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GROUND WATER
A Vital North Dakota Resource

by

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ILLUSTRATIONS

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GROUND WATER — A VITAL NORTH DAKOTA RESOURCE

By

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INTRODUCTION

Within the crust of the earth are many layers, stringers, and pockets of material that are saturated with water. This water is termed ground water, and the water-bearing materials are termed ground-water reservoirs or aquifers. It is the water that is pumped from wells or flows naturally from wells and springs. Some areas of the earth are richly endowed with ground-water resources, others, only poorly so. Probably North Dakota would have to be considered an in-between state. Although we have only begun to study and evaluate properly this vital resource in North Dakota, prospects appear bright for moderate to large-scale development of ground-water in a surprisingly large number of areas. On the other hand, the outlook appears somewhat less favorable for some areas in the State.

Figure 1 shows the locations of areas in the State that have been tentatively identified as having a good potential for ground-water development. The map is intended as a general guide in the location of ground-water resources, not as a map to locate specific wells. Few, if any, aquifers are so uniform in their water-bearing properties that production wells may be drilled in them without preliminary test drilling. As more comprehensive ground-water studies are completed in North Dakota, the map will probably need to be revised, but the revisions most likely will be in the form of presenting additional data that show expanded areas of ground-water potential.

Importance of Ground Water

The importance of ground water to North Dakota hardly can be overstated. Practically the entire rural population obtains its needed supply of water through wells or from springs which are merely agents discharging ground water naturally at the earth's surface. Most municipalities in North Dakota are supplied by ground water. Some of the larger are Minot, Jamestown, Valley City, and Devils Lake. Considerable quantities of ground water are used by industry each year in the Fargo-Moorhead area. Small but rather spectacular beginnings have been made in some parts of the State in the development of ground water for irrigation. The following is a comparison of crop yields obtained from irrigated versus dry-land farming at the Carrington Experiment Branch Station during the 1961 season (Olson, 1962).

Crop	Irrigations	Crop Yields	
		Irrigated	Dryland
Alfalfa	4-5	4.5 ton/ac	Not enough to harvest
Corn	2-3	75-85 bu/ac (est.)	15-20 bu/ac (est.)
Wheat	2-3	20-40 bu/ac	6-10 bu/ac
Rye	3	46 bu/ac	10-12 bu/ac
Barley	3	50 bu/ac	6 bu/ac
Sugar Beets	6	12-15 ton/ac (est.)	None
Potatoes	5	300-500 bu/ac	None

Precipitation in much of North Dakota was below average in 1961. At the Carrington Station about 60 percent of the normal amount was received during the growing season. On the other hand, the Station was still in a development stage in 1961, and some factors such as removal of topsoil during land-leveling operations and soil compaction tended to reduce the irrigated yields.

Early Development and Future Needs

In the early times of settlement, and continuing until fairly recent years, water use in North Dakota was relatively slight — owing largely to the facts that the population was mainly rural and that the State had practically no industry. Obtaining sufficient water for farm and domestic needs presented no great problem except in a few areas. Most farms in the State had at least one well, and many had several. Some utilized springs, particularly for stock watering in the western part of the State. Because these demands were generally small—2 to 5 gpm (gallons per minute) were usually sufficient to supply the average farm and domestic needs—a well could be located almost anywhere without a great deal of geologic or hydrologic study.

Since the end of World War II, however, urbanization in North Dakota, as in many other sections of the United States, has increased. Very likely this trend began in North Dakota even before the war, when many people left the farms in the 1930's because of the prolonged drought.

The concentration of population in urban areas and the accompanying industrial development, even on a moderate scale, has caused greatly increased water demands and has raised many new water-development problems.

Interest in irrigation has been mounting steadily in recent years. Today it is usually a prime topic of discussion at any water meeting held in North Dakota. Proposals have been made for the Garrison reservoir to provide irrigation water for large tracts of land in several parts of the State. However, much of North Dakota is not included in the proposed area, and it is quite likely that some of these areas can be irrigated from wells.

Sources that would yield quantities of ground water sufficient for the large requirements of municipalities, industries, and irrigation are, of course, much less plentiful than those that supply the average household or farm. Comprehensive ground-water investigations made by trained personnel are generally required to locate, delineate, and evaluate the geologic and hydrologic factors that control the occurrence, availability, and quality of ground water.

OCCURRENCE AND AVAILABILITY OF GROUND WATER IN NORTH DAKOTA

Ground Water in Relation to Geology

A knowledge of the composition and structure of the earth is necessary to the understanding of the occurrence and availability of ground water in any area. An essential tool needed for most ground-water studies is a geologic map prepared by a trained geologist. This map, generally on a scale of 1-inch or one-half inch to a mile, shows the distribution of the various geologic formations in the area of study. It may, for example, indicate that some areas are underlain by thick deposits of sand and gravel that would be favorable for ground-water exploration, whereas other areas are underlain chiefly by clay or shale from which little or no ground water could be obtained.

Glacial Drift

The casual observer may believe that the surficial geology of a relatively flat prairie State such as North Dakota must be fairly simple and straightforward. Indeed, until the advent of glaciation, the surficial geology may have been fairly simple. Prior to glaciation the geologic formations consisted mainly of nearly flat-lying beds of shale in approximately the eastern two-fifths of the State and sandy shale, lignite, and soft fine-grained sandstone in the western three-fifths.

As far as the development of ground-water resources is concerned, we are very fortunate that glaciers moved across most of North Dakota, as the older formations of shale and sandstone are generally too fine grained and thus too impermeable to yield large amounts of ground water.

As the glaciers moved southward across the State they carried huge quantities of durable rock materials such as granite and limestone eroded from parent outcrops in Canada. Large amounts of the durable rocks were ground into fragments by glacial action and were deposited directly from the ice as morainic hills and ridges or as sorted and stratified beds of sand and gravel by streams of melt water issuing from the margins of the ice (fig. 2).

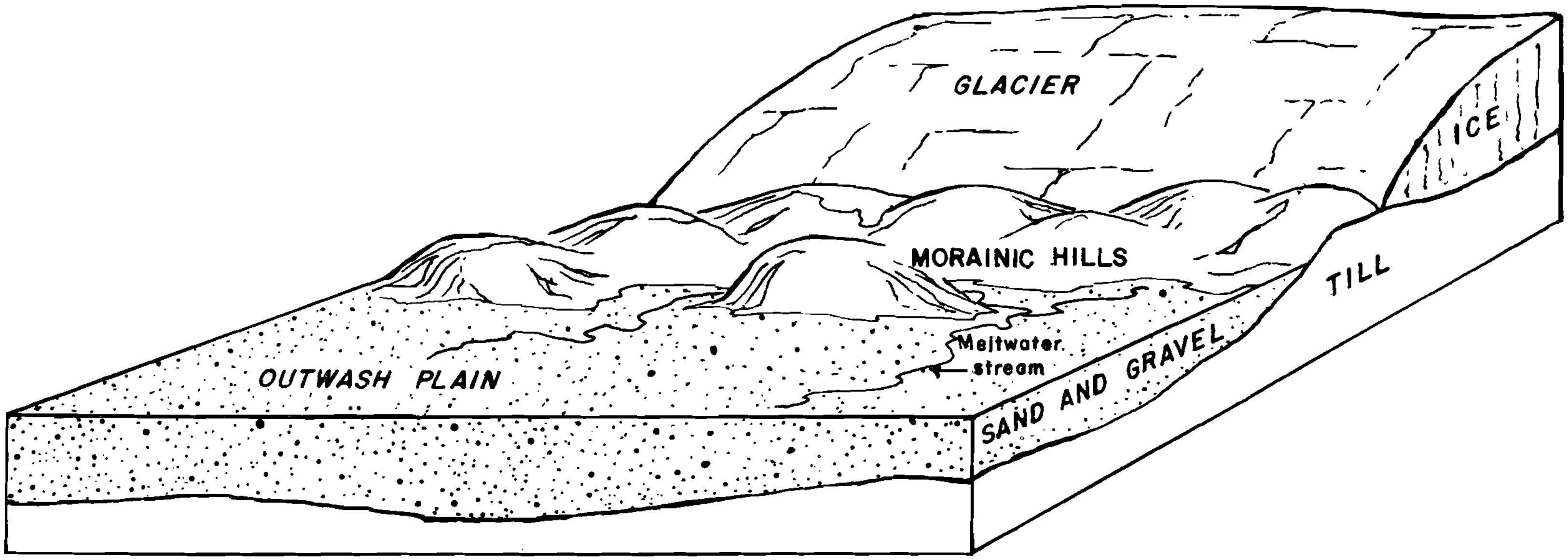


FIGURE 2. FORMATION OF END MORAINE AND OUTWASH DEPOSITS

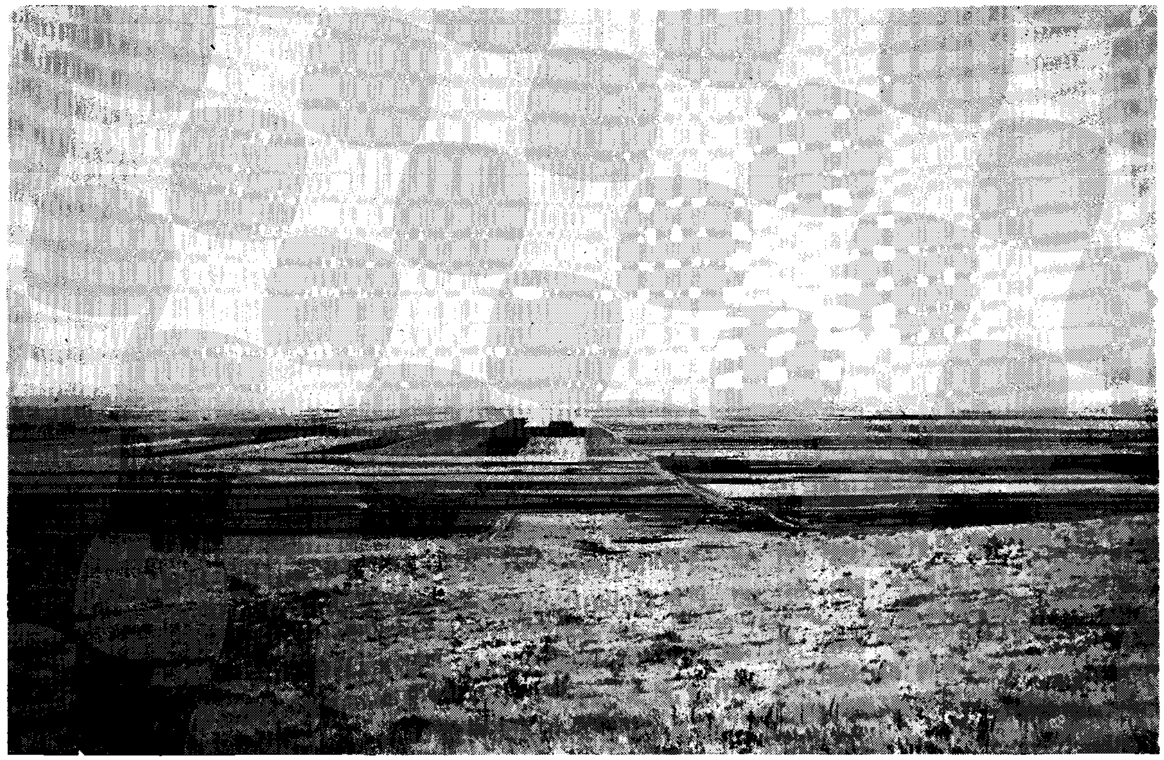


Figure 3. A typical outwash plain in North Dakota.

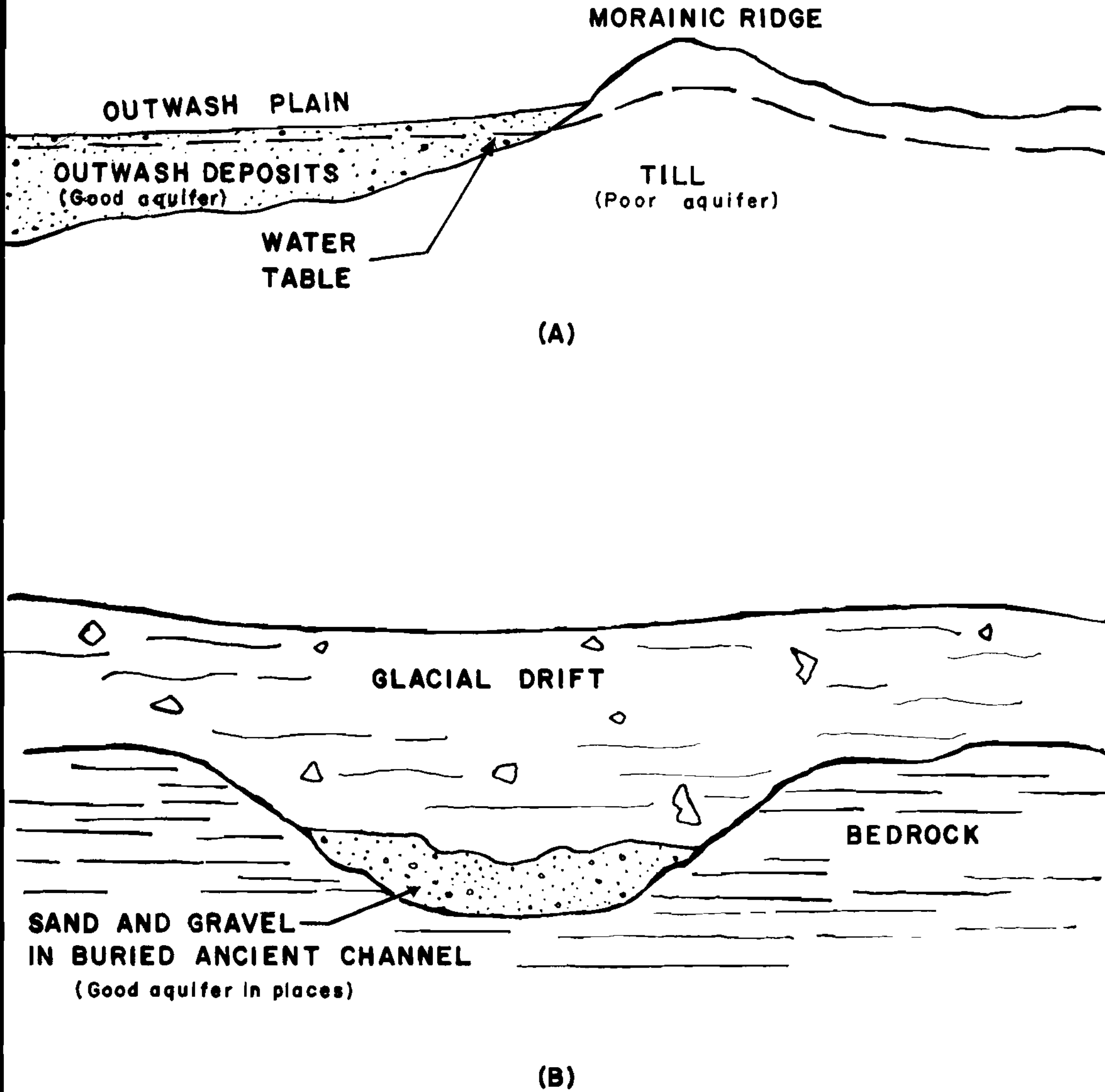


FIGURE 4. TYPICAL GROUND-WATER OCCURRENCE IN OUTWASH DEPOSITS (A) AND BURIED ANCIENT CHANNEL DEPOSITS (B)

These melt-water deposits of glacial sand and gravel constitute our most productive ground-water sources in North Dakota. In like manner, large amounts of local shale and sandstone formations were incorporated and redeposited by the ice, but these deposits, called glacial till, are too fine grained to be of importance as ground-water sources.

Outwash deposits—In some parts of North Dakota the glacial sand and gravel occur in broad sheetlike deposits called glacial outwash (fig. 3). Deposits such as these, which were laid down by melt-water stream discharging from the edges of the ice sheet as it stagnated and melted for prolonged periods, are common in several areas in the State (fig. 1). Probably the largest are in south-central North Dakota, but extensive deposits occur in other parts of the State also, notably south of Devils Lake in Benson, Eddy, and Nelson Counties. In places they cover hundreds of square miles and are 100 feet or more thick. The outwash sand and gravel deposits probably contain the most productive aquifers in the State (fig. 4), and in places they should yield as much as 1,000 gpm to individual wells. The municipal water supply for the city of Devils Lake, in northeastern North Dakota, is obtained through a 20-mile pipeline from wells tapping outwash deposits in the Warwick area south of the city. Initial tests on these wells indicate a high rate of yield, and the wells are producing at rates from 350 to 700 gpm.

Buried aquifers in the glacial drift—Other types of water-bearing sand and gravel deposits also are found in the glacial drift. Many of these are buried within the drift and have little or no surface expression. Their location and extent are determined mainly on the basis of subsurface data obtained from test drilling, study and analysis of locations and records of wells, quality-of-water analysis, and possibly other sources. The buried-drift aquifers range from narrow linear bodies to extensive sheetlike bodies, similar to the surficial outwash deposits previously described.

Among the major buried-drift aquifers in North Dakota are those in or associated with ancient stream channels (fig. 4). Prior to glaciation the drainage system in the State had quite a different pattern than it does today. However, as the glaciers moved southward they disrupted the previous pattern. Stream valleys were blocked by ice and filled with glacial drift, causing lakes to form and stream courses to be diverted, usually southeastward along the ice margins. Today most of the ancient valleys are completely masked by thick deposits of drift, and their locations are determined mainly by test drilling and well data.

Geologic evidence indicates that the Missouri River formerly flowed northeastward from a point near Poplar, Mont., and across the northwestern corner of North Dakota into Canada. The Yellowstone and Little Missouri Rivers also had northeastward trends, their preglacial courses probably extending along Little Muddy

Creek and Tobacco Garden Creek - White Earth River (?) valleys, respectively (fig. 1).

Test drilling in the Little Muddy Creek valley penetrated as much as 379 feet of glacial drift. In places the drift contained as much as 65 feet of permeable water-bearing sand and gravel (Schmid, 1961, p. 3). Test drilling in the valley of Tobacco Garden Creek indicated drift as thick as 169 feet, (data in files of U. S. Geol. Survey) and water-bearing beds of sand and gravel as thick as 60 feet. Moderate to large-capacity wells probably could be developed in deposits such as these, but the quality of the water may be a problem in some areas.

Buried ancient channels occur in other parts of the State also, and future studies will no doubt add to our knowledge of this former drainage system. Irrigation wells south of McKenzie in Burleigh County tap sand and gravel deposits that probably are associated with an ancient stream course (fig. 1). The channel in which these deposits occur may be tributary to a large preglacial channel that trends northeastward near Moffitt into Kidder and Stutsman Counties. This channel has been referred to as the preglacial Cannonball River channel. Long Lake is oriented along its axis.

A large buried channel was discovered by test drilling in eastern Stutsman and western Barnes County during ground-water investigations in those counties (fig. 1). In places this channel, which probably trends more or less north-south, contains nearly 500 feet of glacial drift and as much as 100 feet of water-bearing sand and gravel (Huxel, 1961, p. D-180).

Other buried-drift aquifers whose origins are not readly understood, are found in various parts of the State. Among some of the more productive are those in the Fargo-Moorhead area, which have supplied water for a large part of the municipal and industrial needs in this area for many years.

Deltas of glacial Lake Agassiz—Along the western edge of the Red River Valley in eastern North Dakota are three widely separated areas of possible future ground-water importance (fig. 1). These areas consist of broad elevated tracts of sand and smaller amounts of gravel, which probably were deposited as deltas along the western edges of extinct glacial Lake Agassiz. From north to south the deltas have been named the Pembina delta just west of the city of Walhalla, the Elk Valley delta near Larimore, and the Sheyenne delta east of Lisbon. Large yields are not generally anticipated from these deposits because they are largely fine grained. However, they form very extensive aquifers in a region where ground water otherwise is scarce, and, in places, wells tapping these deposits may yield as much as 200 gpm.

Bedrock Formations

Where the glacial drift is thin or absent, as in much of the southwestern part of the State, ground water is generally obtained from the bedrock formations. The bedrock formations that crop out in southwestern North Dakota are composed chiefly of clay, shale, soft sandstone, and lignite. Ground water occurs mainly in the beds of sandstone and lignite and is obtainable through wells in most places. However, yields are generally small as compared to those from the more productive aquifers in the glacial drift.

Springs are common in the more rugged areas such as the Badlands along the Little Missouri River. Many of the larger springs are major sources of stock-water supply in these areas.

In some areas in the eastern part of the State wells have been drilled through the glacial drift and into the underlying bedrock in search of water. Many of these wells obtain water from cracks and crevices in shale just beneath the glacial-drift contact. In some areas, particularly in the southeastern part of the State, wells are drilled to considerable depths into the bedrock in search of ground water under large artesian head. Wells 800 to more than 1,000 feet deep are common in this part of North Dakota. They obtain water from sandstone beds in the Dakota Sandstone. Most of the wells, which were drilled during the late 1800's and early 1900's originally had substantial flows and pressure heads (Wenzel and Sand, 1942, p. 3-140). However, the yields and pressures have greatly diminished over the years.

Stream Valleys

Southwest of the Missouri River, the valleys of the major streams such as the Little Missouri, Knife, Heart, and Cannonball Rivers contain variable thicknesses of unconsolidated clay, sand, and gravel. These deposits, which generally are shallow, were formed by the streams as they meandered across the valley floors. The beds of sand and gravel are generally water bearing and will yield water in sufficient quantity for average farm and domestic needs and possibly in places for small-scale municipal or industrial requirements.

Northeast of the Missouri River, in the glaciated parts of North Dakota, surface drainage is poorly developed and alluvial deposits are very thin. However, the valleys of the Missouri, Sheyenne, James, Souris, and Des Lacs Rivers formerly carried large quantities of melt water from the melting glaciers. These valleys, in places, contain thick deposits of outwash sand and gravel from which moderate to large quantities of ground water are available. The cities of Minot, Jamestown, and Valley City obtain their municipal supplies from wells tapping glacial sand and gravel deposits in the Souris, James, and Sheyenne River valleys, respectively. Irrigation wells have been developed in deposits of outwash sand and gravel in the Missouri River valley south of Bismarck (unpublished data in files of U. S. Geo. Survey).

Ground Water in Relation to Hydrology

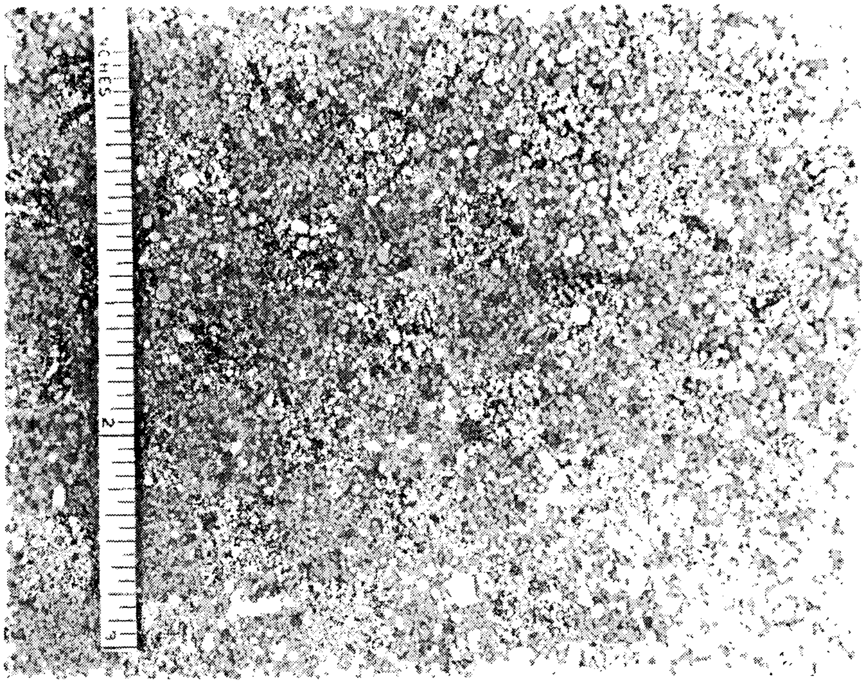
Source of Ground Water

Nearly all ground water of economic importance is derived from precipitation. Water that enters the ground and contributes to the ground-water reservoirs is called recharge. The average annual precipitation in North Dakota ranges from slightly more than 15 inches in the northwestern part of the State to about 22 inches in the southeastern part. Of this amount, generally a small proportion, perhaps only an inch or two, is available as recharge to the ground-water reservoirs.

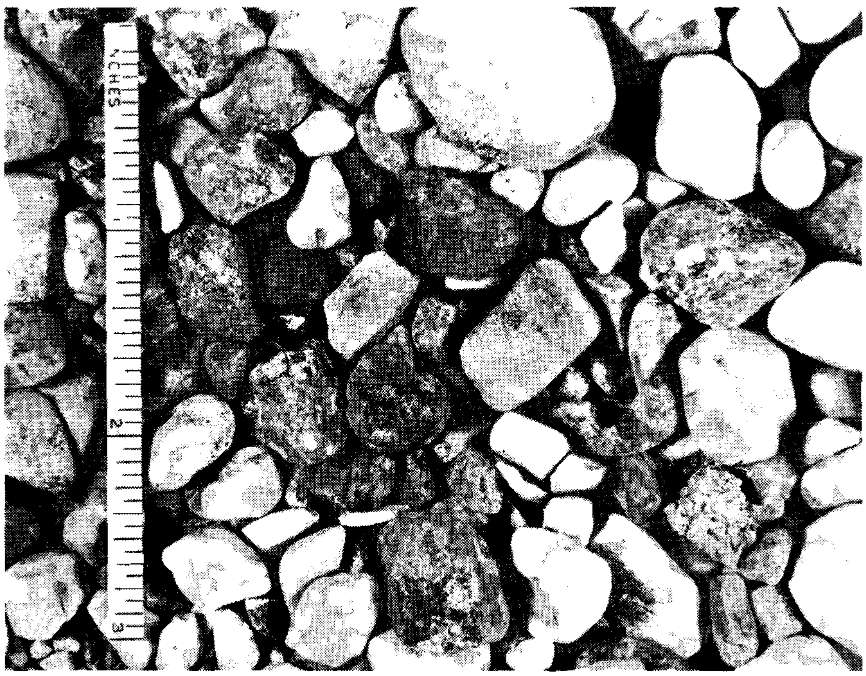
Several factors account for the relatively low recharge. Precipitation is greatest during the growing season, when crops and other plants consume huge quantities of water, thus preventing much of the potential recharge from ever getting beyond the root zone. Evaporation and transpiration losses also are high during this period. Large areas of the State are covered with glacial till, or other fine-grained material, which, because of its low permeability, does not allow the ready absorption of water. Finally, for periods ranging from 3 to 5 months of the year, precipitation is "locked up" in the form of snow and ice. During much of this period, the top several feet of ground are frozen, so that infiltration can not occur. These are some of the facts that must be taken into account in evaluating the potential of North Dakota's ground-water resources. The water pumped from any ground-water reservoir either must be replaced by an equal amount of recharge or by a decrease in natural discharge, or a decline in water level will result. The greater the withdrawals (or losses) beyond the ability of the reservoir to receive recharge, the greater the decline in water level.

Fortunately, conditions are favorable for recharge to some of the more promising aquifers in the State, provided, of course, precipitation is adequate. The outwash deposits such as those in Kidder County and in the Warwick area south of Devils Lake readily absorb precipitation because of their sandy soils. Similarly the delta sediments in the eastern part of the State are readily recharged.

On the other hand, some types of aquifers are recharged very slowly. Typical of aquifers that are not adequately recharged are those in the Fargo-Moorhead area and some of the aquifers in pre-glacial stream channels. Pumping in the Fargo-Moorhead area has had to be curtailed in places because of seriously declining water levels. A study by Dennis and others (1949, p. 5-6) revealed that whereas flowing wells could be obtained nearly anywhere in the Fargo-Moorhead area prior to 1885, by 1941 water levels had declined to more than 30 feet below the land surface in an 80-square-mile area. These represent water levels considerable distances away from heavily pumped wells, where water levels have declined from



(A)



(B)

Figure 5. Examples of permeable sand (A) and gravel (B).

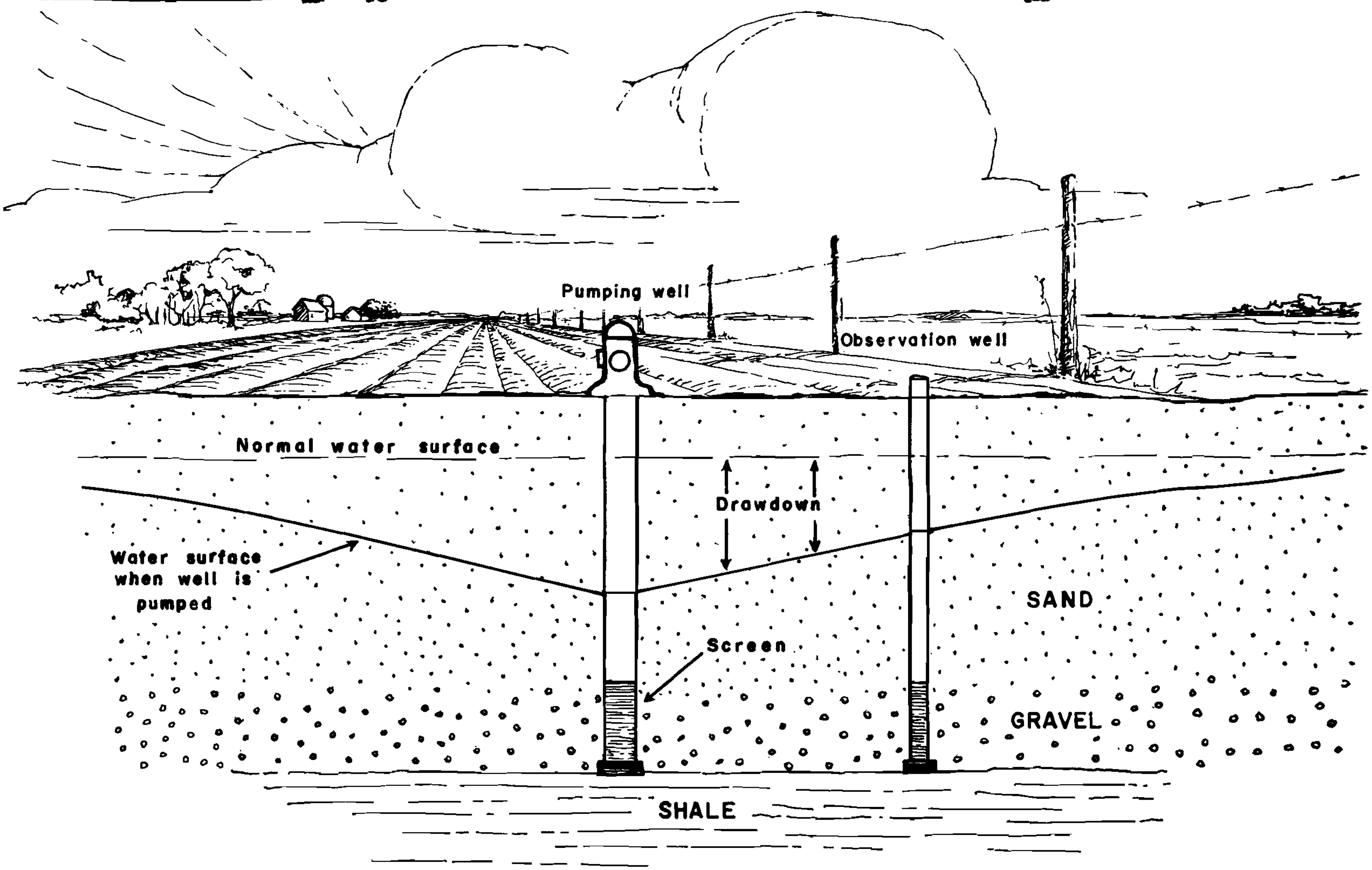


FIGURE 6. SUBSURFACE CONDITIONS IN VICINITY OF PUMPING WELL

100 to 200 feet below the land surface.

As a partial solution to the problem of declining water levels in the Fargo-Moorhead area, the possibility of providing artificial recharge from surface-water sources to the aquifers, possibly through the use of injection wells has been considered in recent years. An intensive study of the geology and hydrology of the area would be required to find out if such a solution would be feasible.

Movement and Storage of Ground Water

Nearly all ground water is in motion from areas of recharge downward and laterally through the rocks to areas of discharge. The movement is very slow, generally a few tens or hundreds of feet per year. For a given hydraulic gradient, the rate of movement through various types of rocks is determined mainly by the size of openings in the rocks and the degree of interconnection of the openings. Some rocks, such as clay or shale, are dense and contain only microscopic openings through which water may move; they are impermeable or nearly so. Others, such as gravel and coarse sand, have relatively large interconnected openings through which the water moves freely. These have high permeability. Figure 5 shows samples of permeable sand and gravel obtained from a test hole drilled in outwash deposits in Logan County. Still other rocks, although dense and fine grained, may have been subjected to earth pressures that caused them to fracture, thus producing a secondary permeability. Common among these are sandstone, limestone, and granite.

If a well has been efficiently constructed, its rate and duration of yield is determined mainly by the permeability, thickness, and areal extent of the aquifer supplying the water. Permeability is a basic property of an aquifer that is involved in the solution of a wide range of ground-water problems. Another basic property, related mainly to porosity (number and size of openings between rock particles), is an aquifer's ability to release water from storage. The properties of permeability and storage can be determined by several methods (Wenzel, 1942). However, the most reliable results generally are obtained by the pumping-test method. The pumping-test method, to supply the most informative data, involves the use of two or more closely spaced wells that obtain water from the same aquifer (fig. 6). While one of the wells is pumped, periodic measurements are made in the other well or wells and in the pumping well, when possible. The pumping rate must be kept as uniform as possible throughout the test. The tests usually are continued for at least 24 hours, but periods of several days or a week generally yield more informative data. After the pump is shut off, measurements are continued until the water in the wells has recovered or nearly recovered to its previous nonpumping level.

The data collected during the test usually are analyzed by methods developed by C. V. Theis (1935) and others to determine the properties of permeability and storage. If these properties are known, it is possible to obtain practical solutions to such problems as: How far apart should production wells be spaced to provide a maximum amount of water with a minimum of mutual well interference? What would be the drawdown in a well after a prolonged period of steady pumping at a constant rate? Knowing the thickness of saturated sand and gravel deposits in a valley, how much ground water moves through a given section of the valley as underflow (movement underground)? These are typical of the many hydrologic problems that are often encountered in large-scale ground-water development.

METHODS OF OBTAINING GROUND WATER

Ground water is obtained from wells, horizontal collectors, and springs. The varieties of wells used in North Dakota are drilled, dug, bored, and driven.

Drilled Wells

Drilled wells are used to reach aquifers that lie at considerable depth or where it is necessary to penetrate hard rocks. Drilled wells consist of three types, rotary, cable-tool, and jetted.

Rotary drilling involves the use of a derrick, draw works, rotary table, and mud-circulation pump. The rig may be mounted on a truck or carriage. The source of power may be the truck engine with power takeoff or a separate industrial engine. The drilling is accomplished by rotating a drill stem that has a cutting tool or bit fastened on the end. The bit is provided with holes through which water and mud can flow. As the drill stem is turning, the drilling fluid or mud is pumped down through the stem, out of the bit, up the hole, and into the mud pits — from where it is returned to the top of the drill stem by means of a flexible hose. Thus continuing circulation is maintained during the drilling process.

Rotary drilling has the advantages of speed and versatility. Casing is generally not needed until the hole is completed. However, special care must be taken in obtaining representative samples of the rocks penetrated because the continuous circulation may mix the samples so that they are difficult to identify.

The cable-tool rig consists of a derrick, wheels and spools for cable, and a "walking-beam" which alternately raises and drops the cable and bit. The hole is made by the bit, which has a chisel point, striking and crushing the rock. The crushed material is raised from the hole by means of a bailer. Cable-tool drilling is often used where a great deal of hard-rock drilling is anticipated or where boulders are numerous. Casing is necessary as the hole is deepened.

The jetting process employs some of the features of both rotary and cable-tool drilling. The rig is similar to that used in cable-tool drilling but it uses a hollow drill stem similar to that used in rotary drilling. A circulation pump is used and water is forced down the stem and jetted out from small openings in the bit. The jetting action loosens the rock materials, and they are circulated to the surface. This method of drilling was designed about 1900 for particular use in drilling deep artesian wells to the Dakota Sandstone in southeastern North Dakota and northeastern South Dakota (Wenzel and Sand, 1942, p. 27). It proved to be a relatively fast and economical method of drilling through the thick deposits of Cretaceous shale that overlie the Dakota Sandstone.

Dug Wells

A large number of shallow wells in North Dakota were constructed by digging methods, either manual or by use of trenching machinery. They are generally of large width, square or round, and commonly are cased with rock, wood, brick, concrete, tile, or galvanized iron. Dug wells can be constructed in unconsolidated deposits such as glacial outwash, till, or alluvium, where the water table is close to the land surface. They generally extend only a few feet below the water table, and during prolonged drought the water table may drop below the bottom of the well causing the well to dry up. These wells commonly can be restored by deepening. To be sure of an adequate supply of water throughout the year dug wells should be constructed during the fall, when the water table is at a low level.

Bored Wells

Bored wells are similar to dug wells except they are put down by means of an augering device, either manual or mechanical. The problems involved with dug-well construction generally also apply to bored wells.

Driven Wells

Driven wells may be installed where the water-bearing deposits consist of unconsolidated deposits of sand and fine gravel and the water table is shallow. A driven well usually consists of a small-diameter pipe with a sandpoint on the lower end and is installed simply by driving it into the ground. They are common in areas of the State underlain by alluvium, glacial outwash, or glacial-lake deposits.

Springs

Springs are generally not important sources of ground water in North Dakota except in the southwestern part of the State and in a few other widely scattered places. The main reason for this may be that throughout much of the State erosion has not cut down to the water table so that springs may flow. Springs are common in southwestern North Dakota, where water-bearing sandstone and lignite beds have been deeply dissected by stream erosion. These springs are important sources of supply, especially for watering stock. Most springs are developed by "boxing-in" the discharge area with wood, brick, concrete, or tile. Such areas are often subject to pollution, and special care should be taken to insure an adequate seal against surface sources of pollution if the water is for human consumption.

QUALITY OF GROUND WATER

As water moves over the earth's surface and through the underlying rocks it dissolves substances from the materials with which it comes in contact. Generally, the farther the water moves and the longer it is in contact with the materials, the more of the substances it dissolves. Ground water commonly has more dissolved solids than surface water because its rate of movement is much slower, and, therefore, it remains in contact with the rocks for longer periods of time. However, ground water, especially from deep sources, is usually free of pathogenic organisms, whereas most surface water today is contaminated to some extent.

The chemical quality of ground water is often a factor limiting the use of the water. Revised standards by the U. S. Public Health Service (1961) for chemical constituents in drinking water used aboard common carriers include the following recommended maximums:

Arsenic	0.05* ppm (parts per million)
Copper	1.0
Lead	.05*
Iron	0.3
Manganese	0.05
Nitrate	45.0
Selenium	.01*
Zinc	5.0
Chloride	250.0
Fluoride	0.6 - 1.7**
Sulfate	250.0
Hexavalent chromium	0.05*
Phenols	0.001
Total dissolved solids	500.0

* Presence in excess of stated figure constitutes grounds for rejection of supply.

** General range. Actual limits depend on air temperature and fluoridation practices as outlined by U. S. Public Health Servcie.

In addition to the constituents listed in the preceding table, hardness is of much importance in domestic use and in many industrial uses such as laundries or steam-generating plants. The following table has been adapted by the U. S. Geological Survey for use in hardness classification throughout the United States.

Hardness Range (ppm)	Rating
0-60	Soft
61-120	Moderately hard
121-180	Hard
181 +	Very hard

Water to be used in industrial processes often must meet certain standards, depending on the type of industry. If the water is used for condensing or cooling or in some cleansing operations, the quality may not be of primary importance, although the temperature may be. On the other hand, the standards for water used in food processing and in the manufacture of some commodities such as paper and plastic are rigid. Some types of modern high-pressure boilers require water that approaches distilled water in quality.

In North Dakota one of the most important considerations of water quality is for irrigation use. The U. S. Department of Agriculture has listed quality-of-water characteristics that seem to have the most importance as far as irrigation use is concerned, and these are: "(1) total concentration of soluble salts; (2) relative proportion of sodium to other cations (3) concentration of boron or other elements that may be toxic; and (4) under some conditions, the bicarbonate concentration as related to the concentration of calcium plus magnesium." (U. S. Salinity Laboratory Staff, 1954, p. 69). Other factors that are of importance are the water-transmission and drainage properties of the soil as well as the salt tolerance of the plants to be grown. Successful crop irrigation involves the proper relation of water quality, soil characteristics, and types of crop grown. The farmer can usually obtain assistance from his County Agricultural Agent or Soil Conservation District Conservationist in solving specific problems.

The quality of ground water in North Dakota varies greatly, both in total dissolved solids and in the relative proportions of the various constituents. Most glacial-drift aquifers yield water that is moderately hard to very hard. Shallow-drift aquifers composed of sand and gravel, such as those in alluvial or outwash deposits and in the deltas of glacial Lake Agassiz, generally yield water of the best quality. Total dissolved solids (salinity) in water from these aquifers commonly is less than 500 ppm. The content of sodium is low in this type of water, and the water is usually of an excellent quality for irrigation.

Buried aquifers in the glacial drift yield water that is generally of poorer quality and is less suited for irrigation or industrial uses than water in the shallow aquifers. The quality depends mainly on the permeability of the aquifer and its distance from recharge areas. Also, the source or recharge may have an appreciable effect. Some of the aquifers in buried ancient stream channels receive a large part of their recharge from bedrock sources, which contribute water of quite different character than the recharge received from the glacial drift.

Aquifers in the bedrock formations in North Dakota, on the whole, yield water that is of poorer quality than water in the glacial drift. Dissolved solids commonly exceed 1,500 ppm. Natural waters containing more than 1,000 ppm of dissolved solids or having a specific conductance greater than 1,400 micromhos per centimeter at 25°C have been classified as saline (Robinove, Langford, and Brookhart, 1958, p. 3). Generally, water from the bedrock formations is soft or only moderately hard, but it may contain excessive amounts of sodium, thus limiting its use for irrigation. In addition, bedrock water usually is high in one or more of the following constituents — chloride, fluoride, bicarbonate, and sulfate.

GROUND-WATER STUDIES PROGRAM IN NORTH DAKOTA

Early Studies

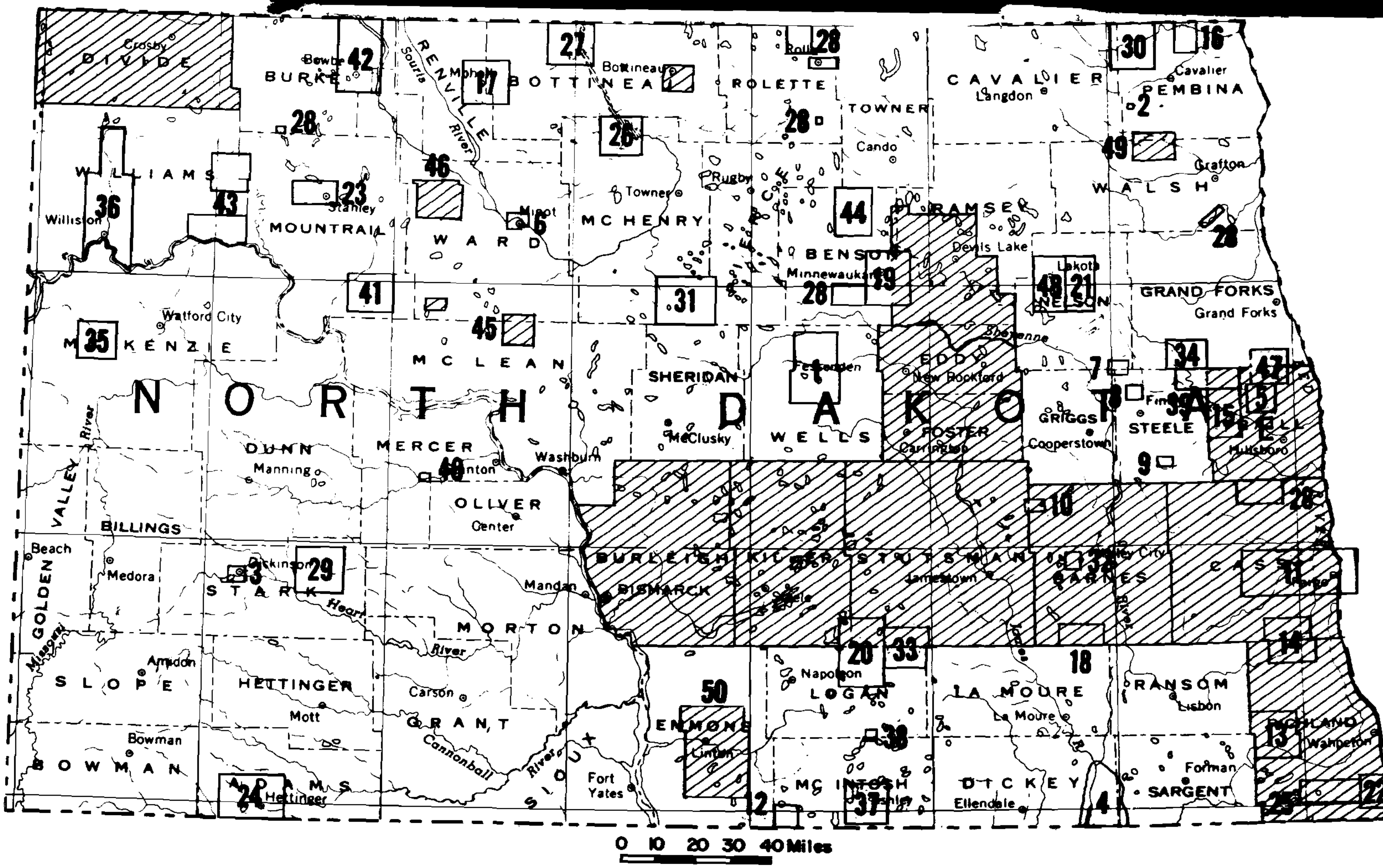
Ground-water data are included in many of the earlier geologic reports, which date back to the late 1800's. As would be expected, the descriptions of ground-water occurrence are very general and are necessarily based on meager accounts of test-hole or well information.

The first ground-water studies, as such, were made by H. E. Simpson, former North Dakota State Geologist, during the field seasons of 1911-1913, inclusive. However, his work was not immediately published owing to lack of funds. The work was added to in succeeding years, including the analyses of 196 samples of water for chemical content, and was published as a Water-Supply Paper of the U. S. Geological Survey in 1929. Although highly generalized and somewhat out of date, this report remains today as the only comprehensive ground-water study of the entire State.

Simpson, during the 1920's, also contributed substantially in his study and recommendations on the problem of declining pressures and yields of flowing artesian wells in North Dakota. He was instrumental in organizing the North Dakota Well Drillers Association in 1915, which, incidentally, was the first organization of this type in the United States. Few ground-water studies were made in North Dakota after the work of Simpson until the early 1940's. Abbott and Voedisch (1938) made a study of municipal ground-water supplies in the State and listed more than 500 chemical analyses in their report.

Federal-State Cooperative Program

A Federal-State cooperative program was begun in 1937 for the purpose of establishing and maintaining a network of observa-



[10] Report completed

[hatched box] Study in progress

FIGURE 7. MAP OF NORTH DAKOTA SHOWING LOCATIONS OF GROUND-WATER STUDIES [1962]

tion wells to measure fluctuations of water levels in various parts of the State. This probably was an outgrowth of the prolonged drought that most of North Dakota had been experiencing since about 1930.

In 1940, under the Federal-State cooperative program, a reconnaissance was made to locate areas in the State that seemed favorable for ground-water irrigation (Rasmussen, 1945). As a result of the reconnaissance, the Oakes area was selected as an area for a more comprehensive ground-water investigation (Rasmussen, 1947). During the following years a large number of Federal-State cooperative ground-water studies were made, mainly in connection with locating and evaluating aquifers that could be used as sources of municipal water supplies. The studies were financed in part by the municipality having the water problem and in part by the State and Federal Governments. Generally the studies included about 100 square miles or less surrounding the municipality. Water shortages in several towns caused considerable urgency in some of the studies, but funds ordinarily were not adequate to explore the ground-water sources fully. It was a "trouble-shooting" type of program, which generally yielded data useful for solving local water-supply problems but did not provide the type of data needed in the systematic appraisal of the State's ground-water resources as a whole.

A new type of program was begun in 1956, when the U. S. Geological Survey, the North Dakota State Water Conservation Commission, and the North Dakota Geological Survey agreed to undertake a ground-water study in Kidder County. In the following years cooperative studies were begun in Stutsman, Burleigh, and Barnes Counties. Several additional county studies are planned to begin during the summer of 1962. The cost of the county studies are shared by the county, State, and Federal governments. Figure 7 shows the location of past and current cooperative ground-water studies in the State.

Missouri River Basin Studies

Ground-water studies were made during 1945-1951 in several areas in northwestern North Dakota and along the Missouri River in the Fort Berthold (Dingman and Gordon, 1954) and Standing Rock Indian Reservations as part of the Department of Interior program for development of water resources in the Missouri River basin. These studies were financed wholly from Federal funds and were made primarily to determine the hydrologic conditions in areas affected by the Garrison diversion plan.

HOW A GROUND-WATER STUDY IS MADE

Under the cooperative U. S. Geological Survey-State agencies program the countywide ground-water studies are generally scheduled to extend over a 4-year period. Each study is supervised directly by a project chief, who ordinarily is an experienced geologist or engineer. The project chief may have one or more assistants under his guidance. A typical study progresses through several main phases of completion, although from time to time the work in one phase may overlap with that in another.

Preliminary Work

As preliminary steps in each study, the project chief makes a search of the literature for all pertinent information regarding his area of study. A master base map of the area is prepared on scale-stable material from latest available source of information. Generally, this map has a scale of 1 inch equals 1 mile and shows locations of all communities, main roads, railroads, drainage, and other features. Maps of the area, such as topographic quadrangles, geologic maps, soils maps, and aerial photographs are obtained.

Field Collection of Data

One of the first phases of fieldwork is an inventory of ground-water development. This is usually done by contacting water officials, residents, well drillers, and others who have a knowledge of local wells and springs. Data such as location of well or spring, depth of well, type of well, depth of water, use of water, quantity and quality of water, and well logs are recorded for as many wells and springs as is practical to inventory. During the well inventory, certain wells may be selected for observation of water-level changes. Generally these wells are not in use and are easily accessible. Periodic water-level measurements are made in these wells to study the recharge effects of precipitation as well as to provide other hydrologic data. Some of the wells may be equipped with recording gages so that a continuous record of water-level fluctuations is obtained.

Also early in the study geologic mapping is begun. The distribution of the various types of rocks that crop out are mapped in the field with the aid of air photographs or topographic maps. The rock materials where exposed in road cuts, stream bluffs, and other places are studied and described with special emphasis on their water-bearing properties.

In the latter part of the data-collection phase of a study, water samples are obtained from representative wells and springs. The samples are analyzed in a laboratory to determine the chemical quality of the water. The quality-of-water data are often useful as an aid to understanding geohydrologic relations as well as being a necessity in evaluating the suitability of the water for various uses.

Test Drilling

For a countywide study the well and spring inventory, geologic studies, and related types of data collection require from one to two field seasons. When this work is completed, the test drilling and other subsurface exploration is begun. For maximum benefits, all available geologic and hydrologic data are analyzed and used in planning subsurface exploration by test drilling and (or) other means.

The amount of test drilling needed to secure adequate subsurface data varies considerably, depending on geologic conditions and on the availability and quality of well data. Representative samples are taken of the various geologic formations penetrated by the drill in each test hole, and these are analyzed for their water-bearing properties by the geologist in charge of the drilling operations. On completion of each test hole, an electric log is obtained to further evaluate the various strata.

Where the data indicate that a significant aquifer has been reached, the hole may be temporarily cased and a pump installed so that a representative sample of the water can be obtained for analysis. Also, the well may be tested by pumping to determine the hydrologic characteristics of the aquifer.

Geophysical methods of ground-water exploration have been used with varying degrees of success in other areas of the U. S. and these methods may have some value in future N. D. studies.

Preparation of Reports

After all available data are collected and field studies are completed within the scope of the allotted time and funds, a report or several reports are prepared for public use. Generally a basic-data report is made available as soon as the data are compiled, checked, and tabulated. This report includes data on inventoried wells and springs, well and test-hole logs, chemical analyses, and other geologic and hydrologic facts. The basic-data report is followed by one or more final interpretive reports. These reports evaluate the data in terms of ground-water occurrence, availability, quantity, and quality. They include several maps, cross-sections, hydrographs, and other illustrations needed for a thorough presentation.

The following is a list of ground-water reports describing various areas in the State and prepared as part of the North Dakota Ground-Water Studies series. Request for reports that are available may be made at the North Dakota State Water Conservation Commission, Bismarck, or the North Dakota Geological Survey, University Station, Grand Forks. The reports that are no longer available may be examined at either of these agencies or at the U. S. Geological Survey, Bureau of Mines Bldg., Grand Forks.

North Dakota Ground-Water Studies

No. 1. Ground water in the Fessenden area, Wells County, North Dakota, by Leonard Filaseta, 1946.

No. 2. Ground water in beach deposits of glacial Lake Agassiz near Mountain, Pembina County, North Dakota, by P. D. Akin, 1946.

No. 3. Ground water at Dickinson, North Dakota, by T. G. McLaughlin, 1946.

No. 4. Ground water in the deposits of ancient Lake Dakota, Dickey County, North Dakota, by William C. Rasmussen, 1947.

No. 5. Ground water near Buxton, Traill County, North Dakota, by P. E. Dennis, 1947.

No. 6. Geology and ground-water conditions at Minot, North Dakota, by P. D. Akin, 1947.

No. 7. Ground water in the Aneta area, Nelson County, North Dakota, by P. E. Dennis, 1947.

No. 8. Ground water in the Sharon area, Steele County, North Dakota, by P. E. Dennis, 1947.

No. 9. Ground water in the Hope area, Steele County, North Dakota, by P. E. Dennis, 1947.

No. 10. Ground water in the Wimbledon area, Barnes and Stutsman Counties, North Dakota, by P. E. Dennis, 1948.

No. 11. Geology and ground-water resources of parts of Cass and Clay Counties, North Dakota and Minnesota, by P. E. Dennis, P. D. Akin, and G. F. Worts, 1949.

No. 12. Ground water in the Zeeland area, North Dakota, by Wilson M. Laird, 1948.

No. 13. Ground water in the Wyndmere area, Richland County, North Dakota, by P. E. Dennis, P. D. Akin, and Suzanne L. Jones, 1949.

No. 14. Ground water in the Kindred area, Cass and Richland Counties, North Dakota, by P. E. Dennis, P. D. Akin, and Suzanne L. Jones, 1950.

No. 15. Ground water in the Portland area, Traill County, North Dakota, by P. E. Dennis, and P. D. Akin, 1950.

No. 16. Ground water in the Neche area, Pembina County, North Dakota, by Q F. Paulson, 1951.

No. 17. Ground water in the Mohall area, Bottinueau and Renville Counties, North Dakota, by P. D. Akin, 1951.

No. 18. Ground water in the Litchville area, Barnes County, North Dakota, by P. D. Akin, 1952.

No. 19. Geology and ground-water resources of the Minnewaukan area, Benson County, North Dakota, by Saul Aronow, P. E. Dennis, and P. D. Akin, 1953.

No. 20. Geology and occurrence of ground water in the Streeter area, Stutsman, Logan, and Kidder Counties, North Dakota, by Q. F. Paulson, 1952.

No. 21. Geology and ground-water resources of the Michigan City area, Nelson County, North Dakota, by Saul Aronow P. E. Dennis and P. D. Akin, 1953.

No. 22. Ground water in the Fairmount area, Richland County, North Dakota, and adjacent areas in Minnesota, by Q. F. Paulson, 1953.

No. 23. Geology and occurrence of ground water in the Stanley area, Mountrail County, North Dakota, by Q. F. Paulson, 1954.

No. 24. Geology and ground-water resources of the Hettinger area, Adams County, North Dakota by C. J. Robinove, 1956.

No. 25. Geology and ground-water resources of the Hankinson area, Richland County, North Dakota, by J. E. Powell, 1956.

No. 26. Geology and ground-water resources of the Upham area, McHenry County, North Dakota, by Q. F. Paulson and J. E. Powell, 1957.

No. 27. Progress report on the geology and ground-water resources of the Westhope area, Bottineau County, North Dakota, J. E. Powell, 1959.

No. 28. Geology and ground-water resources of selected areas in North Dakota, by J. W. Brookhart and J. E. Powell, 1960.

No. 29. Geology and ground-water resources of the Richardton area, Stark County, North Dakota, by J. E. Powell, and Q. F. Paulson, 1960.

No. 30. Test drilling in the Walhalla area, Pembina County, North Dakota, by D. G. Adolphson, 1960.

No. 31. Geology and ground-water resources of the Drake area, McHenry County, North Dakota, by D. G. Adolphson, 1961.

No. 32. Ground-water supply problems in the Sanborn area, Barnes County, North Dakota, by C. J. Huxel, Jr., 1961.

No. 33. Glacial drift aquifers in the Gackle area, Logan and Stutsman Counties, North Dakota, by D. G. Adolphson, 1961.

No. 34. Ground-water sources in the vicinity of Northwood, Grand Forks County, North Dakota, by H. M. Jensen, 1961.

No. 35. Ground-water occurrence in the Alexander area, McKenzie County, North Dakota, by H. M. Jensen, 1961.

No. 36. Report on ground-water availability for irrigation purposes in the Little Muddy Valley area, Williams County, North Dakota, SWCC Project No. 776, by R. W. Schmid, 1961.

No. 37. Ground-water conditions in the vicinity of Ashley, McIntosh County, North Dakota, by P. G. Randich, 1962.

No. 38. Artesian water from glacial drift near Lehr, Logan and McIntosh Counties, North Dakota, by D. G. Adolphson, 1962.

No. 39. Ground water in the Hatton area, Traill and Steele Counties, North Dakota, by D. G. Adolphson, 1962.

No. 40. Testing drilling near Beulah, Mercer County, North Dakota, Edward Bradley and H. M. Jensen, 1962.

No. 41. Ground-water conditions in the vicinity of Parshall, Mountrail County, North Dakota, SWCC Project No. 791, by R. W. Schmid, 1962.

No. 42. Geology and occurrence of ground water near Bowbells, Burke and Ward Counties, North Dakota, by H. M. Jensen, 1962.

No. 43. Geology and ground-water resources of Tioga and Hofflund Flat areas, Williams and Mountrail Counties, North Dakota, by Q. F. Paulson and J. E. Powell, 1962.

No. 44. Ground-water resources in the vicinity of Leeds, Benson County North Dakota, by P. G. Randich and Edward Bradley, 1962.

No. 45. Ground-water near Max, McLean and Ward Counties, North Dakota.

No. 46. Ground-water resources near Berthold, Ward County, North Dakota.

No. 47. Ground water near Reynolds, Grand Forks and Traill Counties, North Dakota, by H. M. Jensen, 1962.

No. 48. Ground-water resources in the Lakota area, Nelson County, North Dakota, by J. E. Powell and S. L. Jones, 1962.

No. 49. Water resources near Hoople, Walsh County, North Dakota by H. M. Jensen and Edward Bradley.

No. 50. Geology and ground-water resources of the Linton-Strasburg area, Emmons County, North Dakota, by P. G. Randich.

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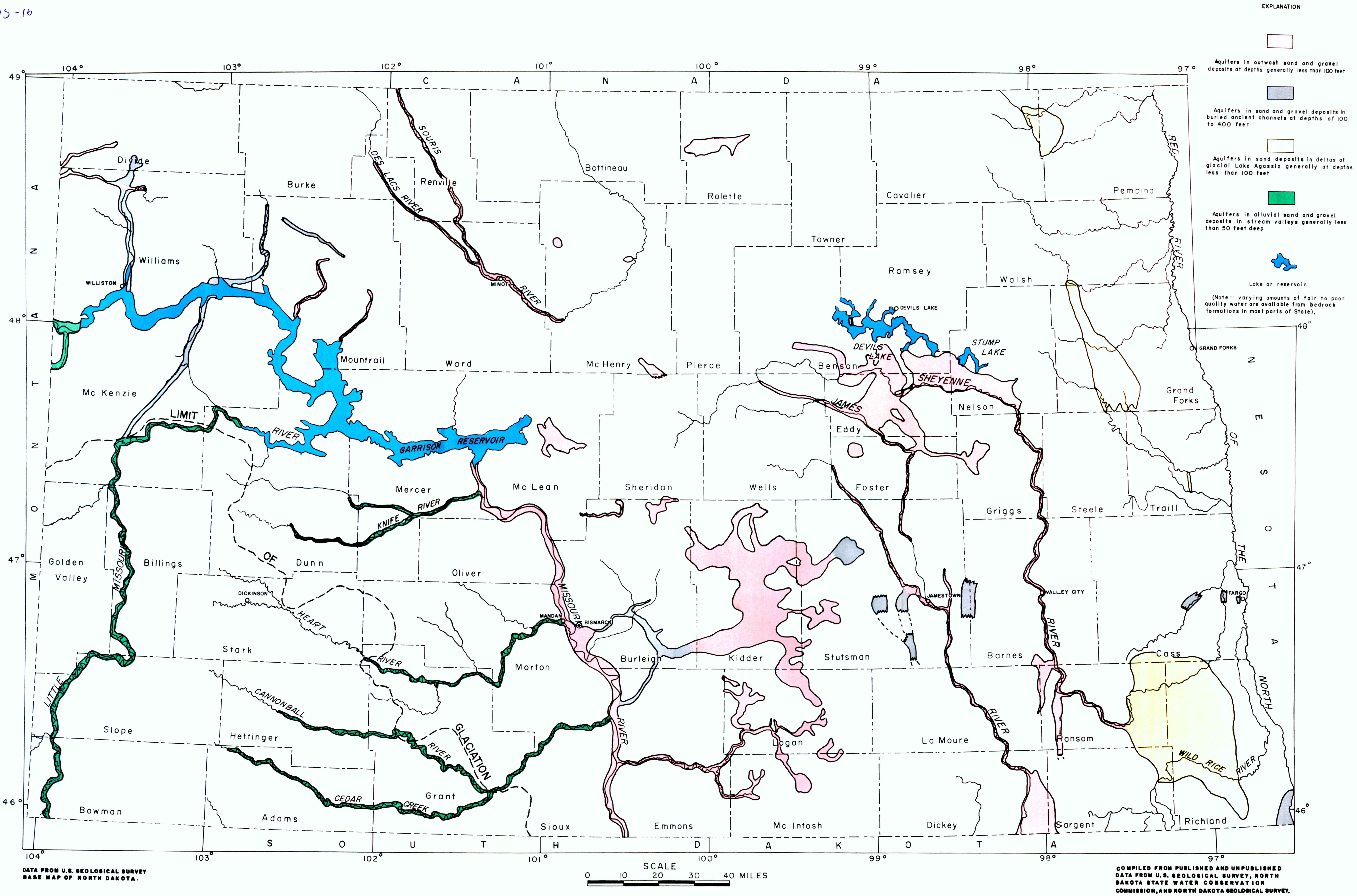

FIGURE I. MAP OF NORTH DAKOTA SHOWING PROBABLE LOCATIONS OF MAJOR AQUIFERS THAT YIELD GROUND-WATER OF FAIR TO GOOD QUALITY.