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County Ground Water Studies I

GEOLOGY AND GROUND WATER RESOURCES OF KIDDER COUNTY, NORTH DAKOTA

PART III GROUND WATER AND CHEMICAL QUALITY OF WATER

By

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Geological Survey

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GROUND WATER AND CHEMICAL QUALITY OF WATER IN KIDDER COUNTY, NORTH DAKOTA

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ABSTRACT

Kidder County is underlain by a relatively thick mantle of unconsolidated glacial drift overlying consolidated bedrock formations of Tertiary and Cretaceous age. The consolidated rocks are the Pierre Shale, Fox Hills Sandstone, and Fort Union Formation. Generally farm and domestic water supplies, and at some places sufficient water for larger uses, can be obtained from the bedrock formations.

The unconsolidated rocks may be subdivided into surficial outwash, buried-valley outwash, ice-contact deposits, lacustrine deposits, till and associated sand and gravel deposits, and Recent deposits. Ground water in relatively large quantities occurs in surficial and buried-valley outwash deposits, especially where they occur together. Medium to moderately large supplies may be obtained from the surficial outwash alone at many places. Ice-contact deposits are generally rather shallow and probably yield only small quantities of water, owing to limited thickness and areal extent. Till and associated sand and gravel deposits occur both at the land surface and buried beneath younger deposits. Small quantities of water are available from wells that tap such deposits.

Recharge from precipitation is rapid in a large area of relatively coarse-grained outwash deposits exposed in the central part of Kidder County. Ground water is discharged from the zone of saturation by evapotranspiration, seepage into springs, lakes and swamps, and flow or withdrawal through wells. Underflow, both into and out of the county, also may account for substantial amounts of recharge to or discharge from the aquifers.

In general the water table or piezometric surface rises and falls according to the ratio of recharge to discharge and in response to changes in barometric pressure. Water levels in wells tapping surficial outwash deposits generally rise or fall in reponse to recharge or discharge within a few weeks, days, or even hours. Water-level changes in the deeper aquifers are generally slower.

Transmissibility coefficients ranging from about 22,000 gallons to about 43,000 gallons per day per foot were determined from pumping tests on wells in outwash deposits. These figures are a rough measure of the permeability of the formations locally near the wells on which the tests were made; probably the permeability is somewhat larger in much of the outwash and buried outwash, where they occur together.

The average daily withdrawal of ground water through wells in Kidder County has been estimated to be 1.2 million gallons. Much larger

withdrawals of ground water are possible through the development of wells in the surficial outwash and the buried outwash deposits.

The ground water in Kidder County generally is very hard; it contains high concentrations of iron and manganese but low concentrations of potassium, fluoride, chloride, and nitrate. Dissolved solids in water from consolidated rocks ranged from 600 to 1,200 ppm (parts per million) and consisted principally of calcium and bicarbonate in the southern half of the county and of sodium and bicarbonate in the northern half. Dissolved solids in water from surficial outwash deposits ranged from 302 to 751 ppm and consisted mostly of calcium and bicarbonate, and those in water from deposits of sand and gravel in till ranged from 497 to 2,410 ppm and were highly variable in composition. Seepage from the Isabel-Alkaline-Long Lake chain causes the dissolved solids in the ground water to increase slightly and causes the relative percentage of sodium in the water to increase downgradient.

Most of the water from outwash deposits could be used for irrigation on nearly all soils with little likelihood that the soils would become saline or that damage to the soil would result from the sodium in the water provided that soil drainage is good enough to allow for a moderate amount of leaching through the root zone. The water has a medium salinity hazard, a low sodium hazard, low boron content, and little or no residual sodium carbonate.

Almost all the ground water in Kidder County contains some constituents that exceed the maximum concentrations recommended by the U.S. Public Health Service for drinking-water standards. If iron and manganese were removed, most of the water from unconsolidated deposits would be satisfactory for domestic use according to the standards, but water from consolidated rocks still would not be satisfactory because of the high sulfate and dissolved solids. According to the Langlier calcium carbonate saturation index, the water is neither corrosive nor scale forming at 80 degrees F, but it is slightly scale forming at 160 degrees F. The water from outwash deposits would be of suitable quality for many industrial uses if it were softened and if the iron and manganese were removed.

INTRODUCTION

Kidder County has an area of about 1,385 square miles and is in Simpson's (1929, p. 5) Missouri Plateau physiographic region of North Dakota (fig. 1). The investigation of the geology and ground-water resources of Kidder County was begun in 1955 by the U.S. Geological Survey, the North Dakota State Water Conservation Commission, and the North Dakota Geological Survey. The main objectives of the part of the investigation discussed in this report were to determine the location, extent, and general yields of ground-water sources for irrigation, industrial, public supply, or farm and domestic use and to determine the chemical quality of the water. This is the first of several countywide ground-water investigations in North Dakota.

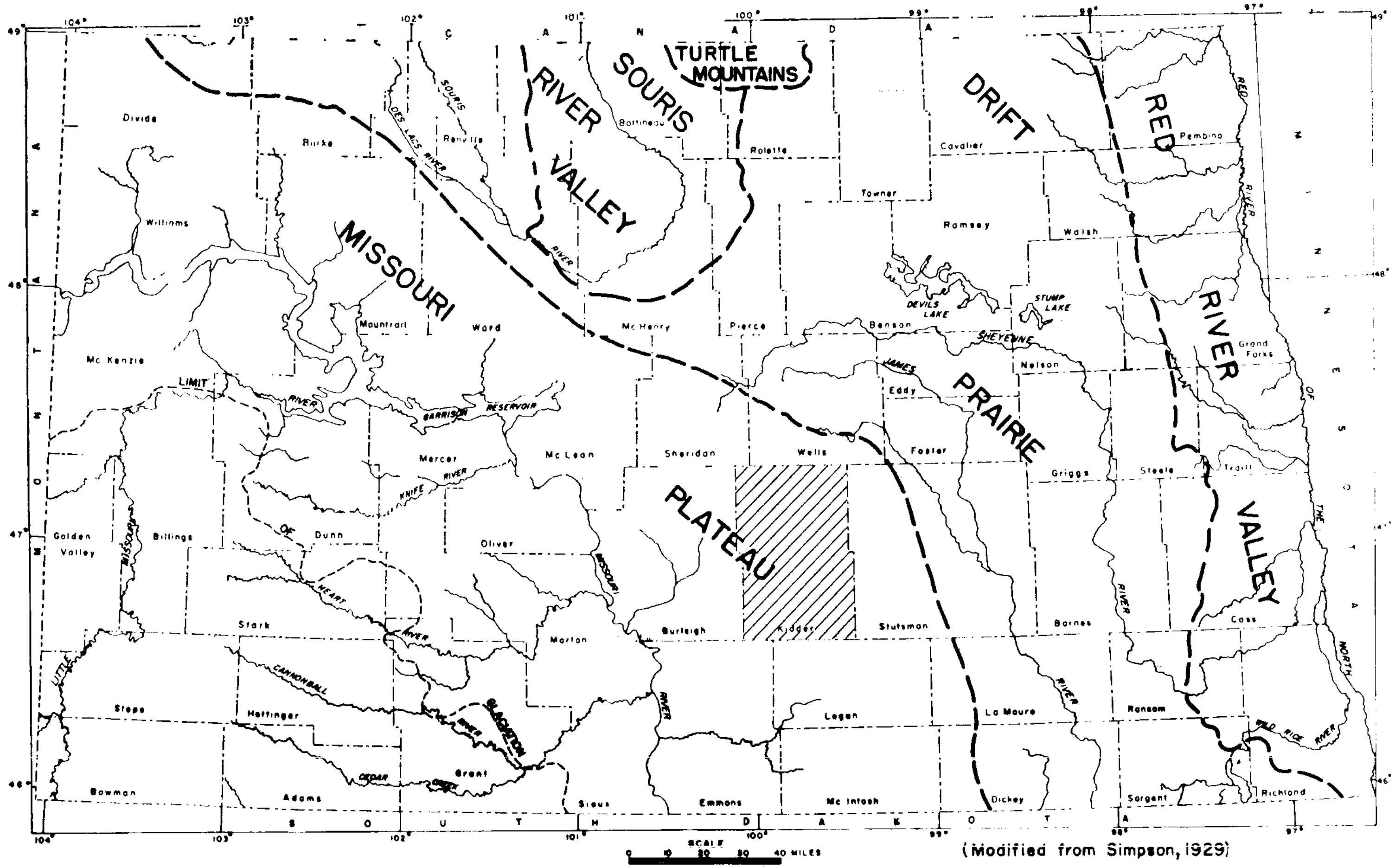


Figure I. MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC PROVINCES AND LOCATION OF KIDDER COUNTY

The geology of the county was studied by the North Dakota Geological Survey (Rau and others, 1962). Records, including depths and water levels, for most of the wells in the county were collected. Ninety-two test holes were drilled by a rotary drilling machine owned by the North Dakota State Water Conservation Commission. Periodic water-level measurements were made in several wells. These records along with chemical-quality-of-water data have been compiled in a basic-data report (Randich and others, 1962). Interpretations made from the records are contained in this report.

The chemical quality of the ground water was studied to determine the suitability of the water for use and the relations of water quality to the geology and hydrology of the county. Emphasis is given to the quality of water from surficial outwash deposits; however, consideration is given to the quality of water from deposits of sand and gravel in till and from consolidated rocks and also to the influence of lake seepage on the quality of the ground water. The suitability of the water for irrigation and industry is discussed because of increasing interest for such use of ground water.

In a reconnaissance report on the geology and ground-water resources of North Dakota, Simpson (1929, p. 148-149) briefly discussed ground water in Kidder County. A report on municipal water supplies in North Dakota contains records and chemical analyses of water samples for seven wells in Kidder County (Abbott and Voedisch, 1938, p. 62-63). General information on ground water in North Dakota has been summarized by Paulson (1962).

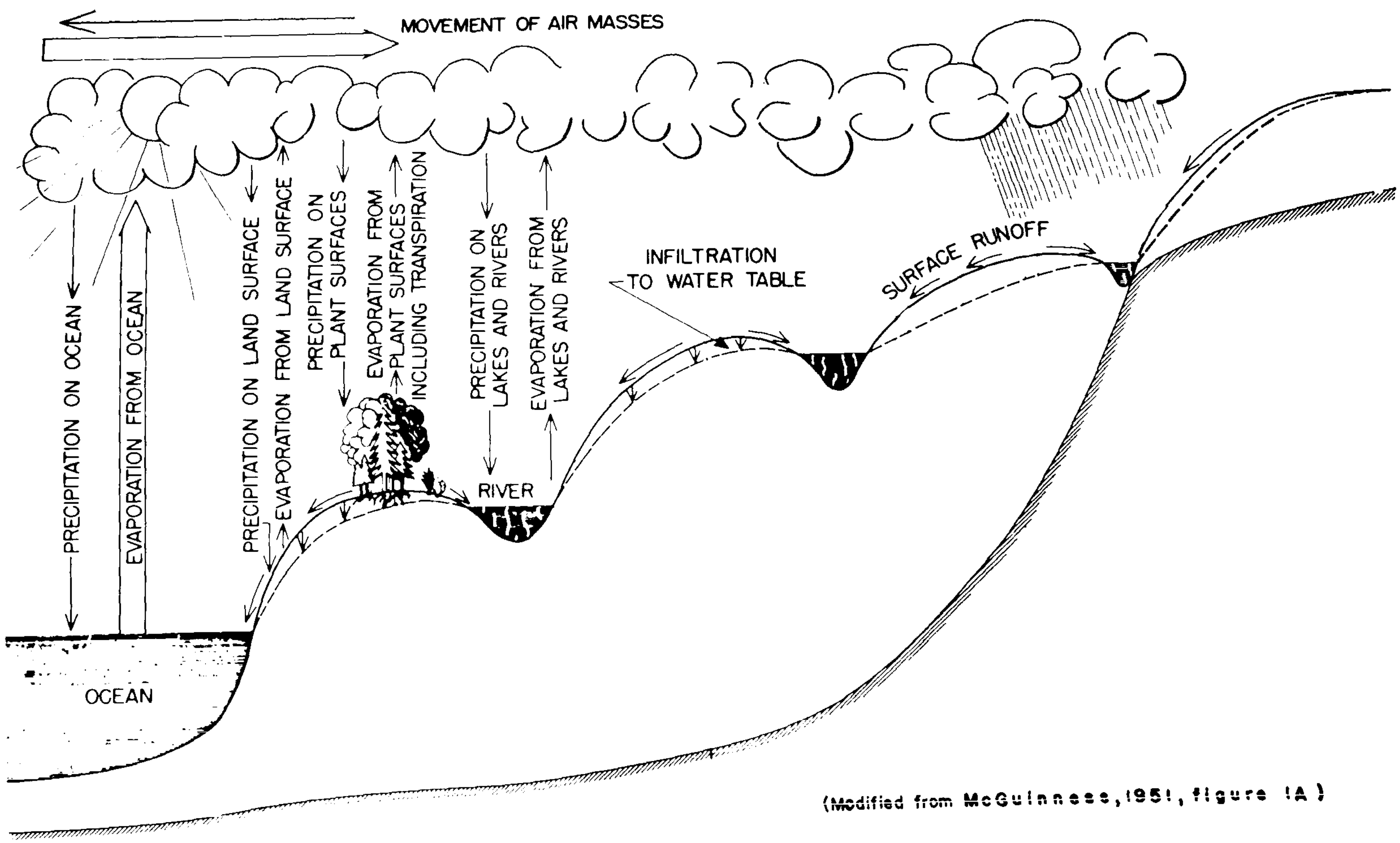
WATER RESOURCES

Nearly all the usable water of the earth is moving in a vast circulatory system called the hydrologic cycle. Surface water occurs in oceans, lakes, rivers, ponds, and marshes. Ground water occurs beneath the earth's surface; it is derived mainly from precipitation that soaks into the ground, moves through rock formations, and eventually is discharged to the atmosphere, into surface-water bodies, or used by plants, animals, or man. (See figure 2.)

Kidder County is unusual in that it has no stream or river that flows throughout all seasons. For indefinite periods after heavy rains or rapid melting of snow and ice, however, small streams flow into many of the depressions and lakes that are scattered throughout Kidder County. Lakes in the area are discussed by Rau and others (1962, p. 4).

Principles of Occurrence of Ground Water

Below certain depths the voids or pore spaces in the rocks of the earth's crust are saturated with ground water. Practically all ground water is derived from precipitation. Water enters the ground by penetration of rain or snowmelt or by percolation from streams and lakes. Ground water generally moves downward and then laterally from areas of recharge to areas of natural discharge.



(Modified from McGuinness, 1951, figure 1A)

Figure 2. Diagram of the hydrologic cycle.

Discharge is by evaporation from lakes, ponds, and the land surface where the water table is shallow, by transpiration, by seepage into streams, and by pumping and flowing from wells and springs.

Any rock formation or stratum that will yield water in sufficient quantity to be a source of supply is called an "aquifer" (Meinzer, 1923, p. 52). Water moving in an aquifer from recharge to discharge areas may be considered to be in "transient storage."

The amount of water that a rock can hold is determined by its porosity. Unconsolidated material, such as clay, sand, and gravel, generally is more porous than consolidated rock, such as sandstone and limestone; however, consolidated rock in some areas is highly porous.

The capacity of an aquifer to yield water by gravity drainage may be much less than is indicated by its porosity because part of the water is held in the pore spaces by molecular attraction to the rock particles; the smaller the pores, the greater the proportion of water that will be held. The amount of water, expressed as a percentage of a cubic foot, that will drain by gravity from 1 cubic foot of an aquifer is called the "specific yield" of the aquifer.

If the water in an aquifer is not confined by overlying, relatively impermeable strata, the water is under water-table conditions. Under these conditions, water can be obtained from storage in the aquifer by gravity drainage — that is, by lowering the water level, as in the vicinity of a pumped well.

Water is said to occur under artesian conditions if it is confined in the aquifer by an overlying, relatively impermeable stratum. Under such conditions, hydrostatic pressure will raise the water in a well, or other conduit penetrating the aquifer, above the top of the aquifer. When water is withdrawn from the well, the aquifer remains saturated, and water is yielded because of its own expansion and because of the compression of the aquifer due to lowered pressure, rather than by gravity drainage. The water-yielding capacity of an artesian aquifer is called the "coefficient of storage" and generally is very much smaller than the specific yield of the same material would be under water-table conditions. The coefficient of storage of an aquifer is the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

The resistance to the movement of water through pore spaces that are relatively large, such as those in coarse gravel, is not great, and such material is said to be permeable. However, the resistance to the movement of water through small pore spaces, such as those in clay or shale, may be great, and such material is said to be relatively impermeable or to have low permeability.

Concise explanations of the coefficients of permeability, transmissibility, and storage as well as an explanation of analyzing pumping-test data are given by Brown (1953). An aquifer test, also frequently called a pumping test, is a reliable means for determining the hydrologic properties of aquifers. A method commonly used for determining hydrologic properties from pumping-test data was developed by C. V. Theis (1935); in this method, transmissibility and storage coefficients are computed by means of the nonequilibrium formula, which has been discussed also by Wenzel (1942, p. 87-89). Derivation of the nonequilibrium formula is based on several assumptions regarding the physical properties of aquifers that are not generally found in nature. Ferris (1948) described use of the nonequilibrium method to interpret subsurface geologic relations that depart from the assumed conditions.

WATER-BEARING CHARACTERISTICS OF THE GEOLOGICAL UNITS

The significant geological units or formations with respect to the occurrence of ground water and their water-bearing properties are described briefly in table 1. The Tertiary and Cretaceous formations are terrestrial and marine sedimentary rocks; they are consolidated or cemented and are referred to as bedrock formations. In contrast, the Quaternary rocks are relatively unconsolidated sediments; all, except dune sand, are of Pleistocene age deposited during the advance and melting of ice sheets.

Consolidated Rocks

The bedrock formations in the county that are exposed or that were penetrated by test drilling are the Pierre Shale, Fox Hills Sandstone, and Cannonball and Tongue River Members of the Fort Union Formation. Older formations are below present (1962) economical drilling depths, and the water in them is generally too saline for most uses.

Wherever bedrock units are more than a few tens of feet below the surface, their pores or openings are probably saturated with water. However, some layers or beds are more permeable than beds directly above or below. Generally the ground water occurs in permeable layers between relatively impermeable beds. In these aquifers the water is under artesian conditions.

Pierre Shale. — The Pierre Shale, which underlines the entire county, is the bedrock formation directly beneath the glacial drift in most of the eastern half of the county. The shale is relatively impervious, but the upper part may yield small quantities of water to wells from fractures or possibly from sandy zones. Wells rarely yield more than 10 gmp (gallons per minute). In searching for ground-water supplies, well contractors do not drill deeper than the Pierre Shale because the next lower water-bearing units or formations are at great depths, and the water in them is highly mineralized.

Fox Hills Sandstone. — The Fox Hills Sandstone occurs in the western and southern parts of the county. It contains water-bearing sand and sandstone beds that yield small to moderate amounts of water to wells. The city of Steele and several farm wells obtain water from these beds. Ground water in the formation is under artesian pressure, but individual sand layers may have considerably different artesian pressures, indicating that the formation does not act as a water-yielding unit. Flowing wells from locally steeply dipping beds of the sandstone

TABLE 1.--Generalized section of the geologic units and their water-bearing characteristics

Era	System	Series		Geologic Unit	Thickness (feet)	Character	Water-bearing characteristics
Cenozoic	Quaternary	Recent		Dune sand	50 ±	Unconsolidated very fine to coarse sand, part of which is actively drifting.	Permeable. Generally contains ground water only where associated with or overlying surficial outwash deposits; transmits water to underlying aquifers readily.
		Pleistocene	Chronological order indeterminate	Surficial outwash deposits	250 ±	Unconsolidated sand and gravel with a little silt of glaciofluvial origin; occur in outwash plains and associated melt-water-drainage channels. Relatively extensive.	Generally highly permeable. Where relatively thick sand and gravel beds occur, yields of about 300 gpm (gallons per minute) are likely. Fine-grained beds yield smaller quantities of water.
				Ice-contact deposits	50 ±	Unconsolidated silt, sand, and gravel of glaciofluvial origin; occurring as kames, eskers, or similar glacial features; small areal extent.	Permeable. Yields relatively small supplies (25 to 100 gpm), where saturated thickness is sufficient.
				Buried-valley outwash deposits	125 ±	Unconsolidated silt, sand, and gravel of glaciofluvial origin occurring in bedrock valleys; underlies surficial outwash, till, and (or) lacustrine deposits.	Permeable. Yield unknown but probably large (500 gpm or more) yields are likely where deposits are thick and (or) extensive. Where overlain by surficial outwash, large yields (1,000 gpm or more) are likely.
				Lacustrine deposits	100 ±	Unconsolidated laminated clay, silt, and fine sand. Occur at the surface and buried under surficial outwash or other unconsolidated deposits.	Relatively impermeable; not a source of water for wells. May act as a barrier to ground-water movement.
				Till and associated sand and gravel deposits	380 ±	Unconsolidated unsorted clay to boulders; locally contains glaciofluvial silt, sand, or sand and gravel.	Till is relatively impermeable; may yield very small quantities of water, but the supply, especially from shallow dug wells, is undependable in long dry periods. Permeable isolated bodies of sand and gravel occur within till; these yield relatively small supplies (25 to 100 gpm), but steady withdrawals are limited because recharge from surrounding till is slow.
	Tertiary	Paleocene		Tongue River Member of Fort Union Formation	1,100 ± a/	Light tan, yellow and white sandstone; sandy, gray, limonitic shale; terrestrial; contains lignite beds at places. Not extensive in Kidder County.	Contains some permeable zones. Yields small quantities (generally only a few gallons per minute) of water at most places.
				Cannonball Member of Fort Union Formation	350 ± a/	Light-to dark-brownish-gray shaley sandstone; dark marine shale; fossiliferous. Not extensive in Kidder County.	Contains some permeable zones. Yields small quantities (generally only a few gallons per minute) of water at most places.
Mesozoic	Cretaceous	Upper		Fox Hills Sandstone	300 ± a/	Grayish-yellow marine sandstone; ferruginous; contains many concretions.	Moderately permeable. Yields as much as 150 gpm at most places; locally contains water under artesian pressure.
				Pierre Shale	2,300 ± a/	Consolidated bluish-gray to dark-gray marine shale; fossiliferous; contains many concretions.	Relatively impermeable. Generally not a source of water for wells in the project area.

a/ Approximate maximum thickness in State are obtained in T. 141 N., Rs. 73 and 74 W., and T. 138 N., Rs. 73 and 74 W. A flow of 140 gpm was measured from test hole 1139 (141-73-8aaa), which probably penetrated the Fox Hills Sandstone between 89 and 112 feet.

FORT UNION FORMATION. — The North Dakota Geological Survey refers to the Fort Union Formation, as used in this report, as the Fort Union Group (Hainer, 1956, fig. 11); also the Cannonball and Tongue River Members of this report are referred to as formations (Hainer, 1956, and Rau and others, 1962).

In the northwestern part of the county, the Cannonball Member, which immediately overlies the Fox Hills Sandstone, is eroded and is present only in scattered or thin deposits. Where saturated, the deposits may yield small amounts of water.

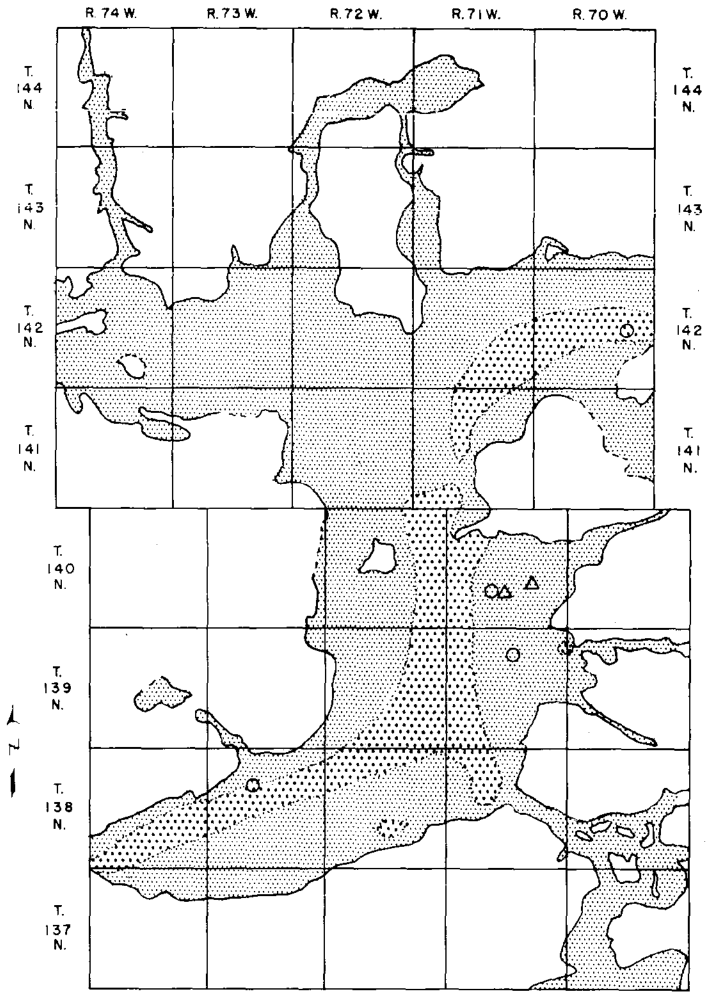
The Tongue River Member of the Fort Union Formation overlies the Cannonball Member and underlies the glacial drift in parts of northwestern Kidder County. It also is eroded and is probably thin. A few sand and sandstone layers in the Tongue River Member may be water bearing locally, but because they are generally small in areal extent, relatively thin, and probably enclosed within clay beds, they are not sources of large ground-water yields.

Unconsolidated Deposits

Ground water occurs in all the Quaternary unconsolidated deposits described in table 1, but certain units may be good sources of water, whereas others may not be. The water-bearing characteristics of the units have been evaluated largely on the basis of the logs and drilling characteristics of the test holes (Randich and others, 1962, table 5).

Surficial outwash deposits. — Outwash deposits are exposed in gently rolling plains that cover about 450 square miles in the central part of Kidder County (fig. 3). The surface of the outwash is somewhat basin shaped; the lowest areas are in the central part of the county.

Paulson (1962, p. 7 and fig. 1) points out that large outwash deposits occur in south-central North Dakota. Kidder County contains one of the State's largest outwash-plain areas. The surficial outwash deposits consist largely of stratified layers of sand and gravel, although silt and clay, as well as pebbles and cobbles, also are present in the deposits. Data from test holes show that the deposits may be at least 85 feet thick (Randich and others, 1962, table 5). The deposits are generally permeable and contain sufficient saturated material at many places to yield moderately large quantities (more than 100 gpm) of water to wells. In general, the yield at a given location depends on the extent and thickness of saturated sand and gravel layers locally. Yields may vary from quantities sufficient only for ordinary farm and domestic purposes to quantities adequate for relatively extensive irrigation. Ground water in surficial outwash deposits is generally under water-table conditions, but locally thin fine-grained deposits — silt and clay — overlie coarse-grained layers, and the ground water occurs under artesian conditions.



(Modified from J. L. Rau and others, 1962)

EXPLANATION

GLACIAL DRIFT UNDIFFERENIATED.

Generally the deposits are relatively impermeable, but at most places ground-water supplies from small scattered sand and (or) gravel bodies on or within glacial till are adequate for ordinary farm and domestic uses.

SURFICIAL OUTWASH DEPOSITS.

Stratified sand and gravel layers at or near the land surface. At most places ground-water supplies are adequate for small commercial or agricultural enterprises or for small municipal water-supply systems.

SURFICIAL OUTWASH UNDERLAIN BY BURRIED VALLEY OUTWASH DEPOSITS.

Stratified sand and gravel layers at more than one interval below the surface. Large ground-water supplies, adequate in quantity for relatively extensive irrigation use, are available at many places, and elsewhere moderately large supplies are probably available.

○ OBSERVATION WELL.

△ AQUIFER TEST.

BOUNDRY BETWEEN OUTWASH DEPOSITS AND UNDIFFERENTIATED GLACIAL DRIFT.

APPROXIMATE BOUNDRY BETWEEN OUTWASH DEPOSITS AND UNDIFFERENTIATED GLACIAL DRIFT.

SCALE

5 0 5 10 MILES

FIGURE 3-- MAP SHOWING THE DISTRIBUTION OF OUTWASH DEPOSITS AND UNDIFFERENTIATED GLACIAL DRIFT AND LOCATION OF OBSERVATION WELLS AND AQUIFER TESTS.

are obtained in T. 141 N., Rs. 73 and 74 W., and T. 138 N., Rs. 73 and 74 W. A flow of 140 gpm was measured from test hole 1139 (141-73-8aaa), which probably penetrated the Fox Hills Sandstone between 89 and 112 feet.

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Buried-valley outwash deposits. — Buried- valley outwash deposits occur in preglacial river valleys and in valleys formed during the intervals between major ice-sheet advances. A large bedrock valley or channel, the so-called ancestral Cannonball River channel, underlies Long Lake in southwestern Kidder County and parts of the outwash plains in the central and northeastern parts of the county. Rau and others (1962, p. 36-37) indicated that the Cannonball River channel system formerly extended from the confluence of the present-day Cannonball and Missouri Rivers through Emmons and Burleigh Counties into Kidder and Stutsman Counties. In central Kidder County it is oriented in a north-south direction (Rau and others, 1962, p. 1), but it extends into Stutsman County in a generally northeasterly direction; it is joined, also, by tributary buried valleys. Most of the buried-channel system in Kidder County is overlain by surficial outwash, but lakes and till overlie parts of it.

Areas where surficial outwash deposits are underlain by buried-valley outwash are shown on figure 3. Because they are extensive and overlie relatively thick sections of permeable sand and gravel, these areas are capable of furnishing large yields to wells. In many of the test holes that were drilled into buried-valley outwash deposits, more than 100 feet of permeable material was penetrated (Randich and others, 1932, table 5; Rau and others, 1962, figs. 7 through 15). The ground-water yields from surficial and buried-valley outwash together may be as much as 1,000 gpm, perhaps more.

Ice-contact deposits. — At some places in the county, deposits of sand and gravel underlying kettles and kettle chains are potential sources of relatively small (50 to 100 gpm) supplies of ground water. In these areas stratified sand and gravel are exposed, and the ground water is under water-table conditions.

Although kame and esker deposits are numerous in Kidder County (Rau and others, 1962, plate 1), most are probably above the zone of saturation; and only a few may be sources of ground water.

Till and associated sand and gravel deposits. — Surrounding the outwash plains in the central part of Kidder County are glacial moraines. The moraines are largely composed of till, which is an unsorted heterogeneous mixture of material deposited by glaciers, ranging in texture from clay to boulders. The till is relatively impermeable and ordinarily yields only small ground-water supplies. At places, however, lenses range from a few tens to several hundred feet in thickness; because these deposits have no surface expression, they can be located and defined only by subsurface exploration. Yields from the deposits are adequate for farm or domestic supplies and at places may be sufficient for small municipal or commercial supplies. If replenishment is less than discharge, however, yields decline as the water stored in the lens is removed.

Other unconsolidated deposits. — Other wind-deposited sediments, known as loess, occur at the surface in part of Kidder County. The deposits are thin, have low permeability, and are not known to be sources of ground water. Lacustrine clay and silt are present in parts of the area both at the land surface and beneath other unconsolidated deposits. The lacustrine deposits are relatively impermeable, are not used as ground-water sources, and may restrict ground-water movement locally. Dune sand directly overlies surficial outwash in parts of the area. The dunes are permeable, and, where they are saturated, the water in them is probably interconnected with ground water in the surficial outwash. Ground water in the dunes is under water-table conditions. The depth to water in wells in the largest dune area — the Dawson State Game Refuge area — ranges from about 6 to 10 feet.

Recent alluvial deposits of clay, silt, and some sand and gravel have been deposited over glacial drift in a few places. The deposits are thin and are probably not a source of water for wells.

Ground-Water Recharge, Movement, and Discharge

Recharge is the term used to describe the addition of water to the zone of saturation. The source of almost all ground water is precipitation on the earth's surface. The quantity and rate of recharge depend on factors such as the type and structure of the soil, topography, vegetation, intensity of rainfall, wind velocity, humidity, and temperature; these factors determine the amount of the precipitation that is returned to the atmosphere through evapo-transpiration and the amount that is left to percolate downward to the ground-water reservoirs.

Large variations in permeability exist between different deposits in Kidder County. Because the surficial outwash plains and associated soils in the central part of the county are permeable, a considerably larger proportion of the precipitation soaks into these deposits than percolates through till, lacustrine, or other relatively impervious deposits.

The quantity of water that flows into the glacial-drift aquifers underground from adjacent areas may be relatively small because, except under Long Lake near the southwestern corner, Kidder County has roughly the same altitude on all sides. However, some underflow may leave Kidder County in buried-valley outwash on the eastern edge of the county in T. 142 N., where permeable deposits occupy the so-called ancestral Cannonball River channel (fig. 3).

Ground water in the bedrock formations is replenished by infiltration of precipitation on exposed surfaces, by vertical and lateral movement of water from one formation to another, and by downward percolation of water through overlying formations, including glacial drift.

Ground water is discharged from the zone of saturation by evapotranspiration; by seepage into springs, lakes, and swamps (or streams in some areas outside of Kidder County); and by flow or withdrawals through wells. Ground water is evaporated where the water table is close to the land surface. Water is transpired by plants whose roots penetrate to the capillary fringe or to the zone of saturation. Evapotranspiration depends on meteorlogical conditions, especially temperature, wind velocity, and relative humidity. During the warm months of the year, large quantities of water are evaporated and transpired from and around lakes, ponds, springs and seepage areas. Probably much of the water that evaporates from lakes and ponds is replaced by ground water discharging into lakes and ponds.

In general, ground water moves in the direction of the slope of the water table from points of higher potential, or head, to points of lower head. The water table is not a plane surface but has irregularities caused chiefly by local differences in geology and topography. Generally the water table is a subdued reflection of the land surface; therefore, ground water in unconfined aquifers moves roughly in the direction of the slope of the land surface.

Locally, however, as water in the zone of saturation moves from one rock unit to another having different water-bearing properties or as the ratio of recharge to discharge changes significantly, the general direction of movement may be altered. Moreover, ground-water movement is three dimensional, having both vertical and horizonal components. In general, ground-water movement in shallow aquifers is toward the relatively low outwash plains in the central part of Kidder County.

In the buried-valley outwash deposits in the south-central part of the county, some ground water may move southwestward toward Long Lake, but in the central and northeastern parts of the county, some ground-water movement in the deepest part of the ancestral Cannonball River channel is probably northeastward and eastward. Thus, a ground-water divide probably exists near the central part of the county in the buried-valley outwash deposits.

Because the bedrock formations dip or slope gently to the northwest, regional movement of water in them is probably northwestward.

The rate at which ground water moves through a given rock unit depends primarily on the permeability of the unit and the slope of the water table or piezometric surface. Under the hydraulic gradients commonly prevailing in nature, the rate of movement in most formations of the type that occur in Kidder County is slow. The rate probably ranges from a few feet per year to a few feet per day.

Water-Level Fluctuations

The water table or piezometric surface rises and falls chiefly in response to changes in barometric pressure and in the ratio of recharge to discharge. Relatively small fluctuations, generally daily or weekly, are generally due to changes in atmospheric pressure. Rises or declines in water levels extending over longer periods of time are generally seasonal adjustments between recharge and discharge. Declining water levels indicate a net loss of ground water from storage. During the summer, when evapotranspiration reduces the amount of water available for recharge and increases natural discharge, water levels in most aquifers decline. Water levels may decline also during the winter because freezing prevents replenishment of aquifers by infiltration from precipitation. In general, during the spring, early summer, and late fall when evapotranspiration is small and precipitation is large, recharge is comparatively large; thus water levels frequently rise. Sometimes despite freezing temperatures near the surface, water levels may continue to rise throughout the winter, owing to the time lag as water below the frost line percolates downward to the zone of saturation.

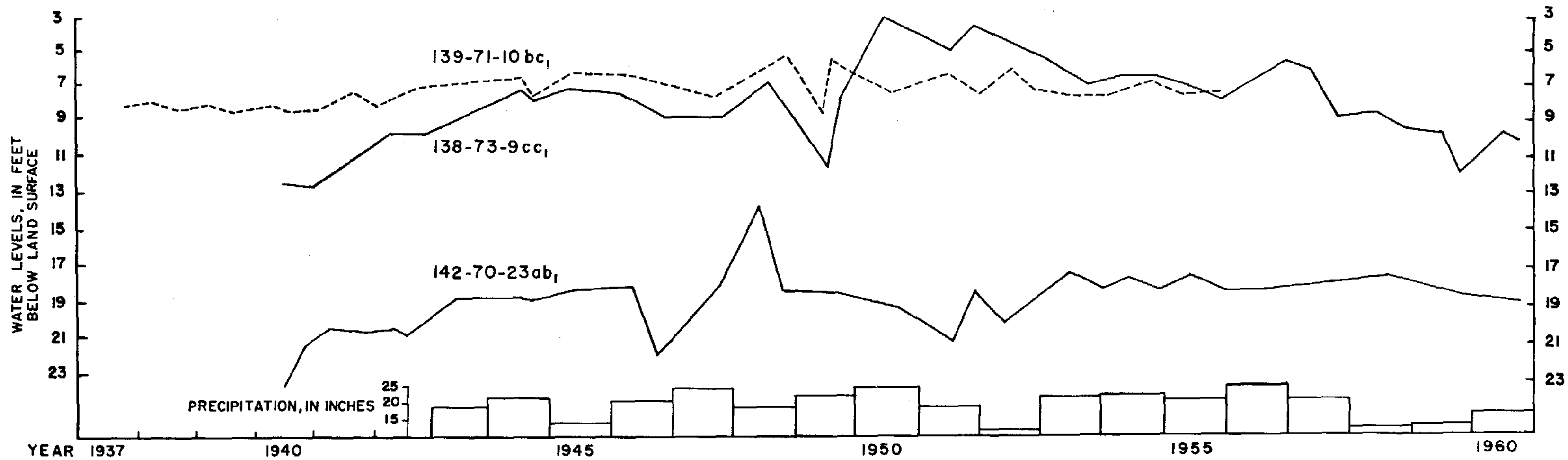


FIGURE 4. WATER-LEVEL FLUCTUATIONS COMPARED WITH ANNUAL PRECIPITATION RECORD FOR CITY OF STEELE.

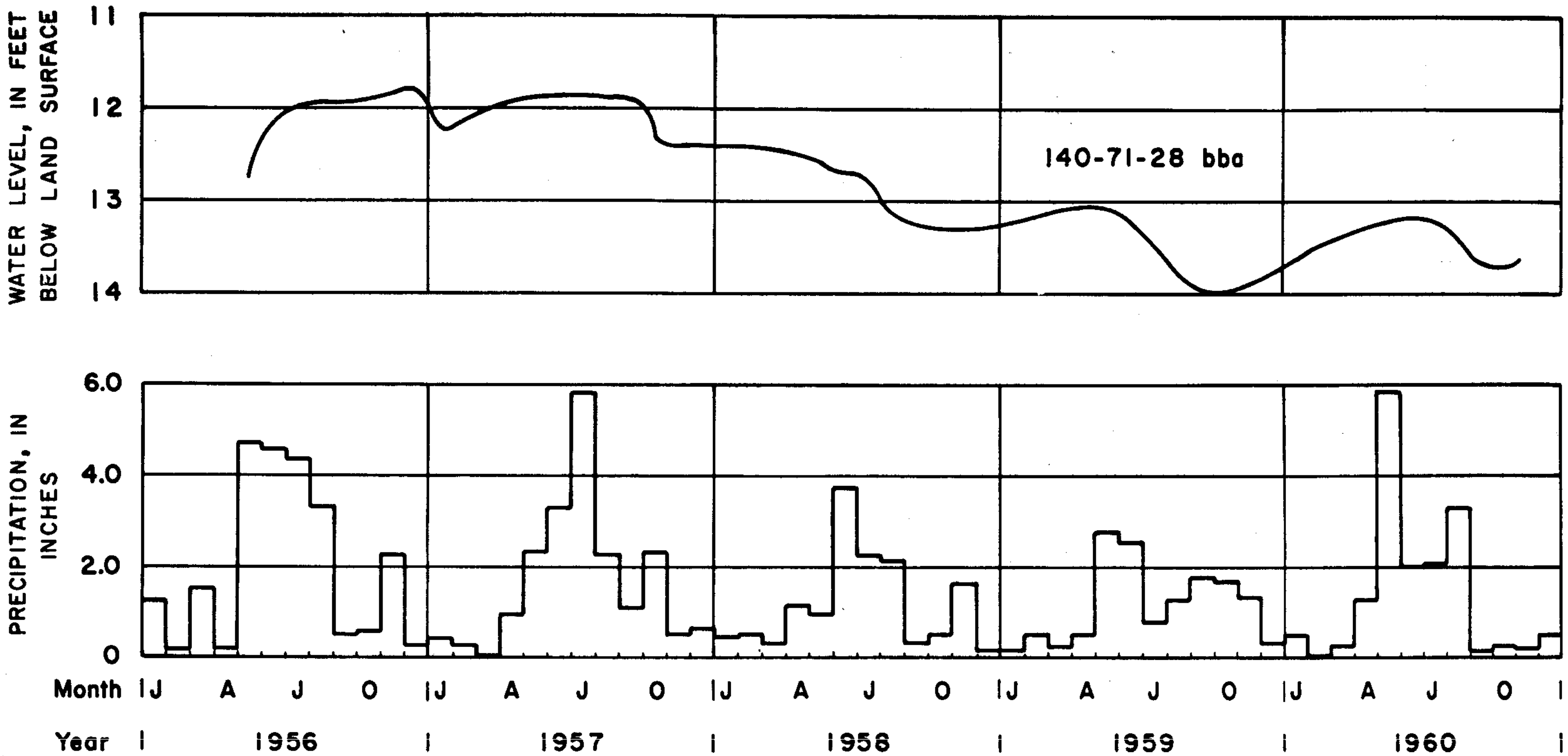


FIGURE 5. WATER-LEVEL FLUCTUATIONS COMPARED WITH MONTHLY PRECIPITATION RECORD FOR CITY OF STEELE.

Records of water-level fluctuations in a few wells in Kidder County have been obtained for more than 20 years. The hydrograph (fig. 4) of observation well 138-73-9cc shows that the water level in this well has fluctuated between 3½ and 12½ feet below the land surface throughout the period for which records are available. The hydrograph (fig. 5) of the observation well 140-71-28bba shows a gradual decline of water level from a depth of about 11.75 feet below the land surface in late 1956 (highest reading on record) to 13.95 feet in late 1959 (lowest reading on record). The well is not affected by nearby pumping; therefore, the decline represents a net decrease in storage as a result of greater natural discharge than recharge during the 3-year period. The average annual precipitation at Steele, N. Dak. (about 20 miles southwest of the well) is 17.10 inches. Precipitation records for 1958, 1959, and 1960 at Steele show that the total annual amount was from 2 to 4 inches below the average. The water level in the observation well for the same period ranges from about 1 to 1½ feet below the 1956 and 1957 water levels.

Aquifer Tests

In October 1954 a test was made on an unused irrigation well (140-71-23ccb); the well was pumped at 52 gpm for 6¼ hours. A second test was made in September 1955 on test hole 1042 (140-71-28baa). The well was pumped at 42 gpm for a few hours. The computation of the results of the pumping tests is based on drawdown and recovery measurements made in observation wells using the Theis (1935, p. 519-524) nonequilibrium formula and methods outlined by Wenzel (1942, p. 87-89) and Cooper and Jocob (1946, p. 526-529). The results of the pumping tests do not necessarily reflect values of coefficients of transmissibility consistent with that of the surficial outwash deposits as a whole because the tests were (1) made at locations that may not be very permeable, (2) of too short duration to obtain reliable results, and (3) made in wells that probably had not had proper development or maintenance. Probably coefficients of transmissibility are larger at many places. The results of the tests are as follows:

Recovery or Drawdown	Average coefficient of transmissibility (T) (gallons per day per foot)
Well 140-71-23ccb	
Drawdown	T - 43,000
Recovery	T - 44,200
Drawdown	T - 39,100
Recovery	T - 38,100
Test hole 1042 (140-71-28baa)	
Drawdown	T - 29,000
Recovery	T - 24,500
Drawdown	T - 31,700
Recovery	T - 22,200

DEPTH TO WATER

The depth to water in many wells in Kidder County is shown by Randich and others (1962, fig. 2 and table 1). In surficial and buried-valley outwash deposits, the depth to water ranges from 0 in flowing wells to about 50 feet. In ice-contact deposits depths to water probably range between 5 and 25 feet. The depth to water in wells finished in till and associated sand and gravel deposits and in the bedrock formations ranges form 0 to about 200 feet below the land surface. (A few have greater reported depths to water.) Most bedrock wells have depths to water that are less than 25 feet below the surface.

UTILIZATION OF GROUND WATER

The residents of Kidder County are almost entirely dependent on ground water for their domestic and farm needs. Household uses, stock-watering, and other farm uses are supplied by wells yielding small quantities of water. Where the water table is less than about 20 feet below the land surface, there are many dug wells; however, most of the wells used now (1962) are drilled wells with diameters ranging from about 2½ to about 8 inches. Some wells, especially those used for stock watering in pastures, have windmills for pumping the water; several flow naturally; many have powered jet pumps or cylinder pumps; and some have hand pumps only. A few farms are supplied by springs.

A relatively large-capacity well in section 25, T. 139 N., R. 72 W., had been used extensively during the drought of the 1930's to supply water to a nearby lake for sustaining water-fowl production. The well reportedly had been pumped for prolonged periods at 280 gpm from 1936 until 1941.

The quantity of water withdrawn through wells in Kidder County probably averages roughly 1,200,000 gallons daily. This quantity was estimated from population and livestock figures compiled from U.S. Bureau of Census (1960), and N. Dak. Crop and Livestock Statistics (Annual Summary, 1959).

Estimated Use of Ground Water, Kidder County in 1960

Usage	Population	Gallons per person	Gallons per day
City of Steele	847	100	84,700
Villages	1,147	75	86,025
Rural (domestic)	3,392	75	254,500
Rural (livestock	....	....	768,000
		Total	1,193,225

The utilization of ground water in the county could be increased considerably by developing wells in selected areas, especially in the surficial outwash and buried-valley outwash deposits. The quantity of water that could be recovered from a given locality depends on the permeability and saturated thickness of the water-bearing materials; therefore, testing of individual sites is needed to determine the yield.

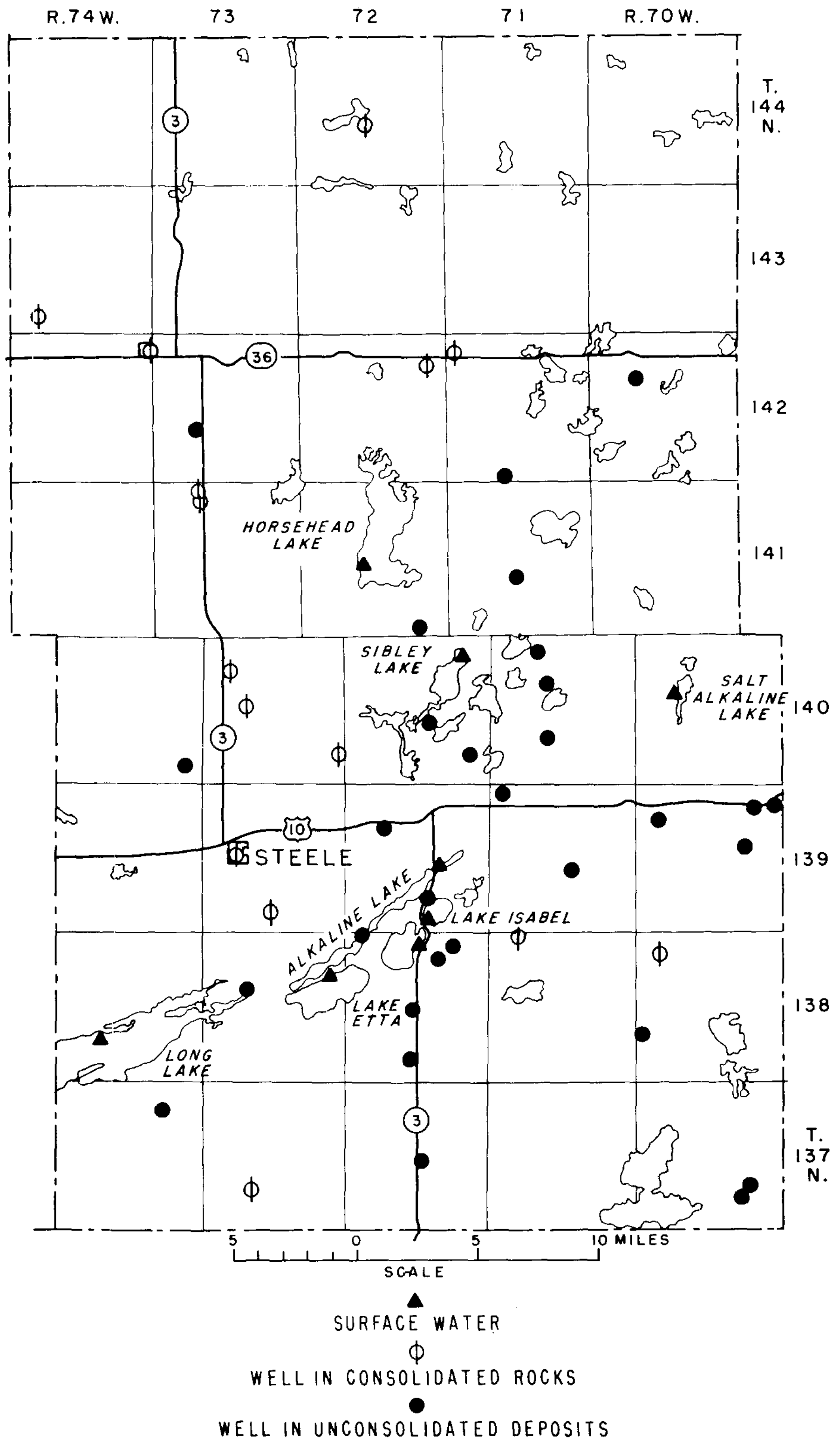


FIGURE 6. MAP SHOWING CHEMICAL-QUALITY SAMPLING SITES

CHEMICAL QUALITY OF THE WATER

The degree to which the water resources of Kidder County may be further developed depends not only on the quantity of water available but also on the chemical quality of the water. Abundant supplies of water in parts of the county will provide a strong inducement for irrigation and industrial development only if the quality of the water is satisfactory. The chemical quality of water depends mostly on the constituents dissolved from the minerals with which the water has had contact. These dissolved constituents limit the economical uses of the water.

Water from the principal types of deposits and from a few surface-water sites was sampled mainly in 1959 and analyzed for chemical quality by the U.S. Geological Survey. Simpson (1929, p. 286) presented two analyses of water from the vicinity of Steele, and the North Dakota State Laboratories Department had on file analyses of water from a few wells. In 1955 and 1956 the U.S. Geological Survey obtained and the State Laboratories Department analyzed water from several wells scattered throughout the county. Most of the wells for which water-quality data were obtained in 1959 were near test holes so that the logs of the holes could be used as an aid in identifying the materials from which the wells produce. All sampling sites are shown in figure 6.

The concentrations of the dissolved constituents in samples obtained in 1959 were determined according to analytical methods described by Rainwater and Thatcher (1960) and are generally given in parts per million. Parts per million are converted to equivalents per million by multiplying parts per million by the following factors:

Calcium	0.04990	Carbonate	0.03333
Magnesium	.08224	Sulfate	.02082
Sodium	.04350	Chloride	.02820
Potassium	.02558	Fluoride	.05263
Bicarbonate	.01639	Nitrate	.01613

Water From Consolidated Rocks

In most of the county there is an interchange of water from one rock unit to another. Although many wells in the county tap consolidated rocks, the stratigraphic unit from which they produce is known for very few wells. Consequently, variations in water quality could not be related to different stratigraphic units.

The chemical analyses of water from the consolidated rocks are given in table 2. The dissolved solids generally are between 600 and 1,200 ppm, or about twice those in water from the surficial outwash deposits. However, considerably higher dissolved solids exist locally.

Water from the consolidated rocks in the southern half of the county contains principally sodium and bicarbonate and is very hard; however, that from similar rocks in the northern half of the county contains principally calcium and bicarbonate and is only moderately hard. (See fig. 7). Also, in most of the water the percentage of sulfate is high. Water from two wells (analysis numbers 3 and 14), which have depths

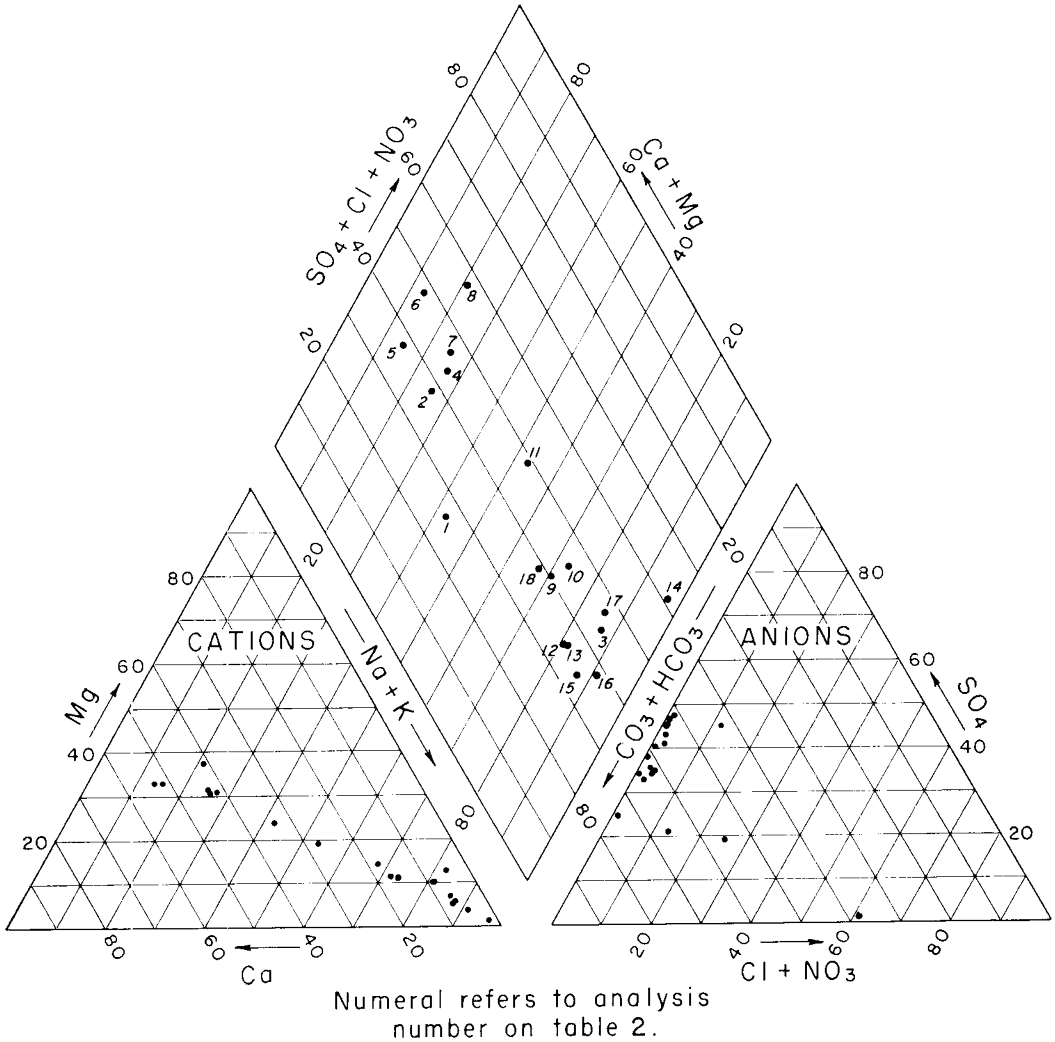


FIGURE 7. PERCENTAGE COMPOSITION, FROM EQUIVALENTS PER MILLION, OF DISSOLVED SOLIDS IN WATER FROM CONSOLIDATED ROCKS

Table 2.--Chemical analyses of water from consolidated rocks

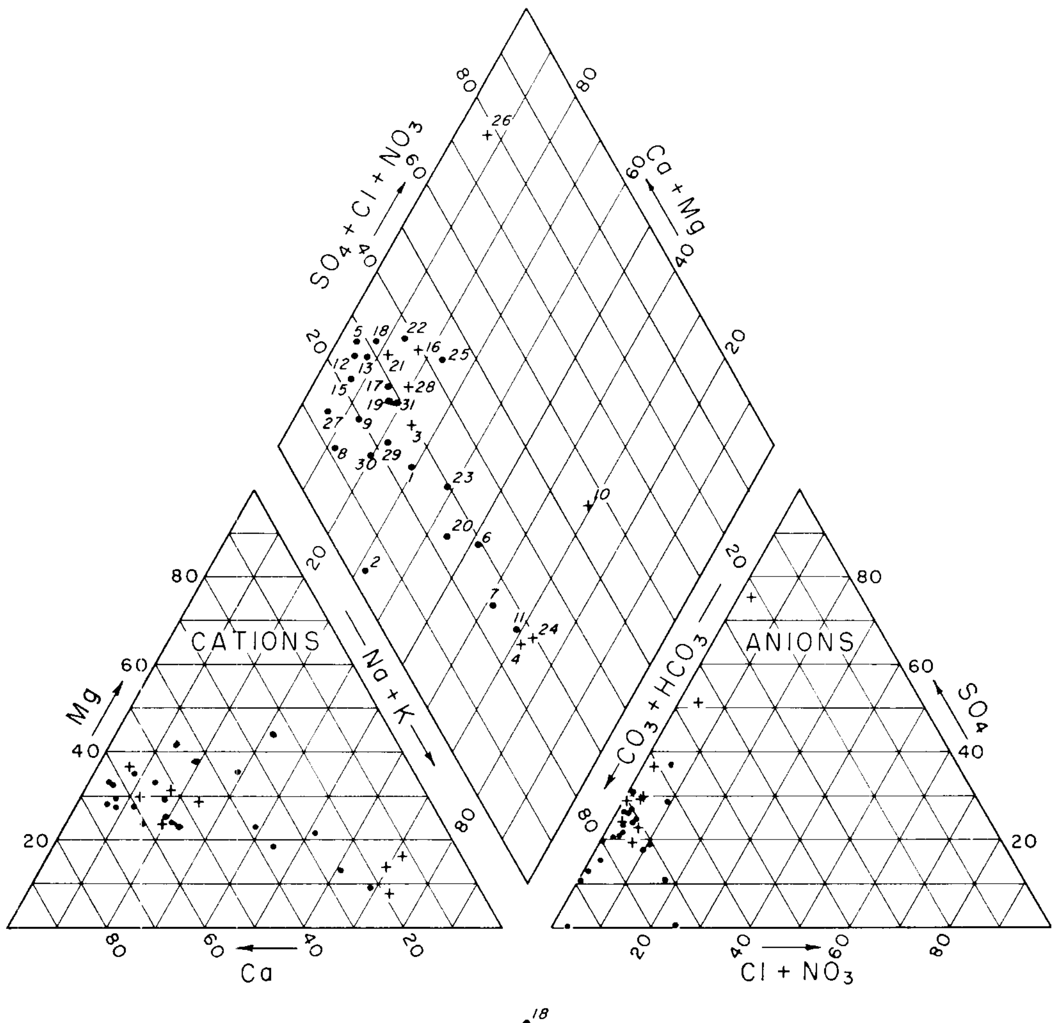
[Results in parts per million except as indicated]

Analysis number	Well number	Depth (ft)	Date of collection	Temperature (° F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos per cm at 25° C)	pH
1	137-73-28bc..	120	1959 Apr. 2...	40	44	8.6	0.33	72	30	95	11	472	0	125	3.6	0.3	2.4	0.34	......	599	304	0	39	2.4	924	7.4
2	138-70-6ddd..	200	Apr. 1...	44	28	3.0	.28	129	56	78	14	562	0	255	7.2	.1	4.9	.37	......	842	552	91	23	1.4	1,240	7.0
3	138-71-5bb...	300	Apr. 4...	45	50	2.7	.16	27	9.1	341	11	598	0	161	158	.2	.3	1.7	1,060	1,070	105	0	86	14	1,680	7.5
4	139-73-17cda1	160	(a b)	.....	25	1.6	....	126	57	......	......	517	0	298	12	.....	.....	.....	......	686	547	124	....	....	....	6.3
5	139-73-17cda3	135	June 1...	47	41	.62	1.3	126	48	36	13	455	0	196	7.8	.3	11	.16	......	718	513	140	13	.7	1,050	7.1
6	139-73-17cad1	110	1921 June 15..	.....	45	....	....	193	65	55		554	0	389	4.0	.....	.3	.....	......	1,060	749	295	....	....	....	...
7	139-73-17cad2	120	...do....	.....	46	.72	....	150	62	101		561	0	366	6.0	.....	.....	.....	......	1,040	629	169	....	....	....	...
8	139-73-33aaa.	100	1959 Apr. 2...	44	48	.15	.16	111	61	56	14	349	0	286	10	.3	79	.33	......	851	526	240	18	1.1	1,160	7.0
9	140-73-8bcd..	73	Apr. 3...	47	48	.96	.17	52	21	250	9.8	553	0	300	5.5	.2	.2	.78	......	957	214	0	71	7.4	1,400	7.3
10	140-73-17ddd.	180	...do....	45	51	.77	.12	53	22	284	11	584	0	361	8.2	.2	7.4	.99	1,090	1,070	224	0	72	8.2	1,550	7.3
11	140-73-25dd..	75	...do....	45	50	.52	.51	95	40	202	18	541	0	400	8.1	.2	1.5	.51	1,080	1,080	400	0	51	4.4	1,530	7.1
12	141-73-5adc..	(c)	1955 Oct. 25 a	.....	......	1.1	....	24	16	240	7.0	497	25	216	11	.5	0	1.3	......	856	124	0	80	9.4	....	8.3
13	141-73-5daa..	(c)	1956 Aug. 15 a	.....	......	2.2	....	15	20	248	7.2	532	0	219	.....	.3	0	1.4	......	828	119	0	81	9.9	....	8.2
14	142-71-6cdc..	280	1959 Apr. 3...	43	37	.25	.02	17	5.2	865	8.9	913	0	1.0	855	.3	.9	3.5	2,240	2,260	64	0	96	47	3,880	7.6
15	142-72-12bbd.	c 150	1955 Oct. 25 a	.....	......	2.9	....	27	14	390	8.8	700	58	202	96	.0	1.0	1.2	1,140	1,190	124	0	86	15	....	8.2
16	142-74-1dca..	155	1959 Apr. 3...	44	34	.71	.10	20	8.3	371	5.5	694	0	307	16	.1	5.1	1.1	1,110	1,120	84	0	90	18	1,660	7.6
17	143-74-32bca.	c 148	1955 Oct. 25 a	.....	......	.7	....	30	18	435	7.8	685	44	464	.....	.3	0	1.2	1,340	1,400	148	0	86	15	....	8.4
18	144-72-21dad.	c 90	...do. a.	.....	......	.4	....	52	25	220	9.5	544	16	283	0	.3	0	1.5	......	923	232	0	66	6.3	....	8.1

a Analysis by State Laboratories Dept., Bismarck, N. Dak.

b Date unknown.

c Flowing well.



Water from surficial outwash

Water from sand and gravel in till

Numeral refers to analysis number on table 3.

FIGURE 8. PERCENTAGE COMPOSITION, FROM EQUIVALENTS PER MILLION, OF DISSOLVED SOLIDS IN WATER FROM UNCONSOLIDATED DEPOSITS

of about 300 feet, contains relatively high percentages of chloride. Water from the flowing wells was assumed to be from consolidated rocks because of the similarity in percentage composition and in dissolved solids between ths water and most of the other water from consolidated rocks in the county.

The Dakota Sandstone of Early Cretaceous age probably underlies all Kidder County and is a potential source of water, but the quality of the water is poor and the formation is below present (1962) economical drilling depths. No wells in Kidder County produce from this sandstone, but a few wells in Stutsman County, contiguous with Kidder County, do produce from Dakota Sandstone; the water from a well (138-63-9bca) 1,350 feet deep had a dissolved solids content of 6,150 ppm, of which 97 percent of the cations was sodium and 92 percent of the anions was chloride.

Water From Unconsolidated Deposits

Water from the unconsolidated deposits is obtained from surficial and buried-valley outwash deposits and from deposits of sand and gravel in till. Most of the chemical-quality data represent water from the outwash deposits because these deposits have the better potential for development of large water supplies, mainly in the south-central part of the county.

The water from surficial outwash deposits is likely to contain smaller amounts of dissolved solids than the water from deposits in till. Because the sand and gravel were deposited from fresh water and generally were leached of readily soluble minerals, they are poor sources of material for solution. The till, however, although not in itself a significant source of water because of its low permeability, is a rich source of material for solution.

Water from the surficial outwash deposits contained dissolved solids that ranged within the rather narrow limits of 302 to 751 ppm, whereas water from deposits of sand and gravel in till ranged within the much wider limits of 497 to 2,410 ppm. (See table 3.) Except that water from all wells less than 50 feet deep in the surficial outwash deposits contained less than 500 ppm of dissolved solids, no consistent relation between well depth and dissolved solids in water from the drift was observed. Water from most wells in the unconsolidated deposits contained much iron and manganese and was very hard, but it contained only small amounts of potassium, chloride, fluoride, nitrate, and boron.

The general chemical composition of water from the unconsolidated deposits is indicated by figure 8, a water-analysis diagram proposed by Piper (1953). Points in the triangular fields show the relative percentages, computed from equivalents per million, of the individual cations and anions in the water; and points in the diamond field show the overall similarities or differences in the chemical composition of the water. Analysis number 14 was not plotted because it represents the same supply as analysis number 15.

Water from most places in the surficial outwash deposits is similar in percentage composition of dissolved solids, which consist predominant-

Table 3.--Chemical analyses of water from unconsolidated deposits

[Source of water: Qow, surficial outwash deposits; Qsgt, deposits of sand and gravel in till. Results in parts per million except as indicated]

Analysis number	Well number	Depth (ft)	Source of water	Date of collection	Temperature (° F)	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids: Calculated	Dissolved solids: Residue on evaporation at 180° C	Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos per cm at 25° C)	pH
1	137-70-26abb..	60	Qow	(a)	.....	......	0.2	....	51	31	48	......	313	9	....	24	0.5	65	.....	......	542	255	0	29	1.3	....	8.6
2	137-70-26cba..	100	Qow	1950 December a/	.....	......	.55	....	28	31	42	......	299	21	....	5.2	.4	0	.....	......	427	196	0	32	1.3	....	8.6
3	137-72-22bb...	60	Qsgt	1959 Apr. 2.....	43	26	.99	0.30	107	39	58	11	482	0	158	1.5	.1	5.9	0.38	......	644	427	32	22	1.2	983	6.9
4	137-74-11bab..	b 110	Qsgt	...do......	46	31	1.1	1.0	26	22	176	7.9	513	0	131	7.3	.4	1.3	.53	......	661	157	0	70	6.1	1,030	7.3
5	138-70-30bb...	38	Qow	...do......	45	28	.12	.00	103	33	5.4	3.8	356	0	42	7.8	.1	71	.32	......	476	392	100	3	.1	740	7.2
6	138-72-2cba...	92	Qow	...do......	45	30	.51	.84	55	27	111	11	436	0	130	4.6	.1	5.2	.39	......	586	246	0	48	3.1	918	7.2
7	138-72-6aba...	80	Qow	...do......	46	29	.05	.97	50	15	128	9.2	441	0	100	9.4	.2	3.2	.47	......	555	187	0	58	4.1	878	7.3
8	138-72-10aab..	15	Qow	...do......	44	30	.02	2.3	68	19	13	3.6	298	0	28	.8	.2	1.0	.10	......	312	248	4	10	.4	500	7.3
9	138-72-21aa...	48	Qow	...do......	46	28	1.1	.55	60	34	19	2.3	320	0	63	.8	.2	.1	.08	......	367	288	26	12	.5	596	7.3
10	138-72-33ab...	96	Qsgt	...do......	45	30	.51	.97	55	28	256	12	458	0	412	13	.3	4.0	.86	1,040	1,030	252	0	68	7.0	1,500	7.6
11	138-73-17ada..	85	Qow	...do......	46	29	.15	1.1	58	14	200	10	573	0	110	41	.3	1.8	.61	......	751	204	0	67	6.1	1,160	7.3
12	139-70-2ddc...	60	Qow	Apr. 1.....	44	32	.06	.83	91	28	7.1	3.0	327	0	81	4.2	.2	.7	.06	......	414	344	76	4	.2	640	7.4
13	139-70-7ad....	30	Qow	...do......	46	28	.04	1.2	77	22	9.7	2.3	267	0	76	.1	.3	3.5	.06	......	353	283	64	7	.2	557	7.4
14	139-70-1dcc...	(b)	Qow	1955 Oct. 25 a/.	.....	......	.4	....	91	31	11	3.5	336	14	76	.....	.1	.....	.1	......	457	354	56	6	.3	....	8.0
15	139-70-1dcc...	(b)	Qow	1959 Apr. 1.....	45	37	1.1	1.1	96	27	10	3.6	353	0	75	3.6	.2	.1	.06	......	426	352	63	6	.2	668	7.7
16	139-70-14bd...	96	Qsgt	...do......	46	31	.33	1.8	159	59	57	7.7	564	0	265	12	.2	.2	.19	......	921	639	177	16	1.0	1,290	7.0
17	139-71-6bd....	40	Qow	Apr. 3.....	45	29	.37	1.6	85	20	22	5.3	308	0	83	10	.0	1.0	.10	......	407	296	43	14	.6	625	7.3
18	139-71-22bd...	40	Qow	Apr. 1.....	47	28	.23	.46	93	25	13	2.0	306	0	106	1.8	.3	1.7	.05	......	431	334	83	8	.3	651	7.5
19	139-72-8db....	60	Qow	Apr. 3.....	45	31	.43	1.5	107	35	32	9.2	433	0	120	4.2	.2	.2	.10	......	551	409	54	14	.7	855	7.1
20	139-72-27cb...	130	Qow	Apr. 2.....	47	31	.15	.92	60	18	76	8.1	375	0	83	6.6	.2	2.3	.29	......	478	225	0	41	2.2	726	7.5
21	140-71-5daa...	80	Qsgt	Apr. 3.....	43	28	.90	1.2	102	31	20	5.6	352	0	121	8.8	.2	.0	.09	......	497	383	94	10	.4	758	7.2
22	140-71-9ccd...	30	Qow	...do......	44	26	.08	1.1	84	32	22	3.0	298	0	106	25	.1	.0	.06	......	454	340	96	12	.5	707	7.2
23	140-71-28bab..	85	Qow	1955 Sept. 21 a/	.....	......	.3	....	61	22	67	5	340	0	82	.....	.2	.1	.4	......	465	244	0	37	1.9	....	7.4
24	140-72-22ca...	150	Qsgt	1959 Apr. 3.....	45	31	1.2	.63	53	13	230	7.5	618	0	158	27	.3	1.8	.60	......	831	187	0	72	7.3	1,280	7.4
25	140-72-25ccc..	50	Qow	...do......	44	29	.49	2.9	113	29	52	8.4	365	0	185	21	.2	1.3	.12	......	625	402	103	22	1.1	921	7.1
26	140-74-36bcb..	90	Qsgt	Apr. 4.....	41	24	21	4.0	415	162	41	20	472	0	1,310	33	.2	.1	.19	2,260	2,410	1,700	1,310	5	.4	2,600	6.6
27	141-71-21ddc1.	55	Qow	...do......	46	29	.32	.72	72	19	6.0	2.6	283	0	33	1.8	.1	.5	.03	......	302	256	24	5	.2	486	7.5
28	141-72-35ddb2.	100	Qsgt	Apr. 3.....	46	29	.32	1.7	109	28	37	8.0	392	0	136	8.8	.2	1.5	.33	......	550	388	67	17	.8	838	7.1
29	142-70-8dda...	72	Qow	...do......	39	27	.41	1.3	101	27	39	7.3	424	0	89	4.2	.2	1.6	.24	......	505	362	14	19	.9	791	7.2
30	142-71-33cda..	54	Qow	Apr. 4.....	46	30	1.2	.63	90	23	32	6.8	397	0	58	4.1	.2	2.2	.28	......	442	318	0	18	.8	706	7.1
31	142-73-20ddb..	21	Qow	Apr. 3.....	43	24	.54	.16	58	31	26	3.8	287	0	60	4.3	.1	33	.13	......	376	272	37	17	.7	604	7.5

a Analysis by State Laboratories Dept., Bismarck, N. Dak.
b Flowing well.

ly of calcium and bicarbonate. (See fig. 8.) Water represented by analyses numbers 6, 7, 11, and 20 was from wells close to large lakes or downgradient from large lakes; the relatively high percentages of sodium in the water probably were caused by seepage from the lakes (table 4).

Water from deposits of sand and gravel in till varies considerably in percentage composition of dissolved solids; the points representing water from these deposits are scattered widely over the diamond field in figure 8. The variations in percentage composition probably result from differences in lengths of time of contact of water with the till or from differences in mineralogy of the till. Rau and others (1962, p. 9) described the till in Kidder County as calcareous and state further that "Most of the till has reddish-yellow spots, caused by the oxidation of fragments of iron oxide from concretions of the Pierre Shale, and a white mottling, which is due to an irregular concentration of calcium carbonate. In several places in the southwest corner of the county, the till contains cavities filled with crystals of gypsum up to 1/8 inch in length." The chemical quality of water from a given well producing from sand and gravel in till is highly uncertain.

The chemical quality of the water in the upper part of the buried-valley outwash deposits may be indicated by analysis 20 in table 2. The well that provided the water for this analysis is 130 feet deep and penetrates nearly to the buried-valley outwash deposits. Additional data on the quality of the water in these deposits are needed. Unfortunately, no wells exist presently (1962) from which samples of water from these deposits can be obtained.

Influence of Seepage From Lakes on Ground-Water Quality

Seepage from the numerous lakes in the county undoubtedly influences the chemical quality of the ground water. Data on water quality were obtained for eight lakes, most of which are in the Isabel-Alkaline-Long Lake chain in the southern part of the county (fig. 6), to get an indication of the nature of the influence; however, only general observations can be made.

The quality of water in the lakes and, consequently, the quality of seepage differ from lake to lake and vary with time and with water level in the lakes. The chemical quality of the water from the lakes in the late spring of 1959, indicated by table 4, is probably poorer than usual. When sampled, water in most of the lakes was at very low levels because during 1958 and early 1959 runoff to the lakes was at very low levels because during 1958 and early 1959 runoff to the lakes was low and evaporation was high. U.S. Weather Bureau records indicate that the annual precipitation during 1958 and 1959 was about 4 inches below average and that the mean annual air temperature was about 1.50 F. above average.

Numbers 4 to 8 in table 4 show analyses of water from the Isabel-Alkaline-Long Lake chain, which actually consists of two parallel chains that converge just upstream from Long Lake. Runoff moves southwest-

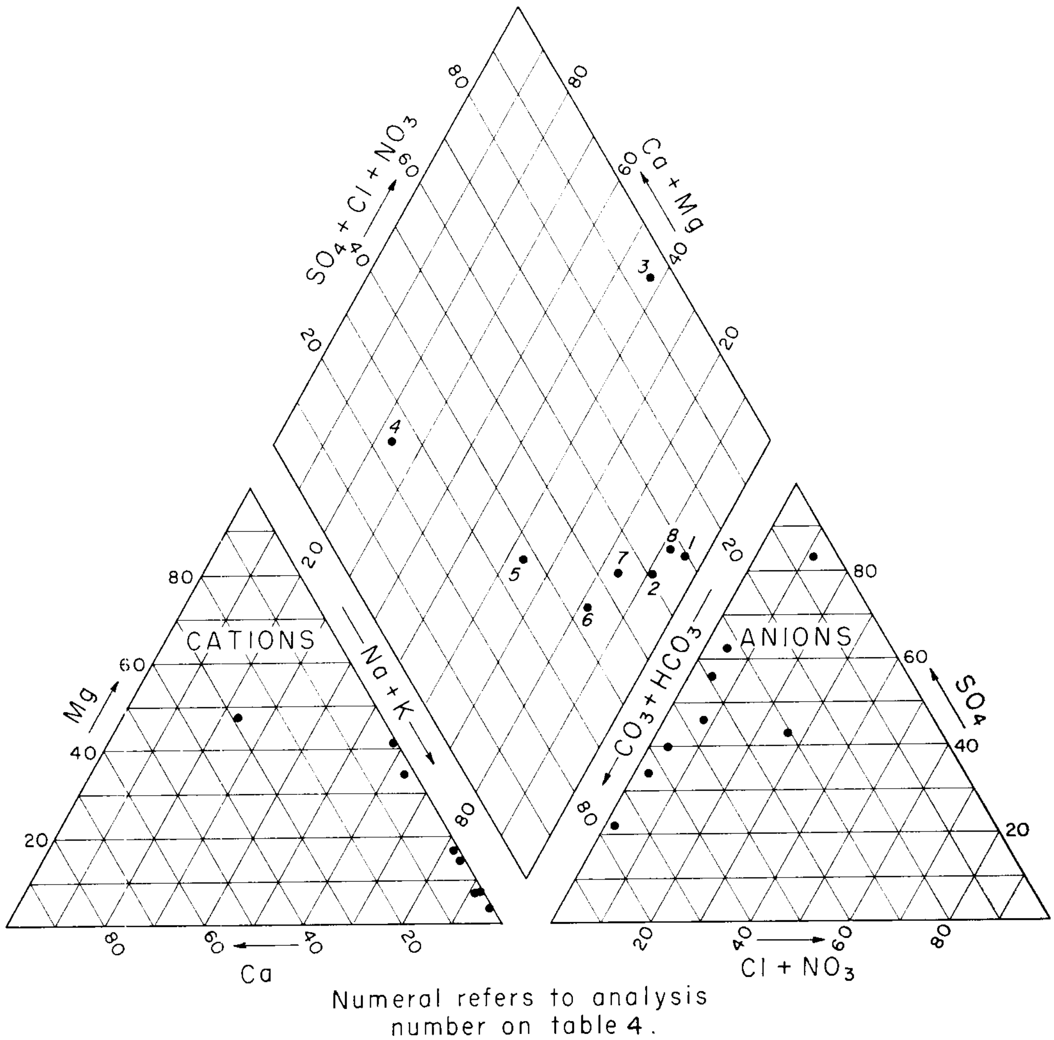


FIGURE 9. PERCENTAGE COMPOSITION, FROM EQUIVALENTS PER MILLION, OF DISSOLVED SOLIDS IN WATER FROM LAKES

ward and, if sufficient, eventually reaches Long Lake. Because salts in the upstream lakes are flushed occassionally from one lake to the next, the dissolved solids in the water are progressively higher from one lake to the next. The dissolved-solids content, which was 457 ppm in analysis number 4, increased by a factor of about 2 for water from each succeeding lake in the chain. This factor probably represents a transitory relation; were the lakes to be resampled, the factor most likely would change. The dissolved solids of water from Long Lake approximate those of water from Horsehead Lake, which is also an end member of a chain of lakes.

The percentage composition of dissolved solids in the water that has been in the lakes for a long time is markedly different from that of inflow to the lake chain. (See fig. 9.) Analysis number 4 represents inflow to Alkaline Lake, which was sampled several hours after a light rainfall, and probably also represents inflow to Lake Isabel. The inflow contains principally calcium, magnesium, and bicarbonate. Analysis number 8 represents water that has been in the lake for a long time. This water contains principally sodium and sulfate; evidently calcium and magnesium precipitated as carbonates. Analysis numbers 5, 6, and 7 represent water in which the prcipitation of calcium and magnsium salts is still far from completion; the water must have been freshened by recent inflow to the lakes.

The pH of the water increased from lake to lake because of the proportionate increase of sodium. Boron likewise increased. However, silica and fluoride tended to decrease. Similar decreases in silica and fluoride with increase in dissolved solids have been observed in other lakes in North Dakota.

Seepage from the chain of lakes causes the dissolved solids in the ground water to increase downgradient, but the increase is surprisingly small compared with the high dissolved solids in the lake water. The dissolved solids in water from three wells (139-72-27cb, 138-72-6aba, and 138-73-17ada), which are near the lakes, were 478, 555, and 751, respectively. Also, seepage causes a downgradient change in percentage composition in the ground water. The change indicated by analyses numbers 20, 7, and 11, which show water from these three wells (fig. 8), is similar to the change in the lake waters (fig. 9), particularly with respect to sodium.

Suitability of the Water for Use

Crieteria for evaluating the suitability of water for use have been developed by numerous investigators. However, most of the criteria have been developed empirically and, when applied, do not provide definitive classifications. When a given water is evaluated for a particular use, several chemical characteristics must be considered; some characteristics may be satisfactory, whereas others may be unsatisfactory. Some background information on the effects of certain chemical characteristics of the water provides a better understanding for evaluating the suitability of the water for use.

Table 4.--Chemical analyses of surface water

[Results in parts per million except as indicated]

Analysis number	Water-surface elevation[a] (ft)	Date of collection (1959)	Temperature (° F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids		Hardness as $CaCO_3$	Noncarbonate hardness as $CaCO_3$	Percent sodium	Sodium-adsorption-ratio	Specific conductance (micromhos per cm at 25° C)	pH
																	Calculated	Residue on evaporation at 180° C						
Horsehead Lake, NE¼NW¼ sec. 21, T. 141 N., R. 72 W.																								
1	6.2	May 31...	.....	6.1	0.02	3.5	81	4,340	255	2,310	701	4,220	1,920	0.1	3.5	13	12,700	13,000	341	0	93	102	16,600	9.1
Sibley Lake, SE¼SE¼ sec. 2, T. 140 N., R. 72 W.																								
2	14.4	May 31...	.....	8.6	0.03	19	57	1,320	87	1,250	146	1,750	126	0.2	1.3	4.1	4,140	4,290	280	0	88	34	5,630	8.8
Salt Alkaline Lake, NW¼NE¼NE¼ sec. 17, T. 140 N., R. 70 W.																								
3	8.1	May 31...	56	5.9	0.01	41	1,660	4,170	371	930	65	13,400	1,380	0.3	0.9	5.1	21,600	22,900	6,940	6,070	55	22	21,300	8.4
Alkaline Lake, SW¼NE¼ sec. 22, T. 139 N., R. 72 W.																								
4	2.2	June 1....	59	5.2	0.02	45	45	38	7.6	359	0	81	5.6	0.3	0.4	0.18	......	457	298	4	21	1.0	699	7.7
Lake Isabel (north part) SW¼NE¼SW¼ sec. 34, T. 139 N., R. 72 W.																								
5	3.1	May 31...	.....	40	0.03	8.8	84	274	35	664	63	338	23	0.3	0.3	0.90	1,190	1,270	366	0	59	6.2	1,760	8.6
Lake Isabel (south part) NE¼NE¼SE¼ sec. 4, T. 138 N., R. 72 W.																								
6	9.8	June 1....	62	21	0.02	11	91	810	71	1,240	126	854	66	0.6	1.1	2.3	2,670	2,800	402	0	78	18	3,710	8.7
Lake Etta SE¼SE¼SW¼ sec. 12, T. 138 N., R. 73 W.																								
7	18.6	June 1....	65	10	0.01	15	137	1,400	160	1,570	283	1,680	218	0.1	0.4	5.6	4,690	4,860	599	0	79	25	6,210	8.9
Long Lake SE¼NE¼NE¼ sec. 29, T. 138 N., R. 74 W.																								
8	9.2	June 1....	68	6.2	0.05	7.4	131	3,190	129	2,110	539	4,740	240	0.2	1.0	7.8	10,000	10,300	558	0	91	59	12,200	9.0

a Below temporary reference mark.

Irrigation. — The main characteristics influencing the suitability of the water for irrigation probably are the specific conductance or dissolved solids and the proportion of sodium relative to the proportion of calcium and magnesium. Also important, however, are the bicarbonate and the boron or other constituents that might be toxic to crops.

High dissolved solids in irrigation water tend to cause an increase of salts in the soil solution and may cause soil to become saline. Because all plants take in water by osmosis, a favorable balance must be maintained between salts within a plant and salts in the soil solution. When the concentration of salts in the soil solution becomes too high for plants to get an adequate amount of water or when the concentration of certain salts in the soil solution becomes so high as to be toxic, the growth of the plants is adversely affected. The tendency of irrigation water to cause an accumulation of salts in the soil is called the salinity hazard of the water. The specific conductance of the water is used as an index of the salinity hazard.

High concentrations of sodium relative to the concentrations of calcium and magnesium in irrigation water can adversely affect soil structure. Cations in the soil solution become fixed on the surface of fine soil particles; calcium and magnesium tend to flocculate the particles, but sodium tends to deflocculate them. Flocculation allows good penetration by water and air and generally gives the soil good tillage properties. Deflocculation promotes packing and prevents free movement of air and water. The tendency of irrigation water to cause an adverse effect on soil structure is called the sodium hazard of the water. An index used for predicting the sodium hazard of a water is the sodium-absorption-ratio (SAR), which is defined by the equation

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

where, $Na+$, $Ca++$, and $Mg++$ are in millequivalents per liter (U.S. Salinity Laboratory Staff, 1954), or equivalents per million.

High concentrations of bicarbonate in irrigation water may cause calcium and magnesium to precipitate in the soil as carbonate salts. Precipitation of calcium and magnesium results in an increase in the proportionate amount of sodium in the water. High bicarbonate concentrations also may cause an increase in the pH of the soil and may eventually lead to a soil condition known as black alkali. The amount of carbonate plus bicarbonate, expressed in equivalents per million, that would remain in solution if all calcium and magnesium were precipitated as carbonate is called the "residual sodium carbonate" of the water (Eaton, 1950, p. 124). Wilcox, Blair, and Bower (1954, p. 275) found that water containing more than 2.5 equivalents per million of residual sodium carbonate is not suitable for irrigation, that water containing between 1.25 and 2.5 equivalents per million is marginal, and that water containing less than 1.25 equivalents per million is probably safe.

Boron, which is an essential plant nutrient, can be highly toxic to some crops. Tolerance to boron differs with plant species, and classification of water for boron content is dependent on the tolerance of the crops to be grown, as indicated by the following table (Scofield, 1936, p. 286):

Permissible limits of boron, in parts per million, for several Classes of irrigation waters

Boron class	Sensitive crops	Semitolerant crops	Tolerant crops
1	< 0.33	> 0.67	< 1.00
2	0.33-0.67	0.67-1.33	1.00-2.00
3	0.67-1.00	1.33-2.00	2.00-3.00
4	1.00-1.25	2.00-2.50	3.00-3.75
5	> 1.25	> 2.50	> 3.75

Several methods have been suggested for classifying water for irrigation so that the long-term effect on soil productivity can be forecast. According to the method of the U.S. Salinity Laboratory Staff (1954), used in this report, the water is classified first for salinity hazard and sodium hazard and then for boron concentration and for the amount of residual sodium carbonate. The originators of this method caution that in classifying water one must assume that: ". . . the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of crop. Large deviations from the average for one or more of these variables may make it unsafe to use what, under average conditions, would be a good water; or may make it safe to use what, under average conditions, would be a water of doubtful quality." (U. S. Salinity Laboratory Staff, 1954, p. 75-76.)

Classification of water for salinity hazard and sodium hazard is determined with a diagram (U.S. Salinity Laboratory Staff, 1954, p. 80). Water having a low, medium, high, or very high salinity hazard is designated as C1, C2, C3, or C4, respectively; and water having a low, medium, high, or very high sodium hazard is designated as S1, S2, S3, or S4, respectively.

The classification for irrigation of water from the unconsolidated deposits in Kidder County is indicated in table 5. Most of the water from surficial outwash deposits could be used on nearly all soils with little likelihood that the soils would become saline or that damage to the soil would result from the sodium in the water, provided that soil drainage is good enough to allow for a moderate amount of leaching. Some of the water from surficial outwash deposits and much of the water from deposits of sand and gravel in till should not be used on soils where drainage is restricted. The classification of water from sand and gravel in till probably is only of academic interest because the

Table 5.--Classification for irrigation[a] of water from glacial drift

Well number	Salinity hazard-sodium hazard class	Boron class			Residual sodium carbonate	
		Sensitive crops	Semi-tolerant crops	Tolerant crops	Amount (epm)	Class
137-70-26abb...	C3-S1 b/.	....	....	....	0.33	Probably safe.
137-70-26cba...	C2-S1 b/.	....	....	....	1.68	Unsuitable.
137-72-22bb....	C3-S1....	2	1	1	0	Probably safe.
137-74-11bab...	C3-S2....	2	1	1	5.27	Unsuitable.
138-70-30bb....	C2-S1....	1	1	1	0	Probably safe.
138-72-2cba....	C3-S1....	2	1	1	2.23	Marginal.
138-72-6aba....	C3-S1....	2	1	1	3.49	Unsuitable.
138-72-10aab...	C2-S1....	1	1	1	0	Probably safe.
138-72-21aa....	C2-S1....	1	1	1	0	Do.
138-72-33ab....	C3-S2....	3	2	1	2.47	Marginal.
138-73-17ada...	C3-S2....	2	1	1	5.31	Unsuitable.
139-70-2ddc....	C2-S1....	1	1	1	0	Probably safe.
139-70-7ad.....	C2-S1....	1	1	1	0	Do.
139-70-1dcc....	C2-S1....	1	1	1	0	Do.
139-70-14bd....	C3-S1....	1	1	1	0	Do.
139-71-6bd.....	C2-S1....	1	1	1	0	Do.
139-71-22bd....	C2-S1....	1	1	1	0	Do.
139-72-8db.....	C3-S1....	1	1	1	0	Do.
139-72-27cb....	C2-S1....	1	1	1	1.65	Marginal.
140-71-5daa....	C3-S1....	1	1	1	0	Probably safe.
140-71-9ccd....	C2-S1....	1	1	1	0	Do.
140-71-28bab...	C2-S1 b/.	2	1	1	.69	Do.
140-72-22ca....	C3-S2....	2	1	1	6.39	Unsuitable.
140-72-25ccc...	C3-S1....	1	1	1	0	Probably safe.
140-74-36bcb...	C4-S1....	1	1	1	0	Do.
141-71-21ddc1..	C2-S1....	1	1	1	0	Do.
141-72-35ddb2..	C3-S1....	2	1	1	0	Do.
142-70-8dda....	C3-S1....	1	1	1	0	Do.
142-71-33cda...	C2-S1....	1	1	1	.15	Do.
142-73-20ddb...	C2-S1....	1	1	1	0	Do.

a/ According to method of U.S. Salinity Laboratory Staff, 1954.
b/ Partly estimated.

supplies of water from such deposits are likely to be too small for irrigation. Most of the water has little or no residual sodium carbonate. The water that is marginal probably could be used satisfactorily on calcium-rich soils if management practices are good. Boron concentrations probably are high enough to supply the amounts required by most crops but are not so high as to be toxic except possibly to highly sensitive fruit crops. Most crops likely to be grown in North Dakota, such as wheat, oats, barley, corn, alfalfa, sugar beets, and potatoes, are semitolerant or tolerant to boron.

As water applied in irrigation decreases in volume because of evaporation and plant use, the dissolved solids gradually become more concentrated, and salts eventually may precipitate in the soil. Large amounts of soluble salts may accumulate in the root zone of the soil profile and cause the irrigated soil to become saline unless sufficient water is applied to leach the salts through the root zone. Eaton (1954) attributes salinity effects in soils mainly to chloride and sulfate ions and gives an equation for estimating the percentage of the applied water that must pass through the root zone to provide adequate leaching. For most of the water from unconsolidated deposits in Kidder County, this percentage is less than 4.

Most of the water from consolidated rocks is of poor quality for irrigation; it is of the C3 class for salinity hazard, of the S2 to S4 class for sodium hazard, has sufficient boron to be potentially toxic to some semitolerant and tolerant crops, and has a high residual sodium carbonate. Classifications of individual water samples from consolidated rocks are not given in the tables of this report because consolidated rocks are not likely sources for irrigation supply in Kidder County.

Public supply and domestic use. — The quality of water for public supply and domestic use commonly is evaluated in relation to standards of the U.S. Public Health Service for drinking water. The standards, adopted in 1914 to protect the health of the traveling public, were revised several times in subsequent years. The latest revisions by the U.S. Department of Health, Education, and Welfare (1962) are, in part, as follows:

Constituent	Maximum Concentration ppm
Iron (Fe)	0.3
Manganese (Mn)	.05
Sulfate (SO_4)	250
Chloride (Cl)	250
Fluoride (F)	1.5 a/
Nitrate (NO_3)	45
Dissolved solids	500

a/ Varies for different parts of the country.

Almost all the ground water in the county contains some constituents that exceed the maximum concentrations. If iron and manganese were removed, most of the water from unconsolidated deposits — especially from outwash deposits — would be satisfactory according to the standards, but water from consolidated rocks still would not be satisfactory because of the high sulfate and dissolved solids. Nitrate was high in water from two wells (137-70-26abb and 138-70-30bb, table 3) producing from the unconsolidated deposits and from one well (139-73-33aaa, table 2) producing from consolidated rocks.

Excessive concentrations of iron and manganese may affect the taste of water and may discolor food products during cooking. Also, they stain porcelain, enamelware, and fabrics. Iron and manganese in water, upon being exposed to air, are readily oxidized and form precipitates that cause the water to become cloudy. In addition, iron bacteria, which thrive in water containing high concentrations of iron, may cause a disagreeable taste and odor. Iron and manganese can be removed from water economically.

Sulfate in high concentrations may have a laxative effect on some people; however, many persons develop a tolerance to the sulfate through continued use of the water.

Nitrate is the end product in the decomposition of organic wastes; therefore, high concentrations of nitrate may indicate pollution. The source of the high nitrate content of the water from the three wells (137-70-26abb, 138-70-30bb, and 139-73-33aaa) is not definitely known. A likely source may be barnyard seepage; some farmers in Kidder County still heap manure around their wells to project the installation from freezing. High concentrations of nitrate in water used for preparing feeding formulas may cause methemoglobinemia, a form of blue-baby disease, in some infants. Also, nitrate, some of which may have come from drinking water, has been recognized in recent years as the cause of cattle poisoning.

No specific standards for hardness have been established, but the following graduations are generally recognized:

Hardness ppm	Rating	Suitability
0 - 60	Soft	Suitable for many uses without softening
61 - 120	Moderately hard	Usable except in some industrial applications.
121 - 180	Hard	Softening required by laundries and some other industries.
181 +	Very hard	Requires softening for many uses.

The water from most of the wells in Kidder County is very hard. Hardness impairs the quality of the water because of curd that forms when soap is added and because of scale that is deposited in water pipes, heaters, and boilers.

Industry. — The uses of water by industry are many, and the quality-of-water requirements are highly diverse. Most uses of water by industry fall into two broad categories—heat exchange and processing.

Water used in heat exchangers, such as heaters, boilers, and air conditioners, should not be corrosive, scale forming, nor conductive to slime formation. Corrosion is a very complex process; among the characteristics of water that may contribute to corrosion are low pH, low alkalinity (reported as bicarbonate), low hardness, high content of free carbon dioxide, and high concentrations of iron sulfate or magnesium chloride. Corrosion is impeded by a thin coating of scale on metal surfaces. Scale formation generally is caused by calcium and magnesium, which precipitate with bicarbonate or sometimes with sulfate; it can also be caused by silicates, oxides of iron, and other substances. The relative corrosiveness or scale-forming tendencies of ground water from Kidder County was estimated with the "Langlier calcium carbonate saturation index" (Powell, 1954, p. 278). The index averaged 0.2 for 80 degree F. and 0.4 for 160 degree F. At the lower temperature the water is neither corrosive nor scale forming, but at the higher temperature it is slightly scale forming. The high concentrations of iron in the water are conductive to the growth of iron bacteria that may form slime.

Boiler-feed water must meet quality requirements that vary with the pressure maintained in the boilers and that become increasingly stringent as the pressures increase. Among suggested limits of tolerance (California Institute of Technology, 1957, p. 129) for feed water used at pressures of 0 to 150 pounds per square inch are hardness, 80 ppm; sodium sulfate-sodium carbonate ratio, 1:1; silica, 40 ppm; bicarbonate, 50 ppm; carbonate, 200 ppm; dissolved solids, 3,000 to 5,000 ppm; and pH (minimum), 8.0. The ground water in Kidder County, if to be used in boilers, should be softened and should be adjusted for pH and bicarbonate. Concentrations of silica in water from consolidated rocks slightly exceed the suggested maximum of 40 ppm.

Water used for processing comes into contact with, or is actually incorporated into, a product. It should be free of offensive taste, odor, and color. The quality-of-water requirements depend on the product manufactured and are very exacting for some products (California Institute of Technology, 1957).

Recommended maximum or range of maximum concentrations, in parts per million, for some industrial processing

Constituent or property	Food processing (general)	Car-bonated beverages	Laun-dering	Plastics, clear, un-colored	Tanning
Color	....	10	....	2	10.100
Dissolved solids	850	850-855	....	200	....
Hardness	10-250	200-250	50	....	50-135
Alkalinity (CaCO3)	30-250	50-128	....	....	135
Iron and manganese	0.2-0.3	0.1-1.5	.2	.2	.2
Sulfate	....	250	....	....	....
Chloride	....	250	....	....	....
Fluoride	1.0	0.2-1.0	....	....	....
pH	....	....	....	....	8.0

The water from surficial outwash deposits would be suitable for many industrial uses if it is softened and if the iron and manganese are removed.

SUMMARY AND CONCLUSIONS

Ground water occurs both in the consolidated bedrock formations and in the overlying glacial drift in Kidder County. However, the rocks underlying the upper part of the Pierre Shale are generally impermeable or are too deeply buried to be of importance as aquifers. The upper part of the Pierre Shale may yield small quantities of ground water, but it rarely supplies more than a few gallons per minute.

The Fox Hills Sandstone of Cretaceous age overlies the Pierre Shale mainly in the western and southern parts of the county. It yields considerably more water than the Pierre Shale, but large withdrawals (greaer than 150 gpm) are not known. Ground water in the formation is derived from sandy layers; it is generally under sufficient artesian pressure to flow at the land surface or to rise nearly to the surface.

The Fort Union Formation of Tertiary age, consisting of the Cannonball and Tongue River Members, yields ground water to wells from thin sand or sandstone layers, or at places from lignite layers. Generally, the formation is not a reliable source of water in Kidder County.

Unconsolidated surficial and buried-valley outwash deposits of glacial origin are the most permeable and productive units in Kidder County. The surficial outwash deposits cover much of the central part of the county. The buried-valley outwash deposits underlie the surficial outwash and extend through the county from southwest to northeast, marking the former course of the ancestral Cannonball River. The largest ground-water yields in the county can be expected in the areas where the surficial outwash overlies the buried-valley outwash; at places they may yield 1,000 gpm or more. Tributary buried valleys, which enter the main valley from the northwest and southeast, also are potential sources for relatively large ground-water withdrawals.

Ground water occurs also in ice-contact deposits consisting of permeable sand and gravel. Because the deposits are thin and have a small areal extent, however, large yields are not likely.

Till and associated sand and gravel deposits are sources of ground water for farm and domestic supplies and at places may furnish sufficient water for small municipal or commercial uses. The water is obtained from wells that tap sand and gravel lenses enclosed in till.

In Kidder County, recharge is derived from rainfall or melting snow. It is relatively rapid on the surficial outwash plains because the soil and underlying material is generally permeable. On surfaces underlain by till, infiltration is hampered by relatively impervious soil as well as by the till which also is relatively impermeable; thus recharge is much slower. Ground water is discharged from springs, lakes, ponds, and swamps. In general water levels decline during the summer, early fall, and winter because recharge is reduced and natural discharge increases. Water levels usually rise during the spring and early summer and again, temporarily, in the fall, when evapotranspiration is small and recharge is comparatively large.

Ground-water use in Kidder County could be increased considerably through the development of wells in properly selected areas. To determine the quantities of water available at particular locations, test drilling and pumping tests are needed, but large withdrawals are likely from most areas underlain by the surficial outwash and buried-valley outwash deposits.

Generally, water from the consolidated rocks has from 600 to 1,200 ppm of dissolved solids. That from the southern half of the county had principally calcium and bicarbonate and was very hard, whereas that from the northern half had principally sodium and bicarbonate and was only moderately hard. The silica, iron, manganese, and boron contents of the water from the consolidated rocks were high, but the chloride, fluoride, and nitrate contents, with only a few exceptions, were low. Most of the water is of poor quality for irrigation, for many industrial uses, and for public supply and domestic use.

Water from outwash deposits had dissolved solids from 302 to 751 ppm. The water contained principally calcium and bicarbonate, except where lake seepage had increased the relative proportion of sodium. Water from deposits of sand and gravel in till was much more variable than that from outwash deposits; it had dissolved solids from 497 to 2,410 ppm, and it differed considerably in principal constituents from one location to another.

Most of the water from unconsolidated deposits was very hard and had high concentrations of iron and manganese but low concentrations of potassium, chloride, fluoride, nitrate, and boron. Most of the water from outwash deposits is of good enough quality that it could be used for irrigation of nearly all soils with little likelihood that the soils would become saline or that damage to the soils would result from sodium in the water. Boron concentrations are high enough to supply the amounts required by most crops likely to be grown in North Dakota but not so high as to be toxic to them. If softened and if treated for removal of iron and manganese, most of the water from outwash deposits would be of fair quality for many industrial uses and for public supply and domestic use.

REFERENCES

Abbott, G. A., and Voedisch, F. W., 1938, The municipal ground-water supplies of North Dakota: North Dakota Geol. Survey Bull. 11, 99 p.

Brown, R. H., 1953, Selected procedures for analyzing aquifer test data: Jour. Am. Water Works Assoc. v. 45, no. 8, p. 844-866.

California Institute of Technology, 1957, Water quality criteria: State Water Pollution Control Board pub. 3, 2d printing, 676 p.

Cooper, H. H., Jr., and Jacob, C. E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: Am. Geophys, Union Trans., v. 27, no. 4, p. 526-534, August.

Eaton F. M., 1950, Significance of carbonates in irrigation waters: Soil Sci., v. 69, no. 2, p. 123-133.

____________________ 1954, Formulas for estimating leaching and gypsum requirements of irrigation waters: Texas Agr. Expt. Sta. Misc. Rept. 111, 18 p.

Hainer, J. L., 1956, The geology of North Dakota: North Dakota Geol. Survey Bull. 31, 46 p.

McGuinness, C. L., 1951, The water situation in the United States with special reference to ground water: U.S. Geol. Survey Circ. 114, 127 p.

Meinzer, O. E., 1923, The occurrence of ground water in the United States with a discussion of principles: U.S. Geol. Survey Water-supply Paper 489, 321 p.

Paulson, Q. F., 1962, Ground water - a vital North Dakota resource: North dakota Geol. Survey miscellaneous series, 26 p.

Piper, A. M., 1953, A graphic procedure in the geochemical interpretation of water analyses: U.S. Geol. Survey open-file report, Ground Water Notes, no. 12, Geochemistry.

Powell, S. T., 1954, Water conditioning for industry: McGraw-Hill Book Company, Inc.

Rainwater, F. H., and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U.S. Geol. Survey Water-Supply Paper 1454.

Randich, P. G., Petri, L. R., and Adolphson, D. G., 1962, Geology and ground-water resources of Kidder County, North Dakota: Ground-water basic data: North Dakota Geol. Survey Bull. 36, pt. 2, 134 p.

Rau, J. L., Bakken, W. E., Chmelik, James, and Williams B. J., 1962, Geology and ground-water resources of Kidder County, North Dakota: Geology: North Dakota Geol. Survey Bull. 36 pt. 1, 70 p.

Scofield, C. S., 1936, The salinity of irrigation water: Smithsonian Inst. Ann. Rept., 1935, p. 275-287.

Simpson, H. E., 1929, Geology and ground-water resources of North Dakota with a discussion of the chemical character of the water, by H. B. Riffenburg: U.S. Geol. Survey Water-Supply Paper 598, 312 p.

Theis, C. V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of a well using ground-water storage: Am. Geophys, Union Trans., 1935, pt. 2, p. 519-524.

U.S. Department of Health, Education, and Welfare, 1962, Public Health Service Drinking water standards: Public Health Service Pub. 956, Washington, Govt. Printing Office.

U.S. Salinity Laboratory Staff, 1954, Diagonsis and improvement of saline and alkali soils: U.S. Dept. Agriculture, Agriculture Handg. 60, 160 p.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials with special reference to discharging well methods, with a section on direct laboratory methods and bibliography on permeability and laminar flow by V. C. Fishel: U.S. Geol. Survey Water-Supply Paper 887, 192 p.

Wilcox, L. V., Blair, G. Y., and Bower, C. A., 1954, Effect of bicarbonate on suitability of water for irrigation: Soil Sci., v. 77, no. 4, p. 259-266.