COUNTY GROUND - WATER STUDIES 17 – PART III

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GROUND–WATER RESOURCES

NELSON and WALSH COUNTIES, NORTH DAKOTA

by

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U. S. Geological Survey

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

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ABSTRACT

Nelson and Walsh Counties are underlain by bedrock of Ordovician, Jurassic, and Cretaceous age. The Fall River and Lakota Formations (Dakota aquifer) and the Pierre Formation of Cretaceous age contain the principal bedrock aquifers. The Dakota aquifer, which consists of sandstone, may yield more than 500 gallons per minute at selected locations. The Pierre aquifer, which consists of fractured shale, yields from 1 to 5 gallons per minute. Water from both aquifers is of poor quality, but usable. The Jurassic and Ordovician aquifers yield a sodium chloride type water that is very saline. Yields greater than 500 gallons per minute may be locally available from the Ordovician aquifers.

The Spiritwood, McVille, and Fordville glacial-drift aquifers are capable of yielding more than 500 gallons per minute of fair to good quality water. Several smaller drift aquifers--the Edinburg, Medford, and beach deposits--supply water of good to poor quality.

The eastern part of Walsh County is the discharge area for a deep regional ground-water flow system that originates in the topographically high parts of Cavalier, Nelson, and Walsh Counties and areas to the west. Water moving in this flow system becomes more saline and becomes a sodium chloride type as it moves to the discharge area. Saline lakes occur in eastern Walsh County as the result of natural artesian discharge from the deep ground-water flow system.

Six communities in the project area use ground-water supplies, and rural water districts are presently being formed that will use ground-water supplies to provide good quality water to many farms and smaller municipalities. The Spiritwood, McVille, and Fordville aquifers are capable of supplying the water needs of these districts and could also provide water for irrigation.

INTRODUCTION

Purpose and Scope

The investigation of the ground-water resources of Nelson and Walsh Counties (fig. 1), which began in July 1967, is part of a statewide

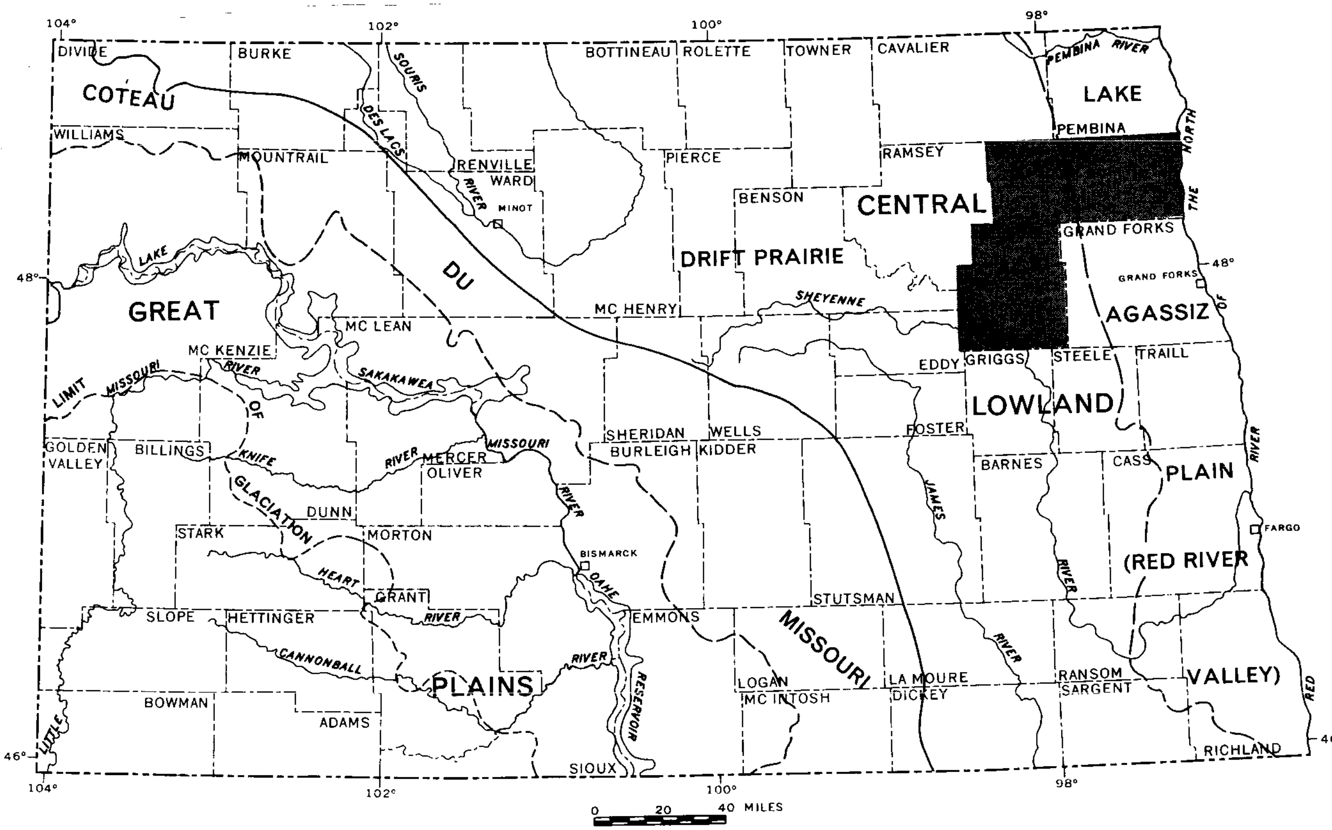


FIGURE 1. Physiographic divisions in North Dakota and location of report area.

program to determine the location and extent of the major ground-water reservoirs (aquifers); to evaluate the occurrence and movement of ground water within the aquifers, including the sources of recharge and discharge; to determine the chemical quality of the ground water; and to determine the amount of water available from storage in the various aquifers. The study has been made cooperatively by the U.S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, the Nelson County Water Management District, and Walsh County Board of Commissioners.

Many sources of data have been utilized in the preparation of this report. A well inventory has provided data on depth, construction, and productivity of the private and public wells in the counties. Test drilling, both private and public, has supplied information on the thickness and extent of the major aquifers. Chemical analyses of water samples from selected wells have furnished data on the quality of ground water. The basic data collected during this study have been published as Part II of the Nelson and Walsh Counties ground-water study (Downey, 1971b). The geology of both counties has been studied by John Bluemle of the North Dakota Geological Survey and is reported as Part I of the series. This report, Part III, is based largely on interpretation of the basic data contained in Parts I and II.

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

Previous Investigations

The earliest report of ground-water data from Nelson and Walsh Counties was by Underhill (1890), who discussed the deep well at Grafton and shallow wells in the Red River Valley in a report to Congress. Upham (1895, p. 574-575) reported on ground water in Walsh County as a part of a study of glacial Lake Agassiz. Upham also described selected geological features in Nelson County in the same report. Simpson (1929) described the ground-water conditions in Walsh County (p. 244-250) and Nelson County (p. 177-181) as part of a statewide survey. Abbott and Voedisch (1938) listed chemical data from selected wells in both counties, and Brookhart and Powell (1961) reported on the geology and occurrence of ground water in the Minto-Forest River region of Walsh County. Jensen and Bradley (1962) reported on the occurrence of ground water in the Hoople area of Walsh County. In Nelson County, Dennis (1947) reported on the occurrence of ground water in the Aneta area; Aronow, Dennis, and Akin (1953) on the geology and occurrence of ground water in the

Michigan area; and Powell and Jones (1962) on the occurrence of ground water in the Lakota area. Selected data from these older reports have been incorporated into this publication.

Acknowledgments

The author expresses his appreciation to members of the Nelson County Water Management District, the Walsh County Board of Commissioners, city officials of Grafton, Lakota, Michigan, McVille, and Tolna, and to the many residents of both counties who contributed time and effort towards the completion of this study. Particular recognition is due M. O. Lindvig, C. E. Naplin, and R. W. Schmid of the North Dakota State Water Commission who were largely responsible for the test drilling and the aquifer-test data.

Well-Numbering System

The numbering of wells, test holes, and other data points in this report is based upon a public lands survey system of the U.S. Bureau of Land Management. The first numeral of the numbering system denotes the township north of a base line, the second numeral denotes the range west of the fifth principal meridian, and the third numeral denotes the section in which the well is located (fig. 2). The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). For example, well 150-60-15DAA is in the NE¼NE¼SE¼ sec. 15, T. 150 N., R. 60 W. Consecutive terminal numerals are added if more than one well is recorded within a 10-acre tract. This numbering system is also used for the location of small areas.

Geography

Nelson and Walsh Counties have an area of 2,303 square miles and a 1970 population of 22,027 (U.S. Bureau of the Census, 1970). The economy of both counties is based upon agriculture–potatoes, sugar beets, and small grains are the main crops.

Both counties are located within the drainage system of the Red River of the North, which is a part of the larger Hudson Bay system. The major tributaries of the Red River that cross the area are the Sheyenne River in Nelson County and the Forest and Park Rivers in Walsh County. The Red River forms the eastern boundary of Walsh County.

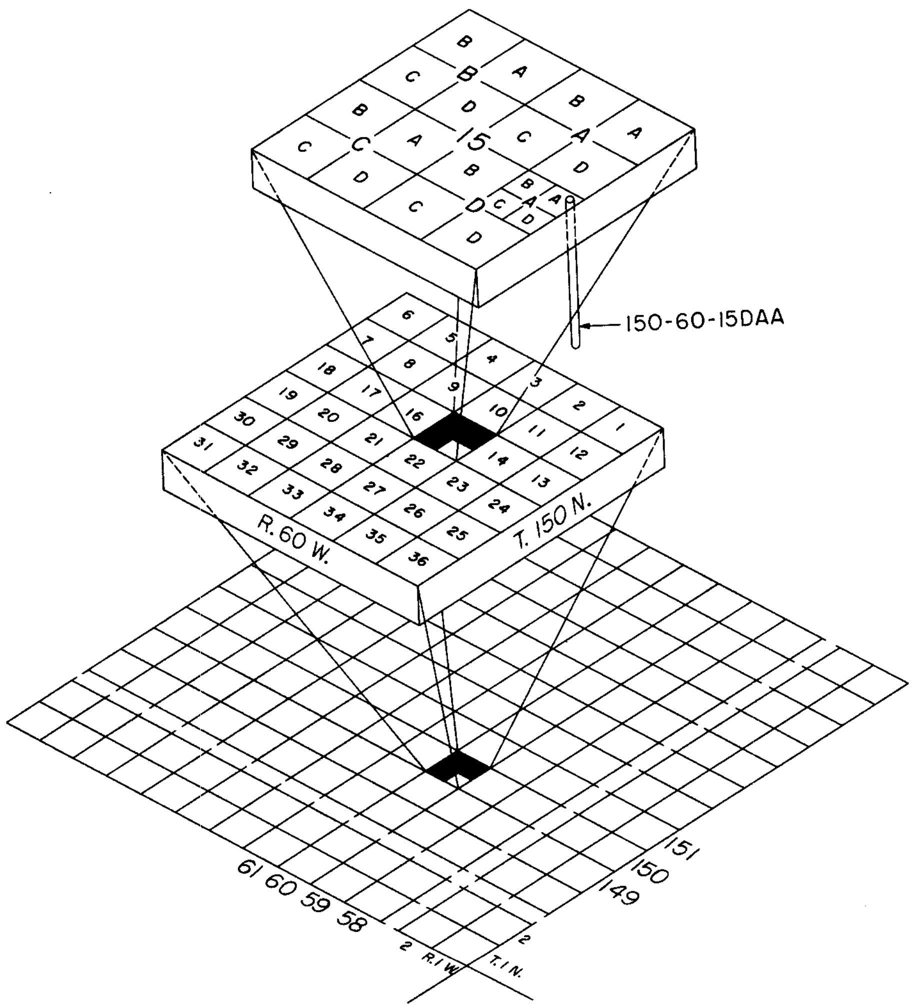


FIGURE 2. Well-numbering system.

The topography is quite varied. Broad, nearly flat plains formed by glacial Lake Agassiz characterize the eastern two-thirds of Walsh County; whereas, rolling prairie (Drift Prairie) dotted with numerous sloughs or prairie potholes characterizes the western part of Walsh County and all of Nelson County. In the central part of Walsh County, long, narrow, northwest-trending beach ridges rise 5 to 10 feet above the surrounding lake plain. Associated with the beach ridges is a glacial moraine, the Edinburg, which rises about 200 feet above the lake plain and trends northwest.

Maximum topographic relief in the report area is nearly 900 feet. The highest altitude is about 1,665 feet above mean sea level at Blue Mountain (sec. 8, T. 151 N., R. 61 W.) in western Nelson County, and the lowest is about 765 feet where the Red River leaves Walsh County at the northeastern corner. Local relief rarely exceeds 100 feet per mile, and in parts of the Lake Agassiz basin it is less than 5 feet per mile.

Nelson and Walsh Counties have a continental climate characterized by cold and rather snowy winters and warm summer days with cool nights. Major weather systems crossing the area bring a variety of weather in all seasons. According to the National Weather Service (1970), the mean annual temperature at Grafton is 4.3°C (Celsius) (39.8°F (Fahrenheit)). Maximum temperatures during June, July, and August average about 27°C (81°F). Temperatures during the winter months average about -13°C (8°F). The mean annual precipitation at Grafton is 19.33 inches. About three-fourths of the precipitation falls as rain during the growing season April through September.

Definition of Selected Terms

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

Artesian well – A well in which the water level stands above an artesian or confined aquifer. A flowing artesian well is a well in which the water level is above the land surface. See confined ground water.

Confining bed – A body of relatively impermeable material adjacent to one or more aquifers. In nature, the hydraulic conductivity of a confining bed may range from near zero to some value distinctly lower than that of the adjacent aquifer. This term replaces aquiclude, aquitard, and aquifuge.

Confined ground water – Water in an aquifer that is bounded by confining beds, and under pressure significantly greater than atmospheric.

Gaining stream – A stream whose flow is being increased by the inflow of ground water from springs and seeps along its course.

Head, static – The height above a standard datum at which the upper surface of a column of water or other liquid can be supported by the static pressure at a given point. The term static head, which is a measure of potential, is sometimes expressed simply as head.

Homogeneous – Identical properties everywhere in space.

Hydraulic conductivity – A term replacing field coefficient of permeability and expressed as feet per day or meters per day. The ease with which a fluid will pass through a porous material. This is determined by the size and shape of the pore spaces in the rock and their degree of interconnection. Hydraulic conductivity may also be expressed as cubic feet per day per square foot, gallons per day per square foot, or cubic meters per day per square meter. Hydraulic conductivity is measured at the prevailing water temperature.

Losing stream – A stream that is losing water to the ground along its course.

Porosity – The ratio of the volume of the voids in a rock to the total volume. The ratio may be expressed as a decimal fraction or as a percentage. The term effective porosity refers to the amount of interconnected pore spaces or voids in a rock or soil and is expressed as a percentage of the total volume occupied by the interconnecting pores.

Potentiometric surface – The surface that represents the static head. It may be defined as the level to which water will rise in tightly cased wells. A water table is a potentiometric surface.

Specific capacity – The rate of discharge of water from a well divided by the drawdown of the water level, normally expressed as gallons per minute per foot of drawdown.

Storage coefficient – The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an artesian aquifer the water derived from storage with decline in head comes mainly from compression of the aquifer and to a less extent from expansion of the water. In an unconfined, or water-table aquifer, the amount of water derived from the aquifer is from gravity drainage of the voids.

Transmissivity – The rate at which water, at the prevailing temperature, is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Transmissivity is normally expressed in units of square feet per day but can be expressed as the number of gallons of water that will move in 1 day under a hydraulic gradient of 1 foot per foot through a vertical strip of aquifer 1 foot wide extending the full saturated height of the aquifer.

Water table – Is a surface in an unconfined aquifer at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the aquifer just far enough to hold standing water.

Zone of saturation – In the saturated zone of an aquifer all voids are ideally filled with water. The water table is the upper limit of this zone. In nature, the saturated zone may depart from the ideal in some respects. A rising water table may trap air in parts of the zone and other natural fluids may occupy voids.

GEOLOGY

The geology of Nelson and Walsh Counties is covered in detail in Part I of this series of reports. However, the following brief discussion of the geology is included here so that the reader may have readily available the basic geologic information necessary to understand the geohydrologic relationships of the various aquifers.

Pre-Pleistocene Rocks

Precambrian crystalline rocks form the basement in both Nelson and Walsh Counties. The upper part of these rocks was generally weathered; however, in many places, the weathered part has been eroded leaving fresh unaltered Precambrian rock in contact with the overlying sedimentary rocks.

The sedimentary rocks, which consist of about 600 to 2,700 feet of mainly shale, sandstone, and limestone, were deposited in a marine environment. The thickest section underlies western Nelson County and the thinnest underlies eastern Walsh County. The rocks include units of Ordovician, Jurassic, and Cretaceous age.

The rocks of Ordovician age include the Winnipeg, Stony Mountain, and Red River Formations, which consist mainly of limestone. Those of Jurassic age are the so-called "red beds," a sequence of shale, siltstone, and sandstone beds that have an overall reddish hue.

The rocks of Cretaceous age include the Lakota Formation, a medium to coarse gray sandstone; Fall River Formation, a fine to coarse quartz sandstone interbedded with siltstone and shale; Skull Creek Formation, a soft gray shale; Newcastle Formation, a silty shaly sandstone; Mowry Formation, a soft flaky gray shale; Belle Fourche Formation, a dark-gray micaceous shale; Greenhorn Formation, a soft dark-gray calcareous shale with thin beds of shaly limestone; Carlile Formation, a light-gray shale; Niobrara Formation, a light-gray to gray calcareous shale; and the Pierre Formation, a dark-gray to black fissile noncalcareous shale that in places has been extensively fractured in the upper part by glacial action.

A summary section of the major units beneath Walsh County is shown on plate 1. The Dakota aquifer is comprised of the Lakota and Fall River Formations.

Pleistocene Deposits

A large part of Nelson and Walsh Counties is mantled by glacial drift. Except along streams where the glacial drift has been removed by erosion, the thickness of the drift ranges from about 1 foot to about 320 feet.

Glacial drift may be subdivided into many types depending upon the system of classification used. In this report the drift is divided into three distinct types; till, outwash, and lake deposits. Till, the most common type, is a nonsorted mixture of clay, silt, sand, gravel, and boulders in various proportions. Till was deposited by active glaciers and its composition is dependent upon the type of the bedrock over which the glacier moved. Percentage composition by grain size of individual till samples from Nelson and Walsh Counties is shown in figure 3. Figure 4 shows the mean distribution by grain size of six samples of till from the study area. Till covers almost all of Nelson County and the western one-half of Walsh County. In the eastern half of Walsh County, the till is covered by lake deposits.

The second type of glacial drift found in the study area is outwash, which includes delta deposits, ice-contact deposits, glacial outwash, and buried sand and gravel deposits. These deposits normally occur as stratified deposits that are sorted according to grain size, were desposited by moving water, and normally are very permeable. They comprise all the major glacial-drift aquifers in Nelson and Walsh Counties. Particle-size analyses of many samples from deposits of outwash were given in tables 6A and 6B of Part II (Downey, 1971b). Particle-size distribution curves of outwash material from the Fordville aquifer are shown in figure 5.

Fragments of many different rock types are found in the various deposits of outwash in Nelson and Walsh Counties. The difference is the result of the glacial ice moving across and eroding many kinds of rock in its passage to the project area. Fragments of these rocks were incorporated into the ice and transported to the point of deposition where they were released by melting. The material was sorted by grain size and was deposited as the velocity of the melt water decreased. This sorting action, caused by the decrease in velocity, resulted in deposits in which the coarser materials are found near the point of melting and the

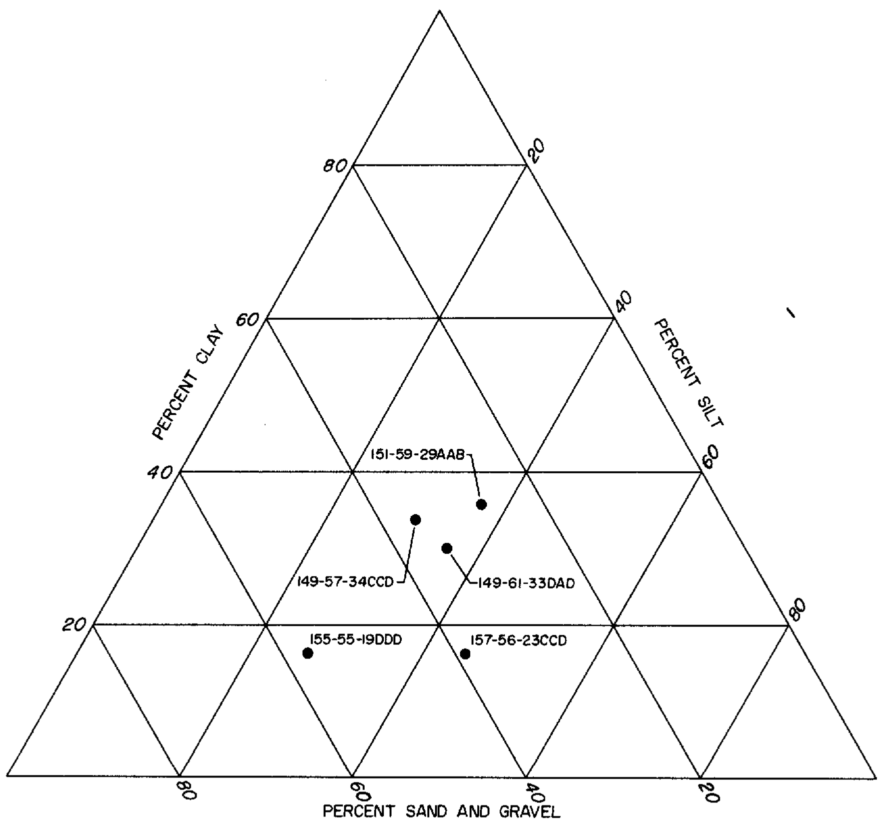


FIGURE 3. Composition by grain size of till samples from Nelson and Walsh Counties.

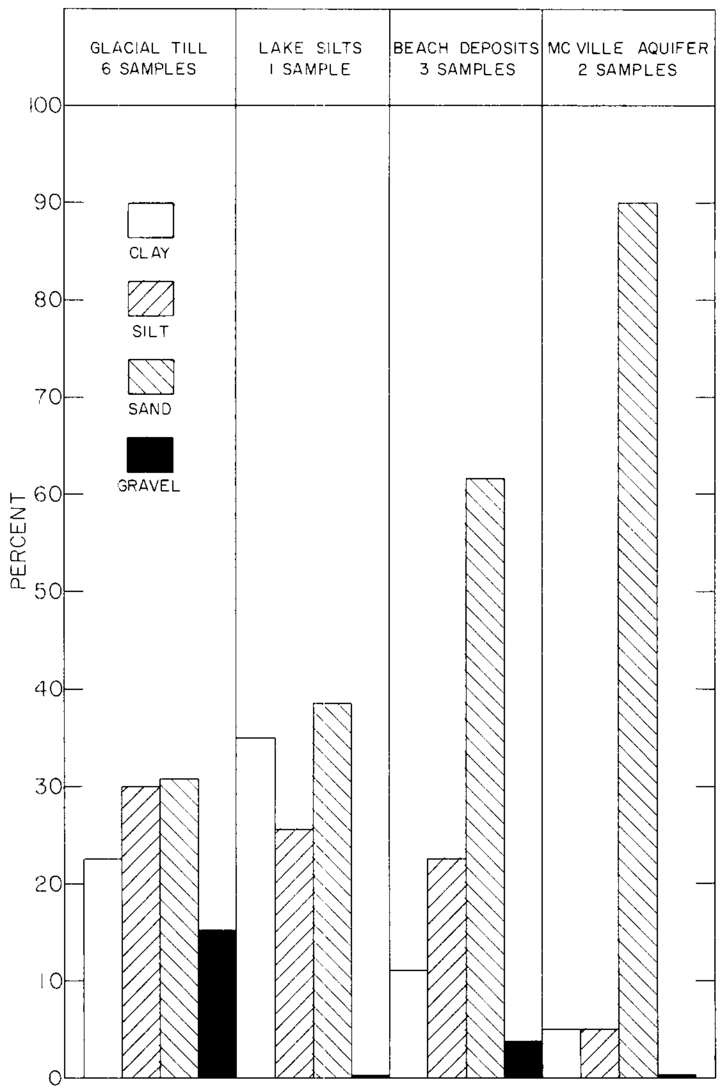


FIGURE 4. Percentage of clay, silt, sand, and gravel contained in samples from various glacial deposits in Nelson and Walsh Counties.

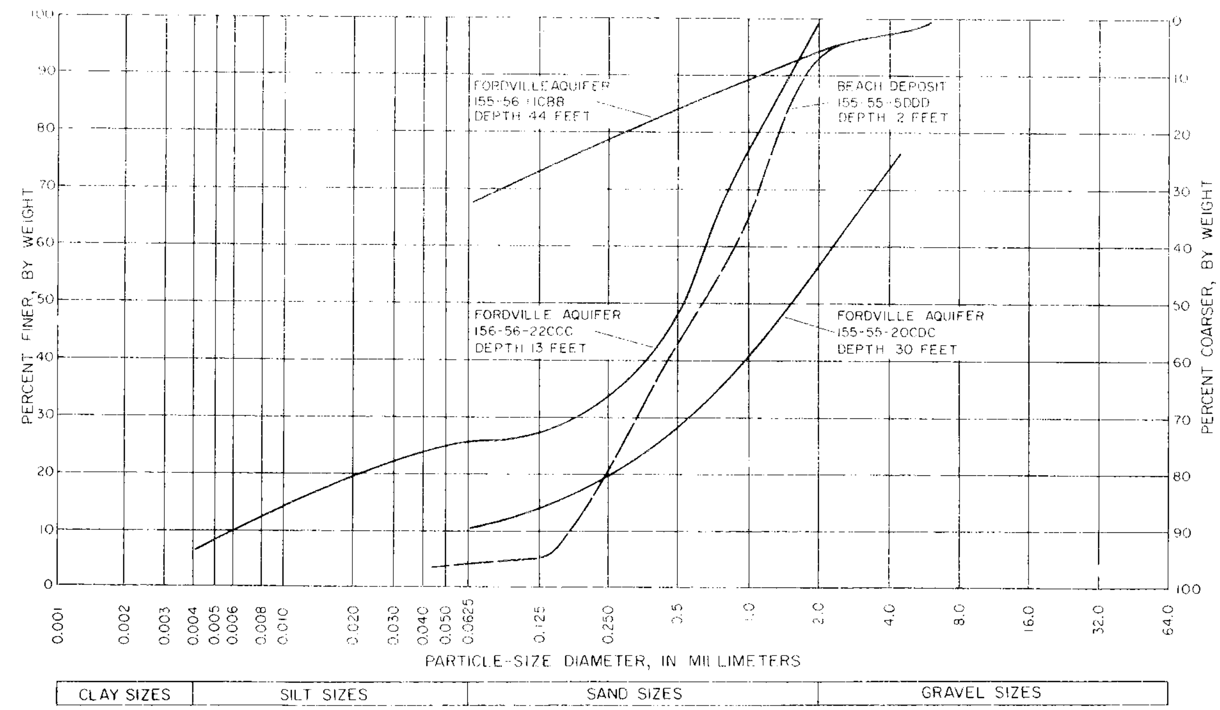


FIGURE 5. Particle-size curves of materials in the Fordville aquifer and a beach deposit, Walsh County.

finer materials further downstream. In Nelson and Walsh Counties a few deposits of outwash, such as the lower unit of the Fordville aquifer and all of the McVille aquifer, are composed mainly of fragments of one rock type (shale). Other deposits, such as the ice-contact features in Nelson County, consist of a mixture of fragments from many rock types.

Lacustrine deposits are the third type of glacial drift found in the study area. They consist of clay, silt, and sand deposited in the proglacial lakes that existed near the edge of the glacier. The extensive deposits of silt and clay in central and eastern Walsh County are included in this type. Also included are beach deposits formed along the shores of the lakes. A particle-size distribution curve for a beach deposit is shown in figure 5.

PRINCIPLES OF GROUND-WATER OCCURRENCE

After precipitation falls on the surface of the earth, part of the water is returned to the atmosphere by evaporation, part runs off into streams, and a part infiltrates into the ground. A large quantity of the water entering the ground is held temporarily in the soil and is then returned to the atmosphere by evaporation or transpiration of plants. A small amount moves downward to the zone of saturation where it becomes ground water.

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

The water level in a well fluctuates in response to changes in recharge to and discharge from the aquifer and to the effects of pumping from wells. Atmospheric pressure changes and land-surface loadings also cause minor water-level fluctuations in artesian aquifers.

When water is withdrawn from a well, the water level in and around the well is lowered, and the potentiometric surface resembles an inverted cone (cone of depression) with the well at its center (fig. 6). The slope produces a hydraulic gradient toward the well. The amount of water-level drawdown, or the difference between the static water level and the pumping water level, is determined by the hydraulic properties of the aquifer, the construction 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

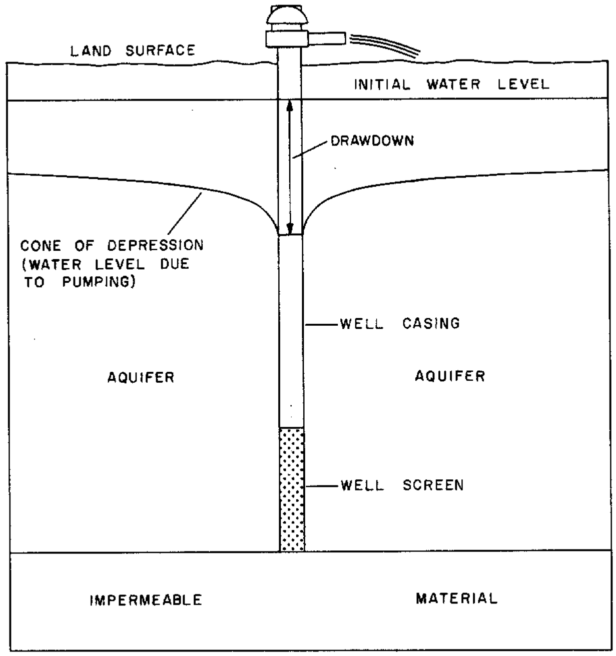


FIGURE 6. Effect of pumping on water levels in an aquifer.

lower at a decreasing rate as the cone of depression expands.

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 may become serious if (1) it causes water of undersirable quality to move into the aquifer, (2) if the yield of the well decreases because of interference from other wells or from aquifer boundaries, or (3) if the pumping lift increases to the point where pumping becomes uneconomical. When pumping is stopped, the water level recovers in and near the well 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 the same.

Withdrawal of water from an aquifer causes two or more 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 and natural discharge do not exceed recharge to an aquifer, the water level in the aquifer 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 from the aquifer.

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 hydrologic and geologic controls and is impossible to quantitatively evaluate without large amounts of data.

CHEMICAL QUALITY OF WATER

General

All natural water contains dissolved mineral matter. As raindrops fall to the earth, they dissolve minerals from the atmosphere. The water continues to dissolve mineral matter as it moves on and through the earth. The amount and kind of material dissolved depends upon the solubility and types of rocks through which the water moves, the length of time the water is in contact with the rock, and the amount of carbon dioxide and soil acids in the water. Water that has been in transit through the earth for a long time or has traveled a great distance from the recharge area generally will be more highly mineralized than water that has just recently entered the earth or has only traveled a short distance. Ground water remains in contact with rocks and soil minerals much longer than surface water, and therefore usually contains more dissolved mineral matter than is present in surface water.

The dissolved mineral constituents in water are usually reported in milligrams per liter (mg/l), parts per million (ppm), micrograms per liter (µg/l), or grains per U.S. gallon (gr/gal). Milligrams per liter is essentially equal to parts per million for waters that contain less than about 7,000 mg/l dissolved solids (DS). Micrograms per liter may be converted to milligrams per liter by dividing micrograms per liter by 1,000. Data reported in parts per million or milligrams per liter may be converted to grains per gallons by dividing the value in parts per million or milligrams per liter by 17.12. Milliequivalents per liter, or less precisely equivalents per million, is the unit chemical combining weight of a constituent in 1 liter of water. These units are not usually reported in tables of analyses but are used to calculate various ratios, such as the sodium-adsorption ratio, and to check the accuracy of chemical analyses.

The suitability of water for various uses is determined largely by the kind and amount of dissolved mineral matter present. The relative importance of the various properties and constituents in water depends upon the planned use of the water. Table 1 lists the major chemical

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

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

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

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

constituents found in water, the sources from which these constituents are normally dissolved, and the effects of the constituents upon usability of the water. Many if not all of the minerals shown in the major source column are present in either the glacial drift or bedrock units of Nelson and Walsh Counties. The properties and mineral constituents most likely to be of interest to the residents of Nelson and Walsh Counties are: dissolved solids, hardness, iron, sulfate, nitrate, fluoride, and the sodium-adsorption ratio.

Dissolved Solids and Specific Conductance

The dissolved solids in a water is significant because it may limit the water's use for many purposes. In general, the suitability of a water decreases with an increase in total dissolved solids. The dissolved-solids limit shown in table 1 for drinking water was originally set for use by common carriers in interstate commerce, but it is useful as a guide to the suitability of a water for other uses.

The specific conductance of water is a measure of the capacity of water to conduct an electrical current; it is a function of the amount and kind of ionized mineral matter present in the water. Specific conductance is normally reported in micromhos per centimeter at 25°C or simply micromhos; however, it may be reported in other units, such as millimhos. An estimate of the dissolved solids in milligrams per liter can be obtained by multiplying specific conductance by 0.68; however, the conversion factor can range from 0.54 to 0.96 depending upon the type and concentration of mineral matter present (Hem, 1970, p. 99).

Irrigation Indices

Two indices commonly used to show the suitability of water for irrigation are the sodium-adsorption ratio (SAR) and the specific conductance. SAR is related to the sodium hazard and is a ratio expressing the relative activity of the sodium ions in an exchange reaction with soil. The sodium-adsorption ratio is expressed by the equation:

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

where the concentrations of calcium (Ca), sodium (Na), and magnesium (Mg) are expressed in milliequivalents per liter. The specific conductance of a water is related to the salinity hazard. Both hazards increase as the numerical values of the indices increase.

The SAR and salinity hazards of water from glacial-drift aquifers in Nelson and Walsh Counties are shown in figure 7. Because of the salinity hazard, much of the water may be of marginal quality for irrigation; however, high-sodium or high-salinity waters have been used successfully for selected crops where soil conditions and proper drainage permit.

Another index used to evaluate irrigation water is residual sodium carbonate (RSC). This index is determined by subtracting the amount of calcium and magnesium, expressed in milliequivalents, from the sum of bicarbonate plus carbonate, also expressed in milliequivalents. Waters having an RSC between 1.25 and 2.5 are considered marginal for irrigation. An RSC greater than 2.5 indicates that the water is not suitable for irrigation purposes. Additional information concerning the use of these indices is contained in the publication "Diagnosis and Improvement of Saline and Alkali Soils" (U.S. Salinity Laboratory Staff, 1954).

Hardness

Hardness is a characteristic of water that should receive attention when the water is being considered for domestic or industrial use. It is commonly recognized by the increased quantity of soap required to produce lather when the water is being used for washing. The use of hard water in boilers, water heaters, and radiators may contribute to scale formation, which results in a decrease of heat transfer and a shorter useful life of the equipment.

Hardness is caused almost entirely by ions of calcium and magnesium. Other constituents, such as iron, manganese, aluminum, barium, strontium, and free acid, also contribute to hardness. However, these compounds are normally not present in sufficient quantities to produce any appreciable effect.

Carbonate hardness is the amount of hardness chemically equivalent to the amount of bicarbonate and carbonate ions present in the water. Carbonate hardness is approximately equal to the amount of hardness removed when the water is boiled, and is termed temporary hardness.

Noncarbonate hardness is the difference between the hardness calculated from the total amount of calcium and magnesium present in solution and the amount of carbonate hardness. If the carbonate hardness (expressed as calcium carbonate) equals the amount of calcium and magnesium (expressed as calcium carbonate) there is no noncarbonate hardness. Noncarbonate hardness is approximately equal to the amount of hardness remaining after the water is boiled.

There is no accepted standard for rating the hardness of water. Water

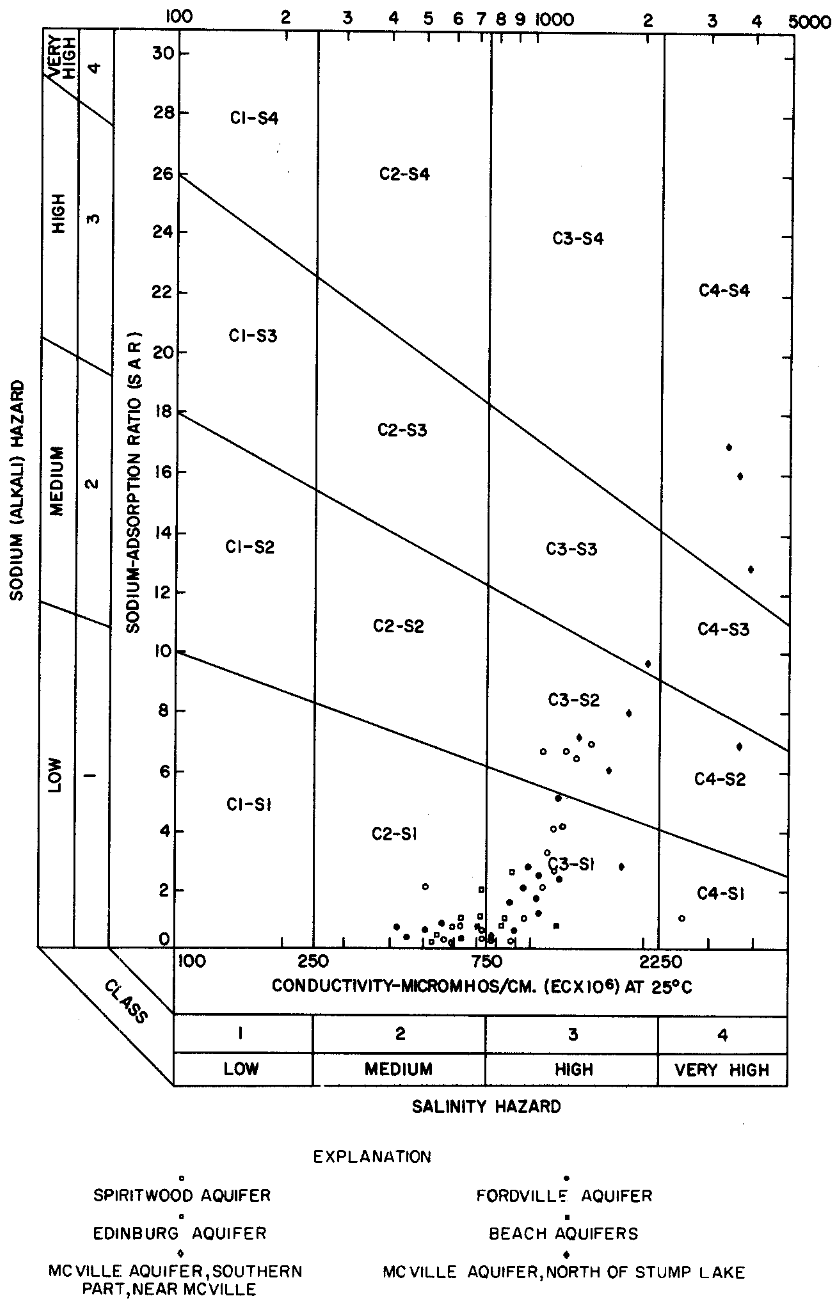


FIGURE 7. Classification of water from glacial-drift aquifers for irrigation use.

that seems soft to one person may seem hard to another. The U.S. Geological Survey has adopted the following classifications:

Hardness range (in milligrams per liter of calcium carbonate)	Hardness description
0-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

GROUND WATER IN THE BEDROCK

Precambrian

Precambrian crystalline rocks form the basement in both Nelson and Walsh Counties. Depth to the Precambrian basement from land surface ranges from about 900 feet in eastern Walsh County to about 2,900 feet in Nelson County. These rocks appear to contain only small amounts of water in joints and fractures, and it is doubtful that substantial quantities of water could be obtained from them.

Ordovician

Rocks of Ordovician age in Nelson and Walsh Counties have been subdivided into the Winnipeg, Red River, and Stony Mountain Formations. The Winnipeg Formation consists of 20 to about 65 feet of shale, sandstone, and shaly limestone overlying the Precambrian basement rocks. In Nelson County an oil-test well at 151-61-32BC penetrated 47 feet of the Winnipeg Formation at a depth of 2,864 to 2,911 feet. Another oil-test well at 151-60-6AA reported 36 feet at a depth of 2,724 to 2,760 feet (Downey, 1971b). The Winnipeg Formation was not identified in test holes drilled in Walsh County as part of the present study; however, test hole 157-52-11CBC penetrated 79 feet of clayey shale at a depth of 631 to 710 feet that may represent the formation in this area. Greenish-gray noncalcareous shale is the principal rock type in adjacent Grand Forks County; however, Kelly and Paulson (1970) reported a sequence of lenticular sandstone and limestone that was water bearing at this stratigraphic interval.

The test-hole data from Grand Forks County indicate that the

Winnipeg Formation contains an aquifer of some importance. Although the areal extent of the aquifer is poorly defined (Kelly and Paulson, 1970), it is likely that the aquifer also underlies a large area of Nelson and Walsh Counties.

Few, if any, wells tap the Winnipeg Formation at the present time and yield data from the formation are lacking. If the lithology is similar to that reported in Grand Forks County, yields of greater than 50 gpm (gallons per minute) may be possible from this aquifer at selected locations.

The Red River Formation overlies the Winnipeg Formation in the report area. This formation was described by Ballard (1963), who divided it into two units; a lower unit of fragmental microgranular dolomite and an upper unit of fragmental limestone, argillaceous dolomite, and minor amounts of anhydrite. Depths to the top of the Red River Formation in Nelson County range from 1,482 feet below land surface in oil test 149-59-15BD to 2,118 feet below land surface in oil test 151-61-32BC. In Grand Forks County a test hole drilled by the North Dakota Geological Survey (Anderson and Haraldson, 1968) at 154-51-35ABA, near the county line between Walsh and Grand Forks Counties, penetrated 54 feet of the Red River Formation between 214 and 268 feet below land surface.

Few data are available concerning the water-yielding characteristics of the Red River Formation in Nelson and Walsh Counties. The productivity of carbonate rocks, such as limestone and dolomite, is dependent upon the number of joints, solution cavities, and fractures that are open to the well. Well yields will be high where a large number of fractures and solution cavities are present, whereas solid limestone will yield little or no water.

The Stony Mountain Formation underlies both Nelson and Walsh Counties and consists of interbedded shale, dolomite, and limestone. In Nelson County the formation ranges in thickness from 142 feet in oil test 151-60-6AA to 92 feet in oil test 149-59-15BD. Test hole 157-52-11CBC in Walsh County penetrated 47 feet of clayey shale and sandy limestone from 333 to 380 feet below land surface that may correlate with the Stony Mountain Formation.

No data are available concerning the water-yielding characteristics of the Stony Mountain Formation in Nelson and Walsh Counties; however, they are expected to be similar to those of the underlying Red River Formation because of similar lithology.

Water obtained from Ordovician rocks in Nelson and Walsh Counties is very saline and the dissolved solids may exceed 20,000 mg/l (Downey, 1971a, 1971b). The principal constituents are sodium and chloride.

Jurassic

Rocks of Jurassic age overlie those of Ordovician age in the report area (Downey, 1971a, 1971b). Test hole 157-52-11CBC in Walsh County penetrated 87 feet of interbedded red shale, silty sand, and sandstone at a depth of 246 feet to 333 feet below land surface that may correlate with the Jurassic Piper Formation. Test hole 157-52-36CCC penetrated 14 feet of siliceous dark-gray to purplish clayey shale from 286 to 300 feet below land surface, and test hole 157-51-6AAA penetrated 24 feet of pale-red clayey shale at the bottom of the hole. These test holes suggest that the Jurassic "red-bed" units are quite widespread in Walsh County. Jurassic "red beds" have not been identified in Nelson County.

Little is known about the yield of the Jurassic units. Yields greater than 50 gpm could be expected from a sandstone unit such as that penetrated in test hole 157-52-11CBC from 286 to 333 feet below land surface.

Water from the Jurassic units is similar in chemical composition to that obtained from the Ordovician rocks; dissolved solids exceed 20,000 mg/l and the principal constituents are sodium and chloride.

Cretaceous

Dakota Aquifer

The Dakota aquifer, or its equivalent, underlies much of the Great Plains in the United States and Canada. It is probably the most productive bedrock aquifer in Nelson and Walsh Counties. The water-bearing materials consist mainly of fine-grained quartz sandstone interbedded with gray shale in varying proportions.

The Dakota aquifer underlies all of Nelson County. Depths to the top of the aquifer range from about 1,100 to 1,300 feet below land surface. Logs from commercial test holes show thicknesses for the Dakota aquifer that range from 276 to 694 feet (Downey, 1971b); however, the individual sandstone lenses are thin, as shown by well 151-60-35DAC2, which penetrated sandstone lenses interbedded with shale from 1,060 to 1,120 and 1,246 to 1,320 feet below land surface.

Only three analyses of water from the aquifer in Nelson County are available. The analyses showed the water had a dissolved-solids content of 3,604, 3,729, and 6,053 mg/l. Little use is made of the water from the Dakota aquifer in Nelson County because of the availability of better quality water at shallower depths.

The Dakota aquifer underlies all of Walsh County except the northeastern part. It is reached at depths of less than 200 feet below land surface in the eastern third of the county but is more than 1,000 feet below land surface in the western part of the county.

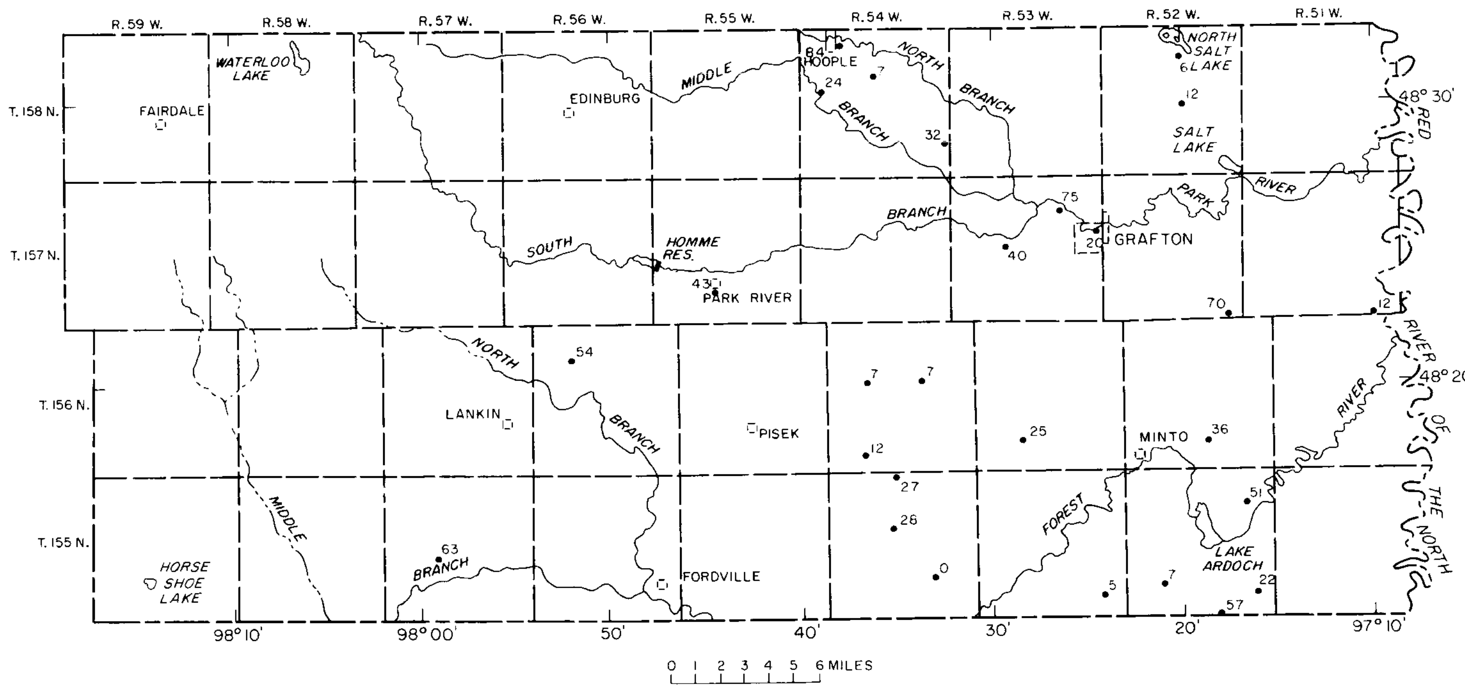
Figure 8 shows the thickness of sandstone beds penetrated in various wells and test holes drilled in Walsh County. Only three of the test holes are believed to have completely penetrated the aquifer. Test hole 157-52-36CCC penetrated 70 feet of sandstone at a depth of 216-286 feet, overlying dark-gray to purplish shale that is probably of Jurassic age. Test hole 158-52-3DCC penetrated 6 feet of well-cemented sandstone at a depth of 270 to 276 feet, overlying pale-reddish-brown shale. Test hole 158-52-22BAA penetrated 12 feet of sand overlying pale-red shale. At both of the latter two locations the reddish shales below the Dakota aquifer probably are Jurassic red beds.

Below a land-surface elevation of about 900 feet in Walsh County most wells completed in the Dakota aquifer flow and many farms use this flow to supply water to livestock without pumping. Water levels in selected wells tapping the Dakota aquifer in Walsh County are shown in table 2. Most of the wells are of small diameter and are screened only in the top few feet of the aquifer. Flows range from less than 1 gpm to about 2 gpm. Wells with greater screened intervals would generally yield larger flows, as shown by a well (152-51-15DDD) drilled for the Agricultural Research Service (ARS) in Grand Forks County. The well tapped the full thickness of the Dakota aquifer and had an initial rate of flow of 50 gpm (Kelly and Paulson, 1970).

An 18-day aquifer test on well 152-51-15DDD was made by the ARS and the data indicated a transmissivity of 6,300 square feet per day, or 47,000 gpd (gallons per day) per foot, and a storage coefficient of 0.0002. The well was pumped at a rate of 500 gpm.

Water from the Dakota aquifer in Walsh County ranged in dissolved-solids content from 3,420 to 5,700 mg/l with a mean value for 24 samples of 4,560 mg/l. In general the water is a sodium chloride type; however, a number of samples contained a significant amount of sulfate and three were of a sodium sulfate type. Mean chemical composition of the 24 samples is shown in table 3.

The Dakota aquifer has yielded large quantities of water for general farm use in Walsh County; however, in recent years use of the aquifer has decreased because of reduced hydraulic head and the general unsuitability of the water in modern plumbing and appliances. The primary use of water from the Dakota aquifer at the present time (1971) is for washing potatoes and for livestock watering.



EXPLANATION

•27
TEST HOLE LOCATION
NUMBER IS THICKNESS, IN FEET, OF SAND UNIT PENETRATED

FIGURE 8. Thickness of sandstone beds penetrated in the Dakota aquifer, Walsh County.

TABLE 2.–Water levels in selected wells tapping the Dakota aquifer in Walsh County

Well	Water level, in feet above land surface 1/	Elevation of water level, in feet above mean sea level
157-52-7DCD	14	826
157-53-10AAC	8	838
157-53-16CBB	16	856
157-53-16DAB	18	858
157-53-22CBB	21	856
157-53-22DDC	9	844
157-54-1CCD1	7	873
157-54-12DAA	16	876
158-52-30CCC	25	852
158-53-20BCA	9	857
158-53-23CCC	21	861

1/ Values shown are those measured or reported during this study. Wells that are many years old may have casing that leaks when the well is closed causing a lower pressure to be shown at the well head than naturally exists in the aquifer.

TABLE 3.–Mean chemical composition of water from the Dakota aquifer in Walsh County

Sample size: 24 analyses

Constituent	Mean, in milligrams per liter
Silica (SiO_2)	12
Iron (Fe)	5
Calcium (Ca)	121
Magnesium (Mg)	43
Sodium (Na)	1,435
Potassium (K)	19
Bicarbonate (HCO_3)	677
Sulfate (SO_4)	794
Chloride (Cl)	1,611
Fluoride (F)	2
Nitrate (NO_3)	12
Boron (B)	3
Dissolved solids	4,510

Pierre Aquifer

The Pierre Formation directly underlies the glacial drift in all of Nelson County and the western one-third of Walsh County and consists of more than 200 feet of light-gray to black shale, marlstone, and claystone. Yellowish to white bentonite layers occur in the lower part of the formation. The upper part of the Pierre Formation in Nelson and Walsh Counties consists of a black fissile shale that has been extensively fractured, apparently by glacial action. The fractured shale forms an aquifer that is a source of water for many of the farms and cities in both Nelson and Walsh Counties. Locally the fracture system is poorly developed and a nearly impermeable boundary exists at the shale-glacial-drift contact.

A study of the hydraulic characteristics of the aquifer at Michigan City (Nelson County) was made by Aronow, Dennis, and Akin (1953). They reported a transmissivity for the aquifer that ranged from about 66 to 121 square feet per day (490 to 900 gpd per foot) and averaged 95 square feet per day (710 gpd per foot). The storage coefficient computed from their test data averaged 0.00042. Similar values were obtained from short-term aquifer tests on the Pierre aquifer near Fairdale in Walsh County.

Yields greater than 5 gpm should not be expected from wells tapping the Pierre aquifer in most areas of Nelson and Walsh Counties. Continuous pumping at the higher rate will cause a decline in water levels similar to that shown in figure 9. This observation well is located about 350 feet west of a public supply well that is reported to be pumped at 6 gpm for 12 hours per day.

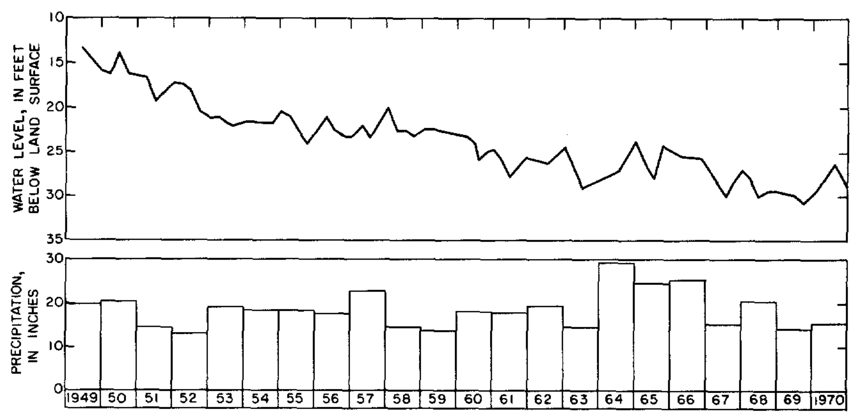


FIGURE 9. Water-level fluctuations in well 153-58-32DBB at Michigan City and precipitation at McVille, Nelson County.

Recharge to the Pierre aquifer is derived mainly from vertical leakage through the overlying glacial drift. In areas where the fracture system has a close hydraulic connection to the glacial drift, water is able to move rather quickly into the shale and along the fractures towards areas of discharge. In such areas, water-level fluctuations in the shale will be closely related to periods of precipitation. Where the fracture system is poorly developed, water will move very slowly through the shale from areas of recharge to areas of discharge.

The amount of water in storage in the Pierre aquifer is directly related to the extent and thickness of the fracture system. Based largely on water-quality data, there appears to be a well-developed system of fractures along a north-south line that passes through Michigan City and extends northward into Walsh County. Wells in this area of the Pierre aquifer yield water with a dissolved-solids content near 2,200 mg/l, whereas wells outside of the area have a much higher dissolved-solids content. The limited data available suggest that the fracture zone is about 3 to 6 miles wide.

Due to the effect of varying development of the fracture zone, water quality ranges from fair to poor. The water generally is a sodium bicarbonate sulfate type; however, a few samples were a sodium bicarbonate or a sodium bicarbonate chloride type. The principal ions present are sodium, calcium, chloride, bicarbonate, and sulfate.

GROUND WATER IN THE GLACIAL DRIFT

Spiritwood Aquifer

The largest glacial-drift aquifer in the two-county area is located in the southwestern part of Nelson County from T. 149 N., R. 61 W., through T. 150 N., R. 61 W., to T. 151 N., R. 61 W. (pl. 2). This aquifer underlies about 52 square miles in Nelson County and extends into Eddy, Benson, and Griggs Counties. The name Johnson Lake aquifer was applied to this deposit in Eddy County by Trapp (1968); however, test drilling in Nelson County indicates that the Johnson Lake aquifer of Eddy County is part of a larger aquifer system that is also found to the south and west of Nelson County. This larger aquifer system was named the Spiritwood aquifer by Huxel (1961).

The Spiritwood aquifer in Nelson County reaches a maximum thickness of about 320 feet with an average thickness of about 100 feet, and consists of interbedded clay, silt, sand, and gravel (fig. 10). In most cases the aquifer material was deposited by flowing water along the course of a pre-existing valley cut into bedrock.

The aquifer deposits had a complex origin, and the lithology is rather

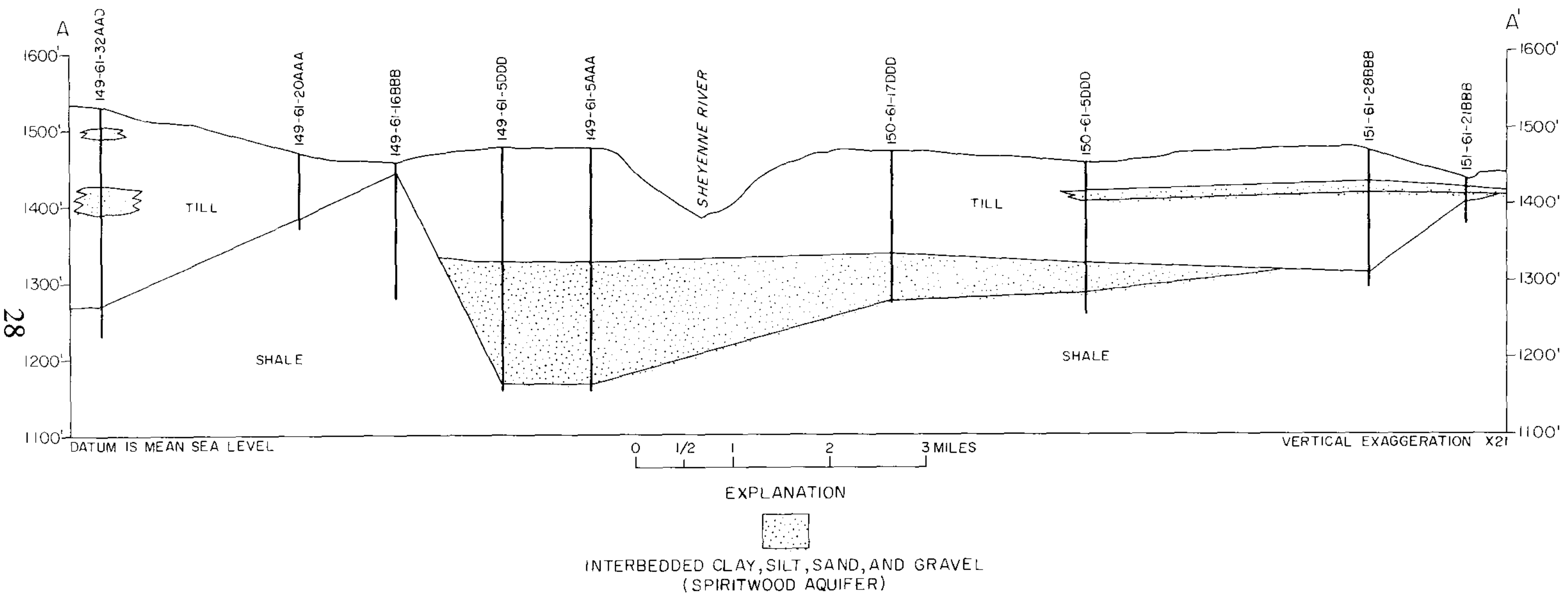


FIGURE 10. Geologic cross section through the Spiritwood aquifer, Nelson County.

variable. As a result, correlation of the various units from one location to another is tenuous.

The lack of roads in much of the area limited access to many drilling sites; therefore, it was difficult to locate test holes where they would be expected to penetrate the full thickness of the aquifer. However, test hole 149-61-5AAA was drilled near the axis of the buried valley and penetrated a total thickness of 162 feet of sand and gravel below 148 feet of interbedded silt, clay, and till. Bedrock was reached at 310 feet.

Test hole 149-61-5CCC, located southwest of the preceding test hole and on the west side of the buried valley, penetrated bedrock at a depth of 200 feet below land surface. A total thickness of 61 feet of sand, interbedded with silty clay, was penetrated in this test hole.

Test hole 150-61-30ABB, located near the western boundary of Nelson County, penetrated a total thickness of 147 feet of sandy gravel interbedded with clay and silt. A continuous sequence of 128 feet of sandy gravel and gravelly sand, from 154 to 282 feet below land surface, was penetrated, and bedrock was reached at 320 feet below land surface.

Test hole 150-61-6BDD, drilled 3½ miles north of test hole 150-61-30ABB, penetrated bedrock at 265 feet below land surface after drilling through lenses of sand and gravel interbedded with silt and clay. The individual sand and gravel lenses ranged in thickness from 4 to 19 feet. A nearby test hole, 150-61-6BBB, was drilled through 143 feet of coarse sand, which was present below 158 feet of silty clay and till. This test hole penetrated bedrock at 301 feet below land surface.

Because of the rapid facies changes of the Spiritwood aquifer in Nelson County, extension of hydraulic parameters from one area to another within the aquifer would be of questionable value. However, preliminary analysis of data from the Spiritwood aquifer complex suggests a transmissivity of 25,000 square feet per day and a hydraulic conductivity ranging from about 36 to 280 feet per day. An average porosity of 35 percent is assumed for the Spiritwood aquifer.

The yield from wells located in the Spiritwood aquifer is dependent mainly upon the thickness of sand and gravel found at the well location. Locations along the central part of the buried valley offer the greatest possibility of penetrating large thicknesses of sand and gravel, and wells located in this area will yield more than 500 gpm. Yields decrease towards the aquifer boundaries due to thinning of the sand and gravel units and the decrease in saturated thickness.

Recharge to the Spiritwood aquifer in Nelson County is from direct precipitation upon the till overlying the aquifer and runoff from nearby highlands. Water-level fluctuations in three observation wells are shown in figure 11. The effects of direct precipitation upon water levels in the

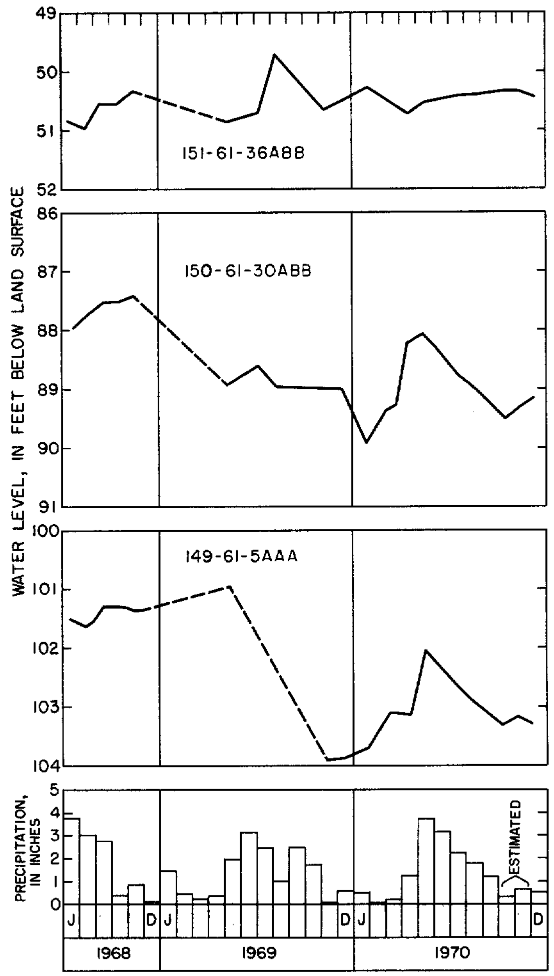


FIGURE 11. Water-level fluctuations in observation wells in the Spiritwood aquifer and precipitation at McVille.

aquifer are illustrated by the correlation between the water-level fluctuations in the wells and the amount of precipitation recorded at McVille.

Discharge from the aquifer is mainly limited, at the present time, to underflow out of the area and by evapotranspiration. Because the depth of the water table below land surface in the Spiritwood aquifer exceeds 100 feet in most places, the loss by direct evaporation and plant transpiration is small to nonexistent.

Based on an average saturated thickness of 100 feet, a storage coefficient of 0.15, and an areal extent of 52 square miles, about 500,000 acre-feet of water is available from storage in the Spiritwood aquifer in Nelson County.

Water in the Spiritwood aquifer is of relatively good chemical quality. The dissolved-solids content of water based on 18 samples ranged from about 315 mg/l to 1,010 mg/l. The mean dissolved solids was 656 mg/l. Hardness ranged from about 136 mg/l to about 500 mg/l, with a mean value of 308 mg/l. In general, the water is a calcium or sodium bicarbonate type; however, two of the samples analyzed were a sodium sulfate type. The sodium sulfate water may be the result of water movement into the aquifer from the Pierre Formation, which forms the walls of the buried valley. Irrigation indices for water from the aquifer are shown in figure 7.

McVille Aquifer

The McVille aquifer, extending from T. 152 N., R. 61 W. to T. 149 N., R. 58 W. (pl. 2), has the greatest potential for development of any aquifer in Nelson County. The McVille aquifer is contained in a buried river valley, which had been cut into the Pierre Formation prior to the last glacial advance. The aquifer ranges in width from a quarter of a mile to about half a mile, with an average width of about three-eights of a mile. It has a length of 31 miles in Nelson County.

Figure 12 illustrates the cross-sectional shape of the valley and geohydrologic relationships of the aquifer materials near the city of McVille. A generalized geohydrologic section along the axis of the McVille aquifer is shown on plate 3, which shows the variable nature of the aquifer materials from the north end of the aquifer to the south and the inferred directions of ground-water movement.

Test drilling indicates that the aquifer is as much as 300 feet thick in the central part. The thickness averages about 200 feet north of the city of McVille, and about 160 feet south of the city.

In general, the McVille aquifer is composed of fine sand, clayey sand, and sandy gravel interbedded with lenses of silty clay and glacial till.

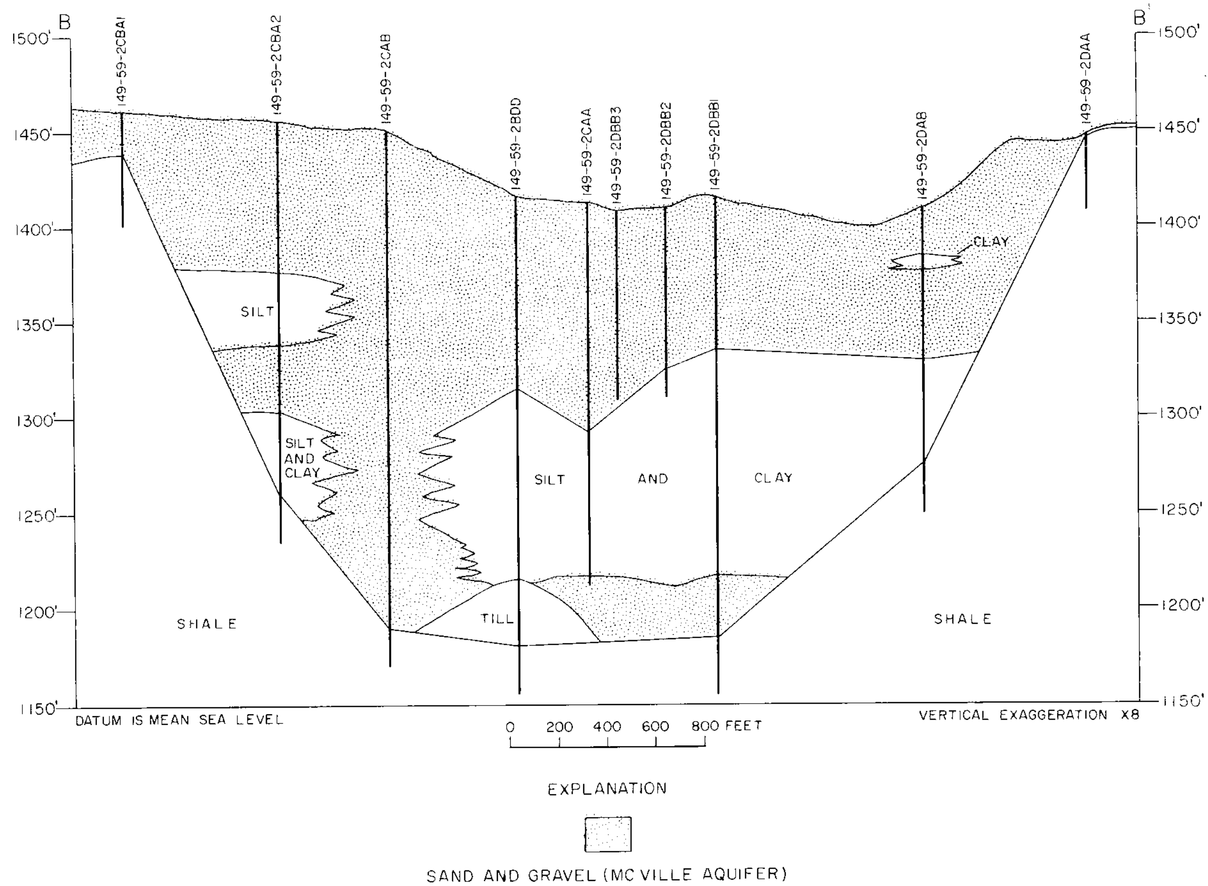


FIGURE 12. Generalized geologic cross section through the McVille aquifer south of McVille, Nelson County.

Test drilling indicates that the aquifer materials become coarser toward the south.

An aquifer test was made on the McVille aquifer as part of this investigation during June 1970 at a site 1 mile south of the city of McVille. A 6-inch production well, completed in fine to medium sand (fig. 12) at a depth of 47 to 95 feet below land surface, was pumped at a rate of 415 gpm for a period of 100 hours (6,000 minutes). Drawdown in the pumped well after this period of time was 19.26 feet and the specific capacity of the well was about 21.5 gpm per foot.

Rainfall during the test period amounted to about 2 inches, mainly from isolated thunderstorms. The surface material of the McVille aquifer readily absorbed the precipitation and the water was able to move quickly to the water table. This resulted in rapid rises of water levels in many of the observation wells during the test. These fluctuations of water levels in the observation wells made the drawdown measurements unreliable for use in many of the methods of analysis of the aquifer test data.

Based upon the specific-capacity data from the test well, laboratory determinations of permeability from samples of material from the aquifer, and grain-size analysis of the aquifer materials, the McVille aquifer is estimated to have a transmissivity ranging from 2,100 square feet per day (15,000 gpd per foot) to 9,400 square feet per day (70,000 gpd per foot).

As shown on plate 2, the highest yielding areas of the McVille aquifer are south of east Stump Lake where yields of more than 500 gpm may be expected.

Recharge to the McVille aquifer is from direct precipitation and snowmelt in the area south of Stump Lake and north of McVille. Water-level rises in the aquifer due to recharge are shown in figure 13. Ground-water movement (pl. 3) generally is from the highland areas south of Stump Lake towards the north and south. The largest part of the water that enters the aquifer as recharge moves towards the south to discharge areas along the Sheyenne River. Smaller quantities of water move north and discharge into Stump Lake.

Based on an areal extent of about 12 square miles, an average saturated thickness of 180 feet, and a storage coefficient of 0.15 about 200,000 acre-feet of water is available from storage in the McVille aquifer.

Water from the McVille aquifer is generally low in dissolved solids. The range was from 285 mg/l in the southern part of the aquifer near the city of McVille to 2,400 mg/l in the area north of Stump Lake.

Plate 3 shows the variation in chemical quality that occurs as the water moves through the McVille aquifer. As the water moves

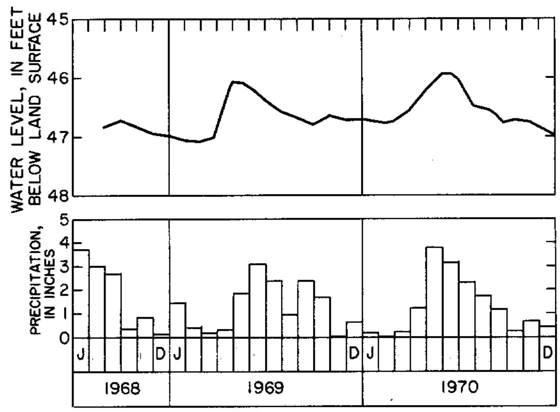


FIGURE 13. Water-level fluctuations in well 150-59-20AAA in the McVille aquifer and precipitation at McVille.

downward and laterally away from the recharge areas, it changes from a calcium bicarbonate type of relatively low salinity to a sodium bicarbonate or sodium sulfate type of moderate salinity. North of Stump Lake the water is a sodium sulfate type of relatively high salinity as the result of substantial inflow from the bedrock.

Fordville Aquifer

The Fordville aquifer (pl. 4) is the largest and most productive glacial-drift aquifer in Walsh County. The aquifer extends from near the northern boundary of T. 156 N., R. 56 W., to south of the city of Fordville (fig. 14). It underlies about 33 square miles and has an average thickness of about 20 feet. Geologically the Fordville aquifer is a part of the Elk Valley delta (Upham, 1895) deposits, which cover parts of Walsh, Grand Forks, and Traill Counties. These deposits accumulated along the western edge of the Lake Agassiz basin during the period of time that glacial Lake Agassiz was in existence.

Although the deposits forming the Fordville aquifer are a part of the Elk Valley delta, the aquifer is hydraulically separated from the Elk Valley delta system by the Forest River, which has cut a channel through the aquifer into the underlying glacial till (fig. 15). Because of this separation, the Fordville aquifer may be treated, hydrologically, as a separate unit from the Elk Valley aquifer described by Kelly and Paulson (1970) in Grand Forks County.

The Fordville aquifer consists mainly of gravel with interbedded silt and sand. Test drilling indicates that the aquifer is composed of two

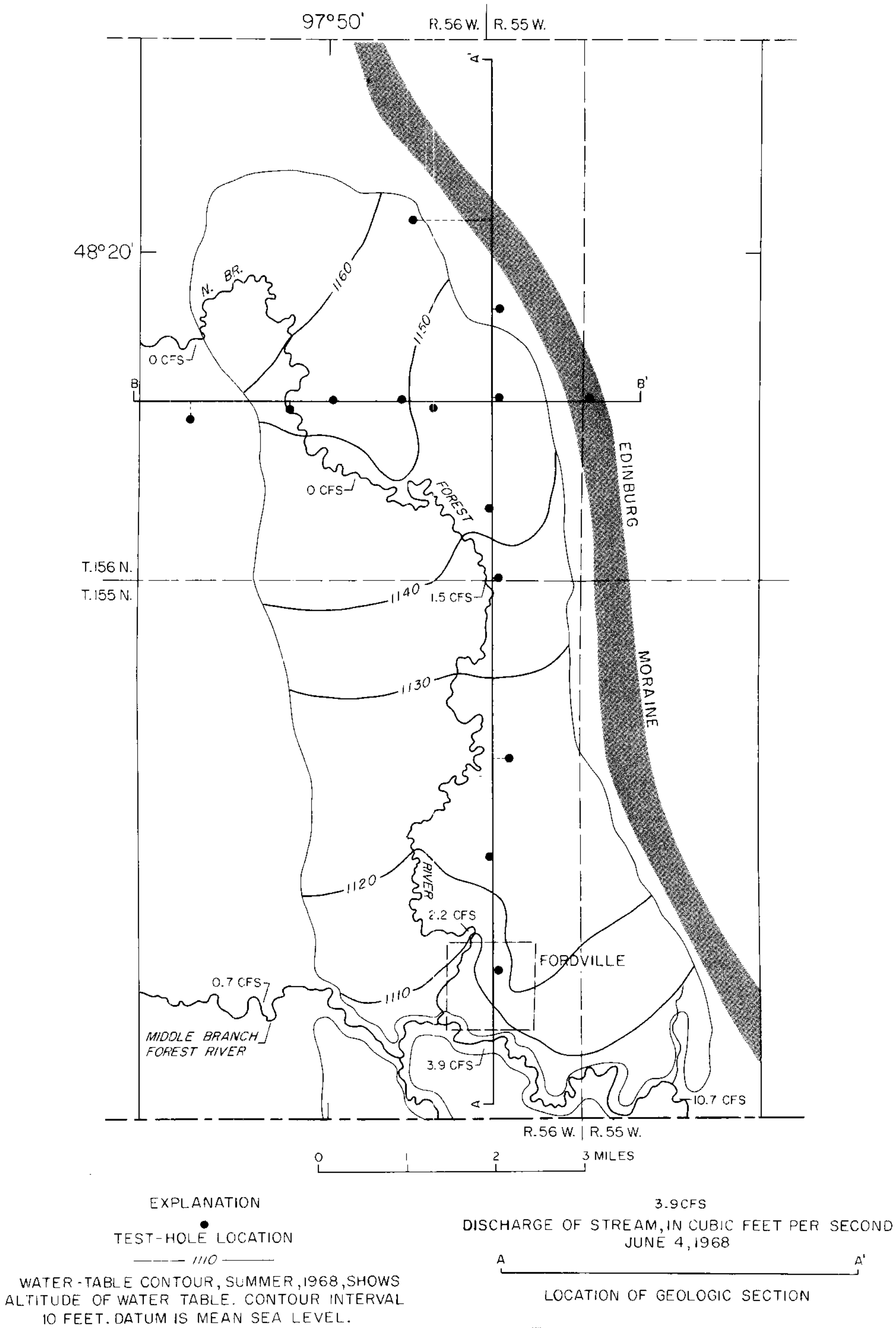


FIGURE 14. Water-table map of the Fordville aquifer, Walsh County.

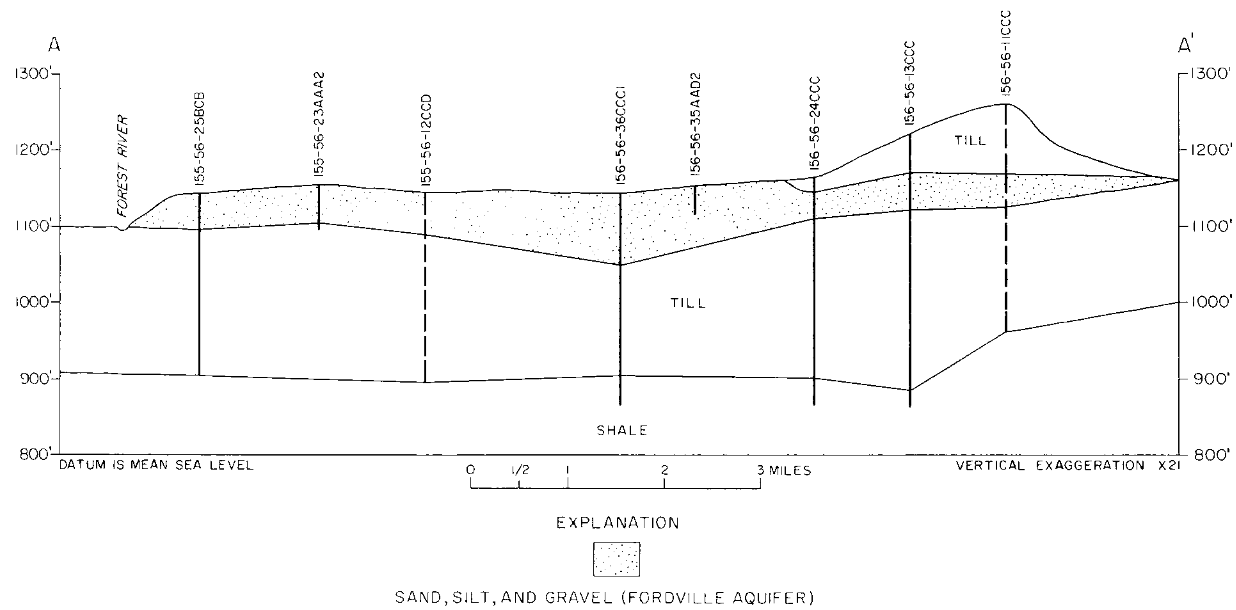


FIGURE 15. North-south geologic section through the Fordville aquifer.

units: a lower unit of silty sand composed mainly of shale fragments, and an upper unit of sandy gravel composed mainly of granitic rocks with minor amounts of limestone and shale fragments. A large part of the aquifer is covered by a thin layer of clayey silt, which has been washed onto the aquifer surface from the nearby highlands. Particle-size analyses of the sediments from the Fordville aquifer are given in tables 6A and 6B, Part II (Downey, 1971b), and particle-size curves for selected test holes are shown in figure 5.

The lower unit of silty sand appears to have been deposited by a stream that flowed into Lake Agassiz from the northwest. The high percentage of shale fragments indicates that the stream drained an area in which the Pierre Formation was exposed. The lower unit is thickest in the northeastern part of the aquifer (figs. 15 and 16) and thins towards the south and west. Test drilling indicates that this unit extends beneath and predates the Edinburg moraine, which forms a topographic high to the east.

The upper unit of the Fordville aquifer, which consists of sandy gravel, probably was deposited in shallow water. Figures 17, 18, and 19 show exposures of the aquifer near the city of Fordville where the

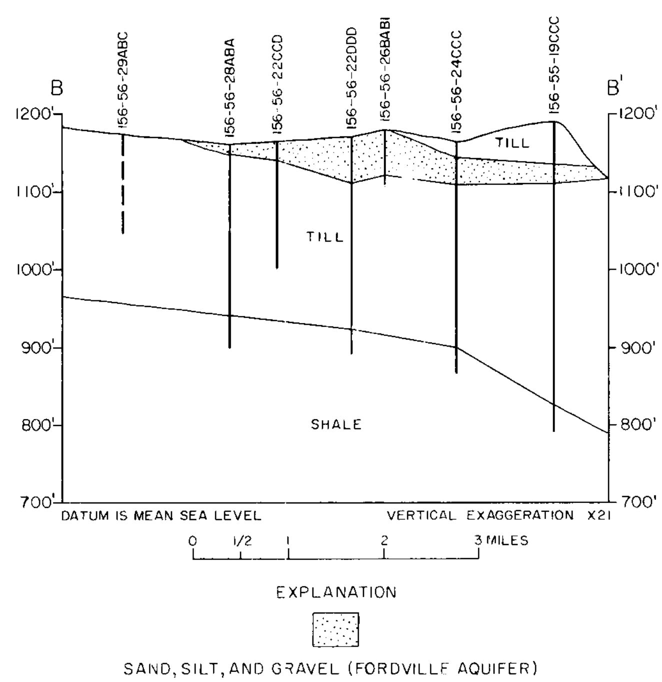


FIGURE 16. West-east geologic section through the Fordville aquifer.

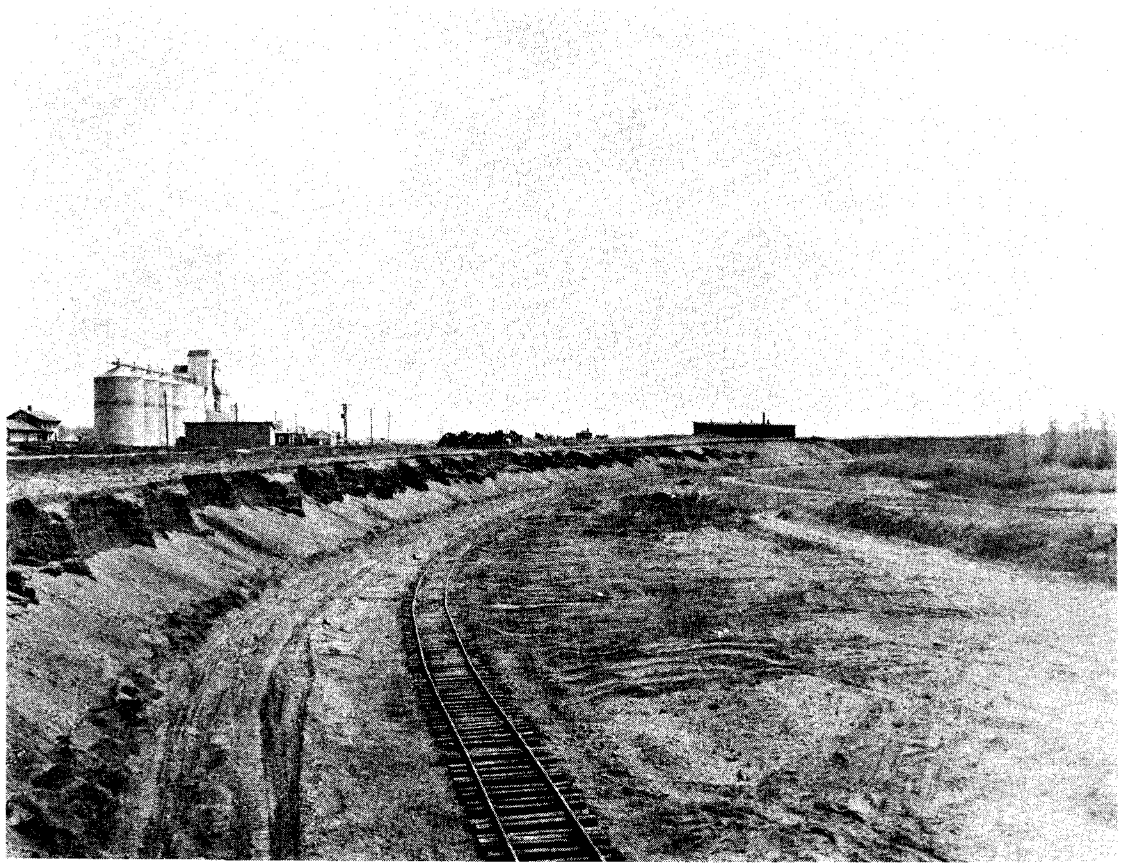


FIGURE 17. Exposure of the upper gravel unit of the Fordville aquifer near the city of Fordville.

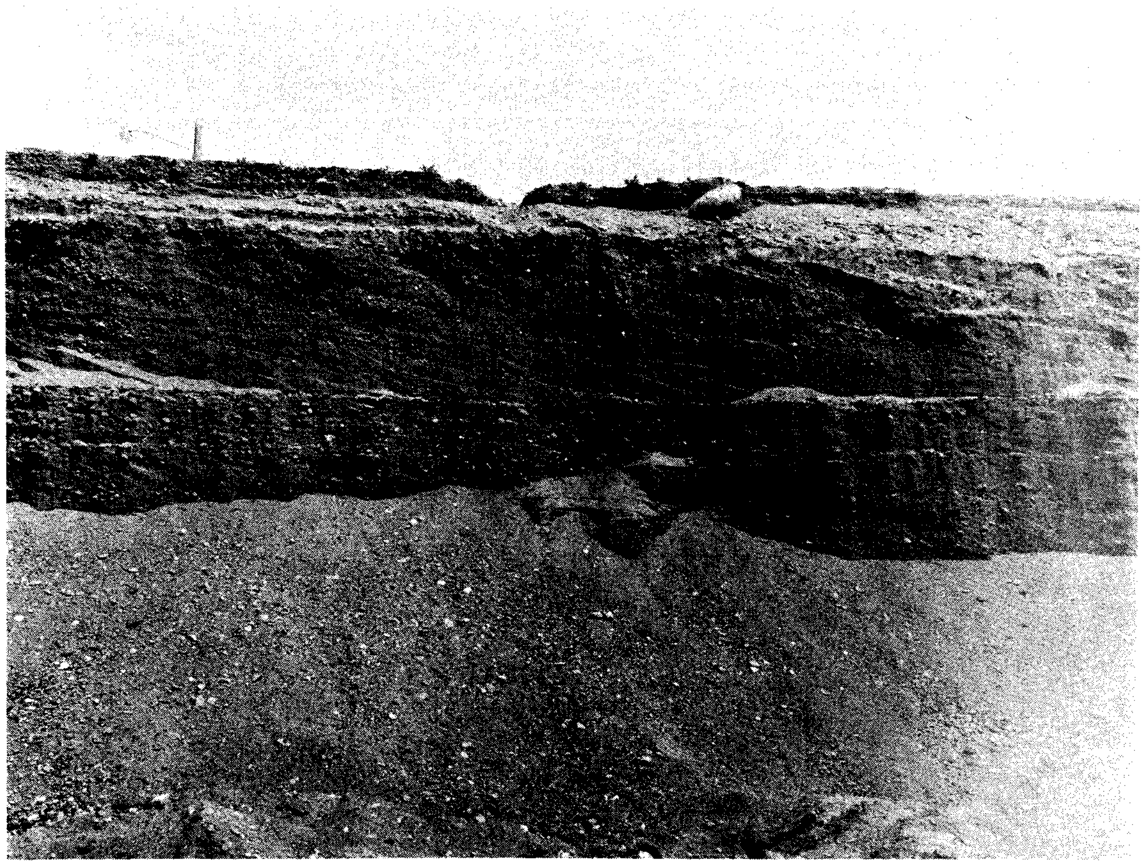


FIGURE 18. Sandy gravel of the Fordville aquifer near Fordville. Crossbedding indicates deposition by moving water.

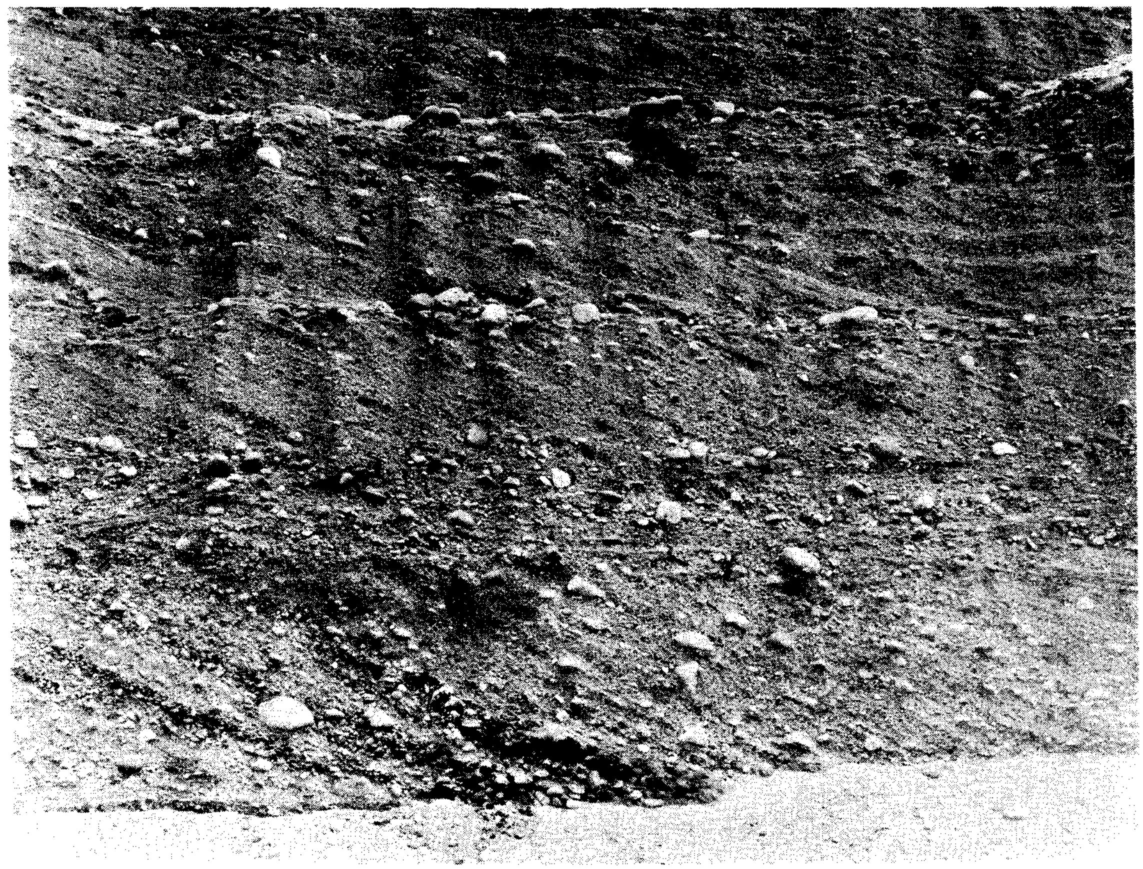


FIGURE 19. Detail of bedding in the gravel unit of the Fordville aquifer.

deposit is being mined for its gravel content. The upper unit is bounded on the east by the Edinburg moraine and thins towards the west.

Recharge to the aquifer is from direct precipitation on the aquifer surface, snowmelt in the spring, and infiltration from the North Branch of the Forest River at times of high flow. The sandy permeable materials of the Fordville aquifer readily absorb rainfall and snowmelt. There is little surface runoff from the deposits, and large areas are undissected by streams. On drainage maps, the Fordville aquifer stands out in contrast with adjacent areas to the west and east because of this lack of surface drainage.

The aquifer is unconfined and under water-table conditions. Ground-water movement is generally southward to discharge areas along the North Branch and the main stem of the Forest River (fig. 14), where the ground-water discharge augments the surface-water flow. However, north of sec. 27, T. 156 N., R. 56 W., the North Branch of the Forest River is a losing stream that provides recharge to the Fordville aquifer. Figure 20 shows little relation between precipitation and water levels in observation well 156-56-16CCB. The high water levels in the observation well, however, coincide with periods of high flow in the North Branch of the Forest River, and indicate that the river is a source of recharge to the aquifer in this area.

Discharge records since September 1940 (U.S. Geological Survey, 1940-68) for the Forest River near Fordville show that the river has not

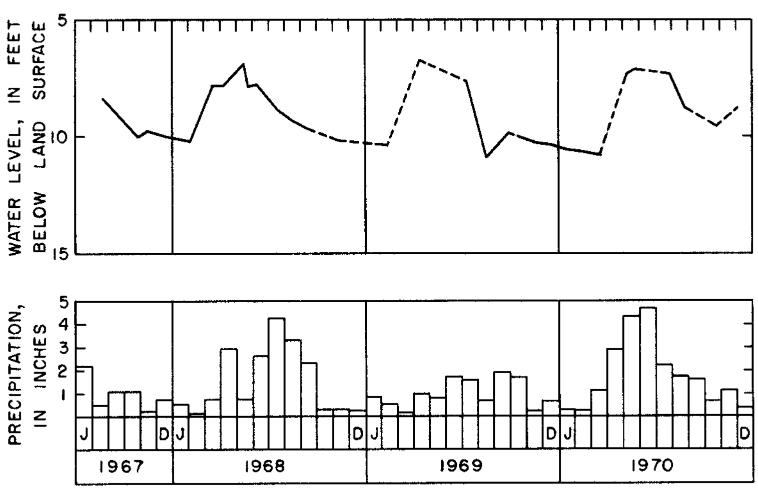


FIGURE 20. Water-level fluctuations in well 156-56-16CCB in the Fordville aquifer and precipitation at Grafton.

been dry during the period of record. Generally during the months of October through February the river is at base flow, and all of the flow is from ground-water discharge from the Medford, Elk Valley, and Fordville aquifers. The mean monthly discharges for these months since records began in 1940 are 6.2, 7.0, 5.9, 5.0, and 5.4 cfs (cubic feet per second). The average for the 5 months is 5.9 cfs, or about 2,648 gpm.

The amount of ground water discharged from much of the Fordville aquifer to the Forest River on June 4, 1968, is shown in figure 14. The flow measurements shown were made after a period of dry weather and the values listed are the base flow of the stream, at the time of measurement. The discharge measurements on the North Branch indicate that about 2.2 cfs, or 990 gpm, was flowing from the aquifer into the stream at the time the measurements were made.

Other forms of ground-water discharge from the Fordville aquifer are by wells and by evapotranspiration. A well field consisting of 10 wells, each capable of producing 100 gpm, has been installed in the northern part of the aquifer by the U.S. Army for the purpose of supplying water to military installations. The city of Fordville, near the south end of the aquifer, pumps about 30,000 gpd. The total well pumpage for all purposes including farm use probably is small compared to the quantities that are being discharged naturally by evapotranspiration and springs.

An aquifer test was conducted (Schmid, 1968) on the Fordville aquifer in June 1968. The test site was located in secs. 26 and 27, T. 156 N., R. 56 W., near the area of maximum aquifer thickness, as indicated by test drilling. The production well was located at 156-56-26BCC and had a diameter of 8 inches. The well was cased to 38 feet with an additional 9.5 feet of 35-slot screen. The well was pumped by a turbine pump set 45 feet below land surface. Seven observation wells were drilled at distances of 49, 100, 143, 304, 402, 700, and 1,320 feet from the production well. All wells completely penetrated the aquifer; however, the observation wells were screened only in the lower 3 feet of the aquifer. All wells were measured at frequent intervals during the test. The rate of flow from the production well was maintained at 300± 10 gpm during the test period of 80 hours (4,800 minutes).

Data from the Fordville aquifer test were analyzed by the Theis (1935) nonequilibrium method. A plot of data from observation well 5 is shown in figure 21 along with the trace of the Theis-type curve. Table 4 lists the transmissivities and storage coefficients determined at four well sites used in the Fordville aquifer test.

Data shown in table 5 from short-term tests on the production wells in the U.S. Army well field indicate that the Army wells have a higher

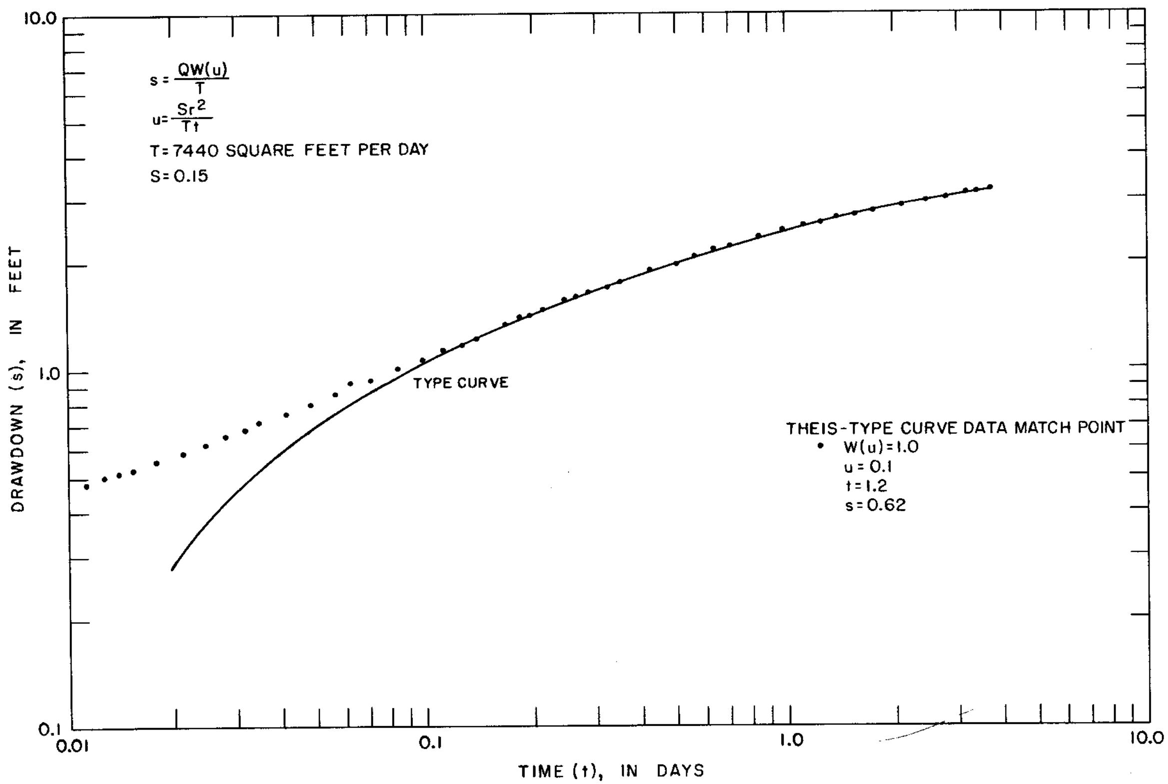


FIGURE 21. Plot of data from observation well 5, Fordville aquifer test.

TABLE 4.--Transmissivities and storage coefficients from the Fordville aquifer test wells

Well number	Transmissivity: Gallons per day per foot	Transmissivity: Square feet per day	Storage coefficient
Production well			
(drawdown)	43,500	5,830	--
(recovery)	52,100	6,980	--
Obs. well 1	53,700	7,200	0.18
Obs. well 2	66,100	8,860	.17
Obs. well 5	55,500	7,440	.15

specific capacity than the aquifer-test well. This may be due, in part, to differences in well construction; however, it may also indicate significant differences in the hydrologic properties of the aquifer between the aquifer-test location and the location of the Army well field.

The aquifer-test data and test drilling indicate that yields of more than 500 gpm are obtainable from the northeastern part of the Fordville aquifer (pl. 4).

Based on an areal extent of 33 square miles, an average saturated thickness of 20 feet, and a storage coefficient of 0.15, about 63,000 acre-feet of water is available from storage.

Water from the Fordville aquifer is a calcium sodium bicarbonate type of relatively good quality. Dissolved solids ranged from about 315 mg/l to 595 mg/l.

Medford Aquifer

The Medford aquifer (pl. 4) underlies an area of about 3 square miles in south-central Walsh County and 3 square miles in northwestern Grand Forks County, for a total extent of approximately 6 square miles. The aquifer is located south of the Fordville aquifer and north of the Elk Valley aquifer described by Kelly and Paulson (1970).

The Medford aquifer is geologically a part of the Elk Valley delta described by Upham (1895) and has a common origin with both the Fordville and Elk Valley aquifers. However, the Medford aquifer is hydraulically disconnected from the Fordville aquifer by the Middle Branch of the Forest River and from the Elk Valley aquifer by the

TABLE 5.--Summary of specific-capacity data of wells tapping the Fordville aquifer

Well location	Date	Well depth (feet)	Saturated interval (feet)	Screened interval (feet)	Pumping rate (gallons per minute)	Test duration (minutes)	Specific capacity (gallons per minute per foot)
155-56-1BBC	11- 4-68	35	14-35	25-35	300	600	47
155-56-1BCD	11- 5-68	36	11-36	26-36	300	600	60
155-56-2DAD	11- 6-68	33	10-33	23-33	300	600	107
155-56-2DDD2	11- 7-68	34	13-34	24-34	300	600	50
155-56-11AAD	11- 8-68	35	16-35	25-35	300	600	136
156-56-26DBC5	10-31-68	55	31-55	45-55	300	600	77
156-56-35ABA	11- 1-68	42	18-42	32-42	300	600	70
156-56-35DAA	11- 3-68	30	14-30	20-30	300	600	71
156-56-36CCD	10-30-68	32	10-32	22-32	300	600	44
156-56-26BCC	6-19-68	47	18-47	38-47	300	4,800	24

South Branch of the Forest River.

One test hole, 154-56-1DBB, was drilled in the Medford aquifer as a part of the ground-water study of Grand Forks County (Kelly, 1968a). This test hole, in the thickest part of the aquifer, penetrated 47 feet of fine sand similar to the aquifer materials found in the Elk Valley aquifer.

Recharge to the aquifer is from direct precipitation upon the aquifer surface and infiltration from the spring snowmelt. Natural discharge from the aquifer occurs at springs along the Middle and South Branches of the Forest River.

Yield data from wells tapping the Medford aquifer are not available; but, as the aquifer materials are similar to those found in the southern part of the Fordville aquifer, well yields of about 10 to 50 gpm should be available.

Chemical analyses of water from the Medford aquifer are lacking; however, the water quality would be similar to that of the Fordville aquifer.

Edinburg Aquifer

The Edinburg aquifer is located in north-central Walsh County (pl. 4). The aquifer underlies an area of about 13 square miles and is composed of silty sand and gravel that is buried, in places, by glacial till associated with the Edinburg moraine.

Test drilling and geologic studies indicate that the Edinburg aquifer reaches a maximum thickness of about 35 feet in the central part. Test hole 158-56-34BBB, drilled near the center of the aquifer, penetrated 35 feet of sand and gravel beneath 37 feet of till. Test hole 157-56-10AAA, near the southern edge of the aquifer, penetrated a total thickness of 13 feet of sand and gravel beneath 52 feet of till. In the northern part of the aquifer, test hole 158-56-9CDD penetrated 7 feet of sandy gravel beneath 20 feet of glacial till.

Based on the aquifer material penetrated in test holes, well yields from the Edinburg aquifer will range from about 10 to 50 gpm. Approximately 22,460 acre-feet of water is available from storage, based on an average assumed aquifer thickness of 18 feet.

Water from the Edinburg aquifer was low in dissolved solids, ranging from about 450 to 900 mg/l. The water ranges from a calcium bicarbonate type in the near-surface parts of the aquifer to a calcium sulfate type in that part of the aquifer beneath the Edinburg moraine.

Minor Drift Aquifers

Beach Aquifers

The Lake Agassiz beaches (fig. 22) are long, narrow deposits of silt, sand, and gravel that mark the various stages of the former glacial lake. Test holes drilled into the beaches show that the deposits are thin and overlie till or lake sediments having very low permeability. Kelly and Paulson (1970) reported an average thickness of the beach deposits in Grand Forks County of less than 10 feet, with a maximum of 20 feet. The deposits are also quite variable in thickness in Walsh County. Test hole 156-55-5DDD penetrated only 14 feet of medium to coarse sand above the till, whereas test hole 158-56-11AAA penetrated 30 feet of sand and gravel.

Water from rainfall and snowmelt infiltrates the sand and gravel of the beaches and moves downward to the water table, and then moves laterally to springs and seeps on the lower side of the beaches. Where the beaches form prominent ridges, such as near the town of Pisek in Walsh County, large sloughs (shallow ponds) are formed on the upslope sides to the west of the beaches during the spring snowmelt. Water then gradually moves into the aquifers from the sloughs.

Considerable quantities of water discharge from the aquifers through springs and by evapotranspiration. Discharge from the springs along the beaches is quite variable, as shown by measurements made by Jensen and Bradley (1962) in 1959. They reported that the discharge of beach springs located in sec. 1, T. 158 N., R. 56 W., 8 miles west of Hoople, was 120 gpm on April 22, 27 gpm on August 19, and 86 gpm on November 3. These measurements were made on a small stream into which the springs discharge.

Water levels in the beach aquifers are rather shallow, usually less than 20 feet below land surface, and may rise 3 feet or more during spring snowmelt (fig. 23).

Wells located in the beach aquifers may be capable of yielding fairly large quantities of water for short periods of time. One large-diameter well at 158-55-32BAA was reported to have been pumped at 100 gpm for a period of 36 hours. However, the beach deposits store only small quantities of water, and yields of this magnitude should not be expected from the beach aquifers over extended periods of time. During periods of little recharge, the water levels in the beach aquifers will decline and wells may go dry owing to the decreasing thickness of saturation of the aquifer. Water users that are dependent upon the beach aquifers for a water supply may minimize the effects of lower water levels during dry periods by proper well design.

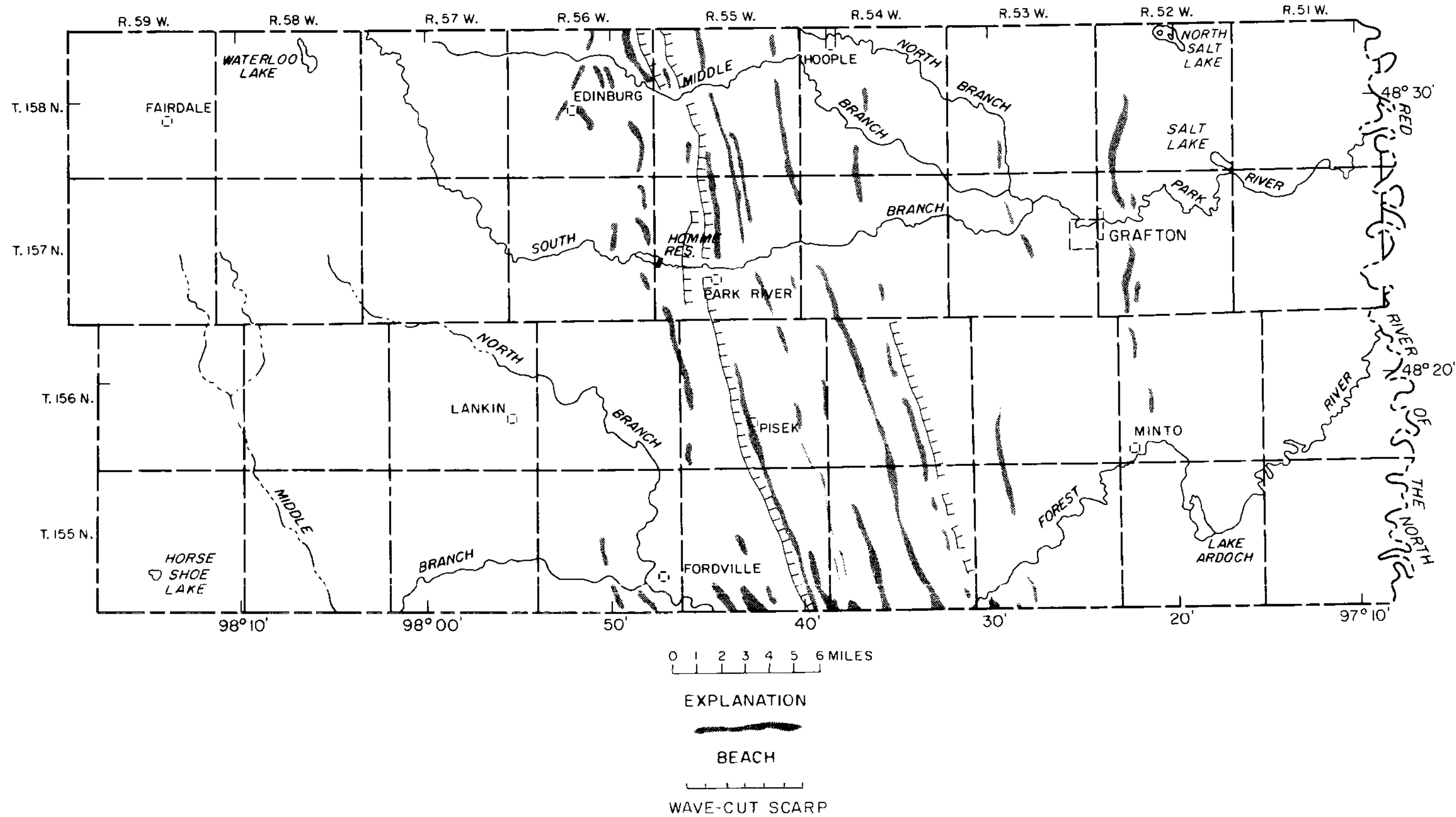


FIGURE 22. Location of Lake Agassiz beaches and wave-cut scarps in Walsh County.

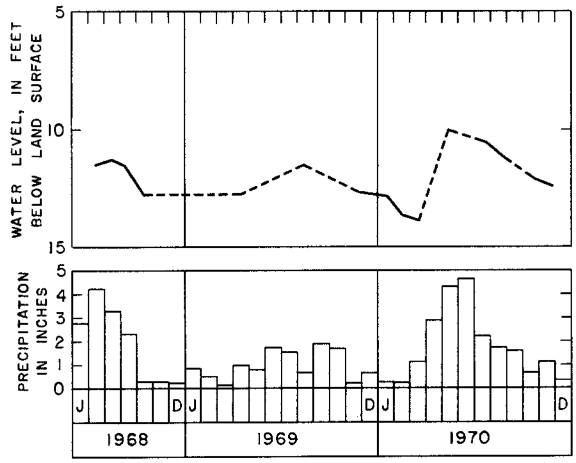


FIGURE 23. Water-level fluctuations in well 156-55-28DDD in a beach aquifer in Walsh County and precipitation at Grafton.

Water from the beach aquifers is, in general, of fair to good chemical quality and of a sodium or calcium bicarbonate type that is relatively soft. Dissolved solids in two samples were 376 and 1,520 mg/l. In most cases water from the beach aquifers may be used on lawns, gardens, and for household use without treatment.

Considerable attention should be paid to the prevention of contamination of water in the beach aquifers from barnyard sources and domestic waste-disposal systems because of the shallow depth of the water table and the close connection between the aquifer and surface water.

Silt Aquifers

The central and eastern parts of Walsh County are covered by deposits of silt and clay that accumulated in glacial Lake Agassiz. These deposits consist mainly of clay, which has a very low permeability. Wells tapping the clay fail to produce significant amounts of water at most locations; however, small quantities of water are produced from the silt deposits associated with the lake clays at certain locations near major streams in eastern Walsh County.

Water in the silt deposits is under water-table conditions and, in most places, the water table is only a few feet below the land surface. Minor amounts of precipitation upon the surface of the deposits often result in abrupt rises of water levels because of very low specific yields. Figure 24 shows the fluctuations that occur in an observation well (155-52-33BCA) tapping a small surface deposit of silt overlying a deposit of lake clay near the city of Ardoch.

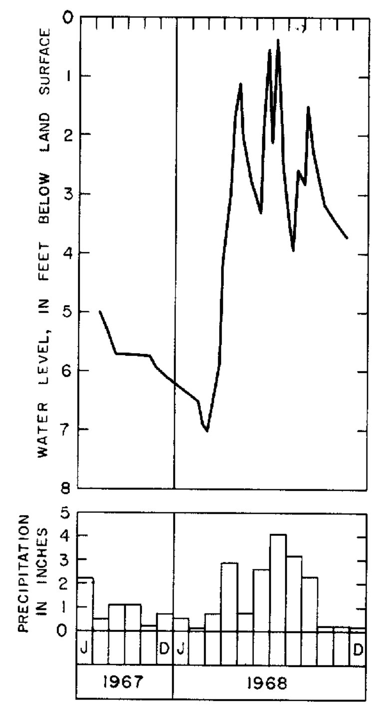


FIGURE 24. Water-level fluctuations in observation well 155-52-33BCA in the Lake Agassiz silt deposits near Ardoch, Walsh County, and precipitation at Grafton.

Where present, silt deposits may yield enough water to meet the needs of small farms, if large-diameter wells providing adequate storage are constructed. Yields of less than 100 gpd should be expected from most wells tapping the silt deposits.

The chemical quality of the water from the Lake Agassiz silt deposits differs widely from one location to another. Water from well 155-51-8ABC, 10 feet deep, had a dissolved-solids content of 932 mg/l and was a sodium chloride type; water from observation well 155-52-33BCA, 9 feet deep, near Ardoch, had a dissolved solids of 3,790 mg/l and was a magnesium sulfate type; and water from well 157-51-22BCC, 15 feet deep, had a dissolved-solids content of 593 mg/l and was a calcium bicarbonate type (Downey, 1971b).

This variation of the water quality in the silt deposits is due mainly to sources of recharge and hydraulic connection to other aquifers. Because in some areas the silt deposits overlie bedrock aquifers that contain highly mineralized water under pressure, ground-water movement is upward (pl. 1) into the silt deposits and, in many cases, results in contamination of the water in the silt aquifer. In those areas where hydraulic connection with the underlying bedrock is limited, such as where the silt aquifer lies above a thick clay unit, the water quality in the silt aquifer is good.

Till Aquifers

Many farm wells in Nelson and Walsh Counties tap deposits of glacial till. Most of these failed to penetrate any signficant thickness of sand or gravel, yet the wells yield sufficient water to meet the needs of small farm operations. In some places the water is produced from thin sand and gravel lenses interbedded with the till (fig. 25), in others the water comes from joints and other fractures in the till. Because joints, fractures, and sand lenses in the till are not apparent at the surface, well-site selection in the till aquifer is a matter of chance.

In general, the sand and gravel lenses are limited both in thickness and areal extent. They are also limited as to recharge because of the overlying till, which ranges in hydraulic conductivity from about 0.00004 to 0.05 foot per day depending upon the amount of clay, silt, and sand present. Composition of glacial till from various sampling sites in Nelson and Walsh Counties is shown in figure 3 and mean composition of the glacial till is shown in figure 4.

Yields from wells tapping deposits of sand and gravel within the till will be higher than those that tap joints and fractures, and may exceed 2 gpm in some cases. Wells that tap jointed or fractured till will yield greater quantities of water than those that tap unjointed till; however, in either case well yields greater than 1 gpm should not be expected.

In order to insure the best possible yield from till aquifers it is necessary to install large-diameter wells that will provide a large area for seepage and also act as reservoirs for storage of water. Proper design of wells tapping till aquifers will minimize the tendency for these wells to pump dry after a short pumping period. It will also decrease the length of time required to refill after being pumped dry.

Hydrographs plotted from water-level measurements from till wells commonly show large fluctuations (Kelly and Paulson, 1970, p. 46). However, these large fluctuations may not be due entirely to effects of precipitation. Willis and others (1964) have shown that large water-level fluctuations in fine-grained materials such as till may occur in the absence of precipitation and may be largely due to thawing of frozen layers during the spring months. Preliminary data from a series of temperature sensors installed in glacial till from 15 to 200 centimeters (5.9 to 78 inches) below land surface in Cavalier County indicate that with the freezing of the till there is a corresponding decrease in water levels in nearby observation wells, and with spring melting there is a rise in water levels.

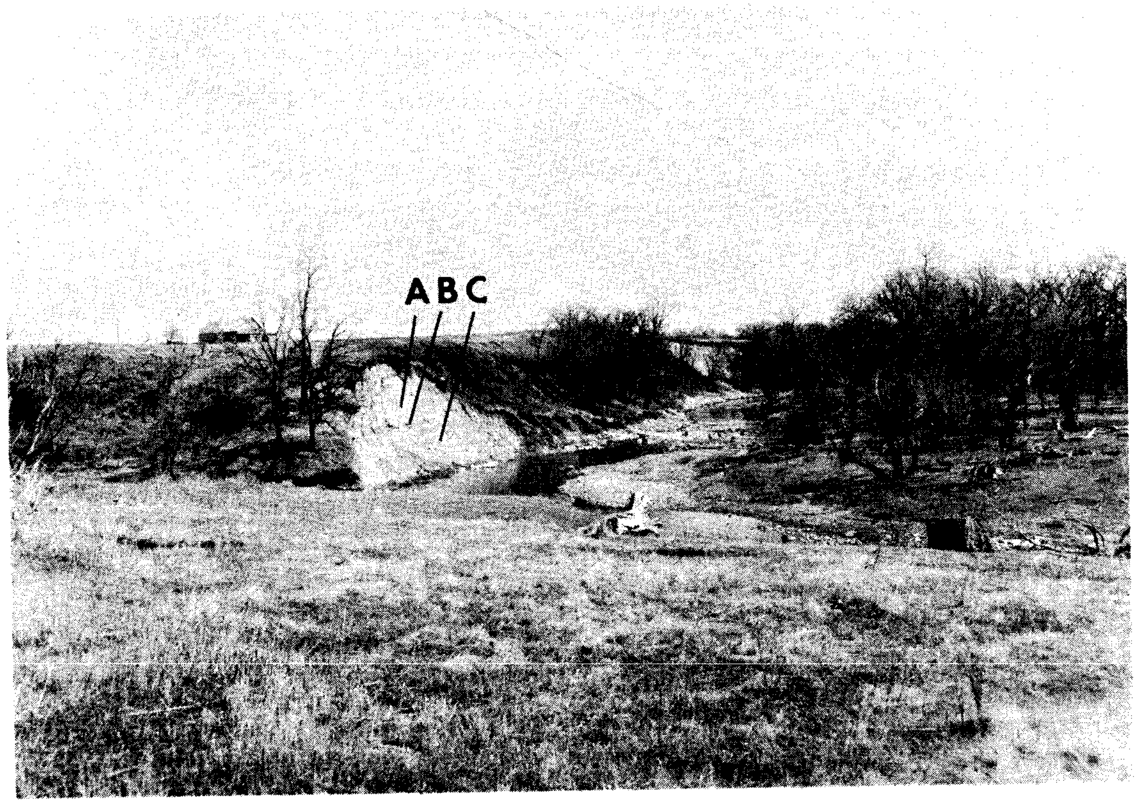


FIGURE 25. Exposures of glacial till along the channel of the Park River west of Homme Dam, Walsh County. The gravel (B) yields water from seeps at the contact between till (A) and till (C).

The chemical quality of water from deposits of till differs widely from one location to another. Samples of water collected from wells tapping the till had dissolved-solids contents that ranged from 414 to 6,350 mg/l. This variation of water quality in the till is due mainly to sources of recharge and hydraulic connection with other aquifers.

Aquifers in Ice-Contact Deposits

Many small deposits of sand and gravel called kames, eskers, and glacial spillways are found in Nelson and Walsh Counties. In general, these deposits are the result of glacial ice melting in place and leaving a deposit of sand and gravel. Often the bulk of these deposits are above the general water table of the area and only a thin water-saturated zone exists near the base. During periods of the year when precipitation is at a minimum, these deposits may be completely dry.

A few of the larger ice-contact deposits, such as those south of Michigan and west and south of Lakota, may yield sufficient water for general farm use; however, in most localities the ice-contact deposits are not capable of yielding more than 10 gpm to wells over a long period of time.

Water quality from these aquifers is generally fair to good with dissolved-solids content below 1,000 mg/l.

REGIONAL GROUND–WATER FLOW SYSTEM AND GEOCHEMICAL RELATIONS

Nelson and Walsh Counties are located near the eastern edge of a large and complex regional ground-water flow system that originates, in part, many miles to the west. The mechanics of this system probably are quite similar to the system in southern Saskatchewan and Manitoba described by Meyboom (1966), who suggested that the deep ground-water flow system of Saskatchewan discharges in eastern Manitoba as salt springs along the western edge of the Canadian Shield.

The scope of this investigation did not permit the collection and analysis of data that would accurately define the deep ground-water flow system in Nelson and Walsh Counties or relate it to the larger regional system; however, the data did indicate general areas of recharge, discharge, and direction of ground-water movement.

The deep ground-water flow system is recharged in the topographically high areas of Cavalier, Nelson, and Walsh Counties and areas to the west. From these areas, ground water moves eastward and northeastward toward the topographically lower areas in the eastern parts of Walsh and Pembina Counties. Plate 1 illustrates, schematically, the deep ground-water flow system in Walsh County.

Ground-water recharge areas are characterized by decreasing potentiometric head with depth, whereas discharge areas are characterized by increasing head. Wells 156-55-1CCB2 and 156-55-1DBD in Walsh County illustrate decreasing head with depth in a recharge area. Well 156-55-1DBD, 130 feet deep, had a water level of 10 feet (918 feet above msl); whereas well 156-55-1CCB2 is 345 feet deep and had a water level of about 60 feet below land surface (876 feet above msl). These two wells are located less than half a mile apart. Examples of increasing head with depth are wells 156-51-34BAA and 156-51-36CAA (Downey, 1971b), located about 2 miles apart in the discharge area of eastern Walsh County. Well 156-51-36CAA, 165 feet deep, had a water level of 1 foot above land surface (805 feet above msl); whereas well 156-51-34BAA, 265 feet deep, had a water level of 10 feet above land surface (816 feet above msl).

The chemical changes that occur as the ground water moves eastward beneath Walsh County are shown on plate 1. In general, water from the recharge area is a calcium or sodium bicarbonate type of relatively low salinity. As the water moves downward and to the east through the glacial drift and underlying bedrock, it dissolves mineral matter and increases in dissolved-solids content. In addition, the water becomes mixed with the highly saline water from the deeper flow system. As shown on plate 1, calcium bicarbonate water with low dissolved solids from recharge areas, such as the Fordville aquifer, becomes mixed with the water from the deep flow system and changes to a sodium chloride type of high salinity in the discharge area in the eastern part of Walsh County.

This change in water type in Walsh County is similar to the geochemical sequence described by Maclay and Winter (1967) for an area in northwestern Minnesota:

$$HCO_3^- \rightarrow HCO_3^- + SO_4^= \rightarrow SO_4^= + Cl^- \rightarrow Cl^- + SO_4^= \rightarrow Cl^-$$

The sodium bicarbonate type water is developed early in the sequence according to Maclay and Winter. This water type appears to be developed only locally in the Fordville aquifer and the aquifers associated with the Lake Agassiz beaches. Sodium bicarbonate water occurs at isolated locations in the Pierre aquifer.

Origin of Saline Water in Lakes in Eastern Walsh County

Two small saline lakes located in eastern Walsh County are associated with depressions that overlie deposits of fine sand and gravel. Lake depressions such as these have been attributed to artesian water discharging as springs from deep regional flow systems (Laird, 1944). Expanding on this idea is the hypothesis (Downey, 1969, p. 12) that during glaciation of the area, melt water, resulting from pressure melting at the base of the ice sheet, was forced into the Dakota aquifer because of the great hydrostatic pressure present. Upon deglaciation, the hydrostatic pressure was removed allowing large quantities of water to move rapidly out of the Dakota aquifer. This rapid movement of water through the overlying materials resulted in the erosion of the lake sediments, forming the depressions in which the two lakes exist today.

Test drilling during this study indicates that fairly thick deposits of glacial sand and gravel underlie the depressions and appear to be hydraulically connected with the underlying bedrock. Test hole 155-52-27CDC, located south of Lake Ardoch, penetrated 102 feet of clayey sand and sandy clay above bedrock. Test hole 158-51-31CCC, located near the south edge of Salt Lake, penetrated 212 feet of sand and gravel beneath 68 feet of silty clay. Water flowed from both test holes at the time of drilling.

Chemical analyses of water samples taken from the test holes and lakes indicate a similarity to bedrock water and that water is able to move upward from the bedrock aquifers (pl. 1) through the glacial sand and gravel deposits to discharge points at the bottom of the lakes. During periods of low stage, water from Salt Lake had a dissolved-solids content of about 18,900 mg/l. Water from a nearby test hole (158-51-31CCC) had a dissolved-solids content of about 8,060. The higher value of the lake water may be due to concentration of solids by evaporation of water from the lake; however, an analysis of water from a test hole 1 mile to the east (157-51-6AAA) showed 12,300 mg/l dissolved solids, and a test hole 5¼ miles farther east (158-51-25CDC) produced water with a dissolved-solids content of about 23,900 mg/l.

Chemical analysis of water from Lake Ardoch indicated a dissolved-solids content of 21,400 mg/l. The samples were collected from seeps at the bottom of the lake at low stage. The water was a sodium sulfate chloride type. Water from a nearby test hole (155-52-27CDC1) had a dissolved-solids content of 13,800 mg/l and was also a sodium sulfate chloride type.

During most of the year Lake Ardoch probably functions as a ground-water drain for the underlying bedrock aquifer; however, during the winter the lake and lake bottom slowly freeze and ground-water discharge to the lake is decreased. During this period many of the ground-water seeps in the lake bottom continue to flow at decreasing rates until late February or early March, depending on temperature during the preceding months.

GROUND–WATER UTILIZATION

General

A large percentage of the population of Nelson and Walsh Counties is dependent upon ground water for their supply of water for domestic and livestock needs. Three communities–Grafton, Park River, and Minto–obtain their water from surface sources. All other communities in both counties obtain their municipal supply of water from wells.

Rural Domestic and Livestock Use

Many of the older domestic and livestock wells in both counties are of large diameter and of hand-dug or bored construction. In general, these wells are less than 100 feet deep and normally penetrate only the first water-bearing zone. Most of these wells tap lenses of sand and (or) gravel interbedded in the glacial till, or tap sand units within silt and clay deposits. Yields from these large-diameter wells are normally below 10 gpm, but are sufficient for most domestic uses and for small herds of livestock.

Most of the farm wells drilled in recent years are about 4 to 6 inches in diameter and are completed in the most productive aquifer available. In many cases these wells tap a bedrock aquifer such as the Pierre or the Dakota. In most of the area the Pierre aquifer will supply from 1 to about 5 gpm to properly constructed wells. Yields within this range provide sufficient water for most small farm and domestic needs.

The Dakota aquifer is capable of yielding more than 500 gpm to wells at selected locations; however, most farm wells tapping the Dakota aquifer yield much less because of type of construction. Wells tapping the Dakota aquifer that are located in areas with a land-surface elevation below 900 feet flow without pumping. This artesian flow is used to provide water for livestock in the eastern part of Walsh County. However, use of water from the Dakota aquifer has declined in recent years and only a few new Dakota wells are drilled each year. Most of the new wells provide water for washing potatoes.

Public Supplies

Nine communities in Nelson and Walsh Counties have municipal water supplies; six use ground-water sources. The daily pumpage for each city, if not otherwise specified, is based on the 1970 population. Further growth of a community would increase the amount of water used. A change in local industry also would affect the quantity of water used. Chemical analyses of water from the various communities or municipal supplies are given in tables 4 and 5, Part II (Downey, 1971b) of this series.

Adams

Adams, in northwestern Walsh County, obtains its municipal supply from one well located about 1 mile north of the city. This well taps highly fractured shale of the Pierre Formation, and is reported to be capable of yielding more than 25 gpm. Water from this well had a specific conductance of about 2,000 micromhos. Reported daily pumpage during 1969 was 33,000 gallons. Additional water for the city system may possibly be obtained by locating wells near the present production well. However, the fracture system may be of very limited extent and well yields similar to the present production well should not be expected.

Aneta

Aneta, located in southeastern Nelson County, obtains its supply from a well that taps a small deposit of glacial outwash. Reported daily pumpage for 1969 was 25,000 gallons. Additional water may be obtained by developing wells to the south of the present well.

Grafton

Grafton, the major population center of Walsh County, uses the Park River as a source for its municipal water system. Daily pumpage ranges from about 800,000 to 1,200,000 gallons depending upon the season of the year. Average pumpage is about 1,000,000 gpd.

Lakota

Lakota, the major population center of Nelson County, obtains water for the municipal system mainly from four wells located in a small deposit of glacial outwash near the city. Two wells are reported to be capable of yielding 125 gpm each, and the other two 40 gpm each. Daily pumpage ranges from about 130,000 gallons during the winter to about 225,000 gallons in the summer. Average daily pumpage is about 170,000 gallons.

Mc Ville

The city of McVille, in Nelson County, obtains its water from two wells tapping the McVille aquifer, and pumps about 70,000 gpd from the aquifer. The McVille aquifer is capable of meeting the future water needs of the city.

Michigan City

Michigan City, in Nelson County, is utilizing both the Pierre aquifer and small glacial deposits as a source of water, for its municipal system. Several wells, tapping both aquifers are pumped to supply the estimated 40,000 gpd required by the city. Wells could be developed in the Pierre aquifer if additional water is required by the city, however, yields greater than about 5 gpm should not be expected.

Minto

The city of Minto, in Walsh County, obtains the 60,000 gallons of water required daily from the Forest River. Daily pumpage ranges from a low of about 50,000 gallons in the winter to about 70,000 gallons in the summer. Additional water could be obtained from the Dakota aquifer, which underlies the city; however, the water is of poor quality.

Park River

Park River, located in central Walsh County, secures its water from Homme Reservoir on the Park River. Estimated daily use is about 200,000 gallons.

Tolna

The city of Tolna, in Nelson County, obtains its water from two wells that tap deposits of glacial outwash associated with the Spiritwood aquifer. Each well is reported to yield about 25 gpm and together supply the city's needs of 15,000 gpd. The Spiritwood aquifer is capable of meeting the future needs of the city.

Rural Water Districts

Rural water districts have been growing in number in recent years in many of the rural areas of the United States, and one recently has been formed in Grand Forks County. With proper planning, these districts are able to provide large quantities of good quality water to farms and small municipalities.

A rural water district could be used in those parts of Nelson and Walsh Counties where wells supply water of poor quality. Three aquifers, the Spiritwood, McVille, and Fordville, could be used as sources of water.

Irrigation

A variety of factors influence the suitability of an area for irrigation, but probably the most important is an adequate supply of suitable water. The Fordville aquifer in Walsh County and the Spiritwood and McVille aquifers in Nelson County offer sources of water for irrigation of most crops. Irrigation indices for water from these aquifers are shown in figure 7. To date little use has been made of these aquifers to supply water for irrigation.

SUMMARY AND CONCLUSIONS

About 600 to 2,700 feet of sedimentary rocks underlie Nelson and Walsh Counties. The thickest section underlies western Nelson County and the thinnest underlies eastern Walsh County. The rocks consist of shale, sandstone, and limestone and include units of Ordovician, Jurassic, and Cretaceous age. The sedimentary rocks in turn are overlain by glacial drift that is as much as 320 feet thick.

The lithology and distribution of geologic units control the occurrence and availability of ground water in Nelson and Walsh Counties. Aquifers in the two-county area are of two main types--those in the bedrock (sedimentary rocks) and those in the glacial drift.

The Dakota aquifer probably is the most productive of the bedrock aquifers. Wells penetrating this aquifer range in depth from about 200 feet in eastern Walsh County to more than 1,300 feet in Nelson County. The aquifer is absent from the northeastern part of Walsh County. Artesian flows from wells tapping the Dakota aquifer range from less than 1 gpm to about 2 gpm, but may be as much as 50 gpm from large-diameter efficient wells. Flow rates are controlled by the thickness and water-yielding properties of the sandstone unit penetrated by the well. Dissolved solids averaged about 4,510 mg/l and the water generally was a sodium chloride type.

The Pierre aquifer underlies western Walsh and most of Nelson Counties at shallow depths and supplies water to a large number of users. The Pierre aquifer yields water from fracture zones that appear to have resulted from glacial action. The best developed fracture zone is about 3 to 6 miles wide and is along a north-south line that passes through Michigan City. Wells tapping the Pierre aquifer may yield as much as 5 gpm; however, most yield less. Transmissivity of the Pierre near the center of the best developed fracture zone ranges from 66 to 121 square feet per day. The storage coefficient is approximately 0.00042. Water from the Pierre is of fair to poor quality. Dissolved-solids content of water from the fracture zone near Michigan was near 2,200 mg/l. Water from wells outside of the zone had a much higher dissolved-solids content.

The largest glacial-drift aquifer in the two-county area is the Spiritwood, which is located in southwestern Nelson County. This aquifer underlies about 52 square miles and has an average thickness of about 100 feet. Parts of the aquifer will yield more than 500 gpm to properly constructed wells. Water from the Spiritwood is, in general, a calcium or sodium bicarbonate type of relatively good quality. The mean dissolved-solids content among 18 samples was 656 mg/l.

The McVille aquifer has the greatest potential for development of any aquifer in Nelson County. It extends about 31 miles across the county and has an average width of about three-eighths of a mile. The aquifer consists of silty clay, sand, and gravel deposited in a buried river valley cut into the Pierre Formation. The McVille aquifer is capable of supporting well yields of more than 500 gpm south of east Stump Lake, where water from the aquifer is a calcium bicarbonate type of good quality. Dissolved-solids content in that area was less than 300 mg/l.

The Fordville aquifer is the largest and most productive glacial-drift aquifer in Walsh County. The aquifer underlies about 33 square miles in the south-central part of the county. Geologically, the aquifer deposits are part of the Elk Valley delta, but hydrologically the aquifer is separate. The Fordville aquifer is exposed at the surface and is readily recharged. Ground-water movement is generally southward to discharge areas along the North Branch and main stem of the Forest River. Transmissivity of the Fordville aquifer ranges from 5,830 to 8,860 square feet per day. The average storage coefficient is 0.16. Well yields of more than 500 gpm are possible in the northeastern part of the aquifer. The water is of relatively good chemical quality and is a calcium sodium bicarbonate type. Dissolved-solids content ranged from 315 to 595 mg/l.

The Medford aquifer, located south of the Fordville aquifer and extending into Grand Forks County, underlies about 3 square miles in Walsh County. Based on the lithology of the aquifer materials, well yields of about 10 to 50 gpm should be available. Water quality would be similar to that of the Fordville aquifer.

The Edinburg aquifer, which underlies about 13 square miles in north-central Walsh County, is capable of supporting well yields of 10 to 50 gpm. The dissolved-solids content of the water was low, ranging from 450 to 900 mg/l.

Lake Agassiz beach deposits may be capable of yielding fairly large quantities of fair to good quality water for short periods of time. However, the beach deposits store only small quantities of water, and long-term high yields should not be expected. Because the beaches are shallow surface deposits of sand and gravel that readily accept recharge, considerable attention should be paid to the prevention of contamination of water in the beach aquifers from barnyard sources and domestic waste-disposal systems.

Small quantities of ground water may be obtained from deposits of silt in the central and eastern parts of Walsh County and from till and (or) associated sand and gravel deposits and ice-contact deposits in both counties. These small aquifers supply water that is generally potable but well yields are small.

Geochemical relationships and data on potentiometric heads indicate that the main direction of ground-water movement in Nelson and Walsh Counties is eastward and northeastward. Ground water is recharged in the topographically high areas of Nelson and western Walsh Counties and regions farther west. The water becomes increasingly saline as it moves from the recharge areas to the discharge areas in eastern Walsh County, and changes in chemical quality from a predominantly calcium bicarbonate type to a sodium chloride type. Saline lakes have been formed in eastern Walsh County as the result of natural artesian discharge.

A large percentage of the population of Nelson and Walsh Counties is dependent upon ground water for their supply of water for domestic and livestock needs. The incorporated communities of Adams, Aneta, Lakota, McVille, Michigan, and Tolna obtain their public supply from wells. Grafton, Park River, and Minto use surface-water sources. Rural water districts offer the advantages of a public supply, similar to those available to city residents, to the rural population. Three aquifers, the Spiritwood, McVille, and Fordville, could be used to supply good quality water at moderate cost to a large area of both counties.

Sufficient quantities of suitable quality water for irrigation are available from the Spiritwood, McVille, and Fordville aquifers in the two-county area.

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