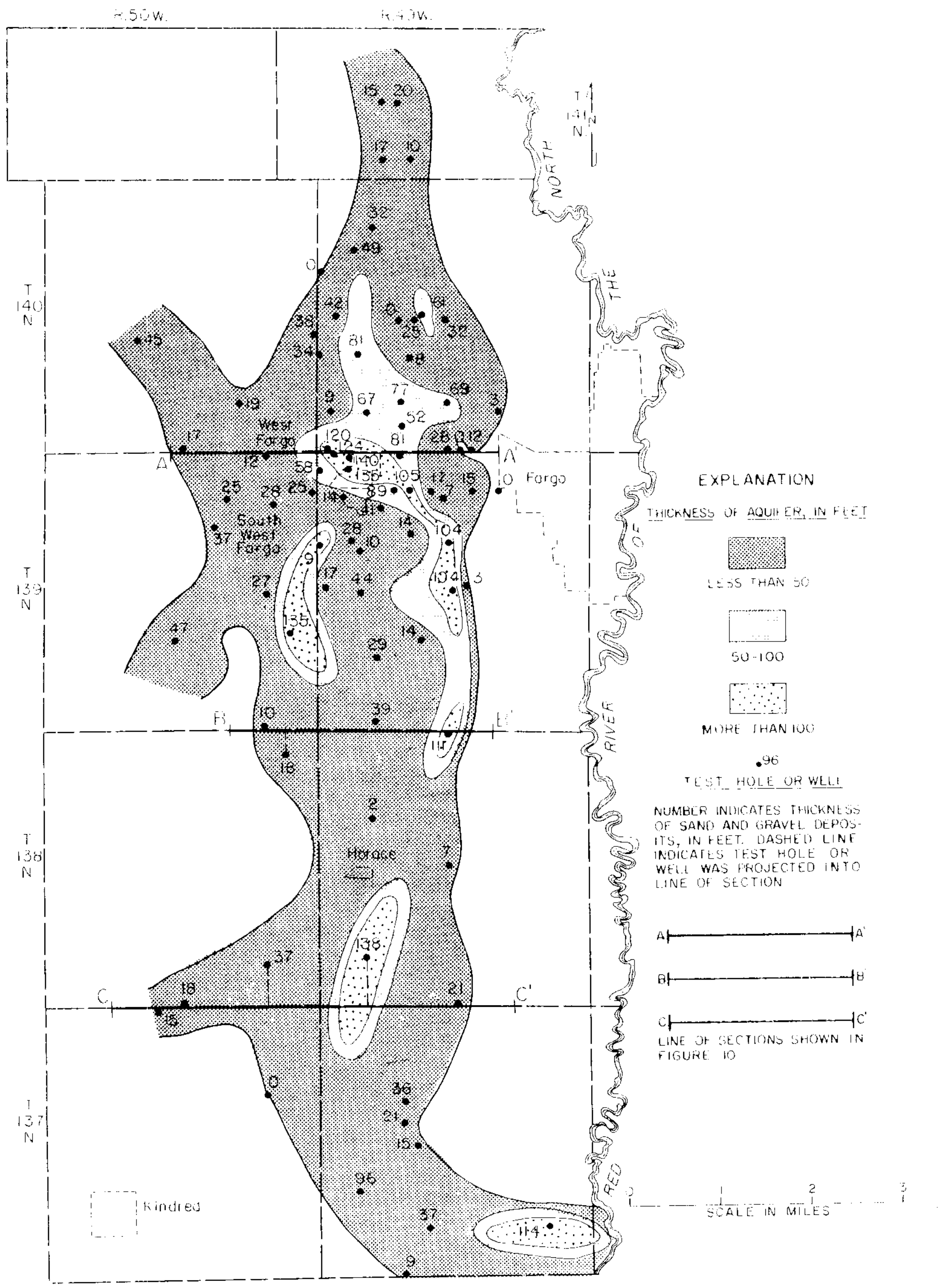


FIGURE 9. Location and thickness of West Fargo aquifer, eastern Cass County.

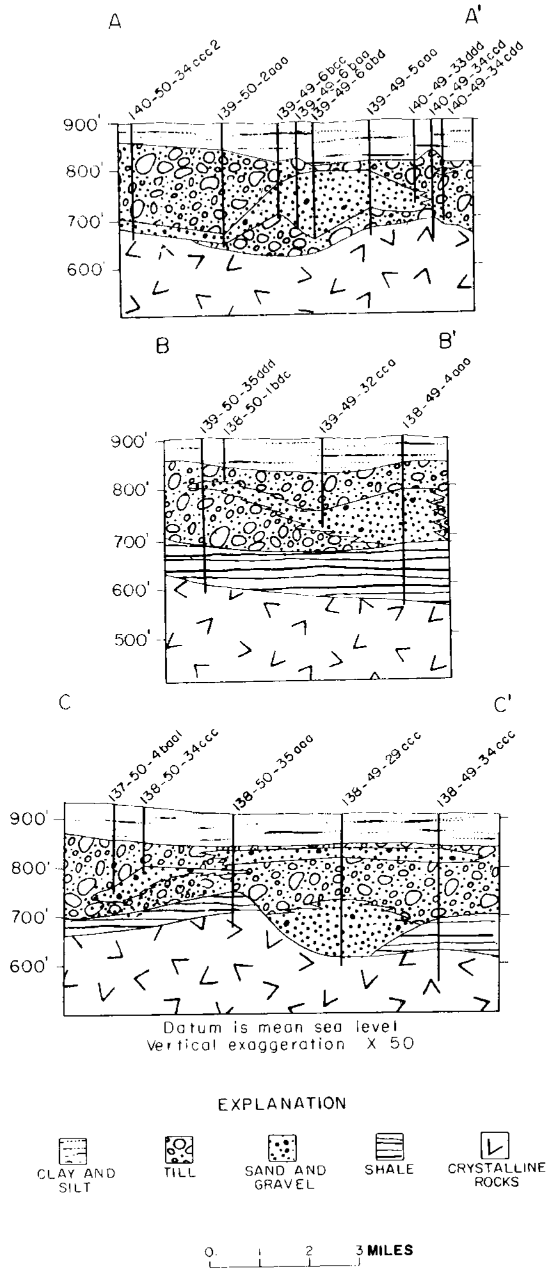


FIGURE 10. Geologic sections in West Fargo aquifer.

The aquifer is composed of material ranging in size from fine sand through boulder, and is mainly fine to coarse sand. In places, the sand and (or) gravel deposits are interlensed with silt and clay. The silt and clay deposits occur most frequently near the top of the aquifer. Non-water-bearing deposits of glacial till lying within the aquifer boundaries were penetrated in a few test holes (Dennis and others, 1949, p. 172-173).

Reservoir characteristics.—The West Fargo aquifer is an artesian aquifer system that is confined at the top by deposits of glacial till and lake clay. The till, which immediately overlies the aquifer, ranges in thickness from 15 to about 90 feet. The till in turn is overlain by lake sediments consisting chiefly of plastic clay that ranges in thickness from 60 to about 90 feet. The aggregate thickness of the top confining beds ranges from 80 to about 170 feet. The basal confining units may be either granite, shale of Cretaceous age, or till. The aquifer is bounded on both sides by deposits of glacial till containing lenses and (or) beds of sand and gravel that may have hydraulic connection with the aquifer.

Dennis and others (1949, p. 87) indicated that the coefficient of transmissibility of the aquifer in the vicinity of Union Stockyards well 139-49-6abd ranged from 33,000 to 125,000 gpd per foot and averaged 71,100. The coefficient of storage as computed by Dennis and others (1949, p. 89) ranged from 1.8×10^{-2} to 4.6×10^{-4} and averaged 3.7×10^{-3}.

In November 1963, a pumping test was run on a newly drilled municipal well in the village of West Fargo. Water levels in the pumped well (139-49-6dcdl) and in three observation wells were measured before, during, and after the pumping period. Computations of the coefficient of transmissibility were made using the Theis nonequilibrium formula (Ferris and others, 1962, p. 62). The computed coefficients of transmissibility ranged from 74,700 gpd per foot to 269,000 gpd per foot and averaged 150,000 gpd per foot. The coefficient of storage ranged from 2.8×10^{-4} to 5.4×10^{-5} and averaged 2.29×10^{-4}.

Records of water-level drawdown occurring in wells during short duration acceptance and development tests were obtained from Siouxland Dressed Beef Co., Union Stockyards Co., and the city of South West Fargo. The drawdown at the end of 24 hours was estimated for each well and the specific capacity of the well was obtained by dividing the pumping rate by the estimated drawdown. Estimates of the coefficient of transmissibility were obtained by using a graph relating specific capacity to transmissibility (Meyer, 1963, p. 338). The physical data and results for the tests made in the West Fargo aquifer are given in table 2.

TABLE 2.--Physical data and results from pumping, development, and acceptance tests in the West Fargo aquifer

Physical data

Owner	Location	Depth	Date of test	Duration (hours)	Pumping rate (gpm)	Drawdown (feet)	Estimated drawdown at end of 24 hours (feet)	Lithology of aquifer at well site
Union Stockyards Co.1/	139-49-6abd	-	7- 7-45	22	900	-	-	Sand and gravel.
City of South West Fargo	139-49-8bda	164	11-19-54	23	610	35	35	Medium to coarse sand.
Union Stockyards Co.	139-49-6acc	208	10-31-57	5	1,290	28	38	Sand and gravel; coarse gravel and boulders with clay lenses.
City of South West Fargo	139-49-7abb2	204	9-22-60	15.50	775	66	68	Sand and gravel.
Siouxland Dressed Beef Co.	139-49-6bda	200	10- 5-60	12	1,150	11	17	Fine sand, sand, gravel, and boulders.
Village of West Fargo	139-49-6dcd1	215.50	11- 8-63	36	508	17.26	-	Fine to coarse sand.

Results

Location	Transmissibility (gpd per foot)	Thickness (feet)	Permeability (gpd per foot)	Storage coefficient	Specific capacity (gallons per minute per foot of drawdown)	Estimated specific capacity, 24 hours (gpm per foot of drawdown)
139-49-6adb1/	71,100	112	634	3.7×10^{-3}	90 estimated	--
139-49-8bda2/	40,000	29	1,380	--	17.4	17.4
139-49-6acc2/	80,000	93	860	--	46.0	34.0
139-49-7abb22/	20,000	14	1,430	--	11.5	11.0
139-49-6bda2/	200,000	107	1,870	--	104.0	67.6
139-49-6dcd13/	150,500	59	2,552	2.29×10^{-4}	29.4	--

1/ U.S. Geological Survey (Dennis and others, 1949, p. 87).

2/ Estimated aquifer coefficients.

3/ Computed aquifer coefficients.

Recharge, discharge, and movement.—Recharge to the aquifer probably occurs by lateral movement of water through the till and associated deposits and by downward percolation of water from the water table in the silt unit of the Lake Agassiz deposits. It is not possible to make an accurate measurement of the amount of water reaching the aquifer, but the following discussions will give some idea to the quantities involved.

The piezometric surface (surface defined by water levels in wells) within the aquifer and adjacent deposits slopes toward the area of heavy pumping. The hydraulic gradient in the area bordering the aquifer on the west and south ranges from about 2 to about 10 feet per mile and probably averages about 5 feet per mile. Assuming that the transmissibility of the till and associated deposits is 1,000 gpd per foot (Dennis and others, 1949, p. 93), the amount of water entering the aquifer along its 28 mile-long western edge would be 1,000 x 5 x 28, or 140,00 gpd. The piezometric surface in the till area east of the aquifer slopes from east to west at about 2 feet per mile. The inflow to the aquifer from the east would be 1,000 x 2 x 28, or 56,000 gpd.

Recharge to the aquifer by downward percolation of water from the silt unit in the Lake Agassiz deposits depends upon the difference in elevation between the water table in the silt unit and the artesian head in the aquifer, and upon the permeability of the material through which the water must pass—the silt and clay units of the Lake Agassiz deposits and the till. Water levels in the West Fargo aquifer range from 22 to about 108 feet below land surface. The average depth to water is 54 feet. The depth to the water table in the silt unit is about 7 feet. Thus, the artesian head in the aquifer is, on the average, 47 feet lower than the water table in the silt unit. The saturated lake deposits and the till have respective average thicknesses of 65 and 50 feet. The water passing downward from the water table to the aquifer will pass through 65 feet of lake deposits and 50 feet of till. The average hydraulic gradient would be $\frac{47}{115}$ feet per foot. Assuming that the lake deposits and the till have a combined average coefficient of permeability of 0.001 gpd per square foot (Dennis and others, 1949, p. 96), the average quantity of water moving downward to the aquifer would be $0.001 \times \frac{47}{115} \times 43{,}560 \times 640 = 11{,}148$ gpd per square mile. The total amount of recharge to the aquifer by movement of water downward from the water table in the silt unit would amount to about 1.2 million gpd over the 110 square mile area considered.

Thus, although the actual amount of recharge reaching the aquifer cannot be measured directly, it seems likely that the daily recharge rate is more than 1 million gallons.

Prior to development, water was probably discharged from the aquifer by lateral and upward movement into the adjacent deposits. The amount of water discharged from the aquifer by natural processes has undoubtedly decreased as the number of wells pumping from the aquifer increased. At the present time it is believed that most of the water leaving the aquifer is discharged by pumping. Approximately 471 million gallons of water was pumped from the aquifer during 1965.

Storage.—A substantial quantity of water is stored in the West Fargo aquifer. Using an estimated porosity of 30 percent and an average saturated thickness of 46 feet, the amount of water in storage would be 110 x 46 x 640 x 0.30, or about 972,000 acre-feet; however, the yield of the aquifer would be much less (see page 9).

The estimated change in storage from November 1964 to November 1965 based on an average water-level change of 1.42 feet and an average coefficient of storage of 4.7 x 10^{-3} is 1.42 x 110 x 0.0047 x 7.5 x 640 x 43,560, or about 153.5 million gallons. This is only 32 percent of the estimated 471 million gallons withdrawn in 1965. The estimated change in storage and the estimated annual recharge together account for about 80 percent of the estimated annual withdrawal. The water levels in the aquifer continue to decline, indicating that discharge exceeds recharge; therefore, it is assumed that an additional 20 percent, or about 90 million gallons of water was withdrawn from storage during the period from November 1964-November 1965.

Water-level fluctuations.—Well 139-49-6adb (139-49-6ad, Dennis and others, 1949, p. 77) is about 700 feet east of the old Union Stockyards supply well, 139-49-6abd (139-49-6ab2, Dennis and others, 1949, p. 54), and about 0.3 mile east of the new supply well, 139-49-6acc (fig. 9). The hydrograph for well 139-49-6adb (pl. 2) spans a period of about 28 years and shows that the water level has declined about 85 feet since January 1938.

The water-level fluctuations occurring between January 1938 and October 1957 reflect variations in the pumping regimen of Union Stockyards well 139-49-6abd. Use of this well was discontinued about November 1, 1957, and the new supply well, 139-49-6acc, was made operational at that time. Thus, the fluctuations of the water level in well 139-49-6adb between November 1, 1957 and September 1960 were caused by variations in the pumping from well 139-49-6acc. South West Fargo municipal well 139-49-7abb2 and Siouxland Dressed Beef Co. supply well 139-49-6bda were developed in the aquifer in 1960. Both these wells were in operation by the middle of November 1960. Pumping from wells 139-49-6acc, 139-49-6bda, and 139-49-7abb2 caused the water level in well 139-49-6adb to decline about 13 feet between November 1960 and November 1962. The water level in this well continued to decline at the rate of about 1 foot per year until October 1, 1964. West Fargo municipal well 139-49-6dcdl was put into operation at this time and the pumping of this well is believed to have caused the 1 foot of water-level decline occurring between the latter part of August and the first part of October.

Well 139-49-8bbal is an abandoned municipal supply well in the city of South West Fargo. The hydrograph (fig. 11) of this well shows that the water level declined about 6 feet between August 1962 and August 1965. The general lowering of the water level represents the combined effect of pumping from municipal and industrial wells in secs. 6-8, T. 139 N., R. 49 W. The short-term fluctuations reflect variations in the pumping regimen of supply well 139-49-8bda, which is about one-third mile southeast.

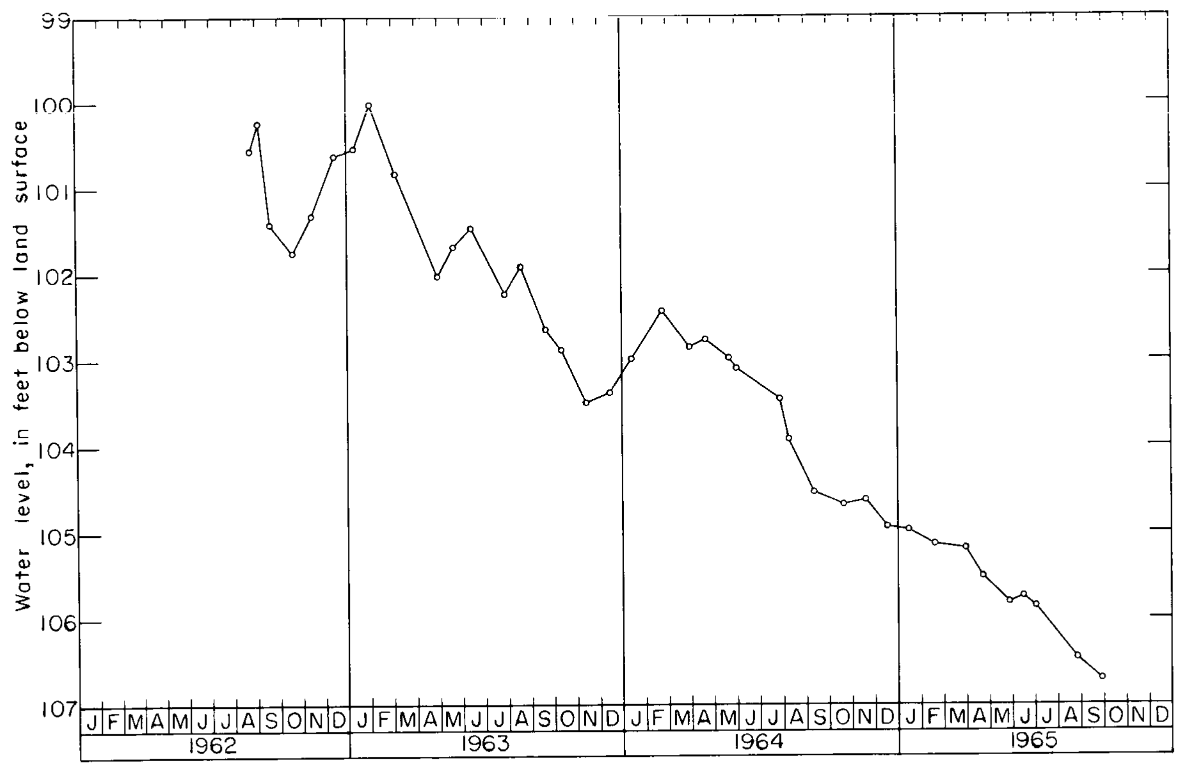


FIGURE 11. Water-level decline in South West Fargo municipal well 139-49-8bbal, 1962-65.

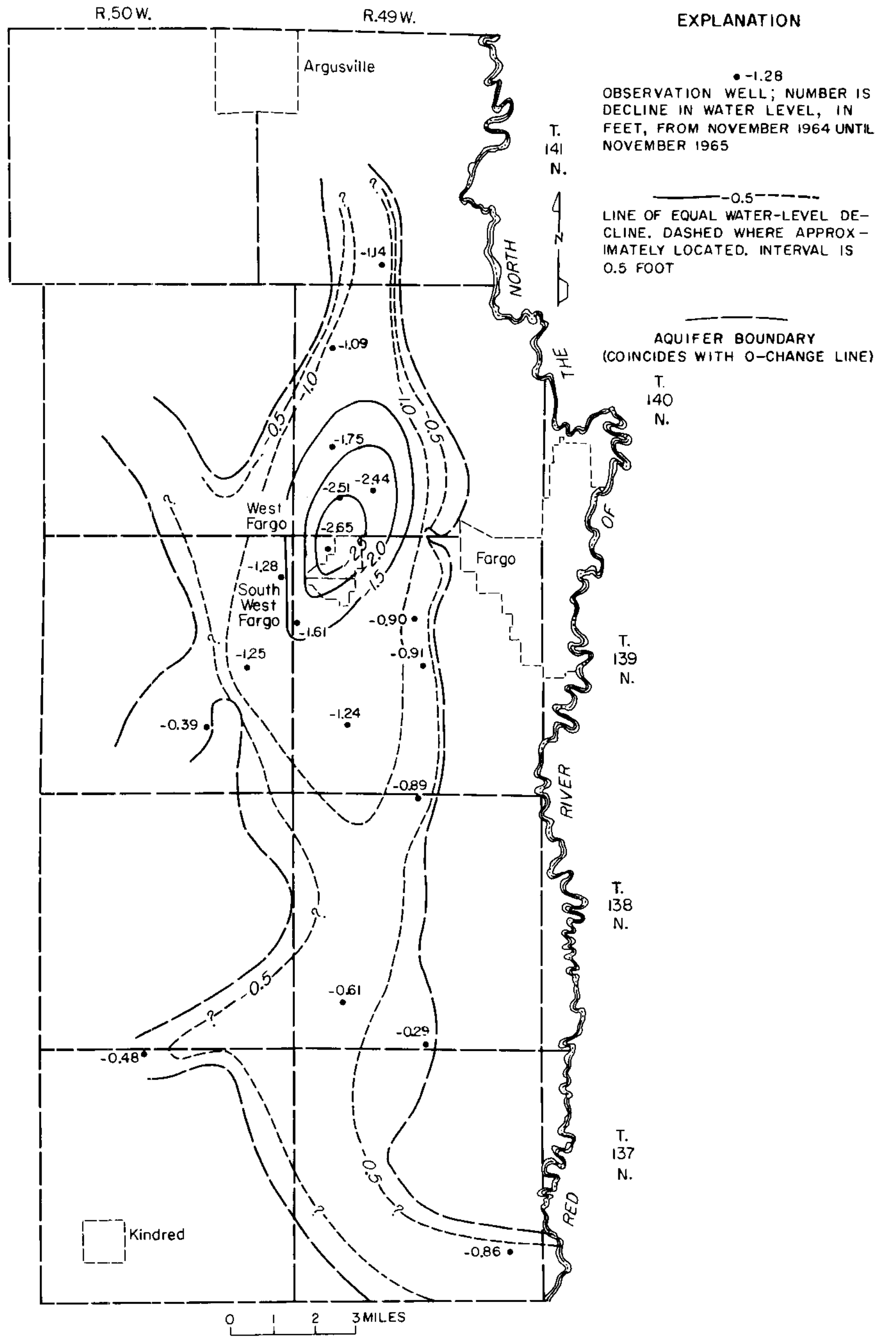


FIGURE 12. Regional water-level decline in West Fargo aquifer from November 1964 to November 1965, eastern Cass County.

Water levels measured during the first week of November 1964 were compared with those measured in the same well during the first week of November 1965. The comparison shows a regional decline of water levels throughout the aquifer (fig. 12). The decline, which ranged from 0.61 to 2.65 feet and averaged 1.42 feet, is attributed to pumping from industrial and municipal wells in the vicinity of West Fargo. The maximum decline of 2.65 feet was in observation well 139-49-6adb, which is near the point of greatest withdrawal.

Quality of water.—Chemical analyses of 21 water samples from the West Fargo aquifer indicate that the water is hard to very hard. Dissolved solids range from 377 ppm to 1,562 ppm. Average iron content is 0.57 ppm.

Sodium is the predominant cation. The predominant anions are bicarbonate and chloride. The bicarbonate content ranges from 256 ppm to 784 ppm and the chloride ranges from 50 to about 480 ppm. Analyses of water samples from wells tapping water-bearing sand and gravel lenses in the outlying areas show that the bicarbonate content of these waters has about the same range as the water in the aquifer. However, this is not the case with chloride. Water samples collected from wells located east of the aquifer generally have a much lower chloride concentration than do those collected from wells west of the aquifer. The general east to west increase in chloride content is accompanied by a transition from a sodium bicarbonate type water to a predominantly sodium chloride type (fig. 13).

The westward increase in the chloride content of the water probably is due to leakage of saline water from the Dakota Sandstone, which underlies the glacial deposits farther west.

A comparison of the following chemical analyses shows that there has been no significant change in the water quality in this part of the aquifer since 1949. Thus, it is possible that the water quality has not changed appreciably since the aquifer was developed.

Owner:	Union Stockyards	Union Stockyards
Location:	139-49-6ab2	139-49-6acc
Date of analysis:	Prior to 1949 (Dennis and others, 1949, p. 112a)	July 25, 1965

Constituents (parts per million)

Silica (SiO_2)	26	23
Iron (Fe)	.39	.66
Calcium (Ca)	57	67
Magnesium (Mg)	21	14

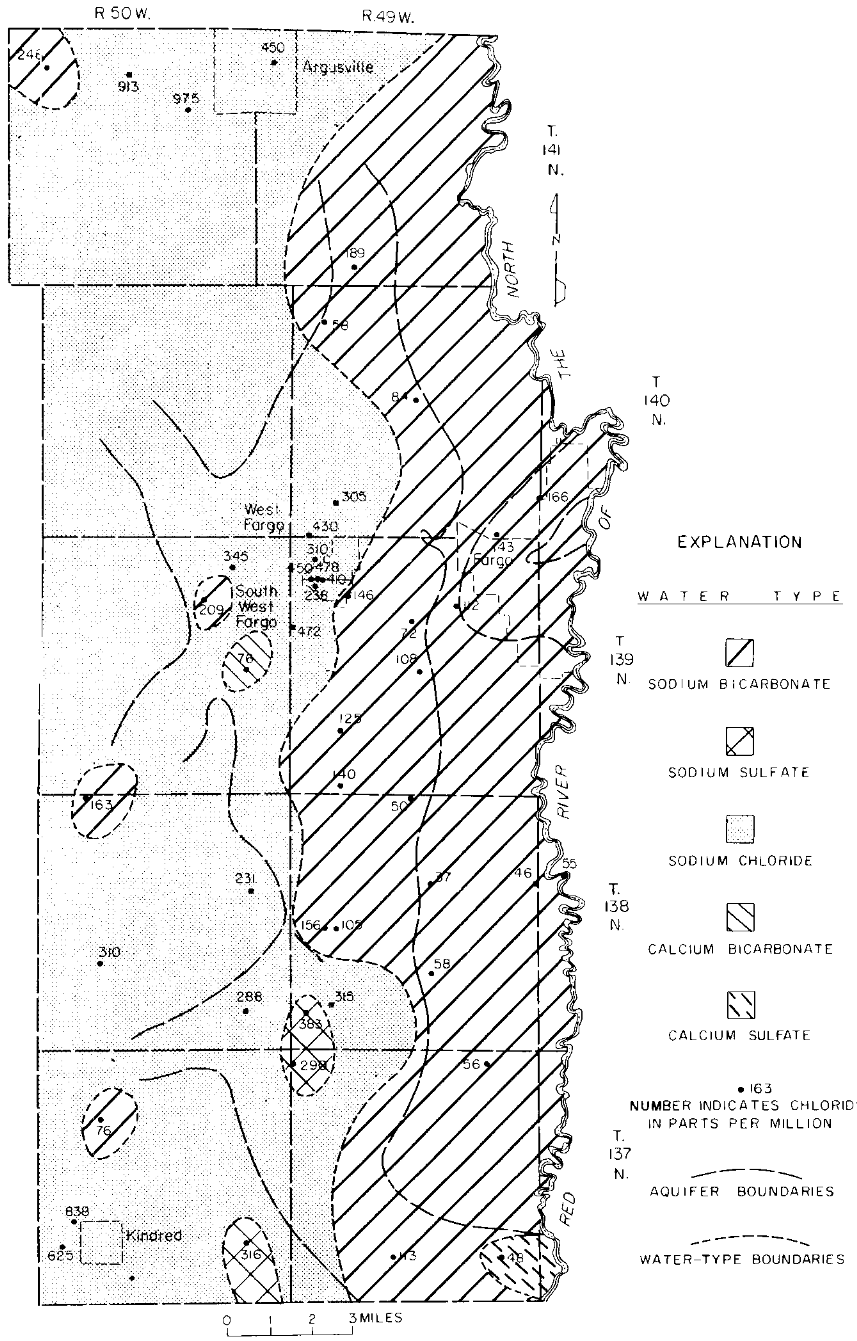


FIGURE 13. Distribution of ground-water types in eastern Cass County.

Sodium (Na) and potassium (K)	325	312
Bicarbonate (HCO_3)	412	377
Sulfate (SO_4)	90	151
Chloride (Cl)	355	310
Fluoride (F)	.6	.5
Nitrate (NO_3)	5.2	5.3
Hardness as $CaCO_3$	228	224
Total dissolved solids	1,090	1,070

Plots of SAR versus specific conductance (fig. 5) show that most of the water samples from the West Fargo aquifer fall in the C3-S1 or C3-S2 irrigation classification.

Utilization and potential for additional development.—The water pumped from the West Fargo aquifer is used to meet industrial and municipal needs in the vicinity of South West Fargo. The use and amount of water pumped annually by individual users are given below.

Pumpage from West Fargo aquifer, 1965

User	Use	Pumpage (gallons)
Union Stockyards [1]	Stock watering and washing	180,000,000
Siouxland Dressed Beef Co. [2]	Cooling and washing	195,616,000
City of South West Fargo [3]	Municipal	83,500,000
Village of West Fargo [4]	Municipal	9,510,000
Goldena Mills [5]	Manufacture of stock feed	600,000
	Total	469,226,000

1 Oral comunication, K. R. Lehman.

2 Determined from sewage records.

3 Metered.

4 Oral communication, Richard Fuller.

5 Oral communication, Howard Emerson.

Another principal user is the Woodlee Water Company, a private company that provides water to 36 residences outside the city of South West Fargo. It is estimated that the pumpage from the water company wells amounts to about 1,730,000 gallons annually. This estimate is based on a water use survey made by the city of South West Fargo, which indicated that the average monthly water use per residence was about 4,000 gallons (J. Dahl, oral communication).

On the basis of these data, about 470 million gallons of water was pumped from the aquifer during 1965. This is believed to be a minimal figure because it does not include pumpage from small industrial, motel, or farm wells.

Water levels are about 22 feet below the land surface in the southern part of the aquifer. Water levels in the northern part range from 60-100 feet below land surface.

Wells 139-49-6acc and 139-49-6bda, which are only about 700 feet apart, are in the center of the ever-expanding cone of depression. The pumping level in well 139-49-6bda was reported to be 112 feet below land surface in October 1964 (Tom Sands, oral communication), which would be about 9 feet below the top of the aquifer. Water levels in observation wells 139-49-6adb, 140-49-29ddd, and 140-49-31cdc also are below the top of the aquifer and indicate that locally the aquifer is being dewatered.

New developments in the aquifer should be located as far as possible from wells 139-49-6acc and 139-49-6bda to avoid large interference effects. Also, the effects of pumping from South West Fargo municipal wells 139-49-7abb2 and 139-49-8bda should be considered before any new development is made in these areas.

Any development in the northern part of the aquifer that requires large daily withdrawals probably will cause the existing low water levels to decline below the top of the aquifer.

Wells developed in that part of the aquifer lying south of the present pumping area probably will intercept water moving toward the wells in secs. 6-8, T. 139 N., R. 49 W. The diversion of water to new wells would decrease the amount of recharge to the original well field. Consequently, the rate of water-level decline in the vicinity of West Fargo would probably increase.

Yields from wells developed in the buried channel deposits comprising the southern extension of the aquifer will be influenced by the aquifer boundaries. For example, if a well developed in these deposits is pumped at a rate comparable to that of well 139-49-6acc (table 2), the drawdown in the new well will be much greater because the flow of water to the well is restricted to the channel segments; whereas the flow of water to well 139-49-6acc is radial. The conditions imposed upon a well pumping from the channel deposits may be such that it would not be possible to pump water at a rate comparable to that pumped by wells tapping more extensive parts of the aquifer.

Interconnection of Fargo and West Fargo aquifers.—Dennis and others (1949, p. 76-77) concluded that the Fargo and West Fargo aquifers were interconnected. Their conclusion was based on the similarity of water-level fluctuations in Union Stockyards well 139-49-6adb in the West Fargo aquifer and in wells 139-49-1ccd2 and 139-48-6ccd, both in the Fargo aquifer. No recent water-level data are available for well 139-49-1ccd2 because it has been destroyed. A comparison of the long-term hydrographs for well 139-49-6ccd and well 139-49-6adb (pl. 2) shows similarity of water-level trends prior to 1952; however, the trends are not believed to be related. From January 1952 to June 1956, the maximum water-level fluctuation in well 139-49-6ccd was only about 1.5 feet, whereas the maximum fluctuation in well 139-49-6adb was about 20 feet. There was no significant change of the water level in well 139-49-6ccd during the period January 1952 to June 1956, but during the same period the water level in well 139-49-6adb declined about 17 feet. If there was good hydraulic connection between the aquifers, the water level in well 139-49-6ccd should have declined in response to the pumping from the West Fargo aquifer.

Although the Fargo and West Fargo aquifers approach each other closely (fig. 8), there is no geologic evidence to indicate that the aquifers are connected (figures 7 and 10). Disregarding the lake deposits, the material lying between the aquifers consists of till, which contains thin lenses of sand and gravel. These lenses generally occur at different horizons and are therefore not considered to be connected.

Page Aquifer

Location and extent.—The Page aquifer, in the northwestern part of the county, extends northward from near the south line of T. 141 N., R. 54 W., into Steele County. In Cass County the aquifer underlies parts of Tps. 141-143 N., Rs. 53-55 W., and has an areal extent of about 155 square miles. The aquifer boundaries are not definitely known; however, the available data indicate that the aquifer probably does not extend beyond the limits shown on plate 1.

Thickness and lithology.—The aquifer consists of two intervals of sand and gravel that are superimposed in the drift. The upper interval, hereafter referred to as "zone A" is a buried glaciofluvial deposit consisting of very fine to coarse sand. It ranges in thickness from 0 to 78 feet. The lower interval, "zone B," is a buried outwash deposit consisting chiefly of fine to medium sand. This interval ranges in thickness from 0 to about 50 feet (fig. 14). Both intervals were penetrated in test holes 142-54-1bbb and 142-54-8ddd where they have respective aggregate thicknesses of 129 feet and 89 feet (fig. 15). In these test holes, zones and A and B are separated by about 30 feet of till; however, it is not known if this separation prevails throughout the extent of zone A.

Reservoir characteristics.—The Page aquifer is an artesian system confined at the top by deposits of glacial till that range in thickness from 9 to 80 feet.

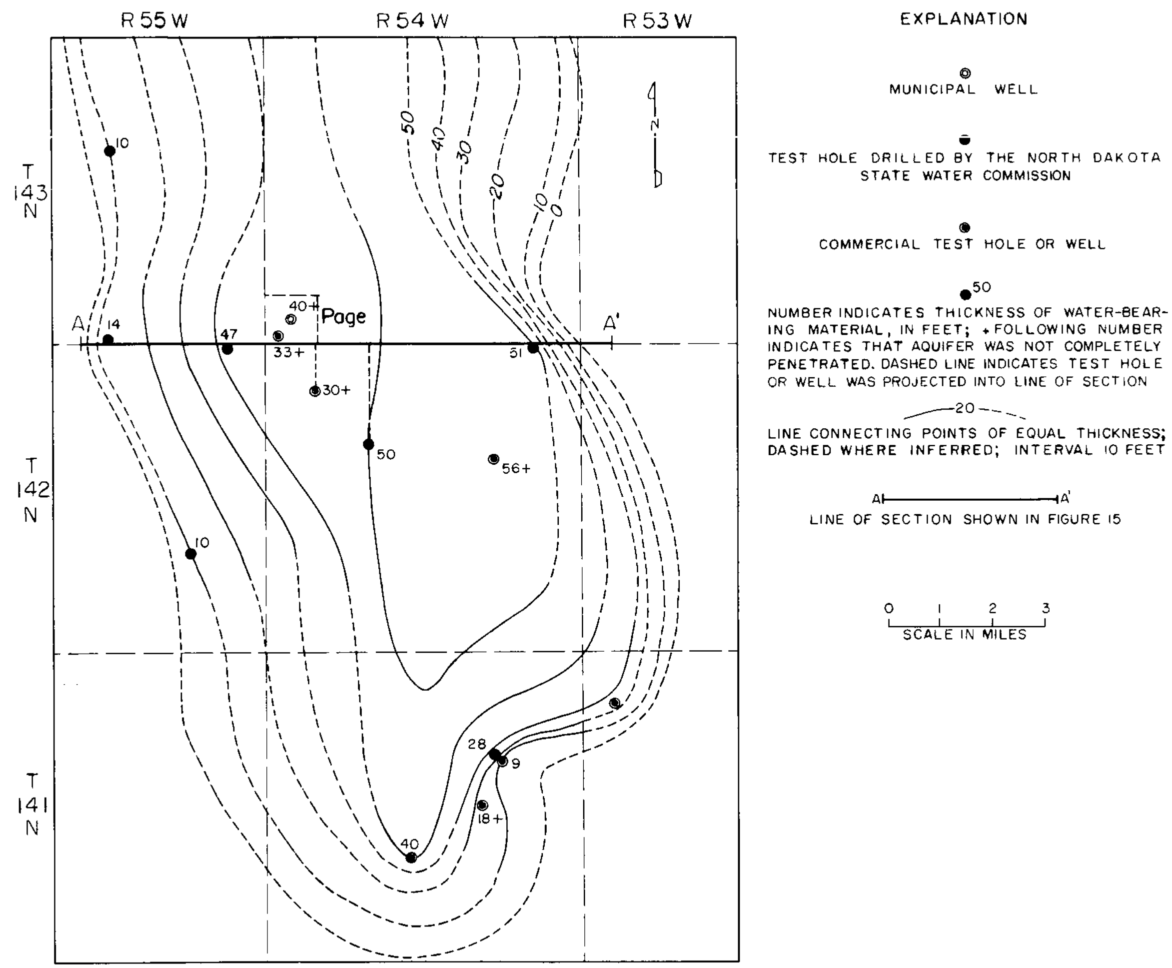


FIGURE 14. Thickness of zone B in Page aquifer, northwestern Cass County.

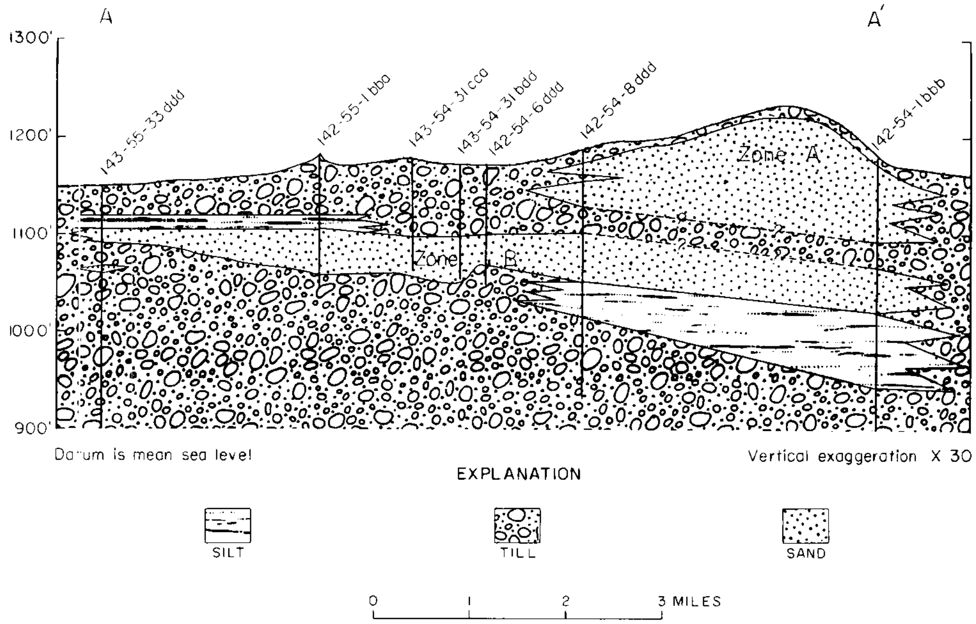


FIGURE 15. Geologic section in Page aquifer.

Page municipal well 143-54-31bdd, which was drilled in zone B and put into operation in July 1962, penetrated 40 feet of fine sand in the interval 81-121 feet and had a static water level of 23.5 feet. During the development test the well was pumped for 12 hours at a rate of 230 gpm with a drawdown of 46 feet. With the exception of 1 foot of water-level rise during the eighth and ninth hours of pumping, the pumping level remained rather constant at 69.5 feet after the second hour of pumping, suggesting that equilibrium between discharge and rate of flow to the well had been reached. Because the pumping level remained relatively constant after the second hour of pumping, it seems unlikely that there would be any appreciable increase in the drawdown at the end of 24 hours.

Assuming that the drawdown remained at near 46 feet, the specific capacity of the well would be 5 gpm per foot of drawdown. Using Meyer's method (1963, p. 338), the coefficient of transmissibility of the aquifer in the vicinity of the well is estimated to be about 10,000 gpd per foot. The estimated coefficient of transmissibility for the aquifer as a whole, based on analyses of drill samples from test holes, ranged from 4,000 gpd per foot to 82,000 gpd per foot.

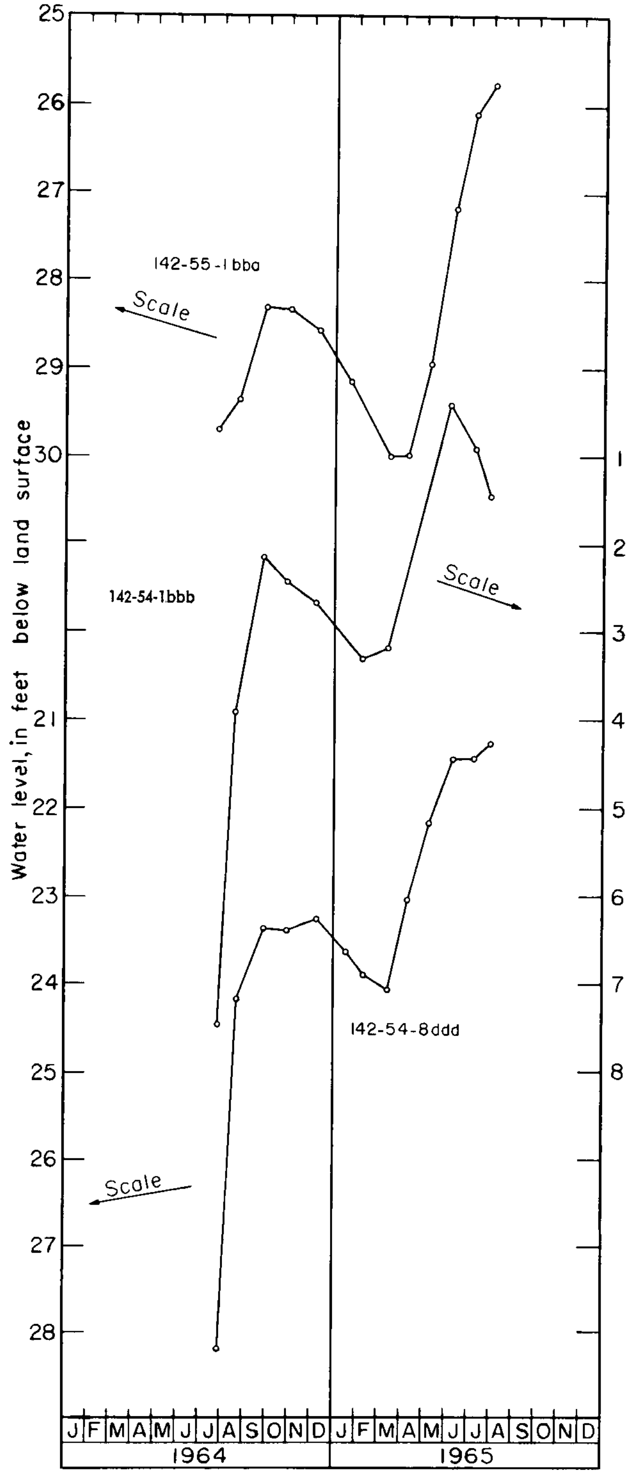


FIGURE 16. Water-level fluctuations in the Page aquifer.

Storage.—Based on an average thickness of 30 feet and an assumed porosity of 30 percent, it is estimated that there is about 900,000 acre-feet of water in transient storage; however, the yield of the aquifer would be much less (see page 9).

Records show that water levels in three wells drilled into the aquifer in 1928, 1951, and 1962 were, respectively, about 26, 27, and 23.5 feet below land surface (Klausing, 1966, p. 77). These water levels are comparable to present-day (1965) levels and indicate that there has been no appreciable decrease in storage in the aquifer during the past 30-40 years.

Water-level fluctuations.—The hydrographs for observation wells 142-54-1bbb, 142-54-8ddd, and 142-55-1bba (fig. 16) span a period of 1 year and are not of sufficient length to permit an accurate analysis of the water-level fluctuations. However, the apparent correlation of the water-level fluctuations in the three wells warrants some discussion.

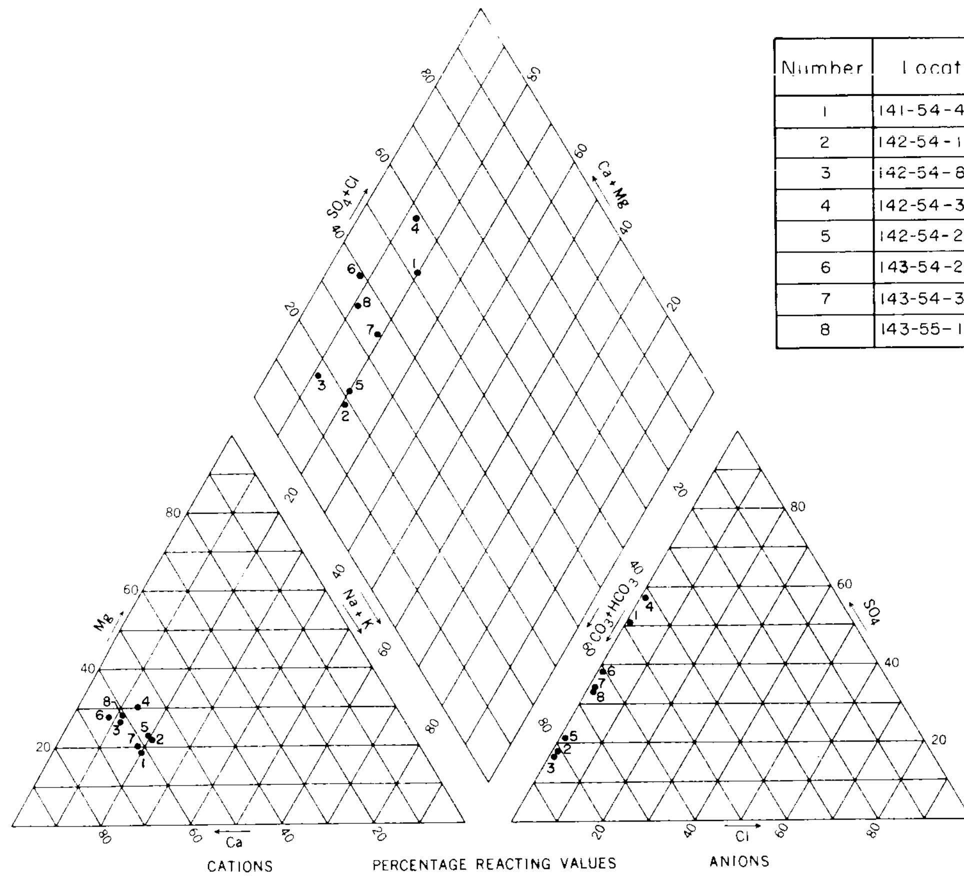
The three observation wells were installed during the latter part of July 1964. The first water-level measurements were made only a few days after the casings were installed. The leveling off and subsequent decline of the water levels, which occur during the late fall and winter, indicate that discharge exceeds recharge and that there is a temporary loss of storage in the aquifer. The rapid rise in water levels in the spring is believed to be the combined result of recharge and compression of the aquifer by water loading on the land surface. Precipitation in the area was unusually high during April, May, and early June.

Quality of Water.—Analyses of eight water samples from the aquifer show that the water is predominantly a calcium bicarbonate type. The water is very hard and the dissolved solids range from 290 to 850 ppm. Average iron content is 1.7 ppm. The percentages of the major constituents in the water are shown on figure 17.

Plots of SAR versus specific conductance (fig. 5) show that most of the water samples from the Page aquifer are classified as a C3-S1 type water for irrigation.

Utilization and potential for additional development.—Most of the water pumped from the aquifer is used for domestic purposes. The public supply well at Page is the only ground-water development of large magnitude in the aquifer. This well pumps about 7 million gallons a year and it is estimated that about 20.4 million gallons of water have been withdrawn from the aquifer during the period extending from August 1962 to July 1965. Lesser amounts of water are pumped from the aquifer to meet rural domestic and stock needs. The total annual pumpage from the aquifer is estimated to be between 8 and 10 million gallons.

From the standpoint of areal distribution and thickness of water-bearing materials, the Page aquifer appears to have a greater potential for additional development than do most of the aquifers in the county. Present information regarding this aquifer is inadequate to estimate the amount of water that could be withdrawn from it under a given set of pumping



Number	Location	Dissolved solids (ppm)
1	141-54-4ccd	850
2	142-54-1bbb	337
3	142-54-8ddd	286
4	142-54-34aad	812
5	142-54-25cbc	553
6	143-54-23bba	611
7	143-54-31bdd	586
8	143-55-15dcd	579

FIGURE 17. Major constituents in water from the Page aquifer.

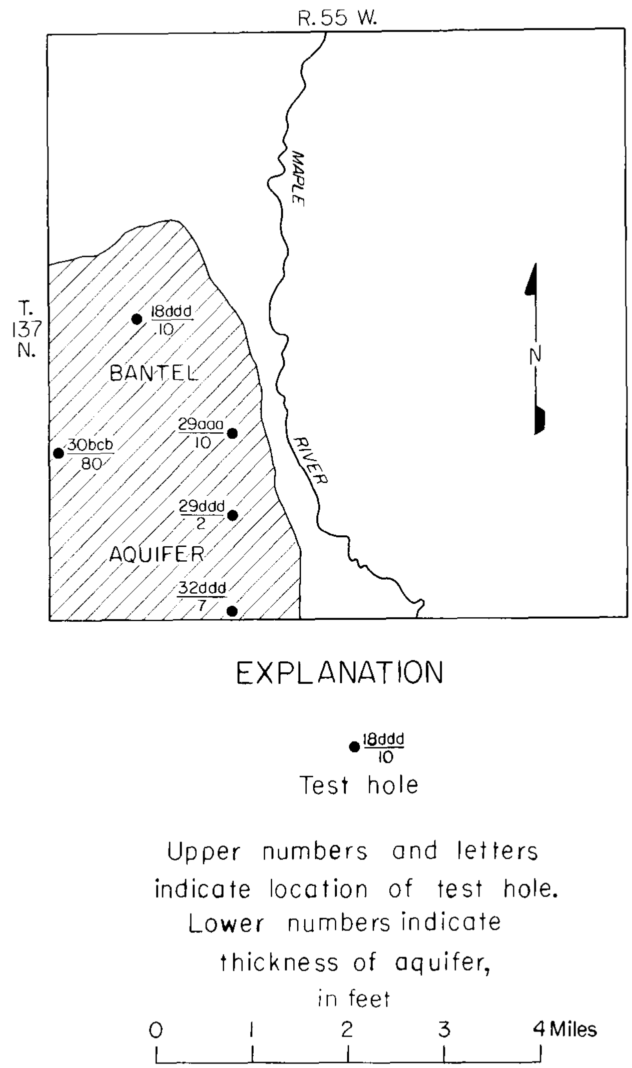


FIGURE 18. Location and thickness of Bantel aquifer, southwestern Cass County.

conditions. Depending upon the local thickness and permeability of the material penetrated, properly constructed wells tapping the aquifer should yield from 250 to 750 gpm.

The drawdown in the Page municipal well (143-54-31bdd) while pumping at a rate of 230 gpm was 46 feet. Comparable drawdowns may be expected in new wells pumping at rates greater than 200 gpm. Although nothing is known about the extent of the cone of depression caused by pumping the Page well, the fairly large drawdown indicates that any new developments should be widely spaced to avoid excessive well interference.

Bantel Aquifer

Location and extent.—The Bantel aquifer underlies about 9 square miles in the southwest corner of Cass County and extends westward into Barnes County (Kelly, 1966 p. 40).

Thickness and lithology.—The aquifer in Cass County ranges in thickness from 0 to 80 feet and consists of fine to coarse sand intermixed with gravel. Two test holes, 137-56-26aaa (Kelly, 1964, p. 68) and 137-55-30bcb (Klausing, 1966, p. 106), penetrated sand and gravel deposits that are 88 and 80 feet thick, respectively. These large thicknesses, when compared with the smaller thicknesses elsewhere, as shown on figure 18, suggest that the thicker parts of the aquifer may be confined to a narrow channel. Also, the aquifer is exposed along the south side of an intermittent stream channel in secs. 31-32, T. 137 N., R. 55 W., suggesting that the aquifer is lenticular and that the thicker sand and gravel deposits may occupy a partly exhumed buried channel.

Reservoir characteristics.—The Bantel aquifer is confined at the top and bottom by deposits of glacial till. The till overlying the aquifer ranges in thickness from 5 to about 40 feet.

The estimated coefficient of transmissibility ranges from about 800 gpd per foot in test hole 137-55-29ddd to about 190,000 gpd per foot in test hole 137-55-30bcb. However, as most of the test holes penetrated 10 feet or less of sand and gravel, the overall transmissibility of the aquifer probably is less than 8,000 gpd per foot.

Recharge, discharge, and movement.—Because the aquifer is small in areal extent, it probably does not receive much recharge from the downward percolation of water derived from melting snow or rainfall. One possible source of recharge to the aquifer is in Barnes County where the aquifer intercepts a glacial melt-water channel (T. E. Kelly, oral communication). The greatest amount of recharge from this source would occur during the spring and early summer when the channel carries runoff from melting snow and rainfall.

Water is discharged from the aquifer naturally by lateral movement into adjacent deposits and by springs where erosion has exposed the aquifer. A small amount of water is discharged by pumping from farm wells.

The available water-level data indicate that the hydraulic gradient within the aquifer slopes from west to east (Kelly, 1966 p. 42).

Water-level fluctuations.—No long-term water-level data are available for this aquifer. The lowest water level measured was 22.75 feet below land surface in January 1965. The highest water level was 21.3 feet below land surface in April 1965.

Quality of water.—An analysis of a water sample taken from observation well 137-55-30bcb shows the water to be a sodium sulfate type. The water is very hard, contains 0.36 ppm iron, and has a dissolved solids concentration of 1,350 ppm. The irrigation classification is C3-S1 (fig. 5).

Utilization and potential for additional development.—Present development in the aquifer consists of farm and stock wells. The amount of water withdrawn annually by these wells is unknown. Developments requiring large daily withdrawals of water probably would not be feasible because the aquifer is small in areal extent and relatively thin.

Sheyenne Delta Aquifer

Location and extent.—The Sheyenne delta occupies an area of about 750 square miles, mostly in Richland and Ransom Counties (Baker and Paulson, 1967, p. 33). The areal extent of the delta in Cass County is about 60 square miles; however, only about two-thirds of this area is underlain by permeable deposits. These are mainly in T. 137 N., Rs. 52-53 W. (pl. 1).

Only four test holes penetrated the full thickness of the aquifer and three of these were near the Cass-Richland county line. The northern limits of the aquifer shown on plate 1 are based on well-inventory data.

Thickness and lithology.—In Cass County, the Sheyenne Delta aquifer consists of two sand bodies that are separated by a silt bed about 20 feet thick (fig. 19). The upper sand, which is fine to medium, ranges in thickness from 0 to about 50 feet. The lower sand, which seems to be finer grained and silty, ranges in thickness from 0 to about 60 feet. The maximum thickness of the aquifer, including the intervening silt bed, is about 120 feet.

Reservoir characteristics.—The estimated transmissibility ranges from 1,500 to 36,500 gpd per foot and averages about 20,000 gpd per foot.

Water in the upper sand and in the underlying silt unit is under water-table conditions. The coefficient of storage of these two units is probably between 0.05 and 0.25. Water in the lower sand is probably under semiartesian conditions caused by the overlying less permeable silt unit. Assuming that the water in the lower unit is semiconfined, the coefficient of storage for that unit may be on the order of 0.01 to 0.001.

Recharge, discharge, and movement.—The aquifer is readily recharged by direct infiltration of water derived from melting snow and rainfall. The greatest amount of recharge to the aquifer occurs during the spring and early summer. Baker and Paulson (1967, p. 25) estimated that the annual recharge in Richland County is about 50,000 acre-feet. The area underlain by the aquifer in Cass County is about 13 percent of the area

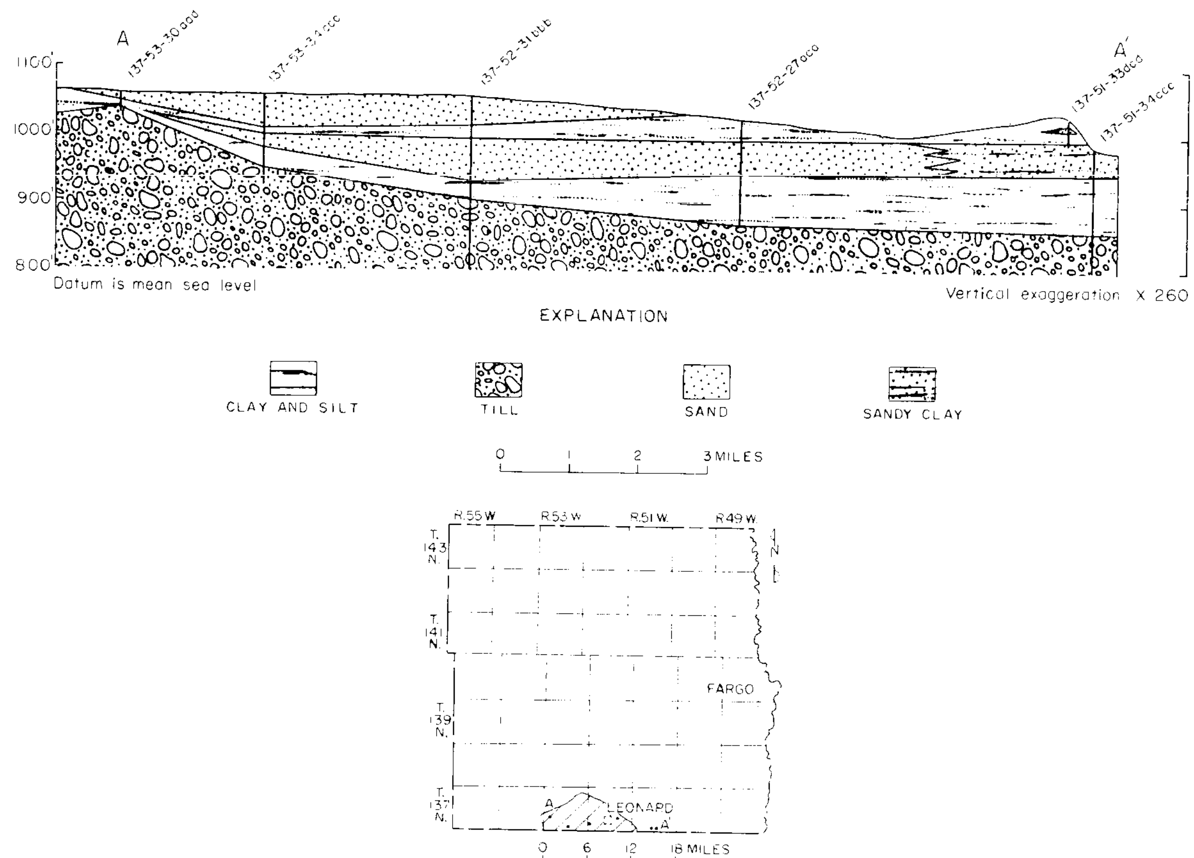


FIGURE 19. Geologic section in the Sheyenne delta.

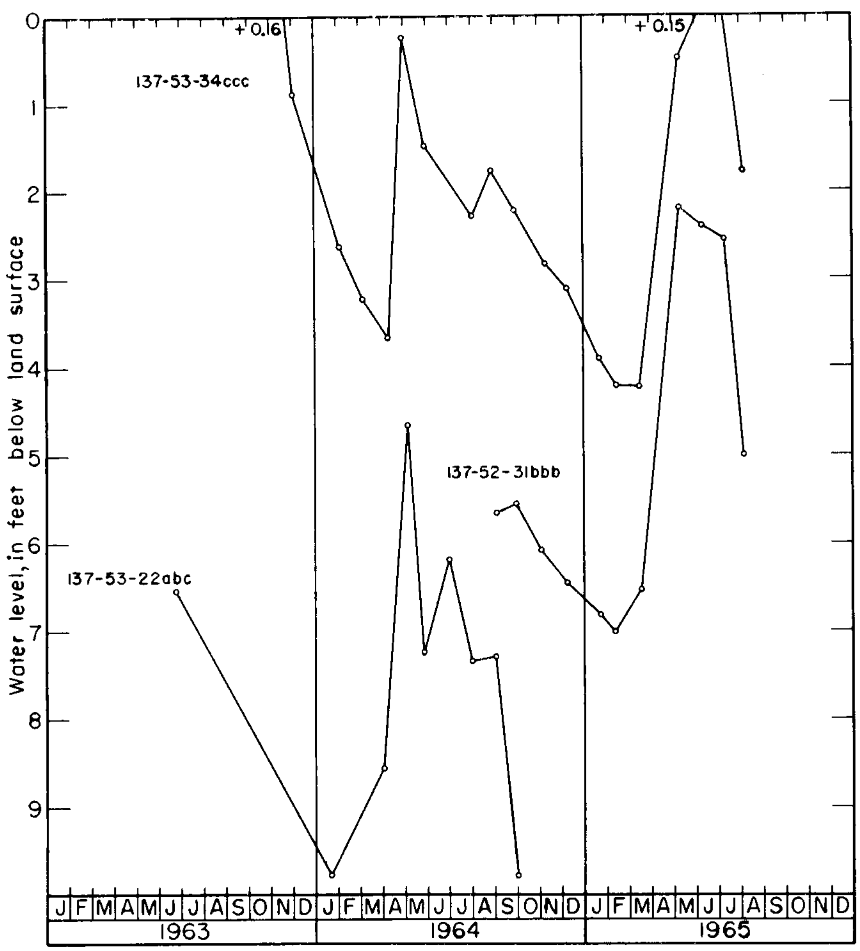


FIGURE 20. Water-level fluctuations in the Sheyenne Delta aquifer.

in Richland County. Assuming similar recharge conditions in Cass County, the annual recharge would be about 6,500 acre-feet.

Water is discharged from the aquifer by evapotranspiration, lateral movement into adjacent deposits, and by pumping. The amount withdrawn to meet rural domestic and stock needs is probably only a small percentage of the total natural discharge.

The hydraulic gradient in the aquifer is to the north and east and ranges from 1 to 2 feet per mile.

Storage.—The average thickness of the aquifer in Cass County is about 40 feet. Thus, if the average porosity is about 40 percent (Baker and Paulson, 1967, p. 21) and the area is 40 square miles, the amount of water stored in the aquifer would be 40 x 40 x 640 x 0.40, or 409,600 acre-feet; however, the total yield of the aquifer would be much less (see page 9).

Water-level fluctuations.—The water-level fluctuations shown on figure 20 reflect for the most part seasonal variations in recharge. The abrupt rise of the water levels in the wells between the latter part of March and the first part of May indicates recharge to the aquifer by infiltration of snowmelt and rainfall. This recharge begins with the spring thaw and continues until May or June. The rise in water levels caused by the recharge appears to be in the order of magnitude of about 5 feet. The subsequent decline of the water levels is a result of discharge from springs, evaporation where the water table is near the land surface, transpiration by crops and other vegetation, and decreased precipitation. Water levels are deepest during January, February, and March when little or no recharge reaches the aquifer.

Quality of water.—Chemical analyses of two water samples from the aquifer indicate that the water is a calcium magnesium bicarbonate type. The water is very hard and the dissolved solids concentration is about 500 ppm. Iron content ranges from 0.3 to 7.2 ppm.

Plots of SAR versus specific conductance on figure 5 show that the water samples have a C3-S1 irrigation classification.

Utilization and potential for additional development.—At the present time there are no large developments in the aquifer. The relatively small amount of water pumped for domestic and stock use has not had noticeable effects on the regional water level in the aquifer.

In view of the areal extent and thickness of the permeable water-bearing deposits, the Sheyenne Delta aquifer appears to have more potential for ground-water development than any of the other aquifers in the county, except possibly the Page aquifer. Very large quantities of ground water should be available to wells, but recovery may be a problem in places because the sand is so fine grained. Although few data are available regarding well yields, it seems likely that properly constructed wells at favorable locations in the aquifer could be pumped at rates ranging from 250 to 400 gpm (pl. 1).

Tower City Aquifer

The Tower City aquifer is a surficial outwash deposit confined in a glacial melt-water channel that enters Cass County near the center of the west line of T. 140 N., R. 55 W. The channel passes through Tower City and extends southeastward to its junction with the Maple River (pl. 1). In most places the channel and deposits are about ¼-mile wide.

The thickness of the aquifer is known in only a few places. The municipal well at Tower City (140-55-19bac2) penetrated 22 feet of sand and gravel and test hole 139-55-16ddd penetrated 9 feet of sandy gravel (fig. 21). This test hole is near the edge of a small delta terrace formed at the mouth of the channel.

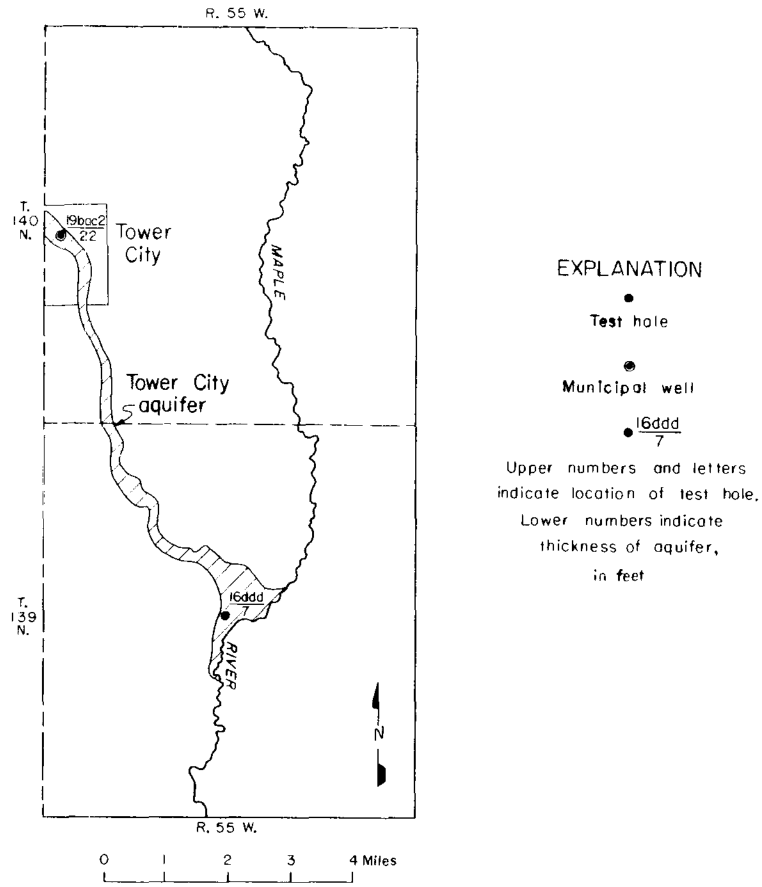


FIGURE 21. Location and thickness of Tower City aquifer, west-central Cass County.

The coefficient of transmissibility of the Tower City aquifer is estimated to be as high as 22,000 gpd per foot. Because the water in the aquifer is under water-table conditions, the coefficient of storage may be between 0.01 and 0.30.

Development-test data show that the Tower City supply well was pumped for 24 hours at a rate of 70 gpm. The drawdown at the end of 1 day was reported to be 13 feet; thus, the specific capacity of the well would be 5.4 gallons per foot of drawdown, indicating a coefficient of transmissibility of 5,400 gpd per foot at that location.

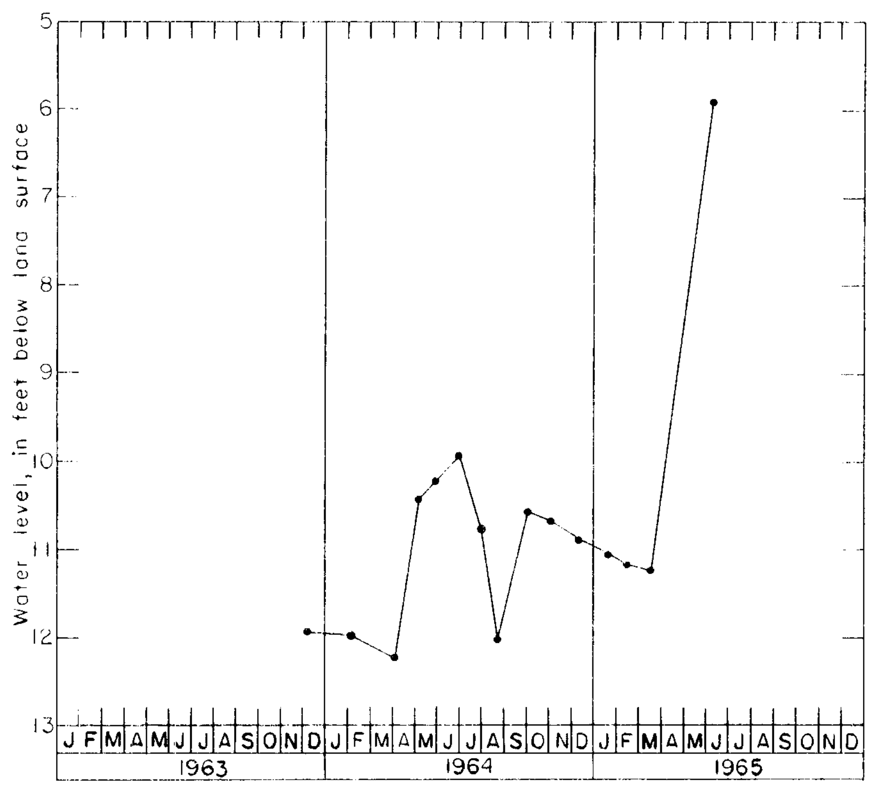


FIGURE 22. Water-level fluctuations in the Tower City aquifer.

Most of the recharge to the aquifer occurs during the spring and early summer when excess water from melting snow and rainfall is diverted into the channel. The channel containing the water-bearing deposits heads in and drains several square miles in Barnes County. Consequently, most of the recharge to the aquifer in Cass County is derived from precipitation that falls in Barnes County.

As far as known, there were no wells pumping from the aquifer prior to the development of the public supply well at Tower City in August 1960. Pumpage records for the period extending from August 1960 to December 1963 indicate that the average annual pumpage is about 2.8 million gallons.

Observation well 140-55-19bacl is about 10 feet south of Tower City supply well 140-55-19bac2. The fluctuations shown in figure 22, though modified somewhat by pumping, are for the most part natural fluctuations. The first three measurements taken during the winter show a low water level and indicate the combined effect of pumping and reduced recharge. The abrupt rise in the water level between March and May 1964 indicates that the aquifer started receiving recharge when the spring thaw set in. This rise continued until about July 1, at which time the amount of recharge to the aquifer declined and pumpage increased. The increased pumpage caused the water level to decline about 2 feet. The subsequent rise in the water level in September 1964 probably was a result of decreased pumpage. The gradual decline extending from October 1964 to March 1965 again shows the effect of pumping and negligible recharge. The 5-foot rise in the water level between mid-March and the first part of May resulted from above-normal precipitation during the spring and early summer of 1965.

An analysis of a water sample taken from the Tower City supply well indicates that the water is a calcium bicarbonate type. The water is hard and has a dissolved-solids concentration of about 500 pm. The sample indicated an irrigation classification of C3-S1 (fig. 5).

The supply well at Tower City is the only known development in the aquifer in Cass County. Pumpage records show that 9,343,000 gallons of water was pumped from the aquifer between August 1960 and December 1963. The average monthly use is about 233,500 gallons. Based on the monthly average, it is estimated that as of July 1, 1965 about 13.8 million gallons had been withdrawn from the aquifer.

In addition to usage by Tower City, the aquifer probably could support a number of farm and stock wells. However, extended drought could seriously limit the amount of water that could be pumped from the aquifer.

Undifferentiated Sand and Gravel Deposits

Undifferentiated sand and gravel deposits that probably were laid down in a glaciofluvial environment are distributed randomly throughout the drift in Cass County. Test holes and wells drilled into the drift commonly penetrate one or more beds of sand and (or) gravel at depths from about 20 feet to more than 400 feet. Individual deposits may range in thickness from 1 foot to 104 feet (test hole 3145, 137-55-35ddd, Klausing, 1966, p. 107). The aggregate thickness of separate beds may be as much as 150 feet. The sand and gravel beds are discontinuous and cannot be correlated from one test hole or well to another.

Wells tapping the undifferentiated deposits may yield less than a gallon per minute to about 100 gpm. The pumps installed on most farm wells are piston or submersible types and have capacities ranging from 3 to 10 gpm. Most of these wells can be pumped at maximum capacity for extended periods. Others, however, are reported to go dry or "suck air" after pumping continuously for several hours.

Some of the wells tapping the undifferentiated deposits flow. Generally they flow only a few gallons per minute, but well 138-52-11ccc, drilled to a depth of 276 feet, was reported to flow 200 gpm from sand and gravel between 245 and 271 feet. The flowing wells are local phenomena and are not indicative of an extensive body of water-bearing material in which flowing wells could be developed.

Water from the undifferentiated sand and gravel deposits differs widely in chemical character and the dissolved solids concentration ranges from 182 to 12,400 ppm; however, 93 percent of the 85 samples collected had dissolved solids concentrations ranging from 445 to 3,220 ppm. The median concentration was 1,020 ppm. Grouping the individual samples according to water type showed that about 33 percent were sodium bicarbonate type, 30.5 percent were sodium sulfate type, 19 percent were sodium chloride, 10.5 percent were calcium sulfate, and 7 percent were calcium bicarbonate type.

On the basis of data from three test holes, Dennis and others (1949, fig. 1) indicated the probable existence of a fairly extensive body of sand and gravel, which they called the Maple Ridge aquifer, in the area west of Mapleton. The deposits comprising the "Maple Ridge aquifer" are herein assigned to the undifferentiated sand and gravel deposits because: (1) the sand and gravel beds in the test holes (139-51-4ccd, 139-51-11abb, and 140-51-34daa, Dennis and others, 1949, p. 116, 168, and 177) do not appear to be correlative, and (2) sand and gravel deposits penetrated in surrounding test holes and wells are not correlative with the deposits penetrated in the test holes listed above (fig. 23).

Most wells tapping the undifferentiated sand and gravel deposits supply water mainly for rural domestic and stock use; however, the villages of Arthur, Kindred, and Mapleton have developed public supply wells in the deposits.

Bedrock Aquifer

Of the bedrock formations underlying the area, only the Dakota Sandstone of Cretaceous age is an important source of ground water. The Greenhorn Formation, the Graneros Shale, and the Precambrian crystalline rocks do not yield water in Cass County.

Dakota Sandstone

Location and extent.—The term Dakota Sandstone is used in this report to include all the Cretaceous rocks older than the Graneros Shale. The Dakota Sandstone underlies all of Cass County except the approximate eastern quarter. The eastern boundary of the Dakota Sandstone shown on plate

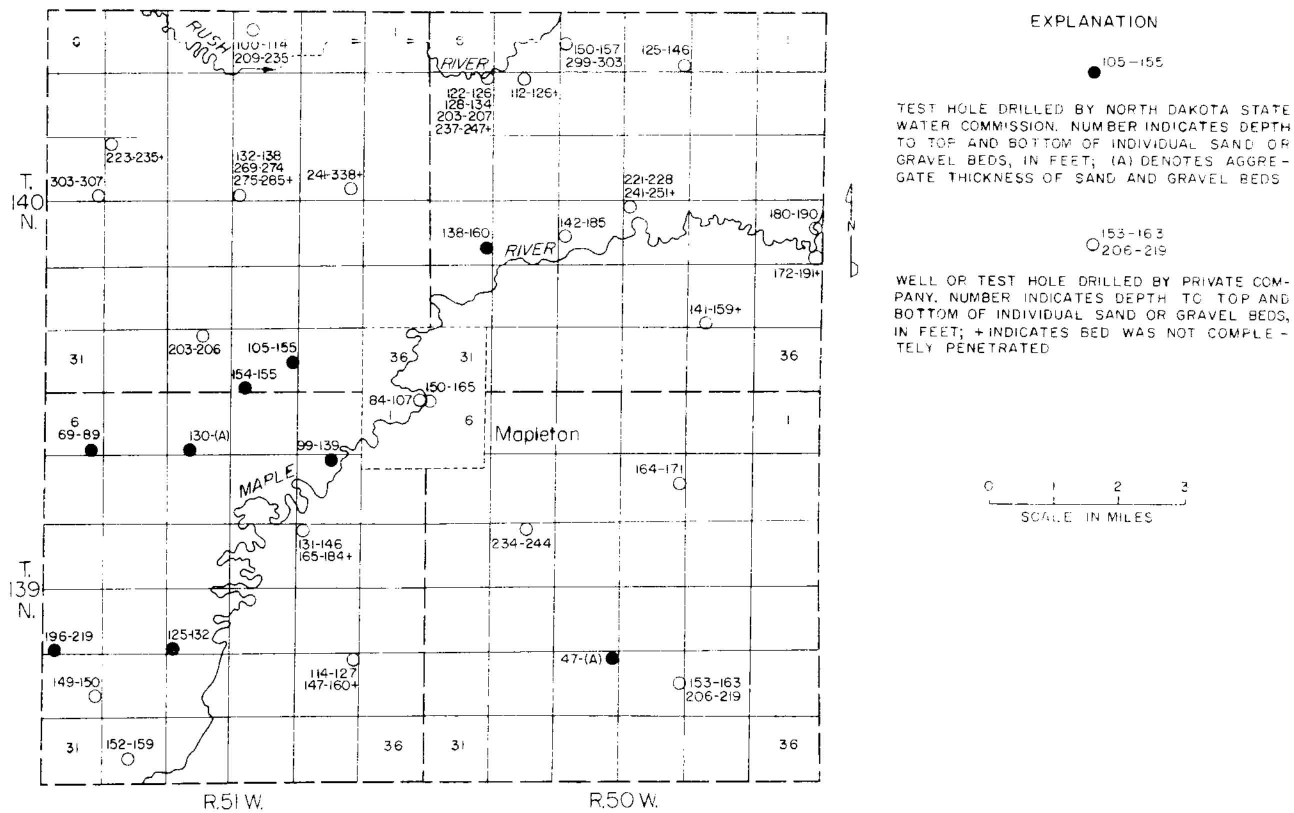


FIGURE 23. Location of wells and test holes tapping undifferentiated glacial drift aquifers in the vicinity of Mapleton, east-central Cass County.

1 is based for the most part on well-inventory data because only a few test holes penetrated the formation. Consequently, the boundary shown is tentative.

Thickness and lithology.—The depth to the top of the Dakota Sandstone ranges from about 300 feet in the eastern part of the area to more than 700 feet in the western part.

The formation underlying that part of the county east of the west line of R. 52 W. ranges from 0 to a known thickness of 158 feet in test hole 139-52-27aaa (Klausing, 1966, p. 127). The total thicknes of the formation underlying the county west of R. 52 W. is unkown.

The Dakota Sandstone consists chiefly of interbedded and (or) interlensed silt, shale, loose sand, and sandstone; however, in places it may consist solely of clay or shale. The water-bearing deposits range in texture from very fine to very coarse sand, but very fine to fine sand is predominant. The sand and sandstone range in thickness from 0 to about 50 feet. Hopkins and Petri (1963, p. 22) estimated that the layers and lenses of sandstone constitute only about one-fourth to one-fifth of the total thickness of the formation in northeastern South Dakota.

Reservoir characteristics.—The Dakota aquifer is confined by the Graneros. Shale, which in turn is overlain by younger Cretaceous rocks and glacial drift. At places along its eastern edge, the aquifer is in direct contact with glacial till that fills pre-Pleistocene drainages that were entrenched into the sandstone.

In its eastern extent, the aquifer is underlain by Precambrian crystalline rocks. The nature of the underlying rocks in the western part of the area is unknown.

Most wells drilled through the Dakota Sandstone penetrate one or more water-bearing sand and (or) sandstone beds. Hall and Willard (1905, p. 6) reported that flows were obtained at 287, 325, 378, 404, and 420 feet in a well drilled to a depth of 420 feet in sec. 15, T. 138 N., R. 53 W. A test hole drilled to a depth of 467 feet in the NE cor. sec. 27, T. 139 N., R. 52 W., penetrated water-bearing sands in the intervals 367-391 feet and 442-449 feet. Neither sand bed produced a flow. A well drilled in the SW¼ sec. 4, T. 139 N., R. 52 W., only 3 miles north of the test hole in sec. 27, penetrated 10 feet of water-bearing sand between 442 and 432 feet. This well was reported to flow 30 gpm. These examples indicate that the sand beds do not have extensive lateral continuity and cannot be correlated from one well to another.

The estimated coefficient of transmissibility for the aquifer ranges from 2,400 gpd per foot to 11,400 gpd per foot. The higher transmissibility was at the public supply well at Buffalo where the aquifer had an aggregate thickness of 57 feet (Klausing, 1966, p. 139). No estimates of the average transmissiblity of the aquifer can be made because so few data are available.

Wenzel and Sand (1942, p. 44) estimated that the coefficient of storage of the Dakota Sandstone in the Ellendale-Jamestown area was 1.1 x 10^{-3}.

Recharge, discharge, and movement.—The aquifer is overlain by thick and relatively impermeable shale of Cretaceous age and by glacial till. Because the water in the aquifer in many parts of the county is under sufficient pressure to flow from wells, the places where water enters the aquifer must be at a higher altitude; therefore, the recharge area is outside the county. It is also possible that the aquifer receives some recharge by upward movement of water from rocks underlying the Dakota.

Water is discharged from the aquifer by upward and lateral leakage into adjacent deposits. Probably the greatest amount of natural discharge occurs near the eastern limit of the aquifer where the overlying deposits are thin. The rate of natural discharge has undoubtedly decreased over the years owing to the large number of flowing wells that have been developed in the aquifer since the late 1800's.

As of 1963 there were at least 326 flowing wells in the county. Most of these wells are allowed to flow continuously. However, because the flow from most wells is reduced by use of a small-diameter discharge pipe, relatively few wells were flowing at their maximum capacity when visited. It was not possible to measure the maximum flow or pressure on most of the wells. However, the reduced discharge was measured at 246 wells. These ranged from less than one-fourth to 45 gpm and averaged 3.4 gpm. Assuming that this is a general average for all 326 wells, the average annual overflow discharge would amount to 582 million gallons. Most of the flowing wells serve as a source of supply for rural domestic and stock needs. The amount of water required to meet these needs is unkown, but is probably on the order of several million gallons a year. Thus, the annual discharge of water from the aquifer through wells is in excess of 582 million gallons.

The piezometric surface slopes from west to east, but the data are inadequate to determine the hydraulic gradient.

Artesian pressure.—Artesian pressure in the Dakota aquifer and well yields began to decline soon after the first wells were drilled and have declined ever since. Willard (1909, p. 10) reported that a well drilled to a depth of 743 feet in the village of Buffalo flowed at the rate of 55 gpm and had an artesian pressure of 50 psi (pounds per square inch). Because 1 psi is the equivalent of 2.3 feet of head, the water in this well would have risen in a pipe to a height of 115 feet above land surface and the piezometric surface would have had an altitude of 1,322 feet. The water level in the public supply well at Buffalo, which was drilled in June 1965 to a depth of 790 feet, was reported to be 49 feet below land surface, or 1,158 feet above sea level. Thus, the altitude of the piezometric surface in the vicinity of Buffalo declined 164 feet in the 56-year interval since 1909.

Quality of water.—Water from the Dakota Sandstone is highly mineralized, but is used extensively in some areas because adequate supplies of more suitable water are not available.

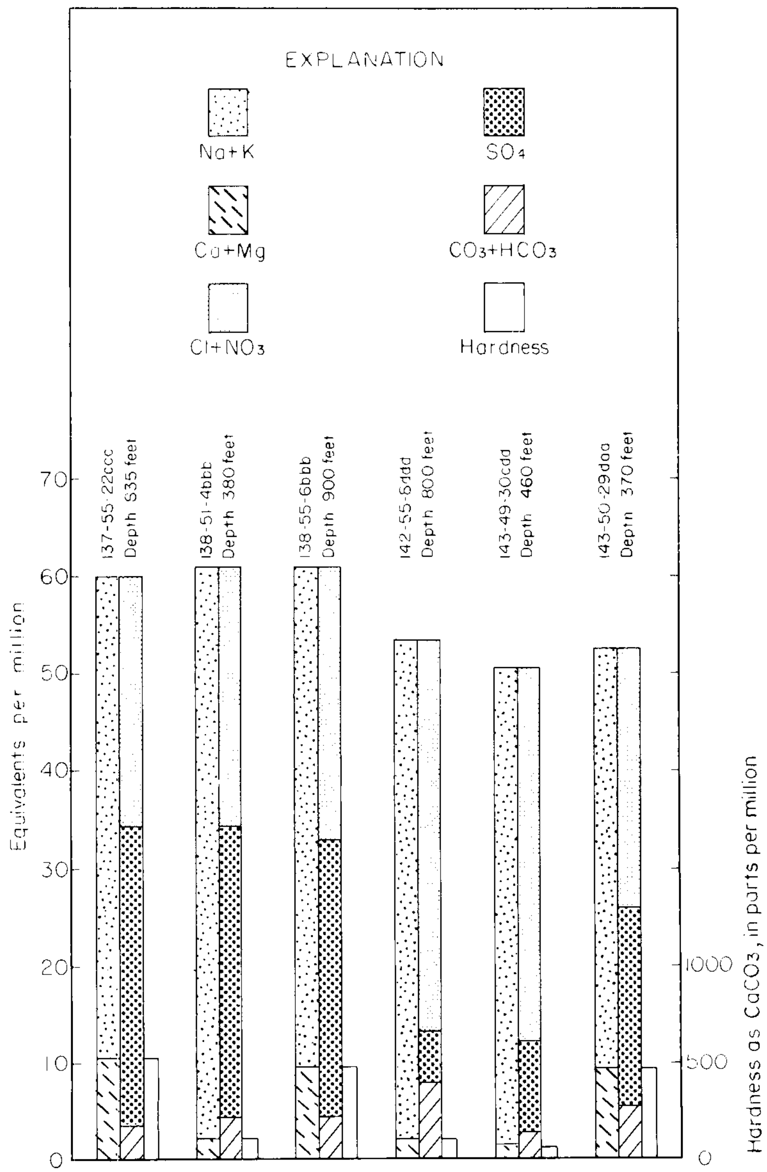


FIGURE 24. Major constituents in and hardness of water from Dakota Sandstone.

The dissolved solids content of 14 water samples from the Dakota ranged from 2,680 to 4,060 ppm. Most of the water is a sodium sulfate type; however, some of the water is a sodium chloride type. The sulfate type water is hard and the sodium chloride type may be either hard or soft.

The average concentrations of boron, fluoride, and silica in water from the Dakota are, respectively, 3.3, 2.9 and 8.2 ppm.

Concentrations of the major constituents in equivalents per million and hardness of water in parts per million from the Dakota Sandstone are shown on figure 24.

Utilization and potential for additional development.—Prior to June 1965, water from the Dakota Sandstone was used only for rural domestic and stock purposes. In June 1965, a public supply well was developed in the aquifer for the village of Buffalo because no other reliable sources of water could be found.

Because water from the Dakota is highly mineralized, it is unsuitable for irrigation and manufacturing purposes. Although the artesian head has decreased greatly over the past 80 years, flowing wells or wells in which the water rises nearly to the land surface can still be developed in the aquifer. The yield of wells tapping the Dakota Sandstone may be expected to range from a few gallons per minute, by natural flow, to as much as 100 gpm, if pumped.

SUMMARY

The surficial deposits in the area consist chiefly of glacial drift that ranges in thickness from 80 to about 470 feet. In the western and central parts of the area, the drift overlies sedimentary rocks of Cretaceous age, but in the southeastern part it rests on Precambrian crystalline rocks.

The important sources of ground water in the county are the sand and gravel deposits in the glacial drift and sand and (or) sandstone beds in the Dakota Sandstone.

Six major aquifers were recognized in the drift. They are the Fargo, West Fargo, Page, Tower City, Bantel, and Sheyenne Delta aquifers. All are artesian aquifers except the Tower City and Sheyenne Delta, which are water-table aquifers. The Page aquifer, with an areal extent of about 155 square miles, is the largest.

The West Fargo aquifer, which underlies about 110 square miles in southeastern Cass County, is the most permeable and productive aquifer in the county. It also is the most heavily pumped aquifer, and water-levels have declined seriously in the West Fargo and surrounding areas. Records show that at the end of 1965, the water level had declined as much as 85 feet since 1938, when the records were started. At the end of 1965, the water level in observation well 139-49-6adb had reached a maxiimum

depth of 110 feet below land surface and was only a few feet above the top of the aquifer. Regional observation-well measurements show that during 1965 water levels in the West Fargo aquifer declined more than 2.5 feet at West Fargo and more than 0.5 foot in areas 20 miles away. Water levels will continue to decline as long as withdrawals exceed recharge.

The quality of the ground water from the major drift aquifers differs considerably from place to place. Generally the water is suitable for domestic and stock use, and some of the water is suitable for irrigation. The dissolved-solids concentration of water from the seven aquifers ranges from about 380 ppm to about 1,560 ppm. The water is hard to very hard and generally contains iron in excess of 0.3 ppm. Water from the Fargo and West Fargo aquifers consists of three types—sodium bicarbonate, sodium chloride, and sodium sulfate. Water from the Page, Tower City, Bantel, and Sheyenne Delta aquifers is of the calcium bicarbonate or calcium sulfate type.

Numerous small aquifers occur in undifferentiated sand and gravel deposits, which generally are only a few feet thick but may be as much as 100 feet thick in a few places. These deposits are distributed randomly throughout the drift and are the chief source of water for many farm wells.

The dissolved-solids concentration of water from the undifferentiated sand and gravel deposits ranges from about 180 ppm to 12,400 ppm; however, most of the water has dissolved-solids concentrations ranging from about 400 to 3,200 ppm. The water types in order of abundance are sodium bicarbonate, sodium sulfate, sodium chloride, calcium sulfate, and calcium bicarbonate.

The Dakota Sandstone of Cretaceous age is the only bedrock unit in the county that is known to yield water to wells. The Dakota consists of interbedded shale, silt, loose sand, and sandstone. Maximum known thickness is about 160 feet. The water-bearing sands in the Dakota have a maximum thickness of about 50 feet.

Water from the Dakota Sandstone is highly mineralized and is unsuitable for most uses except stock watering. The water has dissolved-solids concentrations ranging from about 2,600 ppm to about 4,000 ppm. Chloride and sulfate content generally range from 900 to about 1,500 ppm. The predominant water type is sodium sulfate.

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APPENDIX

137-49-17daa1
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	1	1
	Clay, yellow	24	25
	Clay, blue	17	42
	Shale (clay), soft, sticky, blue	39	81
Till and associated glacioaqueous deposits:			
	Sand and boulders, gray	3	84
	Sand, dirty, gray	4	88
	Sand, fine, gray	14	102

137-49-21bba
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	3	3
	Clay, soft, yellow	20	23
	Shale, soft, blue	46	69
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue	2	71
	Sand	15	86

137-49-28cdd
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	2	2
	Clay, yellow	26	28
	Shale, soft, sticky, blue	39	67
Till and associated glacioaqueous deposits:			
	Clay, sandy, boulders, blue	8	75
	Clay, sandy, hard, blue	23	98
	Shale (clay), blue	23	121
	Clay, sandy, blue	6	127
	Sand, fine, gray	14	141
	Clay, soft, blue	3	144
	Sand, fine, gray	5	149
	Clay, soft, sandy, blue	25	174
	Sand, gray	18	192

Note: Parenthetical remarks are authors interpretation.

137-49-32ddd
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	2	2
	Clay, yellow	21	23
	Shale, blue	37	60
Till and associated glacioaqueous deposits:			
	Sandy clay, blue	17	77
	Sand, colored	9	86
	Clay, blue	3	89

137-50-2dac
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	2	2
	Clay, yellow	31	33
	Shale (clay), blue	34	67
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue	5	72
	Clay, sandy, boulders, hard, blue	21	93
	Clay, sandy, hard, blue	29	122
	Boulder, red	1	123
	Clay, sandy, hard, blue; sand lenses	25	148
	Clay, sandy, soft	14	162
	Sand	15	177

137-51-34ccc
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	2	2
	Clay, sandy, gray	38	40
	Shale (clay), soft, gray	82	122
Till and associated glacioaqueous deposits:			
	Clay, sandy, hard, gray	24	146
	Clay, sandy, soft gray; sand lenses	66	202
	Sand, white	3	205

138-50-1bdc
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	2	2
	Shale (clay), yellow	14	16
	Shale (clay), blue	46	62
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue	7	69
	Sand, gray	18	87
	Clay, sandy, blue	2	89

138-50-34ccc
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	1	1
	Clay, yellow	6	7
	Shale (clay), tan	22	29
	Shale (clay), soft, sticky, blue	41	70
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue	9	79
	Clay, sandy, boulders, hard, blue	4	83
	Sand, brown	1	84
	Clay, hard, blue	30	114
	Sand, fine, brown	3	117
	Clay, blue	½	117½
	Sand, brown	14	131½

139-49-2ccc
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	1	1
	Clay, brown	15	16
	Shale (clay), soft, blue	78	94
Till and associated glacioaqueous deposits:			
	Clay, sandy, boulders, hard, blue	14	108
	Sand, blue	½	108½
	Clay, sandy, hard, blue	22½	131
	Clay, sandy, hard, blue; sand lenses	21	152
	Clay, sandy, soft, blue; sand lenses	137	289
	Clay, sandy, hard, gray	13	302
	Shale (clay), blue	17	340
	Sandstone(?), white	17	357

139-49-3cdd2
(Log furnished by Frederickson's Inc)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	3	3
	Clay, yellow	11	14
	Sand, fine, brown	4½	18½
	Shale (clay), soft, blue	57½	76

139-49-3cdd2--Continued
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue------------------	15	91
	Sand, dirty, gray and white-------	3	94
	Clay, sandy, blue------------------	62	156
	Clay, sandy, hard, blue-----------	5	161
	Clay, sandy, soft, blue; sand lenses-------------------------	22	183
	Sand, dirty, gray------------------	1½	184½
	Clay, sandy, soft, blue; sand lenses-------------------------	5½	190
	Clay, sandy------------------------	12	202
	Sand, gray-------------------------	1	203
	Clay, sandy, blue------------------	6	209
	Sand, gray-------------------------	6	215
	Shale (clay), blue-----------------	7	222
	Sand, gray-------------------------	3	225
	Clay, soft, blue; sand lenses-----	33	258
	Clay, hard, gray-------------------	2	260
	Clay, soft, gray-------------------	19	279
	Sand, blue-------------------------	2	281
Granite:			
	Decomposed granite; white, green, black, and red------------------	77	358

139-49-7ddc
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black---------------------	1	1
	Clay, yellow-----------------------	22	23
	Shale (clay), blue-----------------	43	66
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue------------------	14	80
	Boulder----------------------------	1	81
	Clay, sandy, blue------------------	26	107
	Sand, dirty------------------------	8	115
	Clay, blue-------------------------	3	118
	Sand, gray-------------------------	3	121
	Clay, sandy, blue------------------	18	139
	Sand, fine, dirty, gray-----------	4	143
	Clay, sandy, soft, blue-----------	37	180
	Sand, fine, gray-------------------	13	193
	Clay, gray; sand lenses-----------	6	199
	Shale (clay), brown----------------	24	223
	Clay, sandy, green-----------------	14	237

139-49-9aab
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	2	2
	Clay, brown	10	12
	Sand, fine, brown	8	20
	Shale (clay), blue	50	70
Till and associated glacioaqueous deposits:			
	Clay, sandy, hard, blue	12	82
	Clay, sandy, soft, blue	23	105
	Clay, sandy, blue; sand lenses	7	112
	Clay, sandy, soft, blue	18	130
	Clay, sandy, hard, blue	13	143
	Boulder	1	144
	Clay, sandy, hard, blue	2	146
	Sand, brown	7	153

139-49-9ccb
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	3	3
	Shale (clay), yellow	16	19
	Shale (clay), gray	49	68
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue	19	87
	Clay, sandy, blue; sand lenses	20	107
	Sand, gray	2	109
	Clay, sandy, soft, blue	21	130
	Clay, sandy, hard, blue	22	152
	Sand, gray	6	158
	Clay, blue; sand lenses	22	180
	Sand, gray	2	182
	Clay, blue; sand lenses	4	186
	Sand, gray	4½	190½
	Clay, sandy, hard, blue	17½	208
	Clay, sandy, soft, blue	14	222
	Clay, blue; sand lenses	8	230
Granite:			
	Decomposed granite; red and green	121	351

139-49-11aaa
(Log furnished by Great Northern Railway)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Fill	3	3
	Clay	13	16
	Sand	1	17
	Clay	52	69
Till and associated glacioaqueous deposits:			
	Till(?)	27	86
	Sand and gravel	15	101
	Clay, sandy	7	108
	Sand and gravel	58	166
	Shale (clay), sandy	2	168

139-49-11cdc2
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	2	2
	Clay, yellow	12	14
	Shale (clay), soft, blue	14	28
	Sand, fine, blue	10	38
	Shale (clay), soft, blue	49	87
Till and associated glacioaqueous deposits:			
	Clay, sandy, soft, blue	5	92
	Clay, sandy, hard, blue	25	117
	Sand, coarse	1	118
	Clay, sandy, hard, blue	2	120
	Sand, brown	2	122
	Clay, sandy, hard, blue	136	258
	Clay, sandy, soft, blue	39	297
	Sandstone(?), white	10	307
	Shale(?), blue	3	310
	Sandstone(?), white	6	316
	Shale(?)	2	318

139-49-15cdc
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Fill, variegated	4	4
	Clay, yellow	14	18
	Clay, blue	62	80
Till and associated glacioaqueous deposits:			
	Clay, sandy, boulders, blue; sand lenses	19	99
	Clay, sandy, gray	8	107
	Sand, gray	3	110
	Sand, gray; clay lenses	8	118
	Clay, sandy, hard, gray	25	143
	Shale (clay), gray	45	188
	Shale (clay), gray, sand lenses	21	209
Graneros(?) Shale:			
	Shale, black	30	239
Granite:			
	Decomposed granite, white and green	42	281

139-49-29bcd
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil	2	2
	Clay, yellow	16	18
	Shale (clay), blue	60	78
Till and associated glacioaqueous deposits:			
	Clay, blue	114	192
	Clay, blue; sand lenses	15	207
	Clay, blue	13	220
	Sand, coarse	16	236
	Clay, blue	2	238

139-49-32cca
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	5	5
	Silt, brown	7	12
	Sand, fine	12	24
	Shale (clay), gray	46	70
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue; sand lenses	20	90
	Sand, dirty	2	92
	Clay, sandy, blue; sand lenses	2	94
	Sand	3	97
	Clay, hard, blue	48	145
	Clay, sandy	3	148
	Sand, fine	3	151
	Clay	1	152
	Sand, fine	31	183

139-50-2aaa
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	1	1
	Clay, yellow	8	9
	Sand, fine, brown	7	16
	Shale (clay), blue	53	69
Till and associated glacioaqueous deposits:			
	Clay, blue; boulders	17	86
	Sand, brown	2½	88½
	Clay, hard, blue	17½	106
	Gravel, sandy, brown	1	107
	Clay, hard, blue; boulders	3	110
	Sand, brown	1	111
	Clay, hard, blue; boulders	100	211
	Clay, soft, gray	19	230
	Clay, sandy, soft, gray	8	238
	Sand, gray	8	246

139-50-10dac
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	1	1
	Clay, yellow	6	7
	Sand, brown	5	12
	Clay, sandy, blue	4	16
	Sand, blue	8	24
	Shale (clay), blue	41	65
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue	20	85
	Sand, blue	14½	99½
	Clay, sandy, blue	28½	128
	Sand, blue	2	130
	Clay, sandy	74	204
	Sand, gray	4	208
	Clay, blue	1	209
	Sand, gray	4	213
	Clay, sandy	22	235
	Sand, gray	5	240
Granite:			
	Decomposed granite; clay, sandy, variegated		

140-49-7dca1
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	2	2
	Clay, tan	25	27
	Shale, soft, blue	43	70
Till and associated glacioaqueous deposits:			
	Clay, sandy, soft, blue	16	86
	Boulder	1	87
	Clay, sandy, hard, blue	16	103
	Clay, silty, hard, gray	8	111
	Clay, sandy	3	114
	Sand, dirty; lenses of clay	17	131
	Sand	20	151
	Sand, fine, gray	12	163

140-49-8bbd
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	4	4
	Clay, yellow	22	26
	Shale (clay), blue	50	76
Till and associated glacioaqueous deposits:			
	Clay, sandy, hard, blue	17	93
	Sand, dirty, gray	6	99
	Sand, clean, gray	12	111
	Clay, blue	6	117
	Sand, gray	14	131

140-49-19baa
(Log furnished by Frederickson's Inc.)

Lake Agassiz deposits:			
	Topsoil, black	2	2
	Clay, yellow	22	24
	Shale (clay), blue	48	72
Till and associated glacioaqueous deposits:			
	Clay, sandy, hard, blue	23	95
	Sand, gray; dry	11	106
	Clay, hard, blue	22	128
	Sand, gray	3	131
	Clay, soft, blue; sand lenses	13	144
	Sand, gray	35	179
	Sand, dirty, gray	4	183

140-49-19ccc
(Log furnished by Frederickson's Inc.)

Lake Agassiz deposits:			
	Topsoil, black	3	3
	Clay, yellow	13	16
	Shale (clay), blue	56	72
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue	20	92
	Sand, dirty, blue	14	106
	Sand, blue	5	111
	Clay, sandy	4	115
	Sand, dirty, blue	8	123
	Clay	5	128

140-49-19ccc--Continued
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Till and associated glacioaqueous deposits--Continued:			
	Sand, fine, blue	2	130
	Clay, blue	3	133
	Clay, sandy, blue	30	163
	Sand, blue	5	168
	Sand, gravelly	9	177

140-49-34ccd
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	1	1
	Shale (clay), brown	10	11
	Sand, fine, brown	13	24
	Shale (clay), blue	61	85
Till and associated glacioaqueous deposits:			
	Clay, sandy, soft, blue	7	92
	Clay, sandy, hard, blue	53	145
	Clay, sandy, soft, blue	25	170
	Clay, hard	32	202
Granite:			
	Decomposed granite, white and green	46	248

140-49-35ddd
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	1	1
	Shale (clay), soft, yellow	17	18
	Shale (clay), soft, blue	14	32
	Sand, fine, dirty, gray	7	39
	Sand, fine, gray	20	59
	Shale (clay), blue	12	71
	Shale (clay), soft, blue	23	94
Till and associated glacioaqueous deposits:			
	Clay, sandy, hard, blue	8	102
	Clay, sandy, hard, blue; gravel lenses	15	117
	Sand, fine, gray	2	119

140-49-35ddd--Continued
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Till and associated glacioaqueous deposits--Continued:			
	Clay, sandy, blue; lenses of sand-	12	131
	Clay, sandy, hard, blue-----------	9	140
	Sand------------------------------	49	189
Granite:			
	Shale, hard, white----------------	2	191

140-50-21cbb
(Log furnished by Frederickson's Inc.)

Lake Agassiz deposits:			
	Topsoil, black--------------------	2	2
	Clay, yellow----------------------	21	23
	Shale (clay), blue----------------	32	55
Till and associated glacioaqueous deposits:			
	Clay, sandy, soft, blue-----------	6	61
	Clay, sandy, boulders, hard, blue-	12	73
	Clay, sandy, hard-----------------	8	81
	Sand, dirty, brown----------------	2	83
	Clay, sandy, hard, blue-----------	49	132
	Sand, fine, gray------------------	32	164
	Sand, fine, dirty, gray-----------	11	175
	Shale (clay?), blue---------------	1	176

140-50-24add
(Log furnished by Frederickson's Inc.)

Lake Agassiz deposits:			
	Topsoil, black--------------------	3	3
	Shale (clay), soft, yellow--------	29	32
	Shale (clay), soft, blue----------	47	79
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue; sand lenses----	14	93
	Clay, blue------------------------	27	120
	Sand, fine, blue------------------	1	121
	Clay, blue------------------------	2½	123½
	Sand, fine, blue------------------	23½	147
	Shale (clay), hard, blue----------	26½	173½
	Sand, fine, dirty, blue-----------	3½	177

140-50-24add--Continued
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Till and associated glacioaqueous deposits--Continued:			
	Shale (clay), sandy, blue---------	3	180
	Sand, fine, dirty, blue-----------	7	187
	Sand, fine, clean, blue-----------	3	190
	Shale (clay), blue; sand lenses---	29	219
	Shale (clay), sandy, blue---------	6	225
	Shale (clay), blue; sand lenses---	27	252

140-50-26cdc
(Log furnished by Frederickson's Inc.)

Lake Agassiz deposits:			
	Topsoil---------------------------	2	2
	Clay, yellow----------------------	21	23
	Clay, blue------------------------	45	68
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue-----------------	41	109
	Sand, blue------------------------	1	110
	Clay, sandy, hard, blue-----------	31	141
	Sand, blue------------------------	18	159

141-49-28aca
(Log furnished by Frederickson's Inc.)

Lake Agassiz deposits:			
	Topsoil, black--------------------	1	1
	Clay, yellow----------------------	20	21
	Shale (clay), blue----------------	58	79
	Clay, blue------------------------	13	92
	Sand------------------------------	2	94
Till and associated glacioaqueous deposits:			
	Clay, sandy, hard, blue-----------	35	129
	Clay, soft, blue------------------	29	158
	Clay, sandy, soft, blue; sand lenses-------------------------	15	173
	Sand, dirty, gray-----------------	10	183
	Sand, clean-----------------------	10	193

141-49-28bdb
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	2	2
	Clay, sandy, brown	21	23
	Shale (clay), blue	58	81
Till and associated glacioaqueous deposits:			
	Clay, sandy, hard, blue	9	90
	Boulder	1	91
	Clay, sandy, hard, blue	24	115
	Clay, sandy, soft, blue; sand lenses	7	122
	Sand, dirty, brown	3	125
	Clay, sandy, hard, blue; sand lenses	12	137
	Boulder	1	138
	Clay, sandy, hard, blue	42	180
	Clay, silty, soft, gray	14	194
	Sand	12	206
	Clay, gray	1	207

141-49-33cab
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	3	3
	Clay, yellow	25	28
	Shale (clay), soft, blue	51	79
Till and associated glacioaqueous deposits:			
	Clay, sandy, blue	12	91
	Boulder	1	92
	Clay, sandy, blue	43	135
	Clay, gray; sand lenses	33	168
	Sand, white	17	185

141-49-33daa
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Lake Agassiz deposits:			
	Topsoil, black	2	2
	Clay, yellow	16	18
	Shale (clay), blue	62	80
Till and associated glacioaqueous deposits:			
	Clay, sandy, hard, blue	15	95
	Clay, sandy, soft, blue	11	106
	Sand, gray	10	116
	Boulder		

141-53-6dcd
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Till and associated glacioaqueous deposits:			
	Topsoil, black	1	1
	Clay, sandy, yellow	25	26
	Clay, sandy, blue	35	61
	Clay, sandy, white; sand lenses	24	85
	Sand, fine, gray	25	110

141-54-14baa
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Till and associated glacioaqueous deposits:			
	Topsoil, black	1	1
	Clay, sandy, yellow	25	26
	Clay, sandy, blue	11	37
	Clay, blue	25	62
	Clay, hard, blue	40	102
	Clay, soft, blue	7	109
	Clay, hard, blue	4	113
	Clay, soft, blue	6	119
	Clay, hard, blue	8	127
	Sand, fine, gray	9	136
	Clay, soft, blue	1½	137½

141-54-14ccc
(Log furnished by Frederickson's Inc.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Till and associated glacioaqueous deposits:			
	Topsoil	2	2
	Clay, sandy, soft, brown	3	5
	Sand, brown	2	7
	Clay, sandy, soft, brown	3	10
	Clay, sandy, hard, brown	17	27
	Clay, sandy, hard, blue	93	120
	Clay, silty, soft, blue	26	146
	Sand, gray	18	164

141-54-21ddc2
(Log furnished by Lako Drilling Co.)

Till and associated glacioaqueous deposits:			
	Topsoil	2	2
	Clay, yellow	16	18
	Clay, sandy, yellow	7	25
	Clay, blue	35	60
	Clay, sandy, blue	20	80
	Clay, blue; sand lenses	10	90
	Sand, gray	40	130
	Clay, blue	45	175

142-54-14bac
(Log furnished by Lako Drilling Co.)

Till and associated glacioaqueous deposits:			
	Topsoil, black	2	2
	Clay, yellow	13	15
	Clay, gravelly, yellow	25	40
	Clay, sandy, yellow	10	50
	Clay, blue	18	68
	Sand, blue	27	95
	Clay, sandy, blue	5	100
	Clay, blue	46	146
	Sand, gray	29	175

143-54-31bdd
(Log furnished by McCarthy Well Co.)

Geologic source	Material	Thickness (feet)	Depth (feet)
Till and associated glacioaqueous deposits:			
	Clay, sandy; sand lenses----------	81	81
	Sand, gray------------------------	40	121