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COUNTY GROUND WATER STUDIES 13

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Geology and Ground Water Resources of GRAND FORKS COUNTY

Part III

GROUND WATER RESOURCES

by

T. E. Kelly and Q. F. Paulson

Prepared by the United States Geological Survey
in cooperation with the North Dakota State
Water Commission, the North Dakota Geological Survey,
and the Grand Forks Water Management District.

1970

This is one of a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. The reports are in three parts; Part I describes the geology, Part II presents ground water basic data, and Part III describes the ground water resources. Parts I and II have been published previously.

CONTENTS

ILLUSTRATIONS

TABLES

GEOLOGY AND GROUND WATER RESOURCES OF

GRAND FORKS COUNTY, NORTH DAKOTA

PART 3 - GROUND WATER RESOURCES

By T. E. Kelly and Q. F. Paulson

ABSTRACT

Ground water is obtainable in Grand Forks County both from the bedrock and from the overlying glacial drift deposits. Bedrock aquifers include rocks of Ordovician age and the Dakota Group and Pierre Formation of Cretaceous age. Sustained yields of as much as 500 gallons per minute have been pumped from the Dakota in eastern Grand Forks County. Water from the bedrock aquifers generally is very saline.

Five major aquifers in the glacial deposits were delineated by test drilling. These are the Elk Valley, Inkster, Emerado, Grand Forks, and Thompson aquifers. The Elk Valley and Inkster aquifers are the most productive and yield the best quality of water. The Elk Valley aquifer covers at least 200 square miles, and yields greater than 500 gallons per minute are obtainable locally. The Inkster aquifer is small but contains water of excellent quality. The Emerado, Grand Forks, and Thompson aquifers contain water of poor chemical quality, probably because of contamination by highly mineralized water from the underlying bedrock aquifer.

Regional ground-water movement is eastward, and eastern Grand Forks County is part of a large artesian discharge area. Geochemical data indicate a progressive water quality change eastward across the county from a low-salinity calcium bicarbonate type to a high-salinity sodium sulfate chloride type.

INTRODUCTION

Purpose and Scope

A cooperative study of the ground-water resources and geology of Grand Forks County (fig. 1) was begun in July 1964 and was

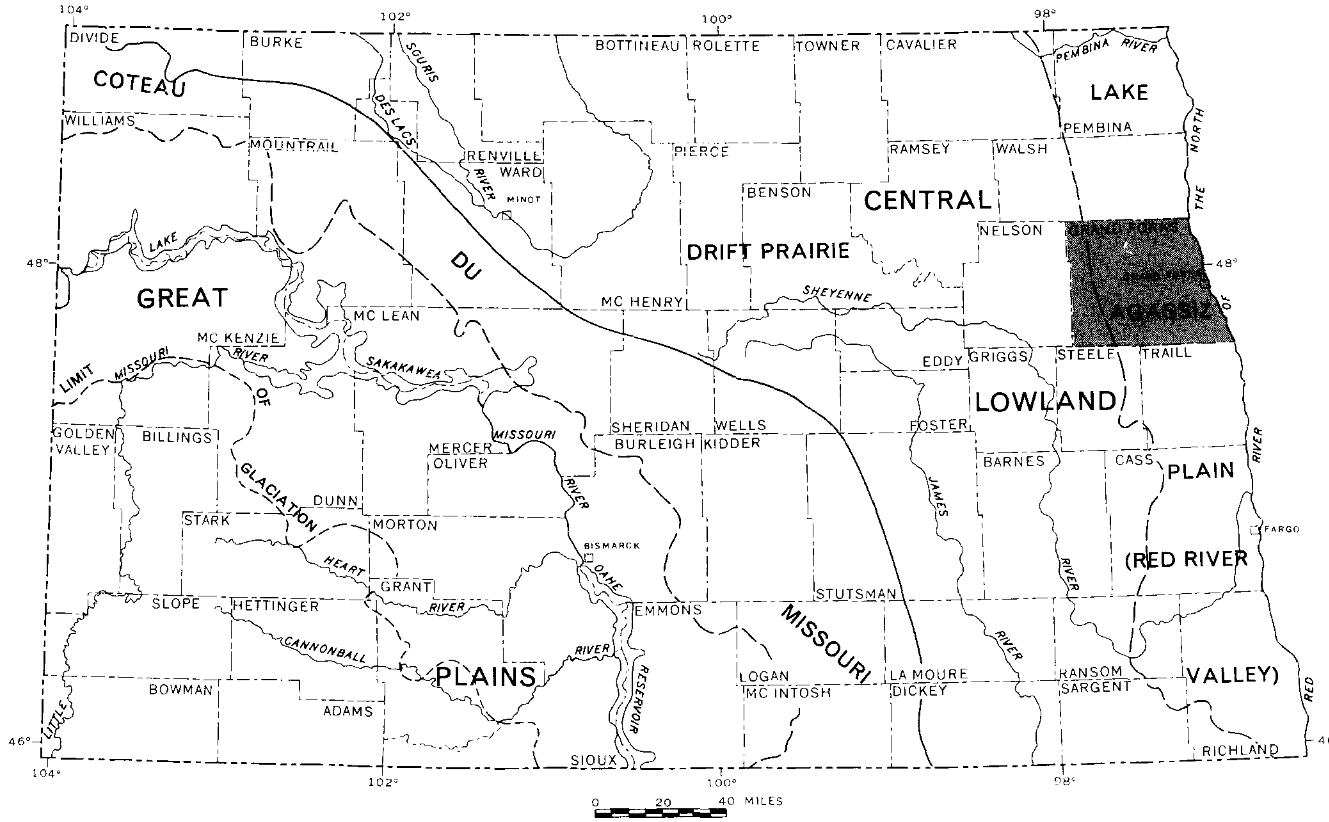


FIGURE 1.—Physiographic divisions in North Dakota and location of report area.

completed in June 1968 by the U. S. Geological Survey, the North Dakota State Water Commission, the North Dakota Geological Survey, and the Grand Forks County Water Management District. The purpose was to determine the quantity and quality of ground water in the county available for municipal, domestic, industrial, and irrigation uses.

Specifically, the objectives within the scope of financing and time available were to: (1) determine the location, extent, and nature of the major aquifers; (2) evaluate the occurrence and movement of ground water, including the sources of recharge and discharge; (3) estimate the quantities of water stored in the aquifers; (4) estimate the potential yields to wells tapping the major aquifers; and (5) determine the chemical quality of the ground water.

Records of more than 1,000 wells and springs were collected during the study and about 160 test holes were drilled. Also, monthly water-level measurements were made in 69 observation wells during the period of study. Approximately 100 wells and springs were sampled for chemical analysis. These data have been published as Part 2 of the Grand Forks County ground-water study (Kelly, 1968a). The geology of the county was studied jointly by Jack Kume and Dan E. Hansen of the North Dakota Geological Survey, and the report will be published as Part 1 of the Grand Forks County ground-water study. This report, Part 3, is based largely on data from Parts 1 and 2.

The stratigraphic nomenclature used in this report is that of the North Dakota Geological Survey and may differ somewhat from that used by the U. S. Geological Survey.

Previous Investigations

The earliest ground-water data for Grand Forks County were reported by Upham (1895, p. 573-574) as part of his study of glacial Lake Agassiz. Simpson (1929, p. 135-140) described generally the ground-water resources of Grand Forks County as part of a Statewide survey. Abbott and Voedisch (1938, p. 60-61) listed the chemical constituents of ground-water samples from the area. Laird (1944) described the ground-water resources of the Emerado area in central Grand Forks County, and Robinove and others (1958) included several chemical analyses of ground water from Grand Forks County. The ground-water resources in the Northwood and Reynolds areas were described by Jensen (1961 and 1962). Beeks (1967) included a small part of Grand Forks County in his ground-water investigation of the

Hatton area. Kelly (1968a) tabulated the ground-water basic data of the county.

Acknowledgments

The authors are grateful to the residents of Grand Forks County who contributed helpful information during the study, and to members of the Water Management District, other county officials, and the Grand Forks Herald for aid and publicity. They made it possible to complete the fieldwork without unnecessary delays. Particular recognition is due R. W. Schmid and M. O. Lindvig of the North Dakota State Water Commission, who were largely responsible for the aquifer-test data in the Elk Valley and Inkster aquifers. L. C. Benz and E. J. Doering of the U. S. Department of Agriculture, Agriculture Research Service, contributed valuable information relating to the water-yielding properties of the Dakota aquifer. Messrs. H. C. Groth and William Groth of Inkster and C. A. Kyllo of McCanna deserve special mention for their cooperation in providing facilities for aquifer testing.

General Features of the Area

Grand Forks County has an area of 1,438 square miles, and in 1960 had a population of 48,677 (U. S. Bureau of the Census, 1960). The July 1966 population was estimated to be 67,100 (U. S. Bureau of the Census, 1968, p. 12). More than 80 percent of the population lives in the city of Grand Forks and at the Grand Forks Air Force Base, 20 miles west. The economy of the county is based on agriculture. Potatoes, sugar beets, and small grains are the principal crops.

The county is located within the drainage system of the Red River of the North, which is part of the Hudson Bay system. Several streams traverse the county and empty into the Red River of the North, which forms the eastern boundary of the County. The major tributaries to the Red River that cross the area include the Goose, Turtle, and Forest Rivers (pl. 1, in pocket). Numerous smaller streams drain into these rivers or into the Red River itself.

The topography of the county ranges from broad, flat plains to gently rolling hills that were produced mainly by glacial activity. Glacial deposits cover most of the county, except where stream valleys have been eroded into the underlying shale in the western part.

Most of the county, except a narrow strip along the western edge, was inundated by glacial Lake Agassiz (fig. 1). The pre-Agassiz topography was eroded by wave action and the eastern part of the county is blanketed by lacustrine deposits. The surface of the lacustrine deposits is extremely flat and slopes northeastward at a gradient of less than 5 feet per mile. The central part of the county is characterized by long, narrow beach ridges that rise 5 to 10 feet above the lake plain and are oriented northwest-southeast (fig. 13). The areas not covered by Lake Agassiz form a gently rolling till plain (Drift Prairie) that contains sloughs and other undrained depressions.

Maximum topographic relief in the county exceeds 700 feet. The highest altitude is more than 1,500 feet above sea level on the summits of hills in the southwestern part of the county, and the lowest altitude is about 775 feet in the Red River channel where it leaves Grand Forks County. Local relief, however, rarely exceeds 100 feet in 1 mile, and in parts of the lake basin is less than 5 feet in 1 mile.

Grand Forks County has a continental climate characterized by extreme ranges in temperature. The average temperature for the winter months of December, January, and February is 8.4°F and for the summer months of June, July, and August is 67.7°F. The average annual precipitation at Grand Forks is 20.12 inches (U. S. Weather Bureau, 1965-68). Normally, more than half of the total precipitation during the year occurs during the 4-month period, May through August. Only about half an inch is received during each of the winter months of December, January, and February.

Well-numbering System

The well-numbering system used in this report (fig. 2) is based on the federal system of rectangular surveys of the public lands. The first numeral denotes the township, the second denotes the range, and the third denotes the section in which the well, spring, or test hole is located. The letters a, b, c, and d designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract). Thus, well 150-51-15aaa would be located in the NE 1/4 NE 1/4 NE 1/4 of sec.

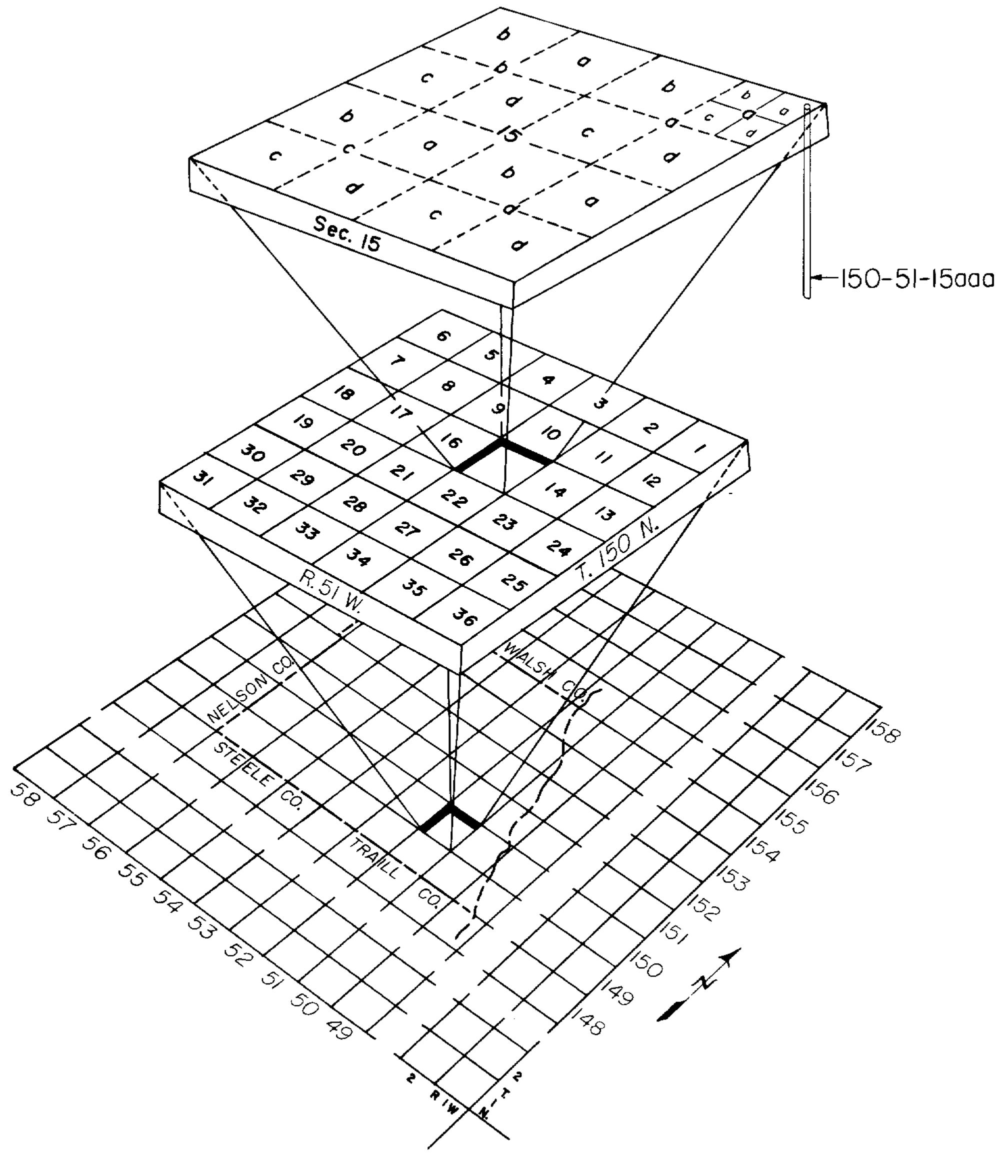


FIGURE 2. System of numbering wells, springs, and test holes.

15, T. 150 N., R. 51 W. If the well were located in the NE 1/4 SW 1/4 SE 1/4 of the section, the letter designation would be dca. This numbering system also is used in this report for the location of small areas.

PRINCIPLES OF GROUND-WATER OCCURRENCE

The ultimate source of ground water is precipitation. After the precipitation falls on the earth's surface, part is returned to the atmosphere by evaporation, some runs off to the streams, and the remainder percolates into the ground. Much of the water that sinks into the ground is held temporarily in the soil and is returned to the atmosphere either by evaporation or by transpiration. The water that infiltrates downward to a saturated zone (zone of saturation) becomes ground water.

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

Definitions

Porosity is the ratio of the volume of the open or pore space in a rock to its total volume and is an index of the storage capacity of the material. Elsewhere in this report, estimates of storage based on areal extent, thickness, and porosity are given for each of the major aquifers. However, these quantities are given only as a means of volumetric comparison. They do not refer to the amount of water that can be withdrawn from the aquifers through wells. Such determinations would require additional quantitative hydrologic data and are beyond the scope of this study.

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

Transmissivity is a measure of the rate of flow through porous material and is often expressed as the number of gallons or cubic feet of water that will move in 1 day under a unit hydraulic gradient (1 foot per foot) through a vertical strip of the aquifer 1-foot wide extending the full saturated height of the aquifer.

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

The term hydraulic conductivity is preferred by many workers in the field of hydrology as a replacement term for coefficient of permeability and defines the rate of flow in cubic feet per square foot, other parameters being equal.

The storage coefficient refers to the volume of water released from or taken into storage per unit of surface area of the aquifer per unit change in the component of head normal to that surface. Under artesian or confined conditions, the storage coefficient is equal to a very small fraction of the porosity. However, under water-table or unconfined conditions, the storage coefficient is much larger and is practically equal to the specific yield, which is the ratio of the volume of water released by gravity drainage to the volume of the material drained. The specific yield may be as much as half the total porosity.

The upper surface of the zone of saturation is called the water table. This surface is irregular and is controlled by the topography, geology, and hydrology of the area. Water-table conditions refer to a ground-water environment that is not confined by overlying impermeable beds, and the water is free to move in response to gravity. If an aquifer is overlain by relatively impermeable beds, the water may be confined under pressure exerted by water at higher elevations and by the confining beds. In those areas where the water is confined, the water level will rise above the level at which it is first encountered; wells supplied from this type of aquifer are said to be artesian.

The water level in a well fluctuates in response to recharge to and discharge from the aquifer. Atmospheric pressure changes and land surface loadings also cause minor water-level fluctuations in confined aquifers. The static level is the water level in a well when it is not being pumped. When water is withdrawn from a well, the water level near the well is lowered and the water-level surface around the well resembles a cone. This is referred to as the cone of depression. The amount of water-level drawdown, or the difference between the static and pumping levels, is controlled by the hydraulic properties of the aquifer, the physical characteristics of the well, and the rate and duration of pumping. During constant and uniform discharge from a well, the water level declines rapidly at first and then continues to lower at a decreasing rate as the cone of depression expands.

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

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

Under natural conditions, over a long period of time, the rate of discharge from an aquifer approximately equals the rate of recharge.

Withdrawal of water from an aquifer eventually causes one or a combination of the following: (1) a decrease in the rate of natural discharge, (2) an increase in the rate of recharge, or (3) a reduction in the volume of water in storage. The maximum rate of ground-water withdrawal that can be maintained indefinitely is related directly to the rate of recharge. However, recharge is regulated largely by climate and geologic controls and may not be possible to evaluate quantitatively without large amounts of data.

QUALITY OF WATER

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

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

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

Table 1, modified from Durfor and Becker (1964, table 2), shows the major constituents in water, their major sources, and their effects upon usability. Most, if not all, of the mineral shown in the major source column are present in the glacial drift or in the bedrock directly underlying the drift in Grand Forks County.

The chemical analyses of water in Grand Forks County were listed by Kelly (1968a, table 4), and are summarized in figure 3.

Dissolved Solids and Specific Conductance

The concentration of dissolved solids is a measure of the total mineralization of water. The dissolved solids concentration is significant because it may limit the use of water for many purposes. In general the suitability of water decreases with an increase in dissolved solids. The

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

(Concentrations are in parts per million)

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

Constituents	Major source	Effects upon usability	U. S. Public Health Service recommended limits for drinking water[1]
Silica (SiO_2)	Feldspars, ferromagnesium, and clay minerals.	In presence of calcium and magnesium, silica forms a scale in boilers and on steam turbines that retards heat transfer.	
Iron (Fe)	Natural sources: Amphiboles, ferromagnesium minerals, ferrous and ferric sulfides, oxides, and carbonates, and clay minerals. Man-made sources: well casings, pump parts, storage tanks.	If more than 0.1 ppm iron is present, it will precipitate when exposed to air; causing turbidity, staining plumbing fixtures, laundry and cooking utensils, and imparting tastes and colors to food and drinks. More than 0.2 ppm is objectionable for most industrial uses.	0.3 ppm
Calcium (Ca)	Amphiboles, feldspars, gypsum, pyroxenes, calcite, aragonite, dolomite, and clay minerals.	Calcium and magnesium combine with bicarbonate, carbonate, sulfate, and silica to form scale in heating equipment.	
Magnesium (Mg)	Amphiboles, olivine, pyroxenes, dolomite, magnesite, and clay minerals.	Calcium and magnesium retard the suds-forming action of soap. High concentrations of magnesium have a laxative effect.	
Sodium (Na)	Feldspars, clay minerals, and evaporites.	More than 50 ppm sodium and potassium with suspended matter causes foaming, which accelerates scale formation and corrosion in boilers.	
Potassium (K)	Feldspars, feldspathoids, some micas, and clay minerals.		
Boron (B)	Tourmaline, biotite, and amphiboles.	Many plants are damaged by concentrations of 2.0 ppm.	
Bicarbonate (HCO_3)	Limestone and dolomite	Upon heating, bicarbonate is changed to steam, carbonate, and carbon dioxide.	
Carbonate (CO_3)		Carbonate combines with alkaline earth (principally clacium and magnesium) to form scale.	
Sulfate (SO_4)	Gypsum, anhydrite, and oxidation of sulfide minerals.	Combines with calcium to form scale. More than 500 ppm tastes bitter and may be a laxative.	250 ppm
Chloride (Cl)	Halite and sylvite.	In excess of 250 ppm may impart salty taste, greatly in excess may cause physiological distress. Food processing industries usually require less than 250 ppm.	250 ppm
Fluoride (F)	Amphiboles, apatite, fluorite, and mica.	Optimum concentration in drinking water has a beneficial effect on the structure and resistance to decay of children's teeth. Concentrations in excess of optimum may cause mottling of children's teeth.	Recommended limits depend on average of maximum daily temperature. Limits range from 0.6 ppm at 90.5°F to 1.7 ppm at 50°F.
Nitrate (NO_3)	Nitrogenous fertilizers, animal excrement, legumes, and plant debris.	More than 100 ppm may cause a bitter taste and may cause physiological distress. Concentrations greatly in excess of 45 ppm have been reported to cause methemoglobinemia in infants.	45 ppm
Dissolved solids	Anything that is soluble.	More than 500 ppm is not desirable if better water is available. Less than 300 ppm is desirable for some manufacturing processes. Excessive dissolved solids restrict the use of water for irrigation.	500 ppm

[1] U. S. Public Health Service, 1962.

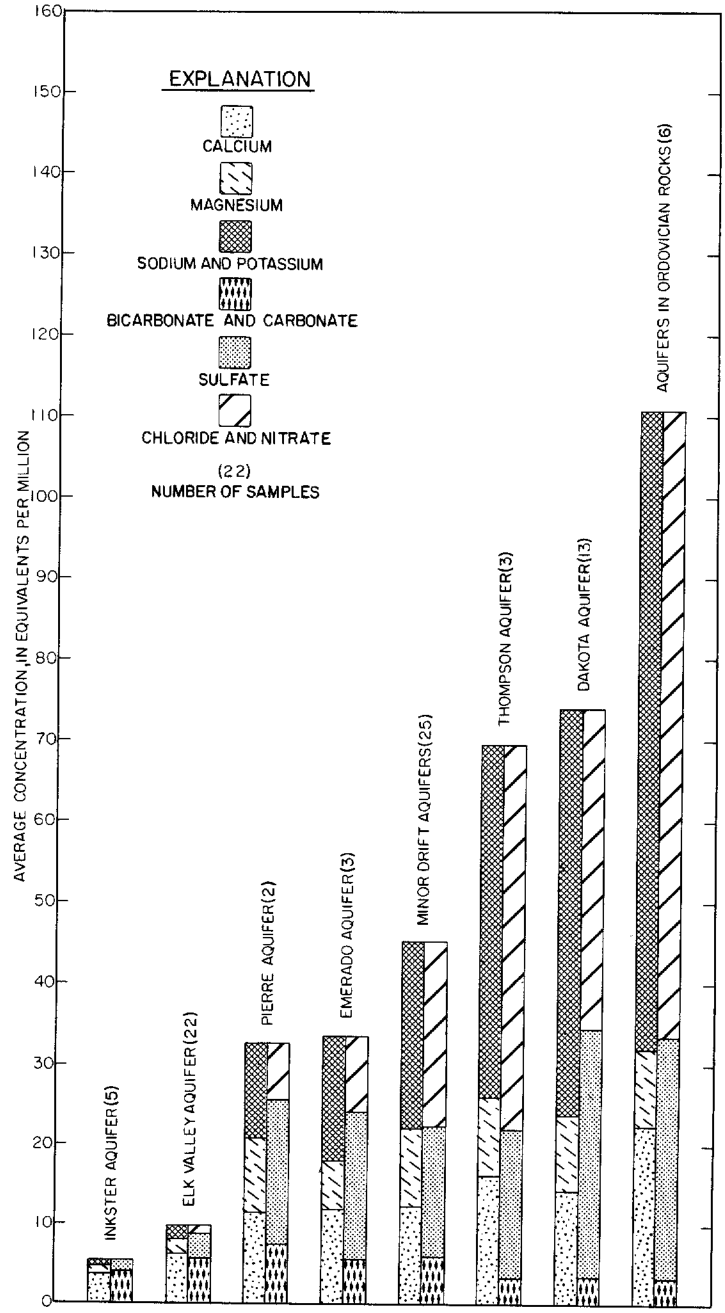


FIGURE 3. Major constituents in ground water in Grand Forks County.

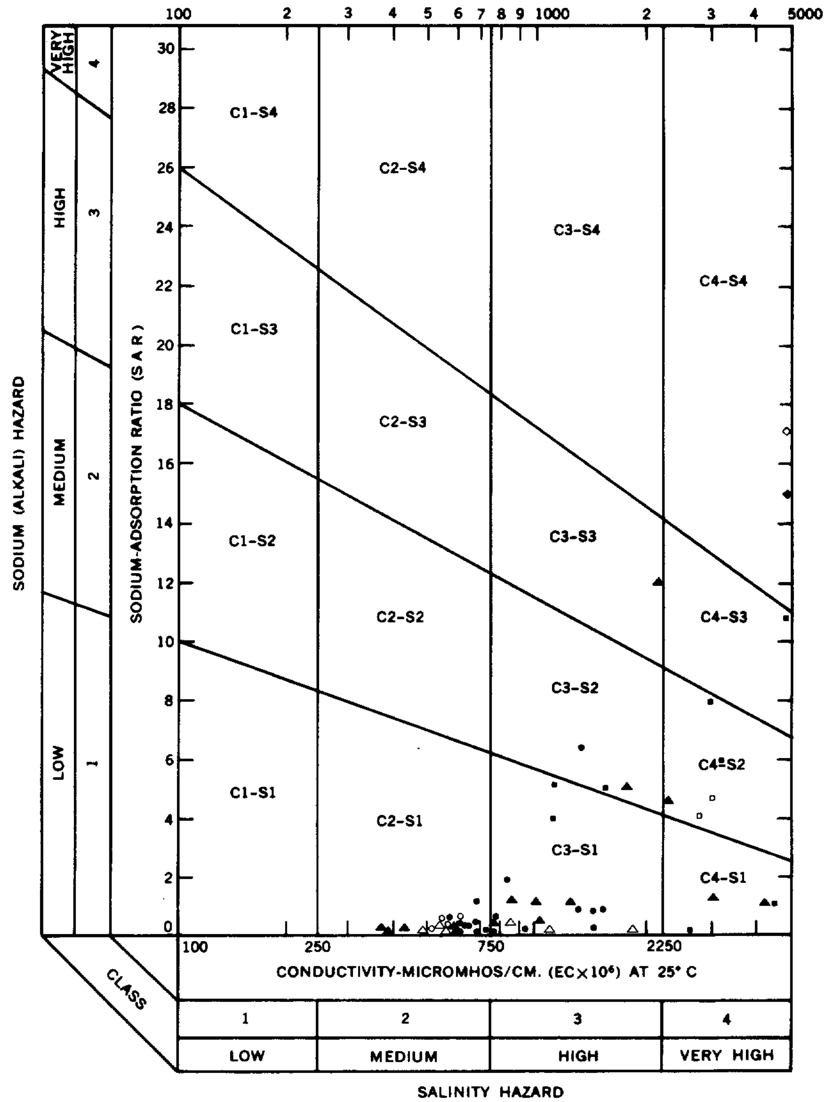
limits shown in table 1 for drinking water were originally set for common carriers in interstate commerce. Residents in areas where dissolved solids are as high as 2,000 ppm have consumed the water with no noticeable ill effects. Livestock has been known to survive on water containing 10,000 ppm. However, growth and reproduction of livestock may be affected by water containing more than 3,000 ppm of dissolved solids.

The specific conductance of water is a measure of the water's capacity to conduct an electrical current; it is a function of the amount and kind of dissolved mineral matter. Specific conductance usually is reported in micromhos. An estimate of the total dissolved solids in parts per million can be obtained by multiplying specific conductance by 0.65; however, the conversion factor may range from 0.5 to 1.0, depending upon the type and amount of dissolved minerals (Hem, 1959, p. 40).

Irrigation Indices

Two indices used to show the suitability of water for irrigation are SAR and specific conductance. SAR is related to the sodium hazard; the specific conductance is related to the salinity hazard. The hazards increase as the numerical values of these indices increase. Figure 4 shows the SAR versus the specific conductance indicated by analyses of water from major drift aquifers in Grand Forks County. Much of the water is of marginal quality for irrigation; however, high sodium or high salinity waters have been used successfully for selected crops where ideal soil conditions and drainage exist.

Another index used to evaluate irrigation water is the residual sodium carbonate (RSC). This quantity is determined by subtracting the equivalents per million of calcium and magnesium from the sum of equivalents per million of bicarbonate and carbonate. Waters having an RSC between 1.25 and 2.5 epm are considered marginal for irrigation. An RSC of more than 2.5 epm indicates that the water is not suitable for irrigation purposes. Generally the ground water in Grand Forks County has an RSC index of less than 2.5 epm. Good management practices might make it possible to use successfully some of the marginal RSC water for irrigation. For further information, the reader is referred to "Diagnoses and Improvement of Saline and Alkali Soils" (U. S. Salinity Laboratory Staff, 1954).



EXPLANATION

ELK VALLEY AQUIFER	AQUIFERS IN LAKE AGASSIZ BEACH DEPOSITS
INKSTER AQUIFER	AQUIFERS IN LAKE AGASSIZ SILT DEPOSITS
EMERADO AQUIFER	AQUIFERS IN THE TILL
GRAND FORKS AQUIFER	
THOMPSON AQUIFER	

FIGURE 4. Classification of water samples for irrigation use.

Hardness

The hardness of water determines its usefulness for laundries and for some industries. The U. S. Geological Survey rates hardness as follows: water having a hardness of 0 to 60 ppm calcium carbonate is soft, between 61 and 120 ppm is moderately hard, between 121 and 180 ppm is hard, and more than 180 ppm is very hard. Hardness does not seriously interfere with the use of water for most purposes, but it does increase the consumption of soap. Its removal by a softening process can be profitable for domestic uses, for laundries, and for some industries. Water from the glacial drift in Grand Forks County is generally very hard; whereas water from Cretaceous rocks, except shallow water in the Pierre Formation, is generally soft.

GEOLOGIC SETTING

Grand Forks County is located near the eastern edge of the Williston basin. Precambrian rocks underlie the eastern edge of the county at depths of only a few hundred feet and crop out farther east in Minnesota. The depth to Precambrian rocks increases rapidly westward and is about 2,000 feet near the western boundary of the county. The sedimentary rocks overlying the Precambrian range in age from Ordovician to Holocene, but many gaps due to nondeposition or erosion interrupt the stratigraphic sequence. For the purpose of describing the occurrence of ground water in the county, these rocks are divided into two main groups; (1) the preglacial rocks and (2) the glacial drift.

OCCURRENCE OF GROUND WATER

Ground Water in the Preglacial Rocks

The Precambrian rocks contain only small amounts of water in joints or fractures, and it is doubtful that substantial quantities of water could be obtained from them. The preglacial sedimentary rocks overlying the Precambrian contain at least three aquifers. These occur in rocks of Ordovician age and in the Dakota Group and Pierre Formation of Cretaceous age.

Aquifers in Rocks of Ordovician Age

The rocks of Ordovician age beneath Grand Forks County have been subdivided by the North Dakota Geological Survey into two units, the Winnipeg Group and the overlying Red River Formation.

The Winnipeg Group consists of a moderately thick sequence of shale, sandstone, and shaly limestone that overlies the granite. Greenish-gray, noncalcareous shale is the principal lithology, but a sequence of lenticular sandstone and limestone is present near the middle of the group. The sandstone beds are water bearing and probably are tapped by a substantial number of wells in eastern Grand Forks County. None of the test holes drilled during the present study are believed to have penetrated the full thickness of sandstone beds in the Winnipeg Group. Test hole 150-50-17dcc penetrated 35 feet of sandstone from 275 to 310 feet and test hole 150-51-27ccc penetrated 59 feet from 224 to 283 feet (Kelly, 1968a, p. 64, 68). Several other test holes penetrated lesser amounts. Carlson (1957) reported 63 feet of Winnipeg sandstone from 902 to 965 feet below land surface in the North Plains Petroleum Inc. Danner No. 1 oil-test well (152-54-24dcc). About 30 feet of sandstone was reported (S. B. Anderson, oral commun., 1968) to have been penetrated by the Sastex Oil and Development Co. No. 1 Nereson oil-test well (152-51-17bbb) below a depth of 410 feet. Anderson and Haraldson (1968, p. 38), in a study of cement-rock deposits of eastern North Dakota, report 20 feet of Winnipeg sandstone at a depth of 320-340 feet in a test hole drilled at 151-51-23add.

The sandstone generally is very fine to fine grained and consists of well-sorted and rounded quartz grains. Commonly the color is reddish brown due to iron staining.

The test-hole data indicate that the sandstone beds contain an aquifer of some importance. The areal extent of these deposits is rather poorly defined; however, it is likely they underlie much of central Grand Forks County.

The Red River Formation overlies the Winnipeg Group. This formation was described by Ballard (1963, p.5) as a lower unit of mottled, fossiliferous, fragmental, microgranular dolomite and dolomitic limestone, and an upper unit of fragmental limestone, argillaceous dolomite, and minor amounts of anhydrite. The Red River

Formation was reported to be 340 feet thick in the Danner No. 1 oil-test well (Carlson, 1957).

The water yield from the Red River Formation is not known. The productivity of carbonate rocks is dependent upon the number and size of joints, fractures, and solution cavities penetrated by a well. Highly fractured or cavernous limestone commonly yields very large quantities of water, whereas solid limestone will yield little or no water.

In general the water in the Ordovician rocks is very saline and the total dissolved solids may exceed 10,000 ppm (Kelly, 1968a, table 4, well 152-50-33bad). The principal constituents are sodium and chloride (fig. 3).

Dakota Aquifer

The Dakota aquifer is one of the most widespread in the United States. It has been described in most of the States of the Great Plains from western Iowa to Montana and as far south as New Mexico. The water-bearing materials consist mainly of fine-grained quartzose sandstone that is interbedded with dark-gray shale. The sandstone and shale occur in varying proportions, and it is the amount of sandstone present that determines the quantity of ground water available.

This aquifer has yielded more water than any other in Grand Forks County. The earliest wells were drilled during the 1880's, but fewer wells are now being drilled to the Dakota because of the greatly reduced hydraulic heads available and the unsuitability of the water in modern plumbing and appliances. The primary use of water from the Dakota at the present time (1968) is for livestock watering.

Wells that tap the Dakota aquifer in Grand Forks County generally are between 100 and 1,000 feet deep. Well depths generally increase westward (fig. 5). Dakota wells are more numerous in the eastern part of the county because of the shallower depths and also because the wells will flow at land surface.

All of the test holes drilled to the Dakota aquifer during this study were drilled in the eastern part of the county (none west of R. 52 W.), where the upper part of the water-bearing rocks has been removed by erosion. Most of the test holes were drilled only a few feet into the aquifer, but three (149-51-15bab, 152-52-9aaa, and 153-51-10ddc) completely penetrated it. The thickness of the sand beds in these three test holes was 51, 78, and 50 feet, respectively. The Scott and Larson No. 1 Scott oil-test hole (151-53-15aaa) near Emerado penetrated a total of 130 feet of sandstone in six separate beds, in addition to numerous thin beds of sandy shale (Nelson, 1955). The ARS

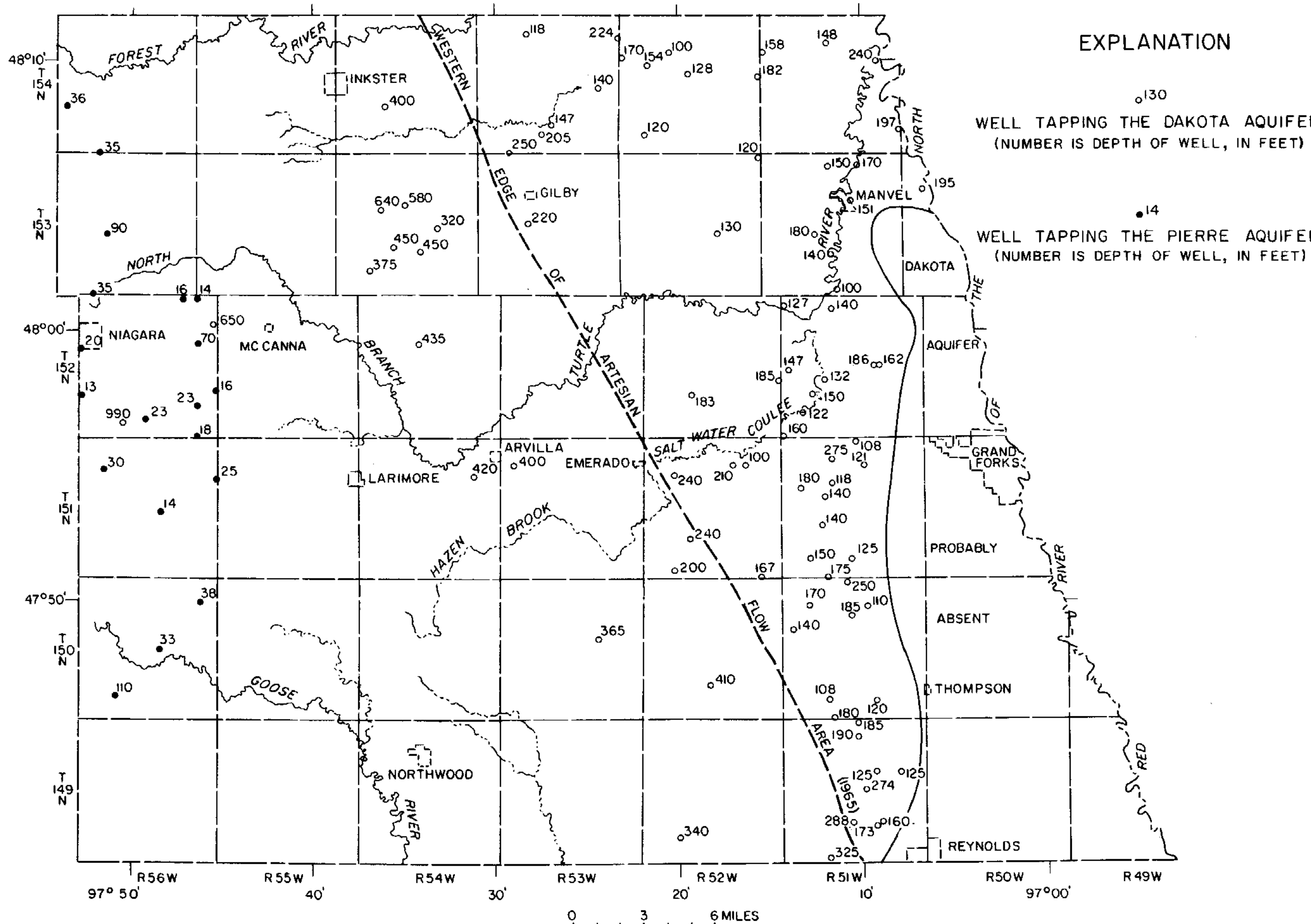


FIGURE 5. Depth of selected wells tapping the Dakota and Pierre aquifers and area of artesian flow from the Dakota aquifer.

(Agricultural Research Service) test well in 152-51-15ddd penetrated 65 feet of sand (Kelly, 1968a, p. 89). It is doubtful that individual sand and (or) sandstone beds persist for any great distance, although many of them interfinger and are hydraulically interconnected. The average overall thickness of the aquifer in Grand Forks County is about 100 feet.

Drill cuttings indicate that the sand and (or) sandstone in the Dakota aquifer commonly is medium to coarse grained, rather well sorted, and free of intergranular clay and silt. However, cores from oil tests in other parts of the State indicate that the sandstone is interbedded with shale laminae, which are not apparent in drill cuttings. Consequently, it is often difficult to determine accurately the lithology of the formation from drill cuttings.

Most of the wells tapping the Dakota aquifer in eastern Grand Forks County flow at land surface (fig. 5). Records of flow rates and pressures during the early years of development are scarce. Upham (1895, p. 574) reported that a well drilled at Manvel initially flowed 40 gpm (gallons per minute). Kelly (1968a, table 1) listed flow rates for small-diameter domestic and stock wells, which were measured mostly in 1964. The average flow was less than 2 gpm. Most of the wells are open end or are screened in only a few feet of sand near the top of the aquifer. Deeper wells with greater screened intervals would generally yield larger quantities by flow, as evidenced by ARS test well 152-51-15ddd, which penetrated the full thickness of the aquifer and reportedly flowed at an initial rate of 50 gpm (Kelly, 1968, p. 28).

Many of the Dakota wells have continued to flow for 40 years or more, although at declining rates. The decrease in flow rates is due primarily to regional head decline, and secondarily to casing failure or incrustation of the well casing by salts precipitated from the water. The amount of head decline that has occurred in the Dakota is difficult to determine because of the lack of historical data. Studies by Hard (1929, p. 59) showed that in southeastern North Dakota there was a large head decline prior to 1900 and a decline of nearly 200 feet between 1902 and 1923.

The Agricultural Research Service made a lengthy pumping test on the Dakota aquifer in October 1967 in order to study the effects of hydraulic-head decline in the Dakota on the overlying water-table aquifers (E. J. Doering and L. C. Benz, written commun., 1968). Well 152-51-15ddd was pumped for 18 days at a constant rate of 500 gpm. Water levels were measured in the pumped well and in four observation wells at distances of 90, 200, 400, and 800 feet from the pumped well. The aquifer at the test site consists of 65 feet of well-sorted very fine to fine quartzose sand from 111 to 176 feet.

The data were analyzed by the nonequilibrium method devised by Theis (1935) and modified by Jacob (1946) to obtain an average transmissivity of 47,000 gpd (gallons per day) per foot and a storage coefficient of 0.0002. The drawdown in the pumped well after 24 hours of pumping was 33.8 feet and the specific capacity was 14 gpm per foot of drawdown. The total drawdown in the pumped well at the end of the test was 39.7 feet. Doering and Benz reported (written commun., 1968) that the flows from domestic and stock wells 2 1/2 and 3 miles away were reduced by from 30 to 85 percent during the test.

Knowing the transmissivity, it is possible to compute the amount of ground water moving through the aquifer from a form of Darcy's law, expressed as Q = TIW, where Q is the volume of water in gallons per day, T is the transmissivity, I is the hydraulic gradient in feet per mile (estimated to be 5 feet per mile toward the east), and W is the width of flow cross section in miles. Thus, the eastward flow across a 1-mile section = 47,000 x 5 x 1 = 235,000 gpd.

The volume of water stored in each square mile of the aquifer, using a porosity of 43 percent (Wenzel and Sand, 1942, p. 41), is about 8 billion gallons or about 25,000 acre-feet. However, because of the low storage coefficient (0.0002), only a small part of the water in storage could be extracted by practical methods.

Water from the Dakota aquifer is very saline and generally unsatisfactory for domestic and most industrial uses. It is a sodium chloride type water (fig. 3), and the average dissolved solids content is about 4,400 ppm. By U. S. Public Health Service standards, the water generally contains excessive amounts of chloride, iron, sulfate, and total dissolved solids. In addition, fluoride usually is of marginal acceptability. The water from the Dakota is highly toxic to most domestic plants and small grain crops, and in places the water is too highly mineralized for use as livestock water. However, it may be suitable for certain industrial uses.

Pierre Aquifer

The Pierre aquifer yields water to a few farms in the western part of the county (fig. 5), where it is thinly covered by glacial deposits.

In Grand Forks County the Pierre has a thickness of more than 200 feet. The formation consists of a lower unit of light-gray, blocky, calcareous marl conformably overlain by an upper unit of dark-gray to black fissile, noncalcareous shale. The black, fissile shale is exposed in the upper drainage of the Turtle River and also has been penetrated by numerous test holes drilled in the western part of the county. The

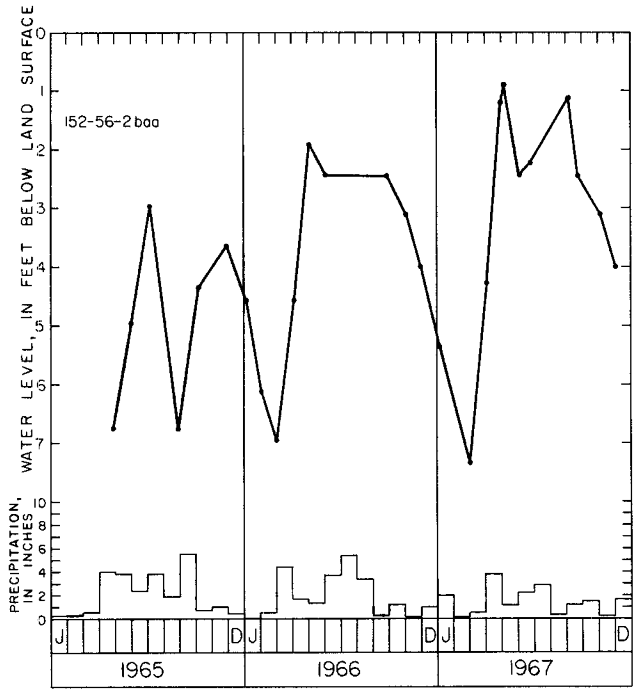


FIGURE 6. Water-level fluctuations in the Pierre aquifer, and precipitation at Larimore, N. Dak.

formation commonly contains thin beds and laminae of bentonite. No sandstone has been observed in outcrops or well cuttings from the Pierre in Grand Forks County, although sandstone units have been reported to occur in the western part of the State.

The Pierre is hydraulically connected with the saturated part of the overlying glacial drift. Consequently, fluctuations of the water levels in the Pierre are closely related to precipitation (fig. 6).

The shale has a low permeability, and water movement is mainly through secondary openings developed along joints and cleavage planes. These openings, which were produced by weathering and glacial erosion, are best developed in the upper part of the shale. Also, owing to the physical nature of the Pierre, the black, fissile shale is more highly fractured than the blocky, calcareous marl. Therefore, wells developed in the Pierre usually obtain water from the fracture system in the upper part of the formation. It is probable that most of the water in the Pierre is derived by vertical leakage from the overlying glacial drift, and once in the fracture systems, the water moves laterally toward areas of discharge.

Locally the Pierre lacks a joint system, thus forming a nearly impermeable boundary to the vertical movement of ground water. In these areas, the ground water moves laterally through the more permeable drift that overlies the Pierre, and a line of springs usually marks the contact.

Very little is known of the volume of water available from the Pierre owing to variations in fracture development. It is doubtful that sustained yields from the shale would exceed 5 gpm per well, except in locations where there is an exceptionally thick fractured zone in the shale. Most domestic and stock wells that tap the Pierre are drilled completely through the fractured zone and into the non-water-bearing shale. The lower parts of such wells serve as reservoirs, which fill slowly when the wells are not in use.

A detailed study of the Pierre was made at Michigan City, N. Dak. (Aronow, Dennis, and Akin, 1953), where more than 40 wells are known to obtain water from the aquifer. Although the area is about 12 miles west of Grand Forks County, the data are probably applicable to Grand Forks County also, owing to the uniform lithology of the Pierre.

Three aquifer tests were conducted on wells penetrating the Pierre in the Michigan City area. "Computed values of the coefficient of transmissibility (transmissivity) ranged from 490 to 900 gpd per foot and averaged 710 gpd per foot. Computed values of the coefficient of storage ranged from 2.8×10^{-4} to 5.8×10^{-4} and averaged 4.2×10^{-4}" (Aronow, Dennis, and Akin, 1953, p. 76). It is readily apparent from these low values that the Pierre would not yield large quantities of ground water to individual wells.

Water quality from the Pierre differs greatly from place to place. The principal ions usually are sodium, calcium, and sulfate and the total dissolved solids usually are more than 2,000 ppm; the water is relatively hard. In general, water from the Pierre is highly toxic to plants and cannot be used for irrigation.

Ground Water in the Glacial Drift

Grand Forks County is mantled with glacial drift, except in a few places in the western part where erosion has exposed the underlying bedrock. Generally the drift thickness increases toward the east where, in places, it is nearly 400 feet thick (Kelly, 1968a, p. 67). The average thickness among 67 test holes that completely penetrated the drift (Kelly, 1968a, table 3) was 211 feet.

The drift is composed mainly of clay-rich till, which has a low permeability and will yield only small quantities of ground water. However, in places the drift is composed of sand and (or) gravel. Where saturated with water, these deposits form aquifers of varying importance–depending on size, permeability, access to recharge, and the quality of water. Five major aquifers in the drift are described in the following sections and are shown on plate 1. They are the Elk Valley, Inkster, Emerado, Grand Forks, and Thompson aquifers. In addition, small quantities of ground water are obtainable from a variety of water-bearing deposits associated with the glacial drift that, either for reason of small storage volume or low permeability, are grouped under the heading "Minor Drift Aquifers."

Elk Valley Aquifer

The ground-water potential of the Elk Valley aquifer (pl.1) was recognized before the turn of the century by Upham (1895, p. 573-574). He reported that the water was not only plentiful but was of excellent quality. Several of the earliest municipal supplies in the county were obtained from the Elk Valley aquifer, and it is one of the more important sources of water in eastern North Dakota.

This aquifer occupies the deposits of the Elk Valley delta. Upham (1895, p. 334) first mapped the delta and reported that it extended southward from McCanna in northwestern Grand Forks County to the vicinity of Portland (in Traill County, about 38 miles southeast of

McCanna). The present study showed that the deposits also extended northward from McCanna into Walsh County. Upham named the linear depression the Elk Valley. For the purposes of this report, the Elk Valley aquifer is considered to include all of the water-bearing deposits in Grand Forks County that were mapped by Upham as part of the Elk Valley, and the delta deposits that accumulated along the west edge of the Lake Agassiz basin in Grand Forks and adjacent counties.

North of the North Branch of the Turtle River the aquifer has a fairly uniform width of approximately 3 miles (pl.1). South of that stream, the aquifer increases in width, and at the southern boundary of the county it is 12 miles wide. The overall area of the aquifer in Grand Forks County is at least 200 square miles.

Data from about 50 test holes show that the Elk Valley aquifer is somewhat lenticular, as shown in the geologic section in figure 7. The maximum thickness penetrated was 61 feet at test hole 153-55-33ddd (Kelly, 1968a, p. 104), and the average is about 34 feet. Much of the aquifer in T. 152 N., R. 55 W. is more than 50 feet thick.

Although the lithology of the aquifer deposits differs locally, there is a general gradation from coarser materials in the north to finer materials in the south. Test holes drilled in the northern part of the aquifer penetrated coarse, subangular, quartzose sand, detrital shale sand, and some gravel. Most of the gravel found was west of Inkster and is fine to medium and subrounded. In the central part of the aquifer, in the vicinity of Larimore, the sand is predominantly fine to medium grained and contains more silt and clay than does the sand farther north. In the Northwood area, at the southern end of Grand Forks County, the principal lithology is very fine sand, and still farther south in Traill County the sand grades into silt and clay.

The gradation of texture from coarse materials in the north to fine materials in the south has an important effect on the permeability and productivity of the aquifer. The largest yields probably are obtainable from the coarse sand and gravel in the north end (pl.1), and the potential yields become progressively smaller toward the south.

The Elk Valley deposits are characterized by sandy, permeable soils that readily absorb rainfall and snowmelt. Consequently, there is little surface runoff and large tracts of the deposits are undissected by streams. On drainage maps, the area underlain by the Elk Valley deposits stands out in marked contrast with areas to the west and east because of the sparseness of surface drainage.

Recharge to the aquifer is marked by a rise in the water table. The magnitude of rise varies inversely with the specific yield of the water-bearing materials. Water-level changes were monitored during the period 1964-67 in 40 observation wells and the hydrographs of 4 of the

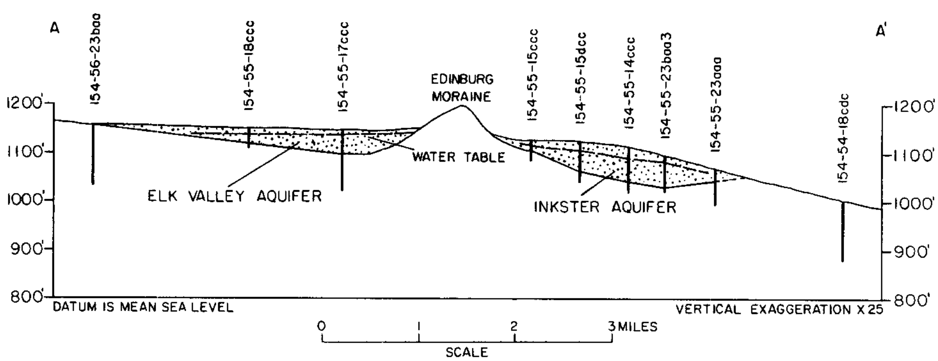


FIGURE 7. Geologic sections across the Elk Valley and Inkster aquifers. (Location shown in figure 9)

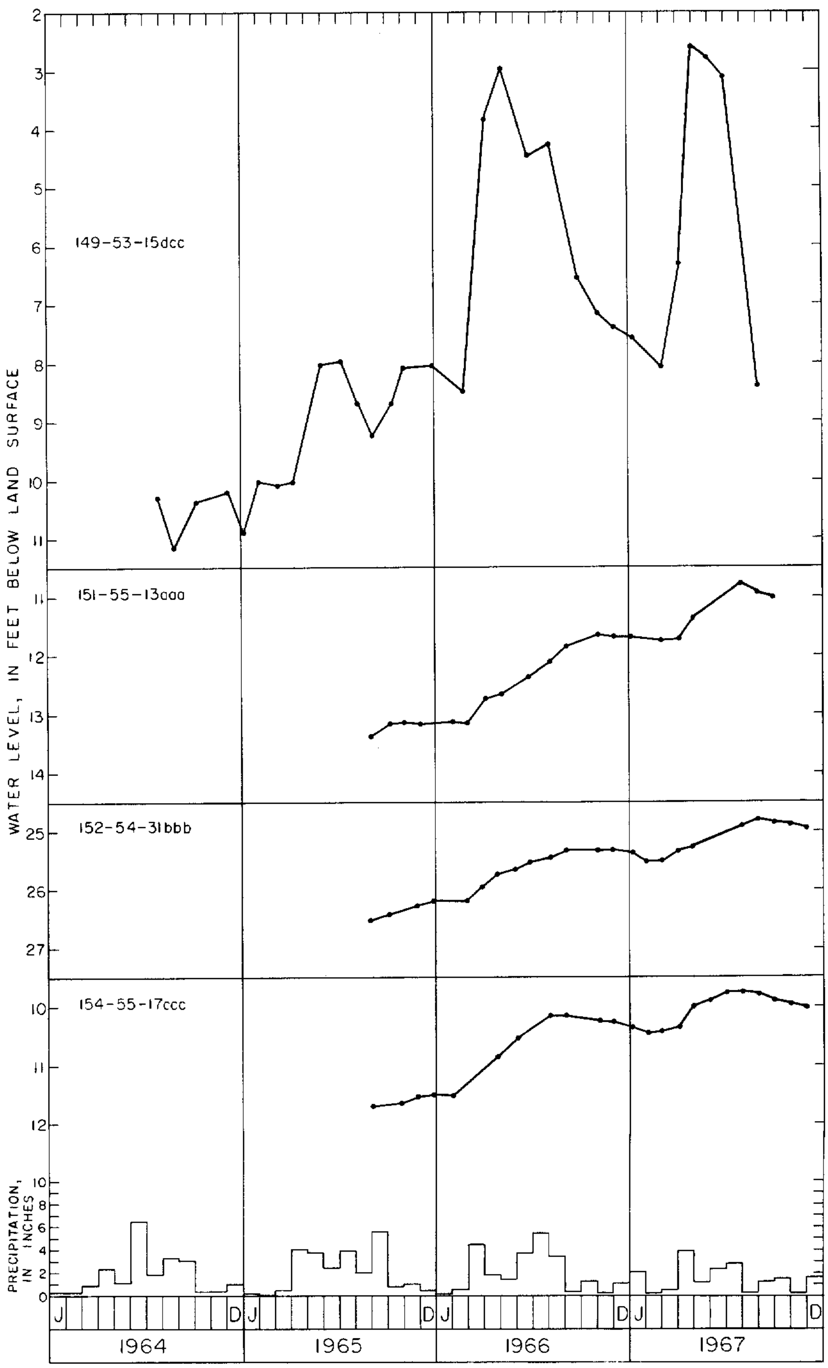


FIGURE 8. Water-level fluctuations in the Elk Valley aquifer, and precipitation at Larimore, N. Dak.

wells are shown in figure 8. Well 149-53-15dcc is only 24 feet deep and is screened in the very fine sand and silt facies that make up the southern part of the deposits. The large fluctuations recorded by this well are indicative of the small specific yield of the aquifer materials. The other three wells (151-55-13aaa, 152-54-31bbb, and 154-55-17ccc), which are deeper, progressively farther north, and screened in coarse sand and gravel, recorded small fluctuations characteristic of water-bearing materials having a high specific yield.

During the period of record the lowest water level for each year was in January or February. The water-level high in the shallow well was recorded in May or June, whereas in the deep wells not until July in one and as late as October in another.

As described previously, the Elk Valley aquifer reaches a maximum known thickness of 61 feet. Logs of about 50 test holes that completely penetrated the aquifer indicate that the average thickness is slightly more than 34 feet, and that it underlies an area of approximately 200 square miles in Grand Forks County. If a porosity of 30 percent is assumed, more than 1 million acre-feet of water is in transient storage within the Grand Forks County segment of the Elk Valley aquifer.

The aquifer is unconfined in most places, and generally the water table is about 10 feet below land surface. During the summer of 1964 the altitude ranged from about 1,140 feet msl (mean sea level) near the northern end of the aquifer to less than 1,020 feet at the southern end (fig. 9). The movement of ground water is in the direction of the water-table slope, which is eastward in most parts of the aquifer. Where the stream valleys have cut below the water table, the movement is toward the streams and, consequently, the streams act as drains.

Large quantities of ground water are discharged from the Elk Valley aquifer through springs in the stream valleys and by evapotranspiration. The major spring discharge is in the valleys of the Forest and Turtle Rivers where these streams transect the aquifer.

Discharge records (U. S. Geological Survey, 1940-67) for the Forest River near Fordville in Walsh County show that the river has not been dry since September 1940. Generally during the months October through February the river is at base flow, and all of the flow consists of ground-water discharge. The mean monthly discharges for these months since the 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 11.7 acre-feet per day. Records are not available for the Turtle River and smaller streams that traverse the Elk Valley aquifer, but it seems likely that the combined discharge of these streams is at least as much as for the Forest River.

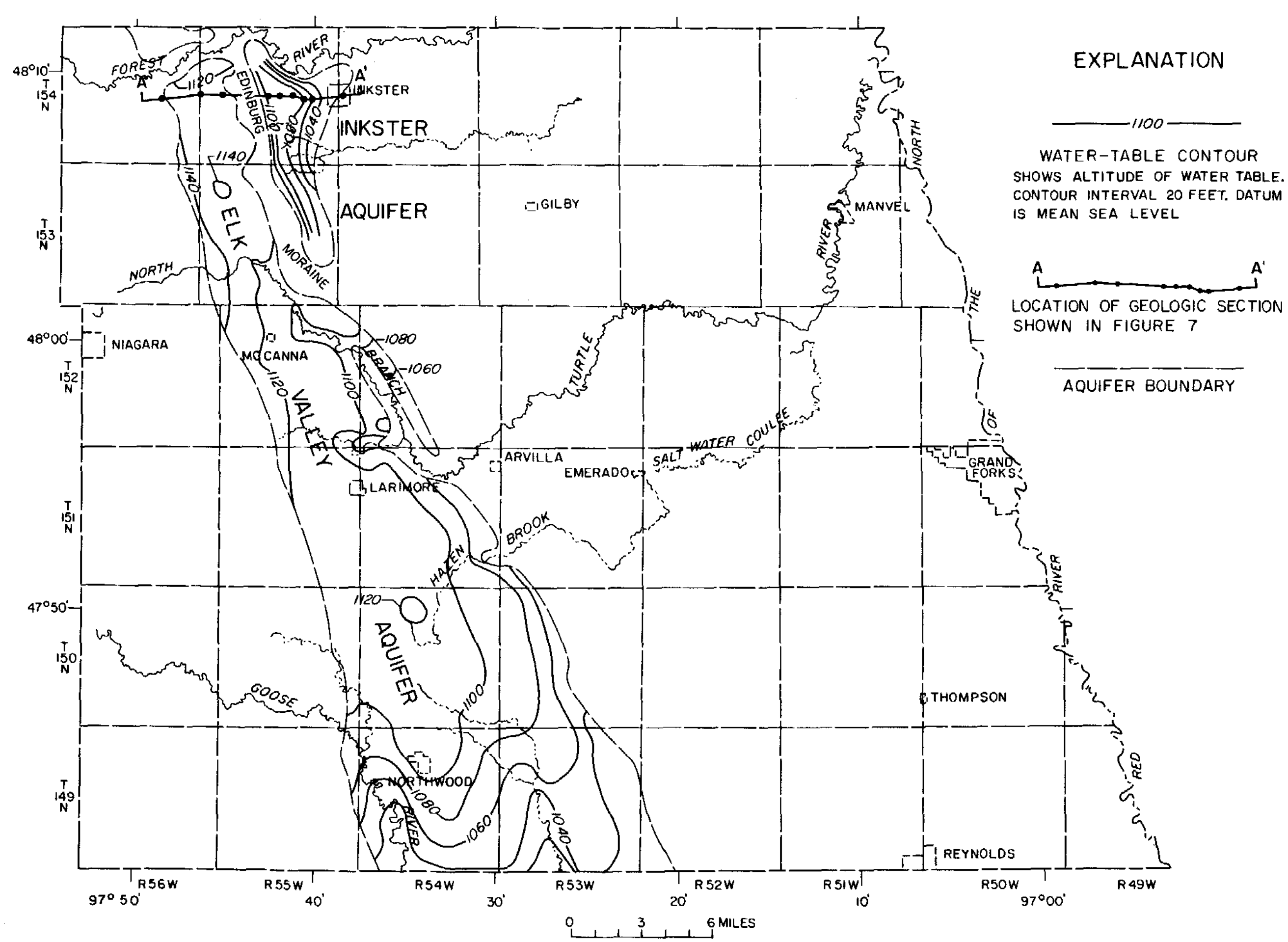


FIGURE 9. Configuration of water tables in the Elk Valley and Inkster aquifers during the summer of 1964.

In addition to spring discharge, considerable quantities of ground water are discharged during the growing season by evapotranspiration. These losses are greatest in areas where the water table is shallow. Also, the capillary rise increases as the grain size of the water-bearing materials decreases. Consequently, evapotranspiration losses probably increase toward the south because of decreasing grain size in that direction.

The amount of discharge by pumpage is comparatively small. The city of Larimore, which is the largest single user, pumps about 0.4 acre-foot per day (U. S. Public Health Service, 1963, p. 123). Probably the total pumpage from the Elk Valley aquifer for all purposes, including municipal, rural domestic, and livestock watering is less than 1 acre-foot per day.

Data are available from four aquifer tests that have been made on wells constructed in the Elk Valley aquifer. One test was made on a municipal well (149-54-9dacl) at Northwood, two on municipal wells (151-54-7ccc2 and 151-55-12dddl) at Larimore, and one on a test well (153-55-34ccc5) near McCanna. Only the test on well 153-55-34ccc5 is considered adequate to yield reliable data on aquifer properties. However, the other tests provided useful data on well performance (table 2).

The McCanna test was made by the North Dakota State Water Commission and the U. S. Geological Survey in June 1967 at the site of test well 153-55-34ccc5, which was constructed as part of this investigation. Five observation wells were drilled at distances of 100, 150, 200, 300, and 500 feet from the test well. All wells completely penetrated the aquifer, but were screened only in the lower 10 feet. The test well was pumped at a rate of 250 gpm for 6,000 minutes (4.17 days). Drawdown and recovery measurements were made on all six wells.

A plot of the drawdowns obtained in the five observation wells after 6,000 minutes of pumping is shown in figure 10. Analysis of the data by the modified nonequilibrium method of Theis (Jacob, 1946) indicates a transmissivity of 64,000 gpd per foot and a storage coefficient of 0.19.

Water samples obtained from wells tapping the Elk Valley aquifer are of relatively good chemical quality (fig. 3). The total dissolved solids ranged from 337 to 1,300 ppm (Kelly, 1968a, table 4) and average 630 ppm. More than half of the samples contained less than 500 ppm dissolved solids and only four contained more than 1,000 ppm. Although most of the samples contained a smaller concentration of the dissolved material than the maximums recommended by the U. S. Public Health Service (1962), there was considerable variation in concentration from one sample to another for any given constituent.

TABLE 2.--Summary of specific-capacity tests in the Elk Valley aquifer.

Test location	Date	Well depth (ft)	Aquifer interval (ft)	Screened interval (ft)	Pumping rate (gpm)	Duration (minutes)	24-hour specific capacity (gpm per ft of drawdown)
City of Northwood 149-54-9dacl	June 1962	52	11-52	32-52	78	1,440	6.2
City of Larimore 151-54-7ccc2	Oct. 1964	60	19-60	43-60	205 250	1,200 240	8
City of Larimore 151-55-12ddd1	May 1964	58	25-58	53-58	100	1,440	6.0
McCanna area 153-55-34ccc5	June 1967	62	19-62	52-62	250	6,000	11.7

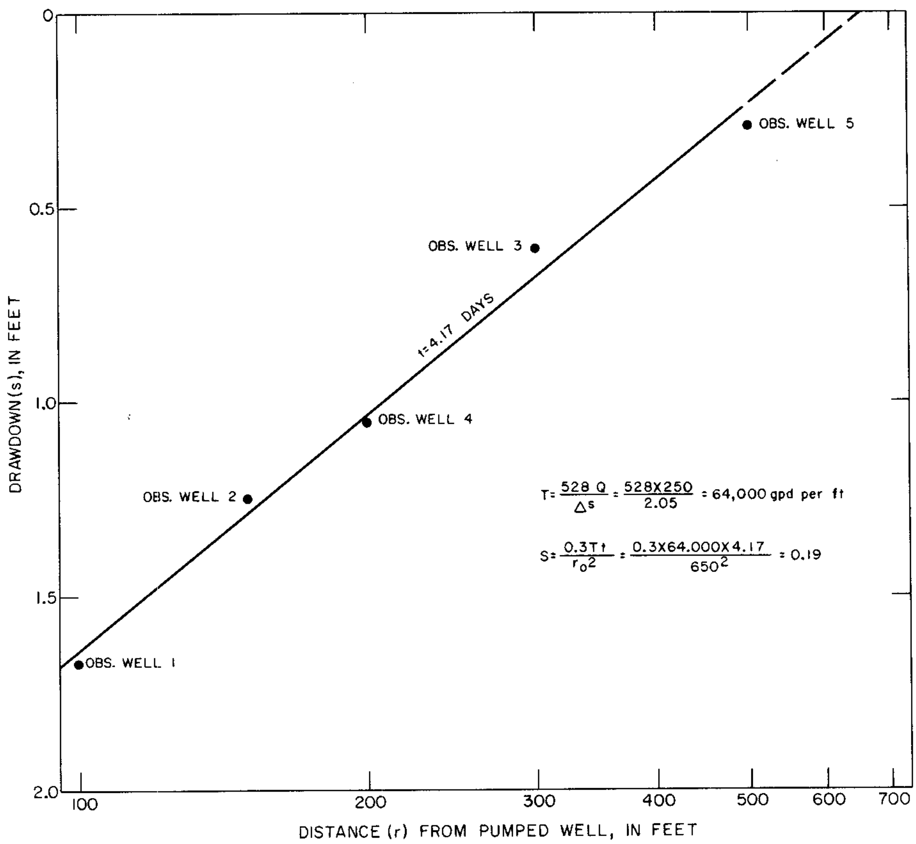


FIGURE 10. Semilogarithmic plot of drawdown (s) versus distance (r) for five observation wells during the Elk Valley aquifer test (well 153-55-34ccc5).

For example: three of the samples contained more than 50 ppm nitrate, whereas nitrate was absent in four of the samples. This variability in chemical constituents probably is due to the shallow depth at which the aquifer is located and the type of soluble material in the overlying soil. Although the water is hard by national standards, it is relatively soft in comparison with water from most of the other aquifers in the county. Water from the Elk Valley aquifer generally is a calcium bicarbonate type and is within the medium-to high-salinity, low-sodium classification (fig. 4). It would be satisfactory for irrigation of moderately well-drained soils.

Inkster Aquifer

The Inkster aquifer is located in Tps. 153 and 154 N., R. 55 W., northwestern Grand Forks County–just west of the village of Inkster for which the aquifer is named (pl.1). The southern end of the aquifer in T. 153 N., R. 55 W., however, is thin and incapable of yielding large quantities of water.

The Inkster aquifer underlies a flat to gently rolling plain characterized by sandy, highly permeable soils. The plain is bounded on the west by the ridgelike Edinburg moraine, which separates the Inkster aquifer from the Elk Valley aquifer (fig. 9). The sand and gravel deposits can be readily mapped on the surface and have an areal extent of approximately 11 square miles. The aquifer is bounded on the north by the South Branch of the Forest River and on the east by the Campbell beach and Tintah scarp of Lake Agassiz. It thins gradually toward the south.

On the basis of 11 test holes, the maximum thickness is about 50 feet and the average thickness is about 27 feet. The thickness increases from the edges toward the north-central part of the aquifer.

In general, the aquifer consists of fine-to coarse-grained sand, but locally small amounts of fine gravel are included. The sand is well sorted and contains very little silt and clay. Although the sand is composed primarily of quartz grains, many tabular fragments of shale give the sand a dark gray color. The gravel is composed largely of shale pebbles.

Owing to similar lithologies, the hydrologic characteristics of the Elk Valley and Inkster aquifers also are similar. As is true of the coarser facies of the Elk Valley aquifer, large amounts of recharge produce only slight rises in water levels (fig. 11). During periods of normal precipitation, the water levels rise in the spring and summer in response to infiltrating snowmelt and rain. During the period of record,

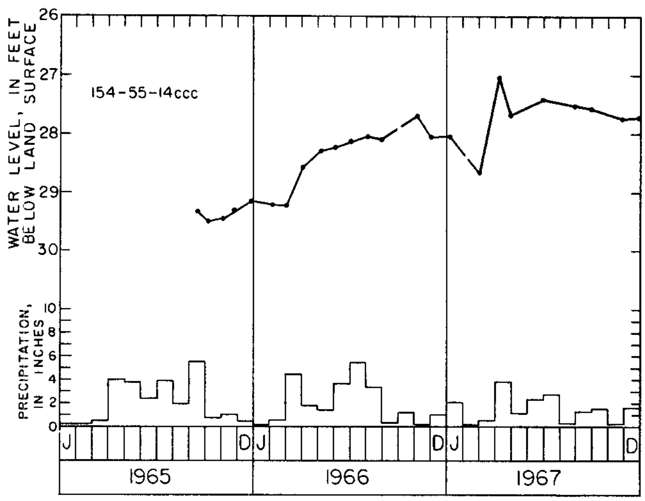


FIGURE 11. Water-level fluctuations in the Inkster aquifer, and precipitation at Larimore, N. Dak.

extending from September 1965 through December 1967, there were few abrupt fluctuations in the water level in the aquifer. The greatest normal monthly change during the period of record was a rise of 1.62 feet in March 1967.

The water table generally is between 5 and 10 feet below land surface and slopes toward the east, except adjacent to the South Branch of the Forest River where it slopes northward toward the river (fig. 9). Springs are common along the south bank of the river where the water table intersects the land surface. One of the larger is known locally as the Inkster Spring (about 1 1/2 miles west of Inkster, see pl. 1), which varies in discharge from 200 to 700 gpm. A series of streamflow measurements made along the South Branch of the Forest River on October 7, 1964 showed a gain of 2.4 cfs (1,100 gpm) along the reach that receives discharge from the Inkster aquifer.

An aquifer test was made of the Inkster aquifer in September 1966 as part of the county ground-water investigation. The Groth Brother's well (154-55-23baal), which was originally installed as a commercial water well, was pumped at the rate of 630 gpm for 4,500 minutes (3.12 days). Measurements were made in the pumped well and in five observation wells during drawdown and recovery of water levels. Three observation wells were located at distances of 75, 100, and 200 feet from the pumped well and contributed usable data during the test. Two other observation wells at distances of 300 and 500 feet, respectively, were not affected by the pumping.

Analyses of the test data indicate a transmissivity of about 53,000 gpd per foot and a storage coefficient of about 0.13 (fig. 12). It is apparent from the Inkster aquifer test that yields greater than 500 gpm can be expected in parts of the Inkster aquifer. However, the aquifer is rather small (about 60,000 acre-feet of storage), and recharge will be an important factor in future development. As is true with the Elk Valley aquifer, large developments near the South Branch of the Forest River will undoubtedly intercept ground water that normally would be discharged into the river.

The chemical quality of the water is considered excellent, except for hardness. The dissolved solids content in 5 samples ranged from 306 to 396 ppm (Kelly, 1968a, table 4) and averaged about 350 ppm. None of the constituents exceeded the maximum concentrations recommended by the U. S. Public Health Service. The water is a calcium bicarbonate type. The water is of the medium-salinity, low-sodium class (fig. 4), which indicates that it can be used for irrigation of most crops with little danger of salt accumulation in the soil.

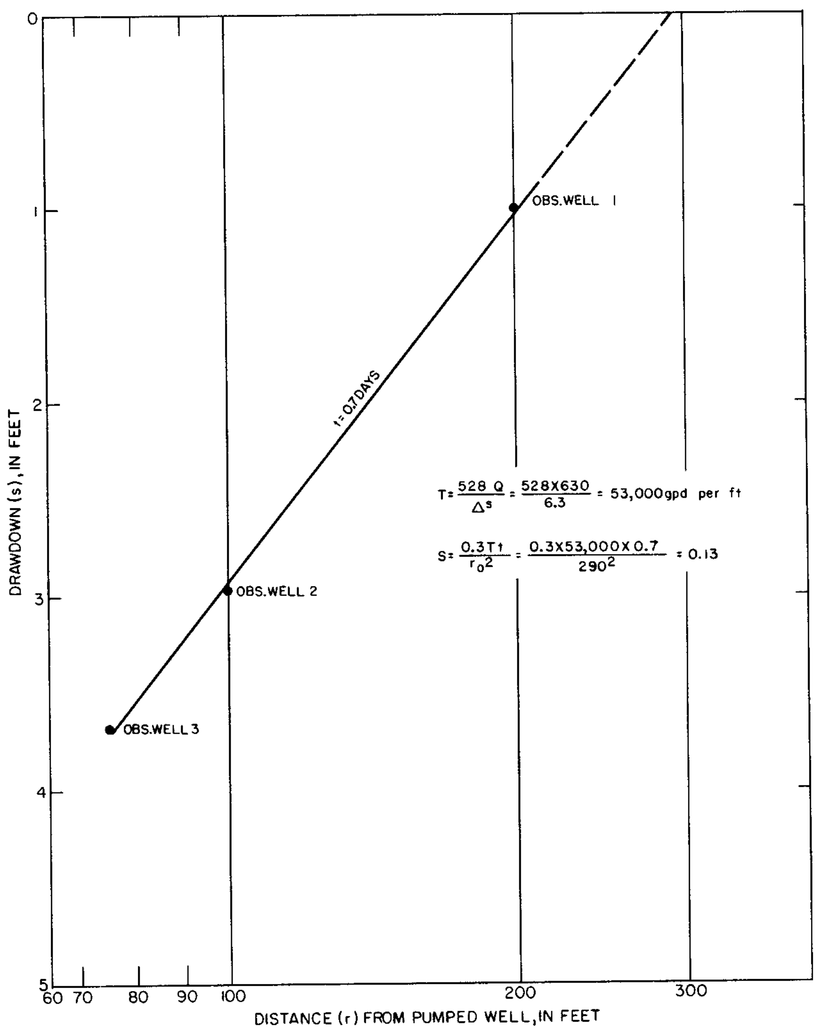


FIGURE 12. Semilogarithmic plot of drawdown (s) versus distance (r) for three observation wells during the Inkster aquifer test (well 154-55-23baal).

Emerado Aquifer

The Emerado aquifer was named for the city of Emerado in central Grand Forks County. The aquifer, which has an areal extent of approximately 15 square miles, underlies parts of Tps. 151-152 N., Rs. 52-53 W., which includes most of the Grand Forks Air Force Base (pl. 1).

The aquifer was outlined by 10 test holes and wells. A well drilled by the Great Northern Railway in Emerado (151-53-1dcd) penetrated 30 feet of water-bearing "quicksand" between the depths of 50 and 80 feet (Kelly, 1968a, p. 83), which is the greatest known thickness of the aquifer. The U. S. Air Force installed a well that penetrated 25 feet of sand and gravel between the depths of 70 and 95 feet in 152-53-36bab (Kelly, 1968a, p. 93). Generally the aquifer interfingers with glacial till, which also confines it above and below. In most places it is separated from the bedrock by more than 60 feet.

The principal lithology is medium- to coarse-grained poorly sorted sand. In some wells thick sections of fine to medium sand are penetrated. In most test holes, however, the sand is coarse and contains abundant gravel. There was little intermixed silt or clay. Test hole 152-53-36bab penetrated sand near the top of the section and an increasing amount of gravel toward the base. Shale fragments comprise a large part of the gravel.

Water in the Emerado aquifer is confined under pressure. Test hole 151-53-lccc indicated a static water level of about 8.6 feet below land surface on September 30, 1966 (Kelly, 1968a, p. 24). This represents a hydrostatic head of more than 70 feet above the top of the aquifer.

An aquifer test was made by the U. S. Air Force on well 152-53-36bab. The well was pumped for 1,260 minutes, but the pumping rate was frequently changed between 690 and 860 gpm. One observation well, 25 feet from the production well, was measured during the test.

The varying pumping rate caused considerable difficulty in interpreting the test data, During the first 90 minutes the pumping rate remained relatively stable at 830 gpm and the transmissivity was computed to be 7,800 gpd per foot. Data from the observation well indicated a transmissivity of 13,400 gpd per foot and a storage coefficient of 0.0001 during the same interval of time. There was little measurable drawdown in either well during the final 750 minutes of pumping at varying rates. The specific capacity was computed to be about 10 gpm per foot of drawdown. The transmissivity determined from the production-well data probably is too low, but may be in the order of magnitude of about 15,000 gpd per foot. The production well may not have been adequately developed at the time the test was conducted.

Water from wells tapping the Emerado aquifer generally is of poor chemical quality, probably because of upward leakage of poor quality water from the bedrock aquifers. Samples from wells 151-53-1ccc and 151-53-1dcd have dissolved solids contents of 1,890 and 2,240 ppm (Kelly, 1968a, table 4). It is a sodium sulfate type, hard, and contains more chloride, sulfate, and total dissolved solids than the recommended maximums set by the U. S. Public Health Service (1962). The sample from well 151-53-1dcd contained an abnormal amount of iron, which may have been due to corrosion of the well casing. Two samples indicated that the water is in the very high salinity and medium-sodium hazard classification for irrigation use.

Grand Forks Aquifer

Wells and test holes drilled in the vicinity of the city of Grand Forks commonly penetrate water-bearing sand and gravel at about 200 feet, which herein is called the Grand Forks aquifer. This aquifer, which is rather poorly defined, seems to underlie most of northern T. 151 N., R. 50 W. (Grand Forks Township) and parts of the adjoining townships (pl. 1). Little is known of the areal extent of the aquifer farther east in Minnesota.

As presently delineated, the Grand Forks aquifer is roughly semi-circular in outline and has an areal extent of about 20 square miles in North Dakota. Test hole 151-50-22bbb, drilled near the corner of South Washington and 32nd Avenue South in Grand Forks, penetrated 10 feet of gravel at a depth between 192 and 202 feet. Test hole 151-50-6dad, drilled at the "old municipal airport" on the western edge of the city, penetrated 25 feet of gravel at a depth between 197 and 222 feet. The latter is the greatest known thickness of the aquifer, and in most places it is less than 20 feet thick.

The principal lithology of the Grand Forks aquifer is fine- to medium-grained sandy, poorly sorted gravel. Generally the deposits are poorly sorted, and locally the aquifer material interfingers with glacial deposits of clay and till.

The aquifer generally overlies a yellowish-brown to brownish-gray oxidized till. This material and the presence of very coarse gravel at the base of the aquifer indicate that the aquifer is a residual gravel or outwash deposit that subsequently was buried by younger drift of a later period of glaciation. The aquifer is quite variable in thickness, and locally may be entirely absent. Most of the test holes showed that the aquifer is overlain by olive-gray till. Additional test drilling is necessary to adequately define the areal extent and thickness of the aquifer.

Records show that initially the hydraulic pressure within the Grand Forks aquifer was sufficient to produce flowing wells. Subsequently, this pressure has declined. In 1885, a flowing well was obtained on the campus of the University of North Dakota (Simpson, 1929, p. 138). The well, which was located approximately at 151-50-5dca, later was plugged and abandoned. A. L. Greenlee and P. D. Akin (written commun., 1945) stated that an old well drilled to 215 feet at 151-50-8abb penetrated about 10 feet of sand. This well also flowed at the surface. When the Armour Packing Co. installed a well in the aquifer in 1946, the static water level was between 9 and 10 feet below the land surface. Thus the potentiometric surface of the aquifer declined at least 10 feet in the 60 years following initial development.

In 1965 an observation well was installed at 152-50-29dda, and water-level fluctuations were monitored from September 1965 to August 1967. During this time the water level fluctuated between 8 and 28 feet below land surface (Kelly, 1968a, p. 49). These fluctuations may be due to local pumping from the aquifer rather than natural changes in recharge and discharge.

Little is known concerning the hydrologic properties of the Grand Forks aquifer. Greenlee and Akin (written commun., 1945) stated the following in regard to a well owned by Bridgeman Creamery in Grand Forks: "The well is reported to yield 250 to 270 gallons a minute and the present average production of the well is reported by the creamery manager to be about 80,000 gallons a day. The specific capacity of the well is reported by the Layne Western Company to be about 3 gallons a minute per foot of drawdown. The temperature of the water is reported to be about 48 degrees F." The Armour Co. well is reported to have a specific capacity of about 4 gpm per foot of drawdown. These data indicate that the Grand Forks aquifer is not highly permeable, but more detailed tests are needed in order to accurately evaluate the hydrologic characteristics of the aquifer.

There has been very little development of the Grand Forks aquifer. Records indicate that fewer than 10 wells have ever produced water from the aquifer, and there have seldom been more than two wells in use at the same time. Most of the old wells have been used for a few years, then plugged and abandoned. In 1968, there were two wells producing water from the aquifer and each pumped at irregular intervals throughout the year.

The Grand Forks aquifer is deeply buried by fine-grained glacial deposits and recharge to it probably is derived largely from subsurface underflow. Most of the water probably migrates from aquifers in the Paleozoic rocks, although some may come from the Dakota aquifer and the glacial till.

It is estimated that the Grand Forks aquifer contains more than 69,000 acre-feet of water in transient storage. This is based on an assumed porosity of 30 percent and an average thickness of approximately 18 feet.

Water from the Grand Forks aquifer is more highly mineralized than water from any other aquifer in the county, except the Paleozoic rocks from which most of the Grand Forks water probably is derived. A sample from well 152-50-29dda (Kelly, 1968a, table 4) indicated that the water is a sodium chloride type, very hard, and has a dissolved solids content of more than 5,000 ppm. The water would be highly injurious to both plants and soil. With the exception of iron and fluoride, all of the chemical constituents in the water are present in concentrations exceeding the maximums recommended by the U. S. Public Health Service (1962).

Thompson Aquifer

The Thompson aquifer is named for the city of Thompson in southeastern Grand Forks County (pl. 1). Although the maximum extent has not been determined, the minimum is 8 square miles. Two test holes penetrated the aquifer and several wells are known to tap it. Additional test holes were drilled adjacent to the Thompson aquifer but failed to penetrate it, suggesting that the aquifer is of rather local extent. It seems to be restricted to the southwestern part of T. 150 N., R. 50 W. and the southeastern part of T. 150 N., R. 51 W. Test holes drilled east and south of Thompson penetrated deposits similar to those of the aquifer, but there are insufficient data to prove a hydrologic connection between them.

Only a few data are available on the thickness of the aquifer. Test hole 150-51-36aaa penetrated 25 feet of sandy, poorly sorted gravel from 121 to 146 feet below land surface. Test hole 150-50-29ddd penetrated boulders, fine sand, and clay from 113 to 126 feet. However, owing to the presence of very coarse gravel and a concentration of boulders, it was not possible to drill these test holes completely through the aquifer. Consequently, the thickness is known to exceed 25 feet, but the maximum is not known. All of the evidence indicates that the aquifer is completely enclosed within the less permeable glacial till.

Water-level fluctuations within the Thompson aquifer were monitored in observation well 150-51-36aaa between September 5, 1965 and October 12, 1967. Fluctuations of about 1 foot per month usually were recorded; however, changes of more than 4 feet per month occurred during the spring of 1967. These large fluctuations are not characteristic of a deeply buried, confined, water-bearing zone and probably indicate that the observation well was influenced by surficial drainage. Other observation wells constructed in deposits similar to the Thompson aquifer had rather stable water levels.

The aquifer is recharged mainly by upward leakage from the Dakota aquifer and aquifers in the Winnipeg Group.

No meaningful estimate can be made of the quantity of water stored in the Thompson aquifer because of inadequate data.

Water from the Thompson aquifer is a highly mineralized sodium chloride type. The dissolved solids content of the water in samples from wells 150-51-34aaa and 150-51-36aaa was 4,740 and 4,500 ppm, respectively (Kelly, 1968a, table 4). The concentrations of iron, chloride, and sulfate all exceed recommended maximums. The water is very hard and it is unsatisfactory for irrigation or other agricultural use. In general, the dissolved solids content is greater than in other glacial drift aquifers in the county, except the Grand Forks aquifer.

Minor Glacial Drift Aquifers

Aquifers in the Lake Agassiz beach deposits.–The Lake Agassiz beaches are long, narrow deposits of sand and gravel that mark the various stages of the former glacial lake. Numerous test holes drilled into the beaches show that the deposits are thin and overlie till or lake clay having low permeability. In Grand Forks County the average thickness of the beach deposits is less than 10 feet, but the thickness ranges from 1 to 20 feet. The Blanchard, McCauleyville, and Campbell beaches (fig. 13) are the most prominent and, locally, will yield small to moderate quantities of water to wells. The beach ridges are preferred as building sites, and numerous farmsteads have been contructed on them. Many of these farms are dependent solely upon the beach deposits for their water supply.

Water-level fluctuations within the beach deposits were monitored from mid-1964 through late 1967. Generally there is an abrupt rise that coincides with the spring thaw, and this usually is followed by a declining water table during the remainder of the year (fig. 14). When heavy precipitation occurs after the main growing season, as in September 1965, significant recharge occurs to raise the water levels. Inasmuch as direct infiltration of precipitation is the only source of recharge to these aquifers, the water table may fluctuate 3 to 4 feet annually. During prolonged dry periods, wells tapping these aquifers may go dry.

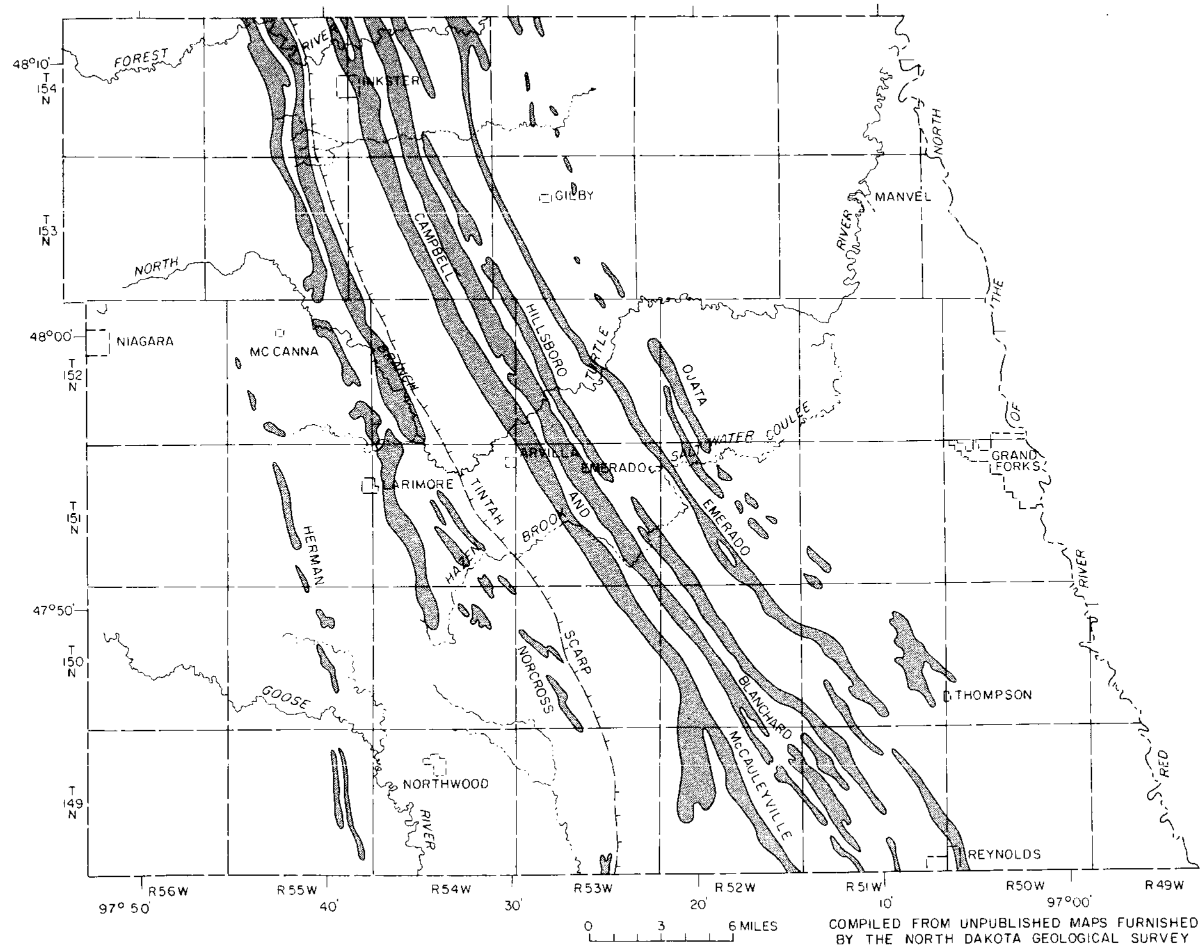


FIGURE 13. Location of Lake Agassiz beaches.

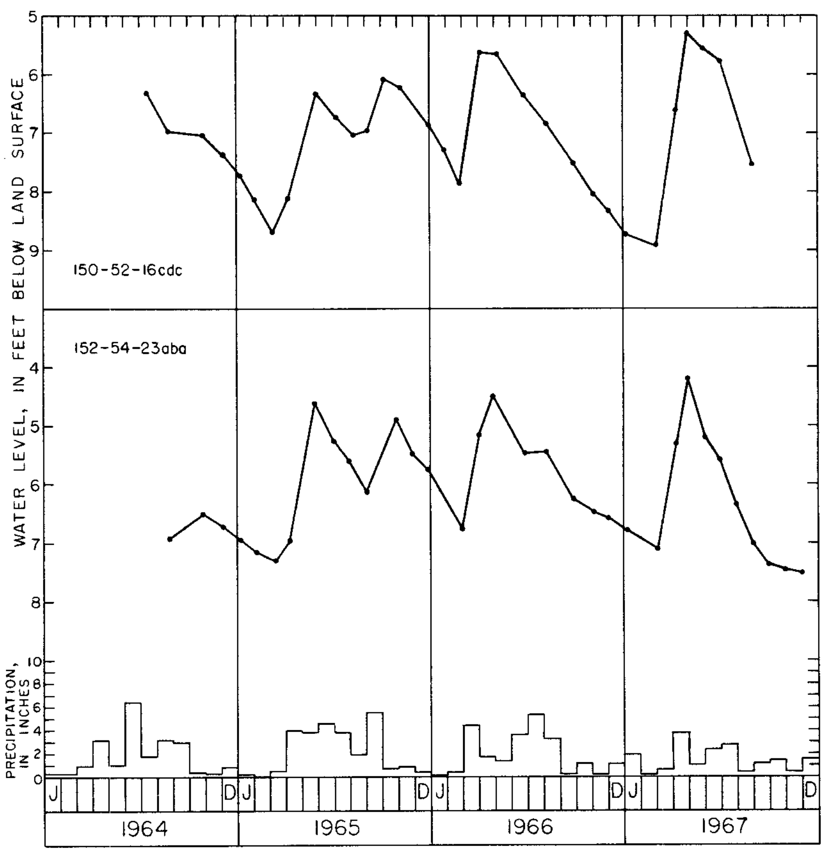


FIGURE 14. Water-level fluctuations in Lake Agassiz beach aquifers, and precipitation at Larimore, N. Dak.

The water tables in all of the beach aquifers are rather shallow, usually less than 10 feet below land surface. Consequently, substantial quantities of ground water are discharged from the aquifer by evapotranspiration. Also, large quantities of water are discharged as springs and seeps. Infiltration from rainfall and snowmelt moves downward through the beach deposits and laterally along the contact with the underlying clay or till toward seepage zones along the east-facing slopes.

The amount of water available to wells tapping beach aquifers is dependent upon the storage capacity of the deposits and the amount of recharge. Where the beaches form prominent ridges, large sloughs are temporarily ponded on the upslope sides of the ridges, and the water gradually infiltrates into the beach deposits. In these areas the water level in the aquifer is maintained by the slough. Well 154-54-32cdd, installed in the McCauleyville beach near a slough, is capable of producing more than 2,000 gpd. However, most wells tapping beach aquifers yield less than 1,000 gpd.

Water obtained from the beach aquifers is generally of good chemical quality. Kelly (1968a, table 4) listed the chemical analyses for seven samples (149-52-22dcd, 150-52-31ddd, 151-52-33aaa, 151-52-34ccd, 151-53-34ddc, 152-54-10bab, and 152-54-14ddc). The water is a calcium bicarbonate type that is relatively soft. The dissolved solids content ranges from 308 to 1,490 ppm and averages 726 ppm. Most of the concentrations were within the U. S. Public Health Service standards. One sample, from well 149-52-22dcd, was high in nitrate, which suggests contamination from barnyard sources where the well is located. Most of the water from beach aquifers is within the medium-to high-salinity, low-sodium classifications (fig. 4). This water would be satisfactory for use on lawns and gardens, if sufficient quantities were available.

Aquifers in the Lake Agassiz silt deposits.–The eastern and central parts of Grand Forks County are mainly covered by lacustrine deposits that may have accumulated in the deeper waters of Lake Agassiz. In most places these deposits consist of clay having very low permeability, but locally the upper part of the deposit is composed of silt. The silt facies is generally less than 10 feet thick, but where present, it may yield small quantities of water to large-diameter wells.

Ground water in the silt deposits is under water-table conditions, and generally the water level is only a few feet below land surface. The low specific yield of these sediments causes large fluctuations in the water table in response to minor amounts of precipitation, and abrupt rises and declines of the water table occur during the year. Each spring the water table rises more than 5 feet in observation well 152-50-20aaa; whereas, during corresponding periods, rises of less than 2 feet were measured in the beach ridge aquifers. Most of the wells tapping the lake silts are not capable of yielding more than 100 gpd; however, in much of the county this is the only available source of usable water.

Water from the Lake Agassiz silt deposits generally is of poor chemical quality. The analyses listed by Kelly (1968a, table 4) for wells 151-50-5acd and 153-54-21cdd2 probably are typical for water from the deposits. The water has a dissolved solids content greater than 2,000 ppm, is extremely hard, and is a calcium sulfate type. Some well owners report that the water is corrosive to plumbing fixtures.

Small sand and gravel aquifers interspersed with the till.–Many of the test holes drilled during the county study penetrated small bodies of sand and gravel interspersed with, and apparently isolated in, the glacial till (Kelly, 1968a, table 3). Most of these are water bearing and are capable of yielding small supplies for domestic and livestock needs. Many of the rural residents of the county obtain their water supplies from these small aquifers. It would be impractical to describe each of the small aquifers but, because they are locally important sources of ground water nonetheless, their general characteristics are described.

Most of these aquifers appear to be rather restricted, both in lateral and vertical extent. For example, test hole 153-53-9ccc, near Gilby, penetrated several thin beds of sand and gravel below 71 feet. These deposits were not found in nearby test holes. A well tapping these thin aquifers may be capable of supplying adequate water for the average farm, but would be inadequate for the needs of Gilby.

Three test holes penetrated fairly thick sand and gravel deposits in the vicinity of Kelly Slough (T. 152 N., R. 52 W.). However, there are insufficient test-hole data to delimit this aquifer, and the poor chemical quality of the water did not seem to warrant further exploration. Wells that penetrate this aquifer will flow at the surface when drilled in topographic lows. A water sample from the Kelly Slough aquifer is similar in chemical characteristics to water from the Dakota aquifer.

Two test holes (153-52-18ddd and 153-52-32cbc) penetrated an undifferentiated drift aquifer. Each test hole flowed more than 20 gpm (Kelly, 1968a, p. 32) and both were plugged and abandoned. The aquifer was not completely penetrated by either test hole; consequently, little is known about its size or hydrologic properties. Measurements made on December 4, 1967 showed that at 153-52-18ddd the hydraulic head was 10.7 feet above land surface, and at 153-52-32cbc it was 12.6 feet above land surface. The water sampled from these two test holes is similar in chemical characteristics to water from the Dakota aquifer.

Jensen (1961, p. 6) described an aquifer at Northwood as "... a lenticular sand and gravel deposit penetrated at depths ranging from 130 to 170 feet. The sediments in the aquifer are silt, sand, and a fine gravel, consisting mostly of shale pebbles and some limestone fragments. The aquifer is thin, about 5 to 20 feet thick, and its subsurface areal extent is small; therefore, large ground-water withdrawals are not possible." Subsequent test drilling showed that the areal extent of the aquifer was less than half a square mile. Subsequently, a well was installed in Northwood and pumped at the rate of 56 gpm. The transmissivity of the aquifer was computed to range from 1,550 to 2,900 gpd per foot.

The city of Hatton, Traill County, attempted to construct a municipal well at 149-53-28ccc in a small glacial drift aquifer in south-central Grand Forks County (Beeks, 1967, p. 11-13). The aquifer, as defined by detailed test drilling, has an areal extent of less than half a square mile. The water-bearing materials consist of clayey to sandy fine gravel from 178 to 199 feet below land surface. The static water level was 40.5 feet below land surface. The well was pumped at 80 gpm for 1,260 minutes. The exact drawdown in the pumped well was not determined but was greater than 100 feet, indicating a low transmissivity.

Till aquifers–Wells that fail to penetrate any significant thickness of sand and gravel but, nonetheless, yield small quantities of water, are not uncommon in Grand Forks County. The water is yielded from the till and, although the rate of yield is very low, the quantities are often sufficient to yield small supplies for domestic or livestock needs. It is necessary that large-diameter wells be installed so as to provide a large area of seepage, and also to provide a reservoir for collection. Wells that obtain water from till generally pump dry readily but refill in a matter of hours.

The permeability of glacial till is increased considerably by the presence of joints or other fractures. Joints serve as paths through which water can move more freely. A well that intersects a joint system usually yields greater quantities of water than a well in unjointed till. The joints in the till are not apparent at the surface, however, and little is known about their distribution.

Records of water levels in wells tapping till commonly show large fluctuations (fig. 15). However, these large fluctuations may not be due entirely to precipitation effects. Willis and others (1964) have shown that large fluctuations may occur even in the absence of corresponding

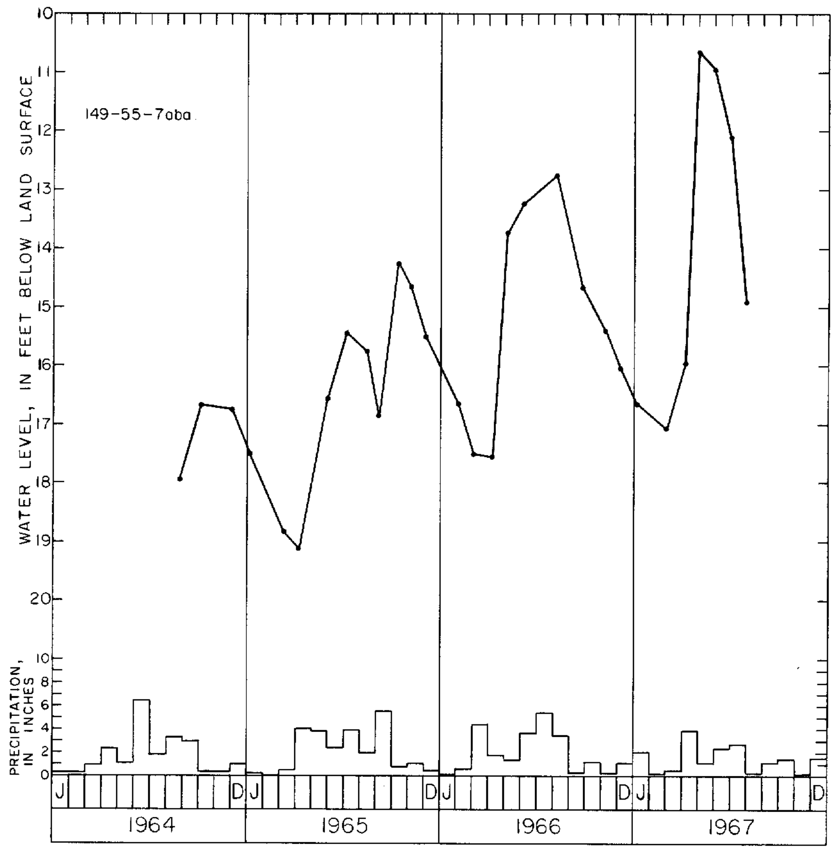


FIGURE 15. Water-level fluctuations in a till aquifer, and precipitation at Larimore, N. Dak.

amounts of precipitation. They attribute large and rapid rises in water levels in the spring to thawing of the frost layer in the ground.

Most of the water from the till is of poor chemical quality. The water is very hard and, in places, is reported to be objectionable for domestic use because of high iron and (or) sulfate content. The samples of water from the till aquifers are in the high to very high salinity and low-to medium-sodium hazard classifications (fig. 4).

REGIONAL HYDROLOGY AND GEOCHEMICAL RELATIONS

Grand Forks County lies near the eastern edge of a large and complex regional ground-water flow system that at least in part originates many miles to the west. The mechanics of this system probably is similar to that described by Meyboom (1966) for southern Saskatchewan. Meyboom (1966, p. 55) constructed regional profiles of ground-water flow systems and suggested that the ultimate discharge of the deep circulating ground water is in eastern Manitoba where salt springs rise along the western edge of the Canadian Shield.

Unfortunately the scope of this investigation did not permit the collection of data that would accurately describe the ground-water flow system in Grand Forks County or relate it to a more regional system. However, areas of recharge and discharge and the general direction of ground-water movement are apparent from scattered data on potentiometric heads, as well as by certain changes in the chemical quality of the water.

Figure 16 contains a schematic hydrogeologic section extending northeastward from near the southwestern corner of the county. The major areas of ground-water recharge are in the topographically high areas in the western part of the county and in regions farther west. From the areas of recharge, the ground water moves eastward or northeastward to the artesian discharge basin in the topographically low areas in the eastern part of the county. Figure 16 shows the extent of the basin in which most drilled wells produced flows at land surface as of 1966.

Ground-water recharge areas are characterized by decreasing potentiometric head with depth, whereas discharge areas are characterized by increasing head with depth. For example, an observation well completed in test hole 154-54-18cdc at a depth of 126 feet in the recharge area had a water level of about 4 feet below land surface in June 1966, whereas the water level in well 154-55-24dbb, 397 feet deep and less than a mile from 154-54-18cdc, was reported to be 155 feet below land surface (Kelly, 1968a, p. 36, 38). Conversely, in the artesian discharge area, well 153-50-7adc, which is reported to be 195 feet deep, flowed at land surface; whereas well 153-50-19aaa, about a mile south and 110 feet deep, was reported to have a water level 20 feet below land surface (Kelly, 1968a, p. 31).

That the eastern part of Grand Forks County is a prominent area of discharge is evident not only because of the increasing head with depth in the basin, but also because of the high salinity of the ground water. Practically all of the ground water in this area except from very shallow sources is saline; much of it contains more than 3,000 ppm dissolved solids. Such high salinity generally is characteristic of ground water that has migrated great distances from the source areas.

Figure 16 illustrates the chemical change in ground water as it moves eastward beneath Grand Forks County. It shows that the ground water in the recharge areas is typically a calcium magnesium bicarbonate water of relatively low salinity. As the water moves downward and eastward through the glacial drift, it becomes more saline as the result of increased rock solution and also as the result of mixing with highly saline water that is moving upward and eastward from the underlying bedrock formations. Thus, it may be seen that the low-salinity calcium bicarbonate water in R. 54 changes to a moderate-salinity sodium chloride sulfate type in Rs. 52 and 53, and eventually to a high-salinity sodium sulfate chloride type in Rs. 49, 50, and 51. This is similar to a geochemical sequence described by Maclay and Winter (1967) for northwestern Minnesota:

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

Ordinarily a zonation of sodium bicarbonate type water is developed early in the sequence, but this is not apparent in Grand Forks County. The lack of sodium bicarbonate zonation may be due to rapid mixing of the recharge waters with the highly saline water discharging from the bedrock subcrop areas.

UTILIZATION OF GROUND WATER

The rural population of Grand Forks County is dependent mainly upon ground water for its domestic and livestock needs. In addition, three incorporated communities–Larimore, Northwood, and Emerado–obtain their water supplies from wells. Thus, the principal uses of ground water are for domestic and livestock requirements by

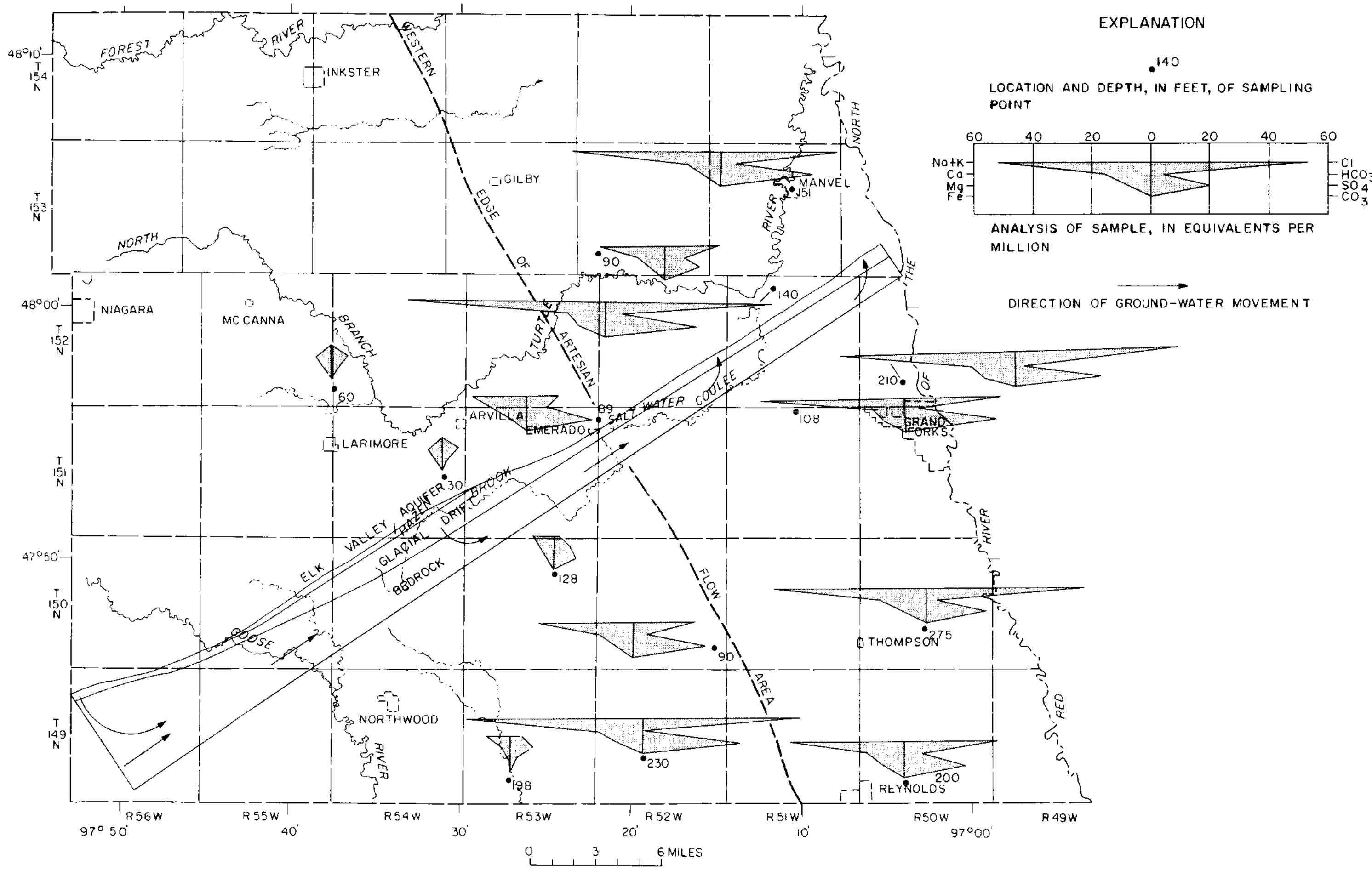


FIGURE 16. Regional ground-water flow system and geochemical relations.

the rural population and for public supply in the incorporated communities. Although the use of water for irrigation is now of minor importance, it probably will increase in the future.

Domestic and Livestock Use

Most of the domestic and stock wells in the county are large-diameter hand-dug or bored wells; they generally range in depth from 10 to 150 feet and usually do not penetrate below the first water-bearing zone. Deepening the wells may result in increased yields and larger storage in the wells.

Most of the wells in the rural areas obtain water from till and associated sand and gravel deposits or from minor surficial aquifers. Yields of several hundred gallons per minute have been reported; but in general, the stock and domestic wells yield less than 10 gpm. This yield is sufficient for most domestic uses or for small herds of livestock.

Water for livestock use can be obtained from wells drilled to the Dakota aquifer. Most Dakota wells produce small flows. Domestic use of water from the Dakota aquifer has declined in recent years.

Public Supply

Four communities in Grand Forks County have municipal water supplies. The city of Grand Forks, which also supplies the Grand Forks Air Force Base, obtains its water from the Red Lake River and the Red River of the North. Larimore, Northwood, and Emerado have adequate supplies of water of good quality that are obtained from wells. Residents of the other communities are dependent upon privately owned wells or must haul water from other sources.

Grand Forks

The city of Grand Forks and the Air Force Base have an average daily usage of more than 6 million gallons from the Red River of the North and the Red Lake River. These rivers have been utilized for a public supply by Grand Forks since 1910. Although the city overlies the Grand Forks aquifer, both the quantity and quality of the water are inadequate for municipal purposes.

Grand Forks Air Force Base is less than 10 miles east of the Elk Valley aquifer. In the event that a secondary water supply should be necessary, sufficient water could be obtained from that aquifer in the vicinity of McCanna. The same area probably would supply adequate water for Grand Forks in the event that the city desired to use a ground-water supply.

Larimore

The city of Larimore has utilized water from the Elk Valley aquifer since 1947. Two wells produce an adequate quantity of water for the community, which had an average daily water use of 150,000 gallons. Any increases in future demands can be met by expansion of the existing well field. The quality of the water is satisfactory for municipal and industrial purposes.

Northwood

The city of Northwood is located near the southern end of the Elk Valley aquifer, where the aquifer yields are considerably less than in the vicinity of Larimore. Consequently, four wells are required to supply the 100,000 gpd that the city uses. An undifferentiated drift aquifer beneath Northwood was described by Jensen (1961, p. 6); but it is too small to yield sufficient quantities for the city's needs. Therefore, the city must depend upon the shallow Elk Valley aquifer, which has rather low yields but excellent quality of water.

Emerado

The city of Emerado directly overlies the Emerado aquifer. This aquifer is capable of supplying the city; however, the water quality is rather poor and not considered satisfactory for municipal use. Consequently, in 1968 several wells were constructed in the Elk Valley aquifer and the water is piped 8 miles to Emerado. A branch pipeline from the same system was constructed to supply the community of Arvilla. This system should be capable of supplying the needs of the two communities in the foreseeable future, although additional wells may be needed to meet increased demands.

Other Communities

There are several other communities in Grand Forks County, none of which have municipal water supplies. However, some of these communities have ground-water sources available.

Inkster is located near the eastern edge of the Inkster aquifer from which water is hauled commercially to the city. As has been pointed out, the Inkster aquifer is one of the more productive aquifers in the county and easily is capable of supplying the needs of the community.

Test hole 153-53-9ccc, which was drilled at Gilby, did not penetrate any significant thicknesses of water-bearing deposits. Also, there are no surficial deposits in the vicinity of Gilby capable of yielding an adequate water supply. Consequently, the community probably could not establish a municipal well in the immediate vicinity.

There appears to be no ground-water source in the vicinity of Manvel that is capable of yielding adequate water for the community. The village is located in T. 153 N., R. 51 W., near the eastern limit of the Dakota aquifer (pl. 1), and the drift aquifers have been contaminated by leakage from the Dakota.

The Thompson aquifer underlies the community for which the aquifer is named. Unfortunately, the water in the aquifer has been contaminated by water from the underlying bedrock aquifers and the water is too saline for most uses. In the event that Thompson should wish to establish a municipal water supply, it would be necessary to pipe the water from a distant aquifer or stream, unless the water from the Thompson aquifer could be successfully treated.

Test holes and wells drilled in the vicinity of Niagara have penetrated the Pierre aquifer at very shallow depths. A supply sufficient for municipal needs may be obtainable from the upper part of the Pierre, but the quality would probably be poor.

The north part of the city of Reynolds is located in Grand Forks County. The availability of ground water in the vicinity of Reynolds was investigated by Jensen (1962); however, no significant aquifers were located during that study. Subsequently, C. E. Naplin and H. M. Jensen (written commun., 1968) have described the Hillsboro and Belmont aquifers, which are located south of Reynolds in Traill County. More detailed study is needed to further evaluate the potential of these aquifers.

Irrigation

Although a variety of factors influence the suitability of an area for irrigation, probably the most important is an adequate supply of suitable water. In 1950 an attempt was made to irrigate sugar beets in the vicinity of Larimore using water from the Elk Valley aquifer. However, the operation was discontinued after a brief trial period even though adequate water was available. Subsequently, there has been no irrigation of crops in Grand Forks County.

The Elk Valley aquifer (pl. 1) offers the greatest potential for irrigation in the county. This aquifer underlies much of the county and it contains large quantities of water of suitable quality for irrigation. Generally the best potential for irrigation is in areas north of Larimore where the deposits have the greatest permeability. Although considerably smaller, the Inkster aquifer also is capable of supporting small-scale irrigation.

Water yield is dependent on the permeability, saturated thickness, rate of recharge, and well construction. Consequently, any anticipated irrigation project should be preceded by a more detailed study of these factors.

SUMMARY AND CONCLUSIONS

The lithology and distribution of the geologic units control availability and occurrence of ground water in Grand Forks County. There are two main types of aquifers in the county–those in the preglacial rocks and those in the glacial drift.

The Dakota aquifer probably is the most productive aquifer in the preglacial rocks. Most wells penetrating this aquifer range in depth from 100 feet in eastern Grand Forks County to 1,000 feet in the western part. Flows from wells in the Dakota generally range from 1 to 3 gpm, but may exceed 50 gpm in large efficient wells. These flow rates are controlled by the depth and water-yielding properties of the sandstone body penetrated by the well. The transmissivity of the Dakota aquifer is approximately 47,000 gpd per foot and the storage coefficient is approximately 0.0002.

The Elk Valley aquifer, a surficial glacial drift aquifer, is the most important ground-water source in the county. This aquifer has an areal extent of at least 200 square miles in western Grand Forks County, an average thickness of 34 feet, and about 1 million acre-feet of water in storage. The aquifer is exposed at land surface and is readily recharged by rainfall and snowmelt. Aquifer-test data indicate that potential yields of more than 500 gpm are available from the northern part of the Elk Valley aquifer.

The Inkster aquifer is located in northwestern Grand Forks County. Although very little water is withdrawn by wells, as much as 1,100 gpm is lost from the aquifer by natural discharge through springs. The water table in the aquifer is stable and fluctuates less than 2 feet per year. It is estimated that the Inkster aquifer contains about 60,000 acre-feet of ground water in transient storage. The aquifer is exposed at land surface and is readily recharged.

The Emerado, Grand Forks, and Thompson aquifers are relatively small, poorly defined water-bearing zones buried in the glacial drift. The water in these aquifers is too highly mineralized for most uses, and the aquifers are recharged slowly.

Small quantities of ground water may be obtained from the Lake Agassiz beach deposits, silt deposits, small sand and gravel bodies interspersed with the till, and from the till itself. Generally yields are less than 2,000 gpd, but some of the sand and gravel bodies interspersed with the till may yield considerably more. Water from the latter source commonly is of poor chemical quality.

Geochemical relationships and data on potentiometric heads indicate that the main direction of regional ground-water movement in the county is eastward or northeastward. Ground water is recharged in the topographically high areas in the western part of the county and is discharged in the low-lying basin of former Lake Agassiz in the eastern part. The water becomes increasingly saline as it moves from the recharge to the discharge area and changes from a predominantly calcium magnesium bicarbonate type to a sodium sulfate chloride type.

Sufficient water for irrigation is available from two aquifers in the county–the Elk Valley and Inkster aquifers. The Elk Valley aquifer offers the greatest irrigation potential because of its size, availability, and water quality. The Inkster aquifer is more limited in areal extent, but locally wells may yield as much as do wells in the larger Elk Valley aquifer.

Larimore, Northwood, and Emerado are the only incorporated communities in the county that have adequate ground-water supplies. Grand Forks utilizes a surface-water source, and most of the other communities do not have municipal supplies.

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