# HYDROLOGIC EFFECTS OF WITHDRAWAL OF GROUND WATER ON THE WEST FARGO AQUIFER SYSTEM, EASTERN CASS COUNTY, NORTH DAKOTA

By C. A. Armstrong

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For those readers who may prefer to use the International System of Units (SI) rather than inch-pound units, the conversion factors for the terms used in this report are given below.

| Multiply inch-pound unit | By | To obtain SI unit |
|---|---|---|
| Acre | 0.4047 | hectare |
| Acre-foot (acre-ft) | 1,233 | cubic meter |
| | 0.001233 | cubic hectometer |
| Foot | 0.3048 | meter |
| Foot per mile (ft/mi) | 0.1894 | meter per kilometer |
| Foot per year (ft/yr) | 0.3048 | meter per year |
| Foot squared per day ($ft^2/d$) | 0.0929 | meter squared per day |
| Gallon | 0.003785 | cubic meter |
| Gallon per day per foot [(gal/d)/ft] | 0.01242 | cubic meter per day per meter |
| Gallon per day per square mile [$(gal/d)/mi^2$] | 0.001461 | cubic meter per day per square kilometer |
| Gallon per minute (gal/min) | 0.000063 | cubic meter per second |
| Inch | 25.40 | millimeter |
| Mile | 1.609 | kilometer |
| Million gallons per day (Mgal/d) | 3,785 | cubic meter per day |
| Square mile ($mi^2$) | 2.590 | square kilometer |

Milligrams per liter (mg/L) is a unit expressing the concentration of a chemical constituent in solution as weight (milligrams) of solute per unit volume (liter) of water; 1 mg/L equals 1,000 μg/L (micrograms per liter).

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order nets of both the United States and Canada, formerly called "Mean Sea Level."

HYDROLOGIC EFFECTS OF WITHDRAWAL OF GROUND WATER ON THE WEST FARGO AQUIFER SYSTEM, EASTERN CASS COUNTY, NORTH DAKOTA

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ABSTRACT

*The West Fargo area is underlain by glaciofluvial deposits, which comprise the West Fargo aquifer system. These deposits range in thickness from 5 to 227 feet.*

*The West Fargo aquifer system extends from the vicinity of Argusville, Cass County, to at least as far south as Richland County. The aquifer system primarily consists of three aquifers, namely the West Fargo North aquifer, the West Fargo South aquifer, and the Horace aquifer. The West Fargo North aquifer is about 2 miles wide near Harwood and about 3.5 miles wide near West Fargo. The West Fargo South aquifer extends from the southeast part of West Fargo to beyond the Cass-Richland county border. It is less than 1.5 miles wide but generally more than 0.5 mile wide. The Horace aquifer extends from north of Interstate Highway 94 west of West Fargo to the Cass-Richland county border. It is less than 1 mile wide in the northern part and somewhat more than 1 mile wide in the southern part.*

*Pumping of large quantities of ground water for the most part has been from the West Fargo North aquifer and has been confined to the area of West Fargo. Here the combined pumpage from all the wells has averaged about 613 million gallons (1,880 acre-feet) per year since 1968. This pumpage has caused water levels to decline from land surface in 1896 to as much as 121.7 feet below land surface in 1981.*

*Recharge to the West Fargo aquifer system is estimated to be about 600 to 650 million gallons (1,800 to 2,000 acre-feet) per year. Almost all discharge from the aquifer system is by pumpage, which is about 683 million gallons (2,096 acre-feet) per year. The difference is derived from available storage, estimated to be about 131,300 million gallons (404,000 acre-feet).*

*Water samples collected from the West Fargo aquifer system contained dissolved-solids concentrations that ranged from 332 to 2,960 milligrams per liter, and chloride concentrations that ranged from 25 to 975 milligrams per liter. Generally both dissolved-solids and chloride concentrations increased from east to west.*

# INTRODUCTION

The study of the geology and water resources of the West Fargo aquifer system began in October 1979 and was a cooperative investigation by the U.S. Geological Survey and the North Dakota State Water Commission. The field investigation was completed in September 1981. However, the North Dakota State Water Commission did additional test drilling in the fall of 1982, and is continuing a quantitative study of the aquifer system. Their data were used to help determine aquifer boundaries. The data used in this report are available at the offices of the U.S. Geological Survey and the North Dakota State Water Commission in Bismarck, N. Dak., unless otherwise referenced.

The West Fargo aquifer system underlies an area of about 58 $mi^2$ and extends from the vicinity of Argusville on the north to the southern county boundary in eastern Cass County, N. Dak. However, because of the complexity of the system, about 230 $mi^2$ was included in the study area (fig. 1). The population of the area in 1980 was as follows: Fargo, 61,383; West Fargo, 10,099; Horace, 494; Riverside, 465; Harwood, 326; and Argusville, 147 (U.S. Bureau of the Census, 1981). In addition, nearly 4,000 people lived in the rural and suburban parts of the study area.

## Purpose and Scope

The population in the area overlying and adjacent to the West Fargo aquifer system is increasing and the need for more water also is increasing. The West Fargo aquifer system is the most feasible source of water, but the quantity of water available in the system that presently (1981) is not allocated is not known. It is important that the historical condition of the system be ascertained so the effects of pumping stresses on the West Fargo aquifer system by the cities of Fargo and West Fargo, other municipalities, and industry can be evaluated. Recent test drilling in the area indicates the aquifer system is much more complex than described in earlier studies.

The first objective was to review the published data and interpretations as well as new data available from recent test drilling in order to thoroughly describe the geometric, geologic, and hydrologic characteristics of the aquifer system. The second objective was to define the spatial distribution of the water-bearing materials of the aquifer system, the hydraulic-head relationships, and the sources and quantities of recharge and discharge. The third objective was to relate hydrologic changes in the aquifer to ground-water withdrawal.

## Location-Numbering System

The location-numbering system used in this report (fig. 2) is based on the Federal system of rectangular surveys of the public lands. The first numeral denotes the township, the second denotes the range, and the third denotes the section in which the well, spring, or test hole is located. The letters A, B, C, and D designate, respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section (10-acre tract); thus, well 139-049-15DAA would be located in the NE1/4NE1/4SE1/4 sec. 15, T. 139 N., R. 49 W. Consecutive

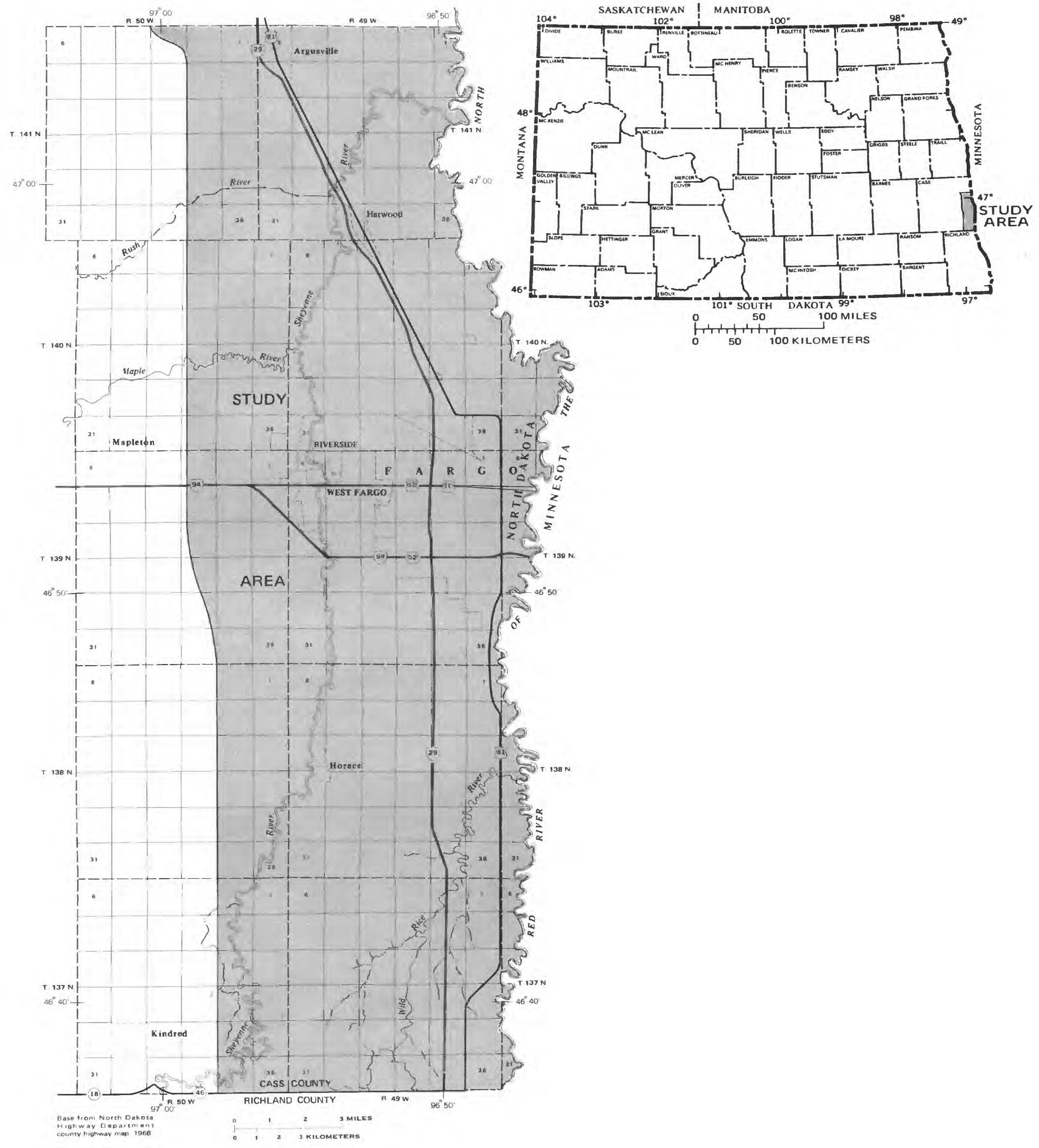



**Figure 1.—Location of study area.**

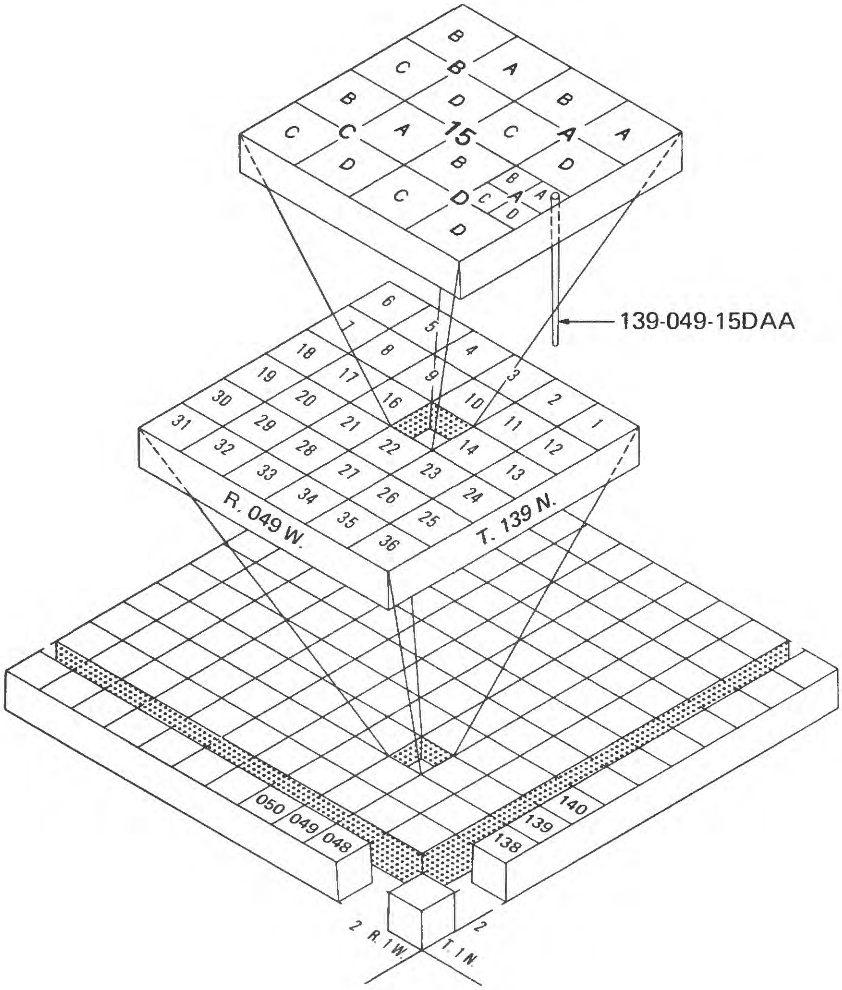



**Figure 2.—Location-numbering system.**

terminal numbers are added if more than one well or test hole is recorded within a 10-acre tract. This numbering system also is used in this report for the location of small areas.

## Previous Investigations

Upham (1895) described the glacial Lake Agassiz deposits and mentioned that a well flowed near Harwood. He also described ground-water conditions in the Red River valley and concluded that water from the Cretaceous strata and basal glacial drift was unsuitable for irrigation. Upham also stated that water from alluvial and lake deposits was alkaline. Hall and Willard (1905) investigated the geology of the Casselton, Fargo, and Moorhead area and cataloged the wells in the area. They mapped areas where flowing wells could be obtained and included well logs where available. Simpson (1929) described the geology and ground-water resources of North Dakota and included a section on each county. He noted that two artesian horizons are found in Cass County--one in the glacial drift in the Red River valley and the other in the Cretaceous sandstones in the Dakota artesian basin, which exists in the western part of the county. Simpson also listed a few well logs. Riffenburg (in Simpson, 1929) presented chemical analyses of nine wells in the county. Two of the analyses were from the area of this report and three from the Fargo area. Byers and others (1946) described the geology and ground-water conditions in the Fargo-Moorhead area and included the West Fargo area. They presented several well logs and constructed geologic sections that were of great help during this project.

The West Fargo aquifer was first described in a report by Dennis and others (1949). Their report included some wells logs and water-level data that were useful in delineating the aquifer. Klausing (1966, 1968) described the reservoir characteristics in greater detail and compiled information from well data and test holes. County ground-water studies completed for adjacent Traill County (Bluemle, 1967; Jensen, 1967; Jensen and Klausing, 1971) and Richland County (Baker, 1966; Baker, 1967; Baker and Paulson, 1967) contain information pertaining to the aquifer's boundaries. Arndt and Moran (1974) did an inventory of mineral, soil, and water resources for land-use planning in Cass County. The stratigraphy of offshore sediment of glacial Lake Agassiz in Cass County was studied by Arndt (1977).

## Acknowledgments

Appreciation is expressed to the Cass County Commissioners, Argusville, Harwood, Fargo and West Fargo city officials who made drilling sites available, and to all the city and company officials who provided pumpage data. Appreciation also is expressed to Ulteig Engineers, Inc., Eugene A. Hickock and Associates, and Moore Engineering, Inc., for the well logs and other water data that they provided. Particular recognition is due North Dakota State Water Commission employees M. O. Lindvig, A. R. Wanek, P. K. Christensen, and G. J. Calheim for their aid in the drilling and logging of test holes and to D. P. Ripley for his aid in planning and for his many ideas and suggestions which have contributed much to the understanding of the West Fargo aquifer system.

## Geologic Setting

The West Fargo area is underlain by Precambrian crystalline rocks or Cretaceous shale at depths ranging from 104 to 425 feet. The Precambrian rocks, which generally are a chlorite gneiss when recognizable, are extremely weathered and appear in drill cuttings as nearly white to greenish-white sandy clay or clayey sand. Locally, red sandy clay has been reported. The Precambrian rocks are overlain either by Cretaceous shale or glacial drift.

The Cretaceous shale, for the most part, appears to be scattered erosional remnants of the Graneros Shale, which locally contains fine-grained sandstone. However, in the extreme western part of the area the Cretaceous shale may be continuous and dips toward the center of the Williston basin, which is more than 300 miles to the west in McKenzie County (fig. 1). In the northwestern part of the area the Cretaceous shale may overlie the Dakota Sandstone. Locally, deposits of white nearly pure quartz sand have formed on the weathered crystalline rocks beneath both the Cretaceous shale and the glacial drift. These sands apparently were eroded from the weathered crystalline rocks and probably vary considerably in age; however, they probably are not much older than either the Cretaceous or glacial material that overlies them. The altitude of the top of either the weathered crystalline rocks or Cretaceous shale, whichever is uppermost, is shown on plate 1 (in pocket).

The crystalline rocks or Cretaceous shale are overlain by till and associated glaciofluvial deposits, which range in thickness from 53 to 349 feet and have a mean thickness of 143 feet. The till generally consists of about 40 to 60 percent sand with some pebbles and bouldery material. The remaining 40 to 60 percent of the till is composed of silt and clay in about equal proportions. Although the stated proportions are most common, variations ranging from slightly silty clay with a few sand grains to clayey sand do occur. Even though the till contains considerable sand, it is not considered to be an aquifer because the interstitial clay causes the hydraulic conductivity of the material to be comparatively small.

An older till locally is present at the base of the glacial drift. This older till, when being drilled, appears to be harder and contains much less sand than the younger till. It also commonly contains a large percentage of dark-colored shale derived from the underlying or nearby Cretaceous shale.

The glaciofluvial deposits consist of lenticular lenses of sand and gravel. The sand and gravel generally ranges in size from very fine sand (0.074 millimeter) to cobble-size material, but boulders as much as 2 feet thick have been penetrated. Boulders generally are most common near the base of the deposits. Aggregate thickness of the sand and gravel lenses in the test holes and wells ranges from 5 to 227 feet. Mean thickness is about 43 feet (lenses less than 5 feet thick were not included in the statistics). The distribution of the sand and gravel lenses is shown on sections A-A' through S-S' (pl. 2, in pocket). The more continuous lenses comprise the major aquifers shown on plate 3 (in pocket).

The till and glaciofluvial deposits are overlain by lake deposits, which range from 51 to 101 feet in thickness and have a mean thickness of about 73 feet. These lake deposits generally consist of silt and clay that was laid down in glacial Lake Agassiz (Upham, 1895). However, some deposits of fine sand are widely scattered through the lake deposits. Dennis and others (1949, p. 8) divided the lake deposits into two units--an upper silt unit that is from 10 to 50 feet thick and a lower clay unit that is from 0 to 80 feet thick. Both of these units are present in the West Fargo area, but are not shown in this report because they generally are not differentiated on most lithologic logs.

Alluvial deposits, which locally overlie the lake deposits near present-day streams, generally are composed of silt or sandy silt. The alluvial deposits have not been differentiated in this report because the boundaries generally have not been adequately mapped and the contact with the underlying lake deposits generally is not noted on lithologic logs.

## HYDROLOGY

The West Fargo aquifer system extends from the vicinity of Argusville in Cass County to at least as far south as Richland County. The aquifer system is divided into three aquifers: The West Fargo North, West Fargo South, and Horace aquifers (pl. 3). The hydraulic connection of sand and gravel lenses within the three named aquifers generally is good, but the hydrologic connections between the three aquifers, if the connections exist, appear to be along circuitous paths or are restricted by material that has small hydraulic-conductivity values. The top and bottom of the aquifer intervals and the depth to bedrock are shown on plate 3.

Ground-water conditions in the West Fargo aquifer system in the late 1800's, before any significant development occurred, can only be postulated based on scanty data. Apparently the potentiometric surface generally sloped from south to north with an easterly component. Therefore, recharge areas apparently were to the south and west of the study area. The potentiometric surface was near land surface. It probably was at or somewhat below land surface in the higher parts of the area and above land surface in the lower parts, such as near the streams. Upham (1895, p. 568) reported that a well at Harwood, which is on the east side of the Sheyenne River, flowed 10 feet above land surface. Byers and others (1946, p. 33) reported that the piezometric surface was 12 to 20 feet below land surface in the vicinity of Harwood and Kragnes, Minnesota (about 6 miles east of Harwood).

The West Fargo North aquifer underlies an area of about 28 $mi^2$. The aquifer extends from the vicinity of Argusville to somewhat more than 1 mile south of U.S. Highway 10, ranges from about 2 to 3.5 miles in width (pl. 3), and is characterized by widespread sand and gravel lenses with some interbedded clay or till lenses. The hydraulic connection between sand and gravel lenses is good and the hydrologic system responds to pumping as though it were a single sand bed of varying thickness. The aquifer was formed in two stream valleys that coalesced in the vicinity of Harwood and extended as a single valley at least to the southern part of West Fargo. The aggregate thickness of the aquifer ranges from less than 5 to 113 feet.

Mean thickness is about 48 feet. Sand and gravel lenses in an east-trending buried valley about 2 miles north of U.S. Highway 10 and east of West Fargo (pl. 3) may connect the West Fargo aquifer system to the Fargo aquifer that underlies the city of Fargo (Klausing, 1968, p. 17). However, sufficient data are not available to establish the presence of a good hydraulic connection between the aquifers.

The West Fargo South aquifer underlies an area of about 15 $mi^2$ and extends from south of U.S. Highway 10 to the Richland county line. The aquifer generally trends south about 1 to 2 miles west of Interstate Highway 29 to the latitude of Horace. The trend is then more southeastward and the southernmost 3 miles are east of Interstate Highway 29. The West Fargo South aquifer is less than 1.5 miles wide, but generally more than 0.5 mile wide, and consists of hydraulically connected sand and gravel lenses that are less than 5 feet thick near the edges and as much as 227 feet thick where the lower part of the aquifer is within a buried valley (138-049-09DDD, pl. 2, sec. N-N'). The mean thickness of the aquifer is about 75 feet. The northern part of the aquifer generally is not reflected as a depression in the bedrock (pl. 2, secs. G-G' through L-L'); however, it may be that test drilling did not penetrate the deepest part of the aquifer. A partial lithologic log of test hole 138-049-04CDD (pl. 2, sec. M-M') and the log of test hole 138-049-09DDD (pl. 2, sec. N-N') indicate that the aquifer may be associated with a bedrock valley south of section M-M' (pl. 2).

The West Fargo South aquifer apparently is not hydraulically connected to a significant degree with the West Fargo North aquifer, but pumpage from the West Fargo North aquifer has affected water levels in the West Fargo South aquifer, and indicates some hydraulic connection. Also, water levels shown on plates 4 and 5 indicate that the water levels in the West Fargo South aquifer are considerably higher than in the West Fargo North aquifer, and that only a restricted or indirect hydraulic connection exists. Water-level differences as well as test drilling indicate a restricted to nonexistent connection with the Fargo aquifer to the northeast.

The Horace aquifer underlies about 15 $mi^2$. It trends southward from about 1 mile west of West Fargo, apparently curving to the east through 138-049-29CCC (pl. 2, sec. Q-Q') along the trace of the buried valley indicated on plate 1, to the Richland county line. The aquifer ranges in width from about 0.5 mile north of Horace to 1.5 miles near the Richland county line (pl. 3). The aquifer predominantly is composed of lenses of medium to coarse sand, but it does contain lenses of fine to medium gravel. The aquifer is as much as 217 feet thick, but the mean thickness is about 115 feet. The relationship to the West Fargo North aquifer is not known, although water levels indicate a restricted hydraulic connection.

The shallow aquifer that underlies the trace of the present-day Sheyenne River from about Interstate Highway 94 to about 5 miles southwest of Horace has not been named. The aquifer generally is composed of coarse sand and gravel and may be as much as 60 feet thick, but generally it is much thinner (pl. 2, secs. H-H' through P-P').

The Fargo aquifer underlies part of the city of Fargo and may extend southeastward into Minnesota (pl. 3). The aquifer varies in thickness from less than 5 feet to 161 feet and has a mean thickness of about 54 feet. The Fargo aquifer may be hydraulically connected to the West Fargo North or the West Fargo South aquifers, but the connection, if one exists, is not apparent. Data from test holes do not indicate a lithologic connection between the aquifers, and pumpage from within the Fargo aquifer is great enough to mask any effects of outside pumpage. Therefore, the Fargo aquifer is not considered to be part of the West Fargo aquifer system.

Many apparently isolated sand and gravel lenses occur in the West Fargo area. Some are as much as 50 feet thick, but most are thinner. These sand and gravel lenses have not been traced or correlated with other lenses or with the major aquifers, but water levels, which apparently have been affected by pumpage at West Fargo and are only a few feet higher than those in the major aquifers, indicate that most of the lenses are hydraulically connected even though the connections may be restricted or circuitous.

## Hydraulic Characteristics

Aquifer tests, using a pumped well and observation wells, generally yield data from which reliable aquifer transmissivities and storage coefficients can be calculated. With optimum observation-well spacing, aquifer boundaries also may be located.

Dennis and others (1949, p. 87) reported that the transmissivity of the West Fargo North aquifer in the vicinity of Union Stockyards (139-049-06ACC) in West Fargo ranged from 33,000 to 125,000 (gal/d)/ft, or in current terms of usage, 4,400 to 16,700 $ft^2/d$, and averaged 71,000 (gal/d)/ft or 9,500 $ft^2/d$. The computed storage coefficient ranged from 0.018 to 0.00046 and averaged 0.0037 (Dennis and others, 1949, p. 89).

An aquifer test was conducted in the West Fargo North aquifer in November 1963 using a newly drilled municipal well at 139-049-06DCD in West Fargo (Klausing, 1968, p. 26). Water levels in the pumped well and three observation wells were monitored before, during, and after pumping. The computed transmissivity ranged from 74,700 to 269,000 (gal/d)/ft, or in current terms of usage, 10,000 to 36,000 $ft^2/d$, and averaged 150,000 (gal/d)/ft or 20,000 $ft^2/d$. The storage coefficient ranged from 0.00028 to 0.000054 and averaged 0.000229 (Klausing, 1968, p. 26).

An aquifer test was conducted in the West Fargo North aquifer in June 1972 by the North Dakota State Water Commission (written commun., 1980) using municipal well 139-049-09BBA near West Fargo. The computed transmissivity was 10,000 $ft^2/d$, which is close to that of the 1963 test, and the storage coefficient was 0.07. The storage coefficient indicated water-table conditions; whereas the storage coefficient computed for the 1963 test indicated artesian conditions.

An aquifer test for the city of Fargo was conducted in the Horace aquifer between July 31 and August 8, 1978, by Ulteig Engineers, Inc., and Eugene A. Hickock and Associates (written commun., 1979). Their test well 1 at 137-049-28AAA was 12 inches in diameter and completed with 50-slot (0.050-inch opening) galvanized screen between 250 and 300 feet. Nine observation wells at various distances and directions were monitored during the test. They reported that the well was pumped at a rate of 1,500 gal/min. Their analysis of the test indicated an average transmissivity of 4,600 $ft^2/d$ and an average storage coefficient of 0.00034. Their data also indicated an aquifer boundary to the east in the vicinity of U.S. Highway 81 about 2 miles north of the southern county line and another to the south, but no distance was given.

## Recharge

Prior to the development of a significant number of wells in the West Fargo aquifer system, the potentiometric surface was near or above land surface so there was practically no recharge to the aquifer system from within the study area. Therefore, the recharge was derived from subsurface seepage from outside of the study area. As well development and ground-water use increased, the potentiometric surface was lowered and recharge from within the study area began.

Recharge to the West Fargo aquifer system presently is from leakage from the overlying lake deposits, through buried channel sands that extend from beyond the borders of the study area into the aquifers being investigated, from till adjacent to the aquifers, and possibly from upward leakage from the Dakota aquifer in the northwestern and extreme western part of the area. Klausing (1968, p. 28), using an assumed hydraulic conductivity of 0.0001 ft/d, estimated that recharge from the lake clays is about 11,100 $(gal/d)/mi^2$, or about 1.2 Mgal/d for the 110 $mi^2$ that he considered. However, only about 58 $mi^2$ overlies the aquifer system so recharge from leakage would be about 234 million gallons (718 acre-ft) per year. Klausing's estimate is reasonable, but his hydraulic-conductivity estimate could be too small or too large by as much as a factor of 10. It is apparent that much more data are is needed to accurately determine leakage through the lake deposits.

Dennis and others (1949, p. 93) estimated that the average transmissivity for the till and the glaciofluvial deposits in the western one-half of the study area was about 1,000 (gal/d)/ft, or 133 $ft^2/d$. This estimate appears to be reasonable; however, if one or more as yet undiscovered large glaciofluvial aquifers are hydraulically connected to the West Fargo aquifer system, the estimate could contain a large error. The hydraulic gradient in the vicinity of the water-level contour at the altitude of 880 feet shown on the 1981 potentiometric map (pl. 5) ranges from about 2 to 5 ft/mi and apparently averages about 4 ft/mi. Using these data, the quantity of water recharging the West Fargo aquifer system from the till along the south and west side would be about 53 million gallons (160 acre-ft) per year.

Data are not now available to estimate gradients throughout the east side of the aquifer system, but assuming similar transmissivities of 133 $ft^2/d$, a negligible gradient in the southern part of the east side, and an average gradient of about 25 ft/mi for an 11-mile stretch in the

Harwood-West Fargo area, the inflow from the east is somewhat more than 100 million gallons (307 acre-ft) per year. In addition, there is an estimated 240 million gallons (740 acre-ft) per year of inflow from buried-channel aquifers; two north of Harwood, two in the southeast part of the county, and one from southwest of West Fargo (pl. 1). Klausing (1968, p. 24) indicated two buried-channel aquifers that were not included in the estimate because of lack of data. If these buried channels are present, the recharge through buried channels would be larger than the 240 million gallons (740 acre-ft) per year indicated. However, the total recharge to the West Fargo aquifer system is estimated to be about 600 to 650 million gallons (1,800 to 2,000 acre-ft) per year and does not include some inflow from smaller tributary aquifers that have not been adequately located or for which there are no data.

## Discharge

Prior to development, discharge from the West Fargo aquifer system probably was by upward movement through the lake deposits to near the land surface where evapotranspiration could occur. Lateral movement into adjacent deposits also occurred. Some water moved downgradient to the north and toward the Sheyenne River and the Red River of the North and became part of the base flow of the rivers. As development increased, water levels were lowered near the wells and water-level gradients sloped toward the areas of pumping. Nearly all, if not all, natural discharge ceased. Pumpage presently is the only known source of discharge from the aquifer system. However, it is possible that small quantities of water still seep into the Sheyenne River and the Red River of the North.

The estimated pumpage from the West Fargo aquifer system during 1980 is as follows: 584 million gallons (1,790 acre-ft) from the West Fargo North aquifer, 72 million gallons (220 acre-ft) from the West Fargo South aquifer, and about 27 million gallons (83 acre-ft) from the Horace aquifer, or a total of about 683 million gallons (2,096 acre-ft). These estimates include both metered pumpage for industrial and public supply purposes and unmetered pumpage based on populations in Harwood and Horace and groups of dwellings that are supplied from one or two wells. The estimates do not include domestic pumpage at the scattered farmsteads in the area.

Water has been pumped from the aquifer system since the late 1800's, but records of quantities pumped by large users were not recorded until 1965. With the exception of Harwood and Horace, nearly complete records of those using more than a few acre-feet of water per year generally are available since 1968. The records from 1968 through 1980 show that the annual pumpage ranged from 366 million gallons (1,120 acre-ft) during 1979 to 788 million gallons (2,420 acre-ft) during 1974. The mean annual pumpage for 1968-80 was 613 million gallons (1,880 acre-ft). All of this pumpage was from the West Fargo North aquifer.

Cass Rural Water Users, Inc., began pumping water from the West Fargo South aquifer in 1976 and began keeping records of their pumpage in 1977. Their records show that pumpage ranged from 41 million gallons (130 acre-ft) during 1979 to 73 million gallons (220 acre-ft) during 1977. The mean annual pumpage through 1980 has been about 59.9 million gallons (184 acre-ft).

Records of pumpage from the Horace aquifer have not been kept, but the population of Horace and the nearby area nearly doubled between 1970 and 1980 so it can be estimated that the water usage also nearly doubled. Estimated pumpage during 1970 was between 6.9 million gallons (21 acre-ft) and 7.3 million gallons (22 acre-ft), so the estimated pumpage for 1980 would have been about 14 million gallons (43 acre-ft).

## Storage

A substantial quantity of water is stored in the West Fargo aquifer system. There also is some water in the till and the undifferentiated glaciofluvial deposits. Part of this water also is available to wells, but at a slow rate. The following table lists the quantity of water in storage in each aquifer that is available to wells:

| Aquifer | Areal extent (square miles) | Average thickness (feet) | Estimated specific yield | Total storage | |
|---|---|---|---|---|---|
| | | | | (million gallons) | (acre-feet) |
| West Fargo North | 28 | 48 | 0.15 | 42,000 | 130,000 |
| West Fargo South | 15 | 75 | .15 | 35,200 | 108,000 |
| Horace | 15 | 115 | .15 | 54,100 | 166,000 |
| Total | 58 | | | 131,300 | 404,000 |

In addition to the available storage in the aquifer system and the till and glaciofluvial deposits, there is storage due to the compressibility of the aquifer system. This storage is referred to as artesian storage and is equal to the storage coefficient multiplied by the vertical distance between the top of the aquifer system and the potentiometric surface. Calculations based on three of the aquifer tests indicate that the storage coefficient varies to some extent, but averages about 0.0003. The vertical distance between the top of the aquifer system and the potentiometric surface is difficult to determine accurately because of the great variation in the depth to the top of the aquifer system. However, considering only those sites where the top of the aquifer system is at or near the base of the lake deposits where the top of the aquifer easily can be determined, an average saturated thickness of 65 feet is assumed for the West Fargo South and Horace aquifers. Using an area of 30 $mi^2$, the total artesian storage in the West Fargo South and Horace aquifers may be as much as 120 million gallons (370 acre-ft). The average saturated thickness is much less in the West Fargo North aquifer because most of the artesian pressure and related storage has been dissipated.

The quantity of artesian storage is insignificant when compared to the total water in storage, but it is important when considering effects on water levels because the artesian storage is the first to be used when discharge exceeds recharge. The decline or rise of water levels in an artesian aquifer are the result of pressure changes, so the resulting water-level changes are widespread and the water levels decline or rise rapidly.

## Water Levels

Water levels in the West Fargo aquifer system generally have declined at an irregular rate since the first wells were drilled in the system. Upham (1895, p. 568) reported that water from a 117-foot well, which was completed in the West Fargo North aquifer, at Harwood flowed 10 feet above land surface. Hall and Willard (1905) reported that wells still flowed in the vicinity of Harwood and unconfirmed reports indicate that flowing wells also existed in the West Fargo area in the early 1900's. Byers and others (1946, appendix A, p. 3) reported that the water levels in two wells in 139-049-08D were 40 feet below land surface in 1942. The owner of the wells reported that the water levels about 15 years previously were about 12 feet below land surface. This indicates a decline of nearly 2 ft/yr.

December water levels in well 139-049-06ADB from 1937 through 1981 are shown in table 1. Except for 1949, 1951, 1952, 1957, 1978, and 1979 when rises occurred, the water levels declined as much as 8.5 ft/yr. The average water-level decline was 2.9 ft/yr until 1969 when water levels were lowered to about 118 feet below land surface and the aquifer in the vicinity of the observation well changed from artesian conditions to water-table conditions. Since 1969 the rate of decline has been less than 1 ft/yr.

Two cones of depression caused by the declining water levels are shown on plates 4 and 5. The larger cone, centered at West Fargo, has been caused primarily by the pumping at West Fargo. The cone has elongated to the north in the West Fargo North aquifer primarily because the aquifer materials have large hydraulic conductivities in that direction, and the adjacent materials have relatively small hydraulic conductivities. The cone also extends to the south, but to a much lesser extent because materials with small, but significant, hydraulic conductivities apparently surround the south end of the West Fargo North aquifer. The smaller cone is in the Fargo aquifer. It has been caused primarily by pumping a well at 139-049-01CCA.

Water levels have declined everywhere in the aquifer system, but at a slower rate with distance from the pumping centers. Water levels in observation well 139-049-09DDD3 (fig. 3), which is 180 feet deep and completed in the West Fargo South aquifer, declined from about 42.9 feet in December 1964 to 48.2 feet in December 1972, a decline of about 0.7 ft/yr. The rate of decline then slowed until mid-1976, possibly because equilibrium conditions were being approached. The water-level decline then increased to nearly 1 ft/yr, probably because of pumping to the south. Water-level declines in observation well 139-049-09DDD3, which reflect pumpage at West Fargo, indicate that the West Fargo South aquifer is hydraulically connected to some degree to the West Fargo North aquifer. However, the difference in altitudes of the water levels in the two aquifers indicates that degree of


**Figure 3.**—Water-level fluctuations in observation well 139-049-09DDD3, which is 180 feet deep and is completed in the West Fargo South aquifer.

Table 1.--December water levels in observation well 139-049-06ADB

| Year | Water level (feet below land surface) | Year | Water level (feet below land surface) | Year | Water level (feet below land surface) |
|---|---|---|---|---|---|
| 1937 | 25.62 | 1952 | 64.92 | 1968 | 114.45 |
| 1938 | 29.56 | 1953 | 70.46 | 1969 | 117.96 |
| 1939 | -- | 1954 | 75.67 | 1970 | 118.29 |
| 1940 | 42.78 | 1955 | 79.58 | 1971 | 118.60 |
| 1941 | 44.66 | 1956 | 83.25 | 1972 | 119.84 |
| 1942 | 51.71 | 1957 | 80.38 | 1973 | 120.20 |
| 1943 | 53.85 | 1958 | 85.48 | 1974 | 120.85 |
| 1944 | 56.60 | 1959 | 89.24 | 1975 | 121.48 |
| 1945 | 60.62 | 1960 | 92.46 | 1976 | 122.57 |
| 1946 | 61.43 | 1961 | 100.98 | 1977 | 122.58 |
| 1947 | 67.34 | 1962 | 105.09 | 1978 | 120.47 |
| 1948 | 71.64 | 1963 | 106.92 | 1979 | 119.52 |
| 1949 | 68.98 | 1964 | 108.54 | 1980 | 121.08 |
| 1950 | 70.50 | 1965 | 110.9 | 1981 | 121.73 |
| 1951 | 67.50 | 1967 | 113.78 | | |

hydraulic connection to the part of the West Fargo North aquifer where large-scale pumping has occurred is restricted or possibly circuitous.

Water levels in observation well 139-049-22BBB (fig. 4), which is 236 feet deep and completed in the West Fargo South aquifer, declined from 47.9 feet in December 1963 to 54.9 feet in December 1972, a decline of nearly 0.9 ft/yr. The rate of water-level decline in this well also decreased between 1972 and 1976 and increased from 1976 to 1981. A comparison of water-level declines in the two observation wells indicates that either well 139-049-22BBB is hydraulically closer to the center of pumping in the West Fargo North aquifer than well 139-049-09DDD3, or that there is another unknown source of pumping nearer 139-049-22BBB.

Water levels in observation well 137-049-25CCC (fig. 5), which is 240 feet deep and completed in the West Fargo South aquifer, declined at a rate of about 0.2 ft/yr from 1964 to 1976. Between June 1976 and December 1981 the water level declined from 25.5 to 37.1 feet below land surface, or an average of about 2.1 ft/yr. The water-level decline since 1976 in observation well 137-049-25CCC indicates that there is a good hydraulic connection with the Cass Rural Water Users, Inc. pumping wells in 137-049-03BA about 5 miles to the north.

Water-level records for 1964 through 1981 for observation well 138-049-29CCC (fig. 6), which is 280 feet deep and completed in the Horace aquifer, show an irregular rate of decline that averaged about 0.7 ft/yr


**Figure 4.—Water-level fluctuations in observation well 139-049-22BBB, which is 236 feet deep and is completed in the West Fargo South aquifer.**

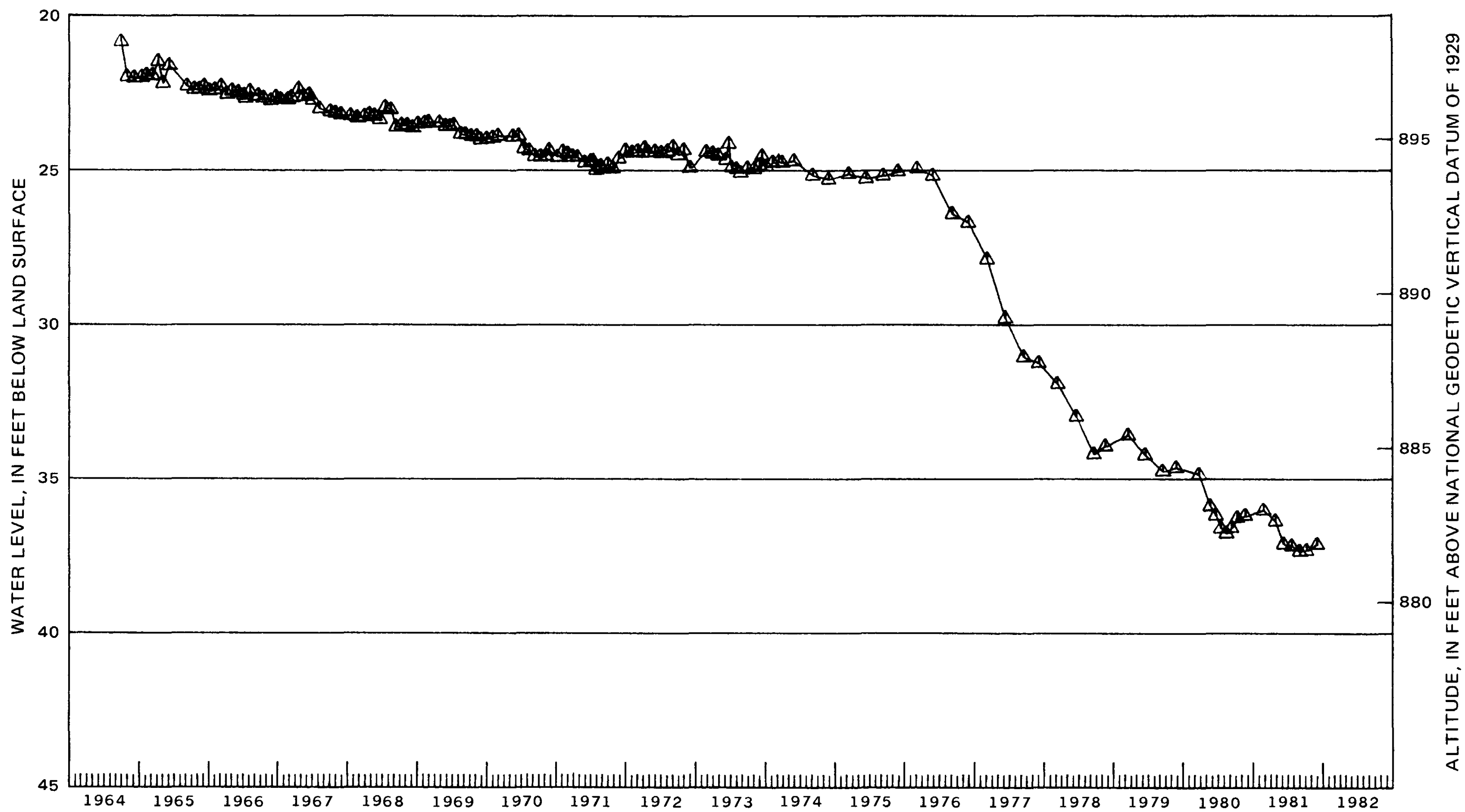



**Figure 5.—Water-level fluctuations in observation well 137-049-25CCC, which is 240 feet deep and is completed in the West Fargo South aquifer.**

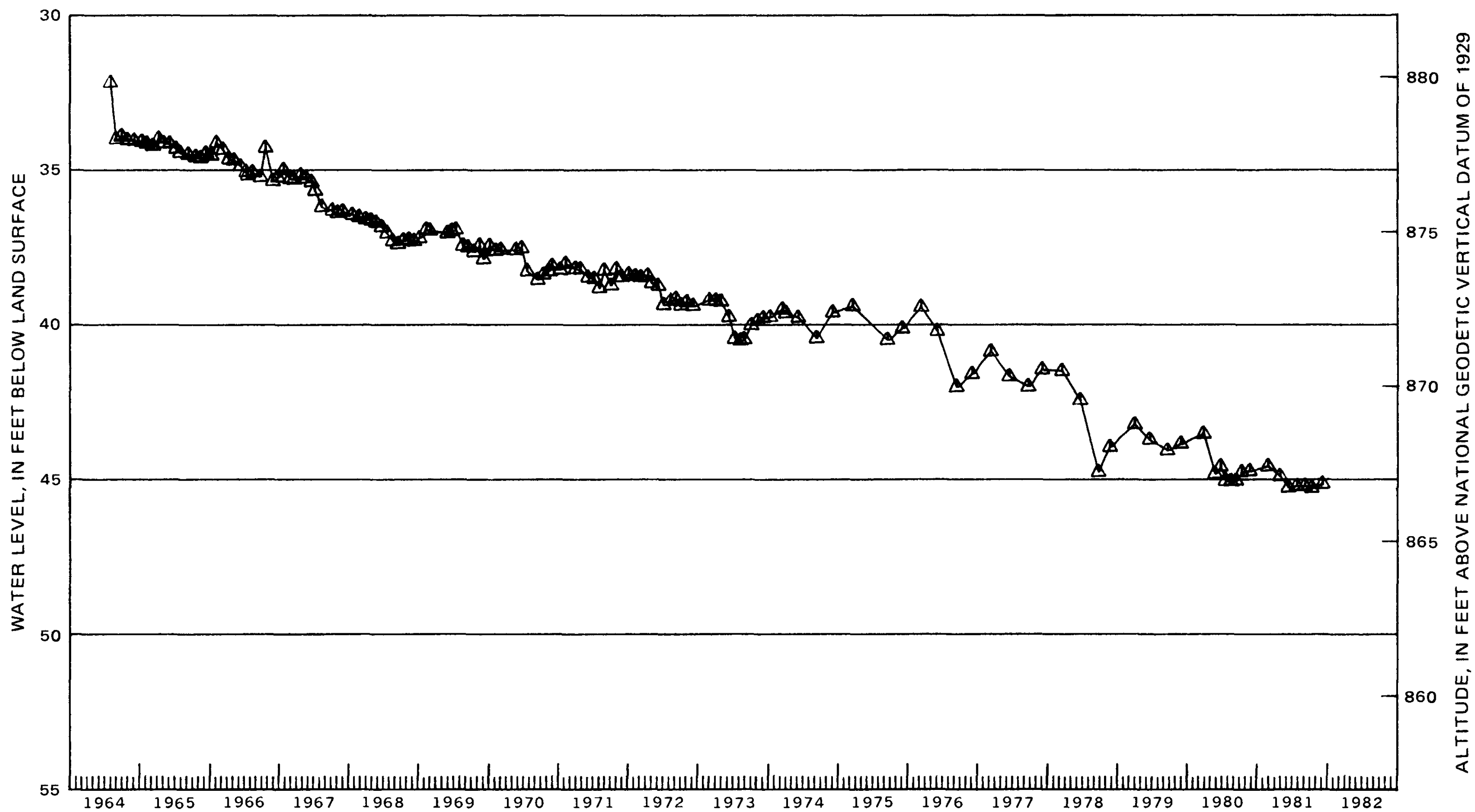



**Figure 6.—Water-level fluctuations in observation well 138-049-29CCC, which is 280 feet deep and is completed in the Horace aquifer.**

from 1964 through 1972. From early 1973 to early 1976 the rate of decline decreased to almost zero, indicating possible equilibrium conditions. However, in 1976, about the time that Cass Rural Water Users, Inc. began pumping at an undetermined rate from wells in 137-049-03BA in the West Fargo South aquifer, the water-level decline increased to about 1 ft/yr, or a total decline of about 5 feet from 1976 through 1981. However, new houses were built in the vicinity of Horace at about the same time (1976-77), and pumpage for domestic use in these houses may have been the principal contributor to the 5-foot water-level decline in observation well 138-049-29CCC. If so, there probably is no more than a limited hydraulic connection between the Horace aquifer and the West Fargo South aquifer.

The total water-level decline at any site in the aquifer system between predevelopment and September 1981 can be approximately estimated by subtracting the altitude of the water level shown on plate 5 from the altitude of the land surface at the site. Altitudes of water levels determined from measurements made in 1963 and 1964 and September 1981 are shown on plates 4 and 5. Based on the 1895 water level (Upham, 1895, p. 568) at Harwood, the estimate of total water-level decline based on land-surface altitude may be as much as 10 feet too small.

## QUALITY OF WATER

Chemical analyses of 126 water samples from 61 wells (table 2) completed in the West Fargo aquifer system and adjacent areas indicate that the water generally is hard or very hard (120 to more than 180 mg/L as calcium carbonate). Sodium is the dominant cation and generally either bicarbonate or chloride is the dominant anion. Sulfate is the dominant anion in a few samples from sand lenses near the edge of but not in the aquifer system. Concentrations of dissolved solids in the samples ranged from 332 to 2,960 mg/L. Bicarbonate concentrations ranged from 198 to 784 mg/L. There is no recognizable pattern to the distribution of bicarbonate. Chloride concentrations ranged from 25 to 975 mg/L and generally increased from east to west and to the north. The increase in chloride concentration is thought to be caused either by contact with Cretaceous shale, in place or locally reworked into the glacial drift, or by upward leakage from the Dakota aquifer. Sulfate concentrations ranged from 6.6 to 1,300 mg/L; however, only 20 samples contained more than the recommended limit of 250 mg/L (U.S. Environmental Protection Agency, 1977). The relative percentage of major ions is shown in figure 7.

A comparison of multiple water samples from wells (table 2) generally indicates that there has been no significant change in water quality in the aquifer system since 1963. However, samples from three wells, 139-049-06DCD, 139-049-07ABB2, and 139-049-08BDA, show a slight decrease in dissolved-solids and sulfate concentrations. These wells are in an area where induced infiltration from the Sheyenne River may be diluting the ground water. Many of the multiple samples from a single well (table 2) show what appears to be significant variations in dissolved iron concentration. However, most, if not all, of the variations probably are due to variations in sampling and filtering techniques.

Table 2.--Chemical analyses of water samples

[DEG. C = degrees Celsius; MG/L = milligrams per liter; UG/L = micrograms per liter; UMHOS = micromhos per centimeter at 25°C]

| STATION NUMBER | LOCAL IDENT-I-FIER | DATE OF SAMPLE | SPE-CIFIC CON-DUCT-ANCE (UMHOS) | PH (UNITS) | HARD-NESS (MG/L AS CACO3) | HARD-NESS, NONCAR-BONATE (MG/L CACO3) | CALCIUM DIS-SOLVED (MG/L AS CA) | MAGNE-SIUM, DIS-SOLVED (MG/L AS MG) | SODIUM, DIS-SOLVED (MG/L AS NA) | PERCENT SODIUM | SODIUM AD-SORP-TION RATIO | POTAS-SIUM, DIS-SOLVED (MG/L AS K) | BICAR-BONATE FET-FLD (MG/L AS HCO3) | CAR-BONATE FET-FLD (MG/L AS CO3) | SULFATE DIS-SOLVED (MG/L AS SO4) | CHLO-RIDE, DIS-SOLVED (MG/L AS CL) | FLUO-RIDE, DIS-SOLVED (MG/L AS F) | SILICA, DIS-SOLVED (MG/L AS SIO2) | SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L) | NITRO-GEN, NITRATE DIS-SOLVED (MG/L AS N) | BORON, DIS-SOLVED (UG/L AS B) | IRON, DIS-SOLVED (UG/L AS FE) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 464247096552701 | 157-049-06BCB | 64-06-24 | 2200 | 8.2 | 520 | 270 | 146 | 38 | 320 | 56 | 6.1 | 16 | 309 | 0 | 550 | 290 | .4 | 22 | 1600 | .68 | 950 | 170 |
| 464123096520701 | 157-049-09DCD | 64-11-18 | 1350 | 7.8 | 340 | 30 | 78 | 35 | 152 | 48 | 3.6 | 10 | 376 | 0 | 130 | 173 | .2 | 22 | 780 | .23 | 150 | 70 |
| 464123096483701 | 157-049-12CDD | 65-05-13 | 1220 | 8.0 | 230 | 0 | 64 | 17 | 144 | 57 | 4.1 | 8.6 | 334 | 0 | 139 | 100 | .4 | 23 | 743 | .41 | 250 | 120 |
| 464051096530401 | 157-049-17DAA | 64-11-18 | 1270 | 7.9 | 310 | 0 | 85 | 24 | 145 | 50 | 3.6 | 8.0 | 382 | 0 | 132 | 139 | .2 | 23 | 737 | .23 | 320 | 480 |
| 464110096551801 | 157-049-18BBD | 64-06-17 | 2390 | 8.2 | 580 | 340 | 156 | 47 | 285 | 51 | 5.1 | 10 | 295 | 0 | 480 | 331 | .6 | 21 | 1590 | .68 | 850 | 260 |
| 464024096552701 | 157-049-19BBB | 64-11-18 | 3000 | 8.1 | 670 | 420 | 191 | 46 | 400 | 56 | 6.7 | 13 | 295 | 0 | 624 | 476 | .2 | 20 | 2030 | .23 | 650 | 2900 |
| 464012096504101 | 157-049-22ADB | 64-11-18 | 811 | 8.0 | 130 | 0 | 35 | 9.4 | 132 | 68 | 5.1 | 5.3 | 344 | 0 | 58 | 56 | .5 | 22 | 498 | .00 | 350 | 370 |
| 464012096463701 | 157-049-24BDA | 64-11-17 | 861 | 7.9 | 220 | 0 | 56 | 19 | 97 | 48 | 2.9 | 7.3 | 305 | 0 | 129 | 45 | .3 | 24 | 530 | .00 | 0 | 130 |
| 463848096490601 | 157-049-25CCC | 64-08-21 | 1760 | 7.6 | 700 | 380 | 147 | 81 | 131 | 29 | 2.2 | 8.2 | 393 | 0 | 583 | 48 | .4 | 25 | 1260 | .45 | 0 | 400 |
| | | 73-07-19 | 1760 | 7.9 | 730 | 380 | 180 | 68 | 140 | 29 | 2.3 | 7.4 | 427 | 0 | 590 | 58 | .2 | 26 | 1310 | .23 | 260 | 3200 |
| 463847096522601 | 157-049-28CDD | 64-11-18 | 1110 | 8.1 | 200 | 0 | 55 | 15 | 167 | 64 | 5.2 | 4.8 | 442 | 0 | 46 | 113 | .6 | 23 | 638 | .00 | 0 | 440 |
| 463933096542001 | 157-049-30AAA | 78-07-17 | 1900 | -- | 430 | 270 | 120 | 32 | 210 | 51 | 4.4 | 11 | 198 | 0 | 410 | 210 | .1 | 19 | 1220 | 2.10 | 160 | 730 |
| 463905096565201 | 157-050-26DAA | 64-11-18 | 2590 | 8.1 | 440 | 190 | 112 | 38 | 396 | 66 | 8.3 | 12 | 305 | 0 | 595 | 316 | .3 | 20 | 1750 | .23 | 1000 | 130 |
| 464813096514801 | 158-049-04AAA | 64-06-06 | 670 | 8.2 | 150 | 0 | 44 | 10 | 80 | 52 | 2.8 | 5.2 | 283 | 0 | 22 | 50 | .4 | 21 | 376 | 1.40 | 0 | 270 |
| 464629096475701 | 158-049-13AAA | 64-11-13 | 1000 | 8.0 | 180 | 0 | 52 | 12 | 148 | 63 | 4.8 | 6.5 | 337 | 0 | 171 | 46 | .4 | 20 | 608 | .00 | 480 | 210 |
| 464629096511901 | 158-049-15BAB | 64-06-25 | 577 | 8.2 | 130 | 0 | 33 | 12 | 66 | 51 | 2.5 | 5.5 | 222 | 0 | 46 | 37 | .5 | 22 | 354 | .00 | 400 | 200 |
| 464536096542301 | 158-049-19AAA | 64-05-04 | 1660 | 7.4 | 55 | 0 | 16 | 3.6 | 345 | 91 | 20 | 13 | 327 | 0 | 323 | 156 | 1.4 | 8.5 | 1070 | .23 | 1900 | 620 |
| 464536096541301 | 158-049-20BBB | 64-11-13 | 1210 | 8.1 | 310 | 21 | 76 | 30 | 135 | 48 | 3.3 | 7.9 | 356 | 0 | 162 | 105 | .4 | 24 | 713 | .23 | 200 | 530 |
| 464445096511001 | 158-049-27BAA | 64-11-13 | 745 | 8.0 | 130 | 0 | 34 | 11 | 126 | 67 | 4.8 | 5.2 | 373 | 0 | 22 | 58 | .5 | 17 | 467 | .00 | 480 | 460 |
| 464359096521701 | 158-049-28DCC | 64-11-13 | 1160 | 8.2 | 230 | 0 | 55 | 23 | 156 | 59 | 4.5 | 8.0 | 390 | 0 | 114 | 105 | .4 | 19 | 652 | .00 | 550 | 310 |
| 464359096541301 | 158-049-29CCC | 64-08-20 | 2020 | 7.8 | 440 | 210 | 108 | 41 | 273 | 57 | 5.7 | 8.0 | 281 | 0 | 358 | 315 | .5 | 24 | 1280 | .68 | 0 | 240 |
| | | 73-07-19 | 2090 | 8.1 | 430 | 200 | 110 | 38 | 280 | 58 | 5.9 | 6.1 | 282 | 0 | 360 | 310 | .5 | 24 | 1320 | .45 | 390 | 830 |
| | | 78-06-12 | 2100 | -- | 420 | 210 | 110 | 35 | 280 | 59 | 6.0 | 5.6 | 252 | 0 | 360 | 340 | .4 | 25 | 1310 | .23 | 730 | 2300 |
| 464352096551101 | 158-049-31BAB | 64-11-13 | 2820 | 7.9 | 77 | 0 | 17 | 8.4 | 610 | 94 | 30 | 10 | 329 | 0 | 516 | 383 | 3.4 | 3.5 | 1620 | .45 | 2800 | 560 |
| 464307096513901 | 158-049-34CCC | 64-06-11 | 658 | 8.2 | 150 | 0 | 38 | 14 | 123 | 63 | 4.3 | 6.4 | 349 | 0 | 39 | 70 | .6 | 23 | 482 | .99 | 300 | 470 |
| 464615096564601 | 158-050-13BCB | 64-11-13 | 1740 | 8.1 | 290 | 0 | 80 | 21 | 264 | 66 | 6.8 | 8.8 | 349 | 0 | 252 | 231 | .2 | 23 | 1120 | .23 | 850 | 2300 |
| 464351096565501 | 158-050-35AAA | 64-07-31 | 1920 | 8.1 | 430 | 160 | 104 | 42 | 240 | 53 | 5.0 | 18 | 332 | 0 | 302 | 268 | .5 | 20 | 1190 | .00 | 0 | 240 |
| 465240096501401 | 159-049-02CCD | 65-05-13 | 1380 | 7.8 | 150 | 0 | 35 | 15 | 255 | 78 | 9.1 | 6.6 | 337 | 0 | 168 | 178 | .5 | 22 | 822 | 1.30 | 1300 | 260 |
| 465305096545201 | 159-049-06ACC | 65-06-14 | 1760 | 7.9 | 230 | 0 | 67 | 14 | 303 | 74 | 8.8 | 9.1 | 377 | 0 | 151 | 310 | .5 | 23 | 1030 | 1.20 | 480 | 660 |
| | | 73-06-27 | 1700 | 7.8 | 220 | 0 | 50 | 24 | 287 | 73 | 8.4 | 6.2 | 387 | 0 | 130 | 278 | .6 | 25 | 978 | .23 | 60 | 340 |
| | | 74-06-11 | 1690 | -- | 200 | 0 | 52 | 17 | 280 | 75 | 8.6 | 5.6 | 379 | 0 | 130 | 270 | .6 | 25 | 979 | .45 | 130 | 490 |
| 465305096544201 | 159-049-06ACD | 79-08-22 | 1660 | 7.8 | 210 | 0 | 56 | 17 | 280 | 74 | 8.4 | 5.8 | 385 | 0 | 120 | 260 | .5 | 20 | 965 | .23 | 470 | 60 |
| 465312096550101 | 159-049-06BDA | 73-06-27 | 1950 | 7.7 | 230 | 0 | 52 | 24 | 335 | 75 | 9.6 | 6.5 | 462 | 0 | 63 | 368 | .7 | 26 | 1080 | .23 | 250 | 360 |
| | | 74-06-11 | 1940 | -- | 200 | 0 | 52 | 17 | 330 | 78 | 10 | 6.3 | 445 | 7 | 65 | 360 | .8 | 25 | 1090 | .23 | 170 | 670 |
| | | 75-06-18 | 1910 | 7.7 | 190 | 0 | 51 | 15 | 330 | 78 | 10 | 6.5 | 450 | 0 | 72 | 340 | .6 | 19 | 1080 | .23 | 980 | 460 |
| 465239096550101 | 159-049-06CDD | 64-05-13 | 2280 | 7.4 | 200 | 0 | 52 | 17 | 415 | 80 | 13 | 15 | 417 | 0 | 134 | 450 | 1.0 | 21 | 1370 | .23 | 550 | 1800 |
| 465239096544201 | 159-049-06DCD | 63-11-09 | 2420 | 7.5 | 230 | 0 | 57 | 20 | 450 | 80 | 13 | 13 | 410 | 0 | 207 | 478 | .9 | 24 | 1510 | .23 | 700 | 960 |
| | | 67-08-29 | 2330 | 8.1 | 220 | -- | 57 | 18 | 417 | 80 | 12 | 8.0 | -- | -- | 204 | 436 | .6 | 26 | 1370 | 1.20 | 850 | 880 |
| | | 68-04-16 | 2220 | 7.6 | 200 | -- | 57 | 13 | 406 | 81 | 13 | 7.9 | -- | -- | 202 | 411 | .7 | 28 | 1320 | .90 | 930 | 220 |
| 465239096544201 | 159-049-06DCD | 68-11-06 | 2230 | 7.6 | 210 | -- | 53 | 18 | 395 | 80 | 12 | 7.8 | -- | -- | 195 | 402 | .7 | 27 | 1290 | 1.00 | 820 | 860 |
| | | 70-06-16 | 2070 | 7.7 | 190 | -- | 53 | 15 | 386 | 81 | 12 | 6.7 | -- | -- | 176 | 383 | .7 | 27 | 1240 | .05 | 450 | 0 |
| | | 72-06-14 | 2030 | 7.6 | 210 | -- | 51 | 19 | 363 | 79 | 11 | 7.1 | -- | -- | 181 | 385 | .6 | 15 | 1240 | .23 | 930 | 90 |
| | | 73-06-27 | 2040 | 8.2 | 220 | 0 | 47 | 24 | 359 | 78 | 11 | 6.7 | 380 | 0 | 168 | 367 | .7 | 26 | 1160 | .23 | 160 | 600 |
| | | 74-06-11 | 2000 | -- | 200 | 0 | 49 | 19 | 340 | 78 | 10 | 6.7 | 376 | 0 | 160 | 360 | .7 | 26 | 1140 | .56 | 90 | 800 |
| | | 76-06-23 | 2600 | 7.7 | 210 | -- | 51 | 20 | 340 | 77 | 10 | 7.0 | -- | -- | 160 | 360 | .6 | 29 | 1140 | .23 | 910 | 1000 |
| 465239096544202 | 159-049-06DCD2 | 63-11-03 | 2420 | 7.8 | 220 | 0 | 57 | 19 | 440 | 80 | 13 | 14 | 388 | 0 | 217 | 472 | .8 | 15 | 1470 | .23 | 750 | 520 |
| 465239096543301 | 159-049-06DDC | 63-11-04 | 2090 | 7.7 | 220 | 0 | 57 | 19 | 372 | 77 | 11 | 13 | 346 | 0 | 179 | 410 | .9 | 18 | 1270 | .23 | 1100 | 400 |
| 465229096544701 | 159-049-07AB | 79-07-01 | 2120 | 7.7 | 220 | 0 | 53 | 21 | 370 | 78 | 11 | 7.8 | 394 | 0 | 160 | 400 | .7 | 29 | 1240 | .23 | 30 | 730 |
| 465233096545202 | 159-049-07ABB2 | 65-06-18 | 1590 | 8.0 | 160 | 0 | 45 | 12 | 287 | 78 | 9.8 | 9.1 | 366 | 0 | 168 | 238 | .6 | 20 | 949 | .54 | 1000 | 440 |
| | | 67-01-12 | 2280 | 7.5 | 220 | 0 | 53 | 21 | 399 | 79 | 12 | 8.5 | 382 | 0 | 196 | 416 | .7 | 28 | 1320 | .25 | 940 | -- |
| | | 67-08-29 | 2260 | 7.9 | 220 | 0 | 60 | 17 | 404 | 79 | 12 | 8.1 | 378 | 0 | 201 | 412 | .6 | 26 | 1300 | .08 | 850 | 130 |
| | | 68-04-16 | 2140 | 7.8 | 200 | 0 | 58 | 13 | 384 | 80 | 12 | 8.2 | 381 | 0 | 195 | 387 | .6 | 27 | 1250 | .00 | 980 | 200 |
| | | 70-06-16 | 2120 | 7.7 | 210 | 0 | 53 | 18 | 382 | 79 | 12 | 7.4 | 382 | 0 | 179 | 387 | .8 | 27 | 1250 | .00 | 410 | 960 |
| | | 71-05-11 | 2130 | 7.7 | 200 | 0 | 49 | 19 | 374 | 80 | 11 | 6.4 | 383 | 0 | 195 | 380 | .8 | 26 | 1160 | .07 | 380 | 760 |
| | | 72-06-14 | 2120 | 7.7 | 200 | 0 | 48 | 20 | 375 | 79 | 11 | 7.8 | 385 | 0 | 152 | 402 | .7 | 15 | 1230 | .02 | 960 | 560 |
| | | 73-07-19 | 2120 | 7.8 | 210 | 0 | 47 | 22 | 370 | 79 | 11 | 7.4 | 388 | 0 | 170 | 370 | .7 | 26 | 1210 | .23 | 650 | 1200 |
| | | 74-06-11 | 2100 | -- | 200 | 0 | 49 | 19 | 370 | 79 | 11 | 7.6 | 387 | 0 | 160 | 380 | .7 | 26 | 1230 | .23 | 90 | 760 |
| | | 75-06-18 | 2100 | 7.7 | 210 | 0 | 51 | 20 | 360 | 78 | 11 | 7.8 | 387 | 0 | 160 | 380 | .6 | 20 | 1270 | .16 | 870 | 360 |
| | | 76-06-23 | 2900 | 7.8 | 210 | 0 | 49 | 21 | 360 | 78 | 11 | 7.8 | 391 | 0 | 170 | 380 | .6 | 29 | 1180 | .07 | 940 | 1000 |
| | | 77-06-22 | 2250 | 8.0 | 210 | 0 | 51 | 20 | 360 | 78 | 11 | 7.7 | 392 | 0 | 150 | 360 | .3 | 8.7 | 1190 | .43 | 800 | 120 |
| 465220096534501 | 159-049-08DBA | 65-06-18 | 1250 | 7.9 | 150 | 0 | 41 | 12 | 214 | 74 | 7.6 | 8.1 | 344 | 0 | 130 | 146 | .6 | 23 | 751 | .36 | 820 | 120 |
| | | 67-08-29 | 1160 | 7.8 | 150 | 0 | 41 | 12 | 197 | 73 | 7.0 | 5.8 | 337 | 0 | 136 | 124 | .6 | 25 | 679 | .45 | 660 | 100 |
| | | 68-04-16 | 1150 | 7.6 | 160 | 0 | 42 | 13 | 194 | 72 | 6.7 | 6.7 | 330 | 0 | 139 | 122 | .7 | 26 | 677 | .72 | 830 | 80 |
| | | 68-11-06 | 1180 | 7.7 | 160 | 0 | 42 | 13 | 198 | 72 | 6.8 | 6.0 | 341 | 0 | 138 | 125 | .6 | 26 | 719 | .23 | 580 | 220 |
| | | 70-06-16 | 1590 | 7.6 | 170 | 0 | 45 | 14 | 241 | 75 | 8.0 | 7.2 | 341 | 0 | 142 | 195 | .6 | 26 | 845 | 1.10 | 0 | 60 |
| | | 71-05-11 | 1180 | 7.8 | 150 | 0 | 37 | 15 | 194 | 72 | 6.8 | 5.6 | 395 | 0 | 133 | 126 | 1.0 | 25 | 634 | .05 | 620 | 520 |
| | | 72-06-14 | 1120 | 7.6 | 150 | 0 | 37 | 14 | 187 | 72 | 6.6 | 5.5 | 331 | 0 | 124 | 116 | .7 | 15 | 679 | .20 | 750 | 310 |
| | | 73-06-27 | 1000 | 7.8 | 160 | 0 | 33 | 19 | 166 | 68 | 5.7 | 5.8 | 355 | 0 | 92 | 90 | .5 | 25 | 583 | .23 | <20 | 150 |
| | | 74-06-11 | 1110 | -- | 140 | 0 | 35 | 13 | 190 | 74 | 7.0 | 5.0 | 334 | 0 | 120 | 110 | .8 | 24 | 650 | .05 | 170 | 240 |
| | | 75-06-18 | 1070 | 7.6 | 150 | 0 | 36 | 15 | 170 | 70 | 6.0 | 5.1 | 327 | 0 | 120 | 100 | .6 | 17 | 638 | .61 | 670 | 460 |
| 465147096532601 | 159-049-08DCD | 76-06-23 | 1700 | 8.0 | 150 | 0 | 35 | 15 | 160 | 69 | 5.7 | 4.4 | 306 | 0 | 100 | 100 | .6 | 26 | 591 | .23 | 570 | 750 |
| | | 77-06-22 | 1040 | 8.4 | 160 | 0 | 40 | 15 | 150 | 66 | 5.1 | 4.5 | 316 | 4 | 99 | 100 | .3 | 8.1 | 591 | .23 | 350 | 670 |
| | | 78-06-23 | 1070 | 7.7 | 160 | 0 | 42 | 13 | 160 | 67 | 5.5 | 7.9 | 340 | 0 | 100 | 100 | .5 | 20 | 610 | .11 | 640 | 220 |
| | | 79-07-17 | 988 | 7.6 | 180 | 0 | 42 | 18 | 150 | 64 | 4.9 | 4.6 | 300 | 0 | 99 | 110 | .6 | 28 | 606 | .23 | 400 | 550 |
| 465233096524701 | 159-049-09BBA | 72-06-10 | 1010 | 7.9 | 120 | 0 | 28 | 12 | 182 | 76 | 7.3 | 4.6 | 369 | 0 | 91 | 87 | .6 | 14 | 600 | .05 | 640 | 270 |
| | | 72-06-11 | 996 | 7.9 | 120 | 0 | 29 | 11 | 177 | 76 | 7.1 | 4.4 | 366 | 0 | 82 | 92 | .6 | 15 | 618 | .23 | 610 | 290 |
| | | 72-06-12 | 995 | 7.9 | 120 | 0 | 30 | 11 | 175 | 75 | 6.9 | 4.4 | 364 | 0 | 104 | 82 | .6 | 14 | 624 | .23 | 680 | 290 |
| | | 72-06-13 | 990 | 7.8 | 120 | 0 | 30 | 12 | 174 | 74 | 6.8 | 4.4 | 365 | 0 | 92 | 84 | .6 | 14 | 589 | .23 | 820 | 310 |

Table 2.--Chemical analyses of water samples--Continued

| STATION NUMBER | LOCAL IDENT-I-FIER | DATE OF SAMPLE | SPE-CIFIC CON-DUCT-ANCE (UMHOS) | PH (UNITS) | HARD-NESS (MG/L AS CACO3) | HARD-NESS, NONCAR-BONATE (MG/L CACO3) | CALCIUM DIS-SOLVED (MG/L AS CA) | MAGNE-SIUM, DIS-SOLVED (MG/L AS MG) | SODIUM DIS-SOLVED (MG/L AS NA) | PERCENT SODIUM | SODIUM AD-SORP-TION RATIO | POTAS-SIUM, DIS-SOLVED (MG/L AS K) | BICAR-BONATE FET-FLD (MG/L AS HCO3) | CAR-BONATE FET-FLD (MG/L AS CO3) | SULFATE DIS-SOLVED (MG/L AS SO4) | CHLO-RIDE, DIS-SOLVED (MG/L AS CL) | FLUO-RIDE, DIS-SOLVED (MG/L AS F) | SILICA, DIS-SOLVED (MG/L AS SIO2) | SOLIDS, RESIDUE AT 180 DEG. C DIS-SOLVED (MG/L) | NITRO-GEN, NITRATE DIS-SOLVED (MG/L AS N) | BORON, DIS-SOLVED (UG/L AS B) | IRON, DIS-SOLVED (UG/L AS FE) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 465233096524701 | 139-049-09BBA | 72-06-14 | 988 | 7.8 | 130 | 0 | 30 | 13 | 172 | 74 | 6.6 | 4.5 | 363 | 0 | 91 | 83 | .6 | 14 | 613 | .23 | 750 | 300 |
| | | 73-06-27 | 1090 | 7.8 | 170 | 0 | 33 | 20 | 181 | 70 | 6.1 | 6.2 | 337 | 0 | 121 | 108 | .7 | 26 | 653 | .68 | <20 | 260 |
| | | 74-06-11 | 982 | -- | 140 | 0 | 36 | 12 | 160 | 71 | 5.9 | 4.3 | 354 | 0 | 88 | 82 | .6 | 25 | 579 | .00 | 170 | 550 |
| | | 75-06-18 | 1000 | 7.6 | 150 | 0 | 37 | 14 | 160 | 69 | 5.7 | 4.2 | 340 | 0 | 89 | 94 | .4 | 19 | 607 | .23 | 590 | 550 |
| | | 76-06-23 | 1180 | 7.8 | 150 | 0 | 39 | 13 | 160 | 69 | 5.7 | 4.8 | 348 | 0 | 100 | 90 | .5 | 28 | 598 | .59 | 530 | 750 |
| | | 77-06-22 | 1080 | 8.5 | 170 | 0 | 42 | 16 | 160 | 66 | 5.3 | 4.6 | 350 | 7 | 99 | 98 | .2 | 7.4 | 601 | .23 | 380 | 280 |
| | | 78-06-23 | 1080 | 7.8 | 160 | 0 | 42 | 13 | 160 | 68 | 5.5 | 4.6 | 339 | 0 | 110 | 100 | .5 | 20 | 610 | .23 | 730 | <10 |
| | | 79-07-17 | 1020 | 7.8 | 170 | 0 | 41 | 16 | 170 | 68 | 5.7 | 5.2 | 343 | 0 | 110 | 100 | 1.8 | 28 | 648 | .23 | 400 | 100 |
| 465147096515003 | 139-049-09DDD3 | 64-07-09 | 638 | 8.5 | 180 | 0 | 50 | 14 | 101 | 54 | 3.3 | 6.6 | 256 | 6 | 92 | 72 | .4 | 20 | 501 | .00 | 600 | 290 |
| | | 78-07-18 | 825 | 8.0 | 190 | 0 | 51 | 15 | 96 | 51 | 3.0 | 6.2 | 270 | 0 | 84 | 76 | .3 | 28 | 459 | .23 | 160 | 430 |
| 465207096502401 | 139-049-11CBB | 64-03-13 | 1120 | 7.7 | 130 | 0 | 38 | 9.0 | 191 | 75 | 7.2 | 7.0 | 351 | 0 | 108 | 112 | .9 | 20 | 680 | .23 | 0 | 460 |
| 465140096553001 | 139-049-18BBB | 63-08-26 | 2616 | 7.3 | 250 | 0 | 62 | 23 | 470 | 79 | 13 | 20 | 381 | 0 | 300 | 472 | 1.0 | 23 | 1624 | .23 | 1550 | 540 |
| | | 73-07-23 | 2190 | 8.0 | 240 | 0 | 31 | 40 | 380 | 77 | 11 | 8.0 | 455 | 0 | 77 | 440 | .5 | 27 | 1290 | 1.10 | 390 | 100 |
| | | 78-07-18 | 2000 | -- | 250 | 0 | 68 | 20 | 370 | 75 | 10 | 10 | 454 | 0 | 77 | 450 | .6 | 31 | 1200 | 1.20 | 290 | 60 |
| 465049096514001 | 139-049-22BBB | 63-08-30 | 1046 | 7.6 | 190 | 0 | 48 | 17 | 126 | 58 | 4.0 | 8.0 | 264 | 0 | 112 | 108 | .5 | 20 | 596 | .00 | 1450 | 200 |
| | | 73-07-20 | 1000 | 8.0 | 250 | 0 | 65 | 21 | 120 | 50 | 3.3 | 6.8 | 357 | 0 | 110 | 75 | .4 | 25 | 612 | .56 | 340 | 1100 |
| 464937096540401 | 139-049-29BCD | 64-11-18 | 1350 | 7.8 | 110 | 0 | 28 | 9.2 | 257 | 83 | 11 | 8.2 | 432 | 0 | 140 | 125 | 1.1 | 16 | 796 | .23 | 850 | 480 |
| | | 67-08-29 | 1350 | 7.9 | 120 | 0 | 30 | 11 | 260 | 81 | 10 | 6.7 | 424 | 0 | 154 | 132 | 1.0 | 18 | 803 | 1.40 | 1300 | 1500 |
| | | 68-04-16 | 1330 | 7.9 | 110 | 0 | 30 | 9.0 | 259 | 82 | 11 | 7.6 | 432 | 0 | 149 | 128 | 1.2 | 19 | 797 | .23 | 1500 | 220 |
| | | 68-11-06 | 1360 | 8.0 | 110 | 0 | 29 | 10 | 252 | 82 | 10 | 7.2 | 433 | 0 | 150 | 130 | 1.1 | 19 | 814 | .00 | 1100 | 920 |
| | | 70-06-16 | 1350 | 7.9 | 110 | 0 | 28 | 10 | 261 | 83 | 11 | 5.8 | 435 | 0 | 141 | 131 | 1.2 | 18 | 804 | .56 | 480 | 1000 |
| | | 71-05-10 | 1350 | 7.9 | 110 | 0 | 27 | 11 | 259 | 82 | 11 | 6.4 | 435 | 0 | 148 | 129 | 1.6 | 18 | 782 | .23 | 900 | 680 |
| | | 72-06-14 | 1350 | 7.9 | 120 | 0 | 26 | 13 | 261 | 82 | 10 | 6.2 | 435 | 0 | 155 | 138 | 1.0 | 10 | 808 | .23 | 1100 | 1300 |
| | | 73-06-27 | 1340 | 7.9 | 120 | 0 | 26 | 13 | 264 | 82 | 11 | 6.4 | 436 | 0 | 144 | 129 | 1.0 | 17 | 807 | .23 | 410 | 1300 |
| | | 74-06-11 | 1360 | -- | 120 | 0 | 26 | 13 | 250 | 81 | 10 | 5.9 | 437 | 0 | 140 | 130 | 1.2 | 17 | 784 | .23 | 1100 | 1400 |
| | | 76-06-22 | 1320 | 7.9 | 100 | 0 | 26 | 8.5 | 260 | 84 | 11 | 5.8 | 439 | 0 | 150 | 120 | .9 | 19 | 800 | .23 | 1200 | 1400 |
| | | 77-06-22 | 1380 | 8.3 | 120 | 0 | 27 | 13 | 260 | 82 | 10 | 5.7 | 450 | 0 | 150 | 130 | .7 | 11 | 805 | .23 | 1100 | 790 |
| 464937096535401 | 139-049-29BDC | 78-06-23 | 1360 | 7.7 | 110 | 0 | 28 | 9.7 | 250 | 82 | 10 | 5.9 | 423 | 0 | 140 | 130 | 1.1 | 13 | 777 | .14 | 1500 | 1000 |
| | | 79-06-22 | 1340 | 7.9 | 120 | 0 | 26 | 13 | 250 | 81 | 10 | 6.0 | 438 | 0 | 140 | 130 | 1.2 | 19 | 830 | .23 | 370 | 1100 |
| 464825096540401 | 139-049-32CCA | 64-11-18 | 1120 | 7.8 | 290 | 32 | 56 | 37 | 142 | 50 | 3.6 | 9.0 | 317 | 0 | 113 | 140 | .4 | 22 | 640 | 2.20 | 150 | 120 |
| 465239096555901 | 139-050-01DCD | 71-05-11 | 1960 | 7.7 | 250 | 0 | 60 | 24 | 336 | 74 | 9.3 | 5.6 | 559 | 0 | 17 | 362 | .6 | 26 | 1040 | .23 | 520 | 1100 |
| 465252096572401 | 139-050-02DBC | 65-05-13 | 1860 | 7.7 | 230 | 0 | 54 | 23 | 340 | 75 | 9.8 | 9.7 | 361 | 0 | 170 | 345 | .5 | 22 | 1080 | .72 | 1800 | 120 |
| 465213096561101 | 139-050-10ADD | 64-07-13 | 1380 | 8.2 | 210 | 0 | 51 | 21 | 227 | 68 | 6.6 | 17 | 381 | 0 | 126 | 209 | .6 | 18 | 886 | .00 | 0 | 310 |
| | | 64-07-14 | 1380 | 7.5 | 210 | 0 | 54 | 19 | 215 | 67 | 6.4 | 11 | 371 | 0 | 94 | 202 | .4 | 25 | 818 | 5.80 | 0 | 280 |
| | | 64-07-15 | 1360 | 7.3 | 220 | 0 | 53 | 20 | 215 | 67 | 6.4 | 11 | 366 | 0 | 94 | 205 | .4 | 24 | 820 | 5.80 | 0 | 260 |
| 465048096565501 | 139-050-23AAA | 64-07-09 | 1400 | 8.0 | 590 | 0 | 139 | 58 | 90 | 25 | 1.6 | 8.5 | 784 | 0 | 42 | 76 | .2 | 24 | 849 | .00 | 650 | 1600 |
| | | 78-07-18 | 650 | -- | 280 | 0 | 77 | 21 | 27 | 17 | .7 | 6.3 | 357 | 0 | 6.6 | 26 | .1 | 17 | 332 | .23 | 100 | 430 |
| 465706096543601 | 140-049-07DCA | 65-05-12 | 1170 | 7.7 | 320 | 0 | 81 | 28 | 159 | 51 | 3.9 | 7.3 | 693 | 0 | 17 | 58 | .3 | 23 | 690 | .27 | 900 | 860 |
| 465628096514801 | 140-049-16DAA | 64-06-26 | 912 | 8.3 | 150 | 0 | 40 | 13 | 145 | 66 | 5.1 | 10 | 412 | 5 | 19 | 84 | .4 | 24 | 572 | .45 | 650 | 440 |
| 465517096460201 | 140-049-24DDD | 65-05-12 | 2090 | 7.6 | 1180 | 670 | 266 | 123 | 85 | 14 | 1.4 | 5.3 | 617 | 0 | 749 | 28 | .2 | 21 | 1740 | 10.0 | 0 | 100 |
| 465405096544801 | 140-049-31ACB | 65-05-12 | 1630 | 7.7 | 910 | 600 | 160 | 124 | 74 | 15 | 1.1 | 14 | 373 | 0 | 435 | 95 | .1 | 16 | 1440 | 47.0 | 350 | 380 |
| 465332096550601 | 140-049-31CDC | 63-08-23 | 2025 | 7.9 | 160 | 0 | 34 | 18 | 402 | 83 | 14 | 12 | 517 | 0 | 18 | 430 | 1.3 | 20 | 1090 | .45 | 1550 | 720 |
| 465411096541001 | 140-049-32BBC | 65-06-16 | 1670 | 7.8 | 260 | 0 | 81 | 15 | 247 | 66 | 6.6 | 9.5 | 494 | 0 | 48 | 305 | .3 | 22 | 904 | .27 | 500 | 500 |
| 465333096491701 | 140-049-35DDD | 64-05-13 | 1180 | 7.6 | 185 | 0 | 49 | 15 | 200 | 69 | 6.4 | 6.0 | 315 | 0 | 162 | 143 | .7 | 18 | 762 | .23 | 0 | 350 |
| 465419096480201 | 140-049-36AAA | 63-08-08 | 1793 | 8.3 | 400 | 150 | 35 | 77 | 220 | 54 | 4.9 | 5.0 | 305 | 15 | 370 | 166 | .7 | 23 | 1129 | .45 | 0 | 390 |
| 470312096561001 | 141-049-06CDB | 65-05-12 | 2310 | 8.5 | 70 | 0 | 14 | 8.5 | 492 | 93 | 26 | 11 | 381 | 5 | 180 | 450 | .6 | 6.4 | 1330 | .81 | 1900 | 380 |
| 465907096533601 | 141-049-33CAB | 65-05-12 | 1330 | 8.0 | 180 | 0 | 44 | 18 | 221 | 71 | 7.1 | 8.0 | 325 | 0 | 139 | 189 | .5 | 20 | 784 | .65 | 1200 | 420 |
| 470212096564201 | 141-050-11CDC | 65-05-12 | 4580 | 7.6 | 530 | 240 | 128 | 50 | 866 | 77 | 16 | 18 | 353 | 0 | 760 | 975 | .1 | 23 | 2960 | 1.40 | 2600 | 220 |

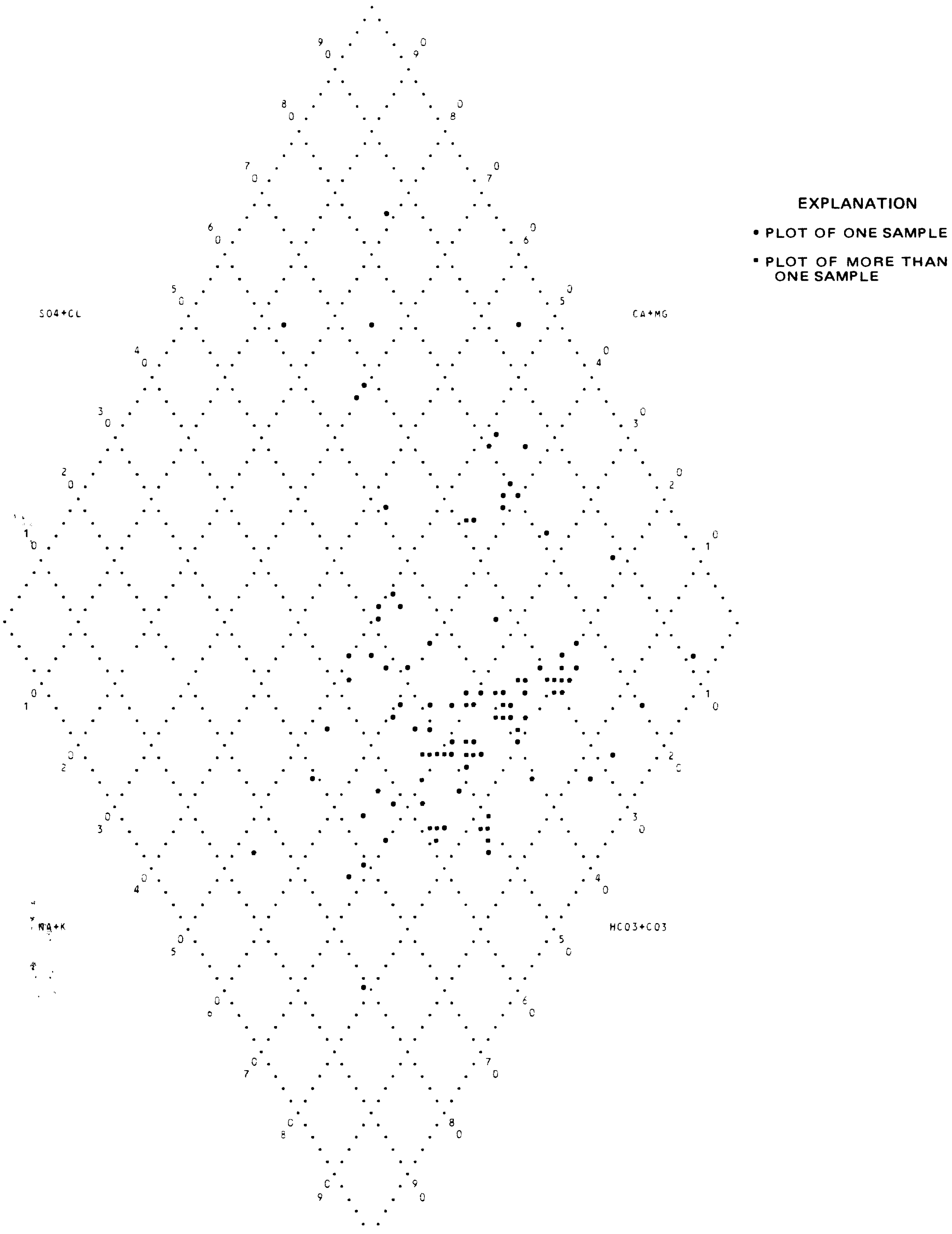



**Figure 7.—Percentage of major constituents in ground water.**

The sodium-adsorption ratio (SAR) ranged from 0.7 to 30, but water from only 12 wells had ratios greater than 10. Most of the water has a low to high sodium hazard and a high salinity hazard (fig. 8) according to a classification for irrigation developed by the U.S. Salinity Laboratory Staff (1954).

## FUTURE INVESTIGATIONS

The present investigation of the West Fargo aquifer system has indicated a need for more data in several areas. Leakage or recharge through the lake deposits needs to be investigated so that a realistic range of vertical hydraulic conductivities can be established. At the present it appears that the lower lake deposits control the leakage rate, so most emphasis needs to be placed on the lower beds.

The glacial till in the West Fargo aquifer system area is commonly sandy and may have hydraulic conductivities much greater than usually is assumed. Therefore, several cores from scattered locations need to be obtained and laboratory analyses of hydraulic conductivities and porosities made so that a reliable range of values can be established. The hydraulic-conductivity values could be very important in long-term evaluations of the aquifer system because they determine the rate at which water stored in till is released.

There are some indications that the Fargo aquifer and West Fargo aquifer system are hydraulically connected. The evidence as of 1981 is inconclusive, so more test drilling and observation wells are needed. The most likely place for a connection is in the vicinity of the buried valley about 2 miles north of U.S. Highway 10 (pl. 1). Water-level fluctuations in the new observation wells may show a definite connection.

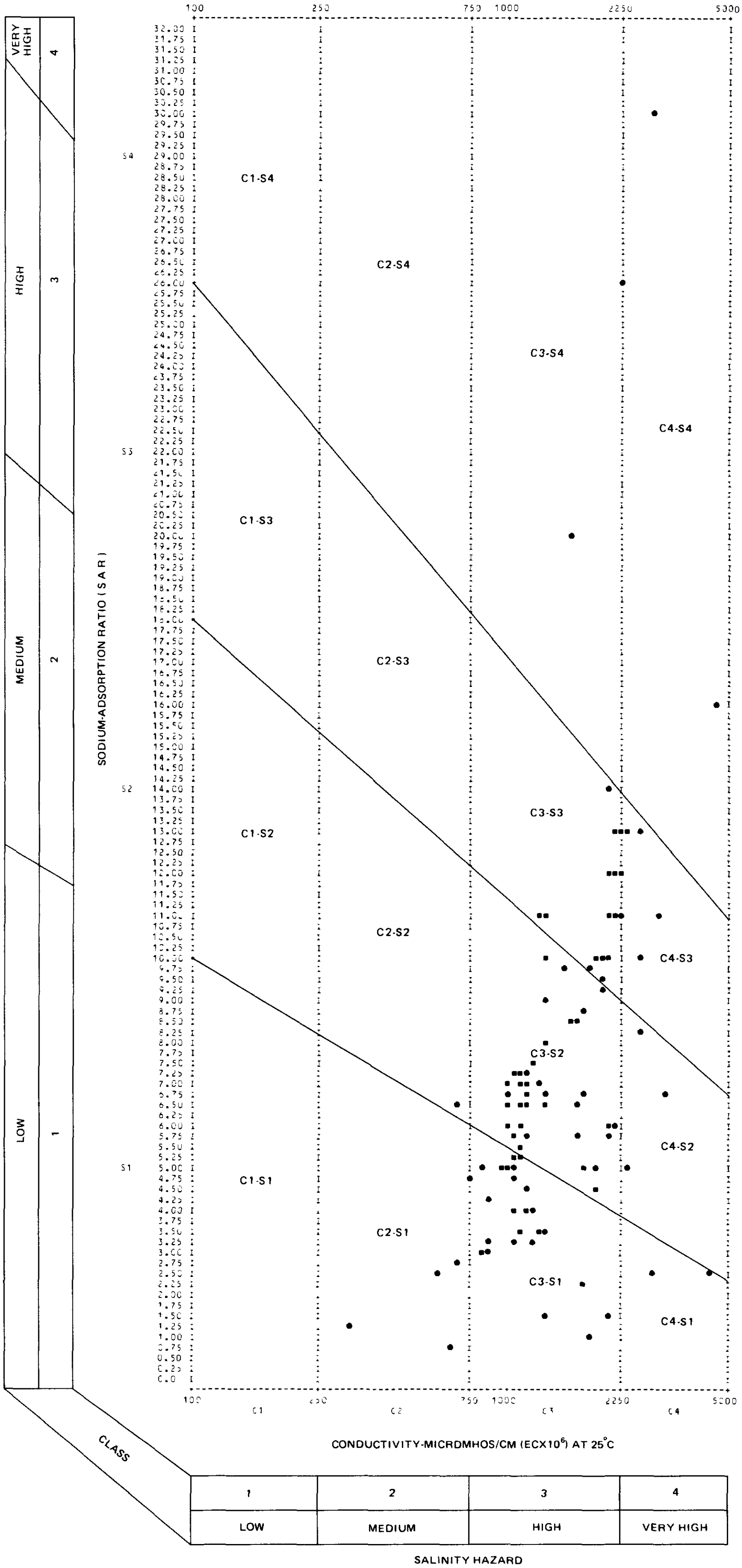
There is a possibility of some recharge from the west. This possibility needs to be explored more thoroughly.

The northern end of the Horace aquifer apparently trends to the northwest, but it may curve eastward and connect to the West Fargo North aquifer. This possibility needs to be explored.

The West Fargo South aquifer is trending southward at the Cass county border and the Horace aquifer is trending southeastward (pl. 3). These trends indicate a possible junction in Richland County. This probability also needs to be explored.

## SUMMARY

The West Fargo area is underlain by glacial-drift deposits that range in thickness from 104 to 425 feet and have a mean thickness of about 216 feet. The upper 51 to 101 feet of the drift generally is composed of lake deposits of clay and silt with some sand lenses. The remainder of the glacial drift is composed of till and associated glaciofluvial deposits ranging from 53 to 349 feet with a mean thickness of about 143 feet. The glaciofluvial deposits range in thickness from 5 to 227 feet, have a mean thickness of




EXPLANATION

- • PLOT OF ONE SAMPLE
- ▪ PLOT OF MORE THAN ONE SAMPLE

**Figure 8.—Classification of selected ground-water samples for irrigation purposes.**

about 43 feet, and form the aquifers in the area. The till and glaciofluvial deposits overlie Cretaceous shale or, where the shale is missing, weathered crystalline rocks. The shale overlies the Cretaceous Dakota Sandstone in the northwestern part of the area and Precambrian crystalline rocks elsewhere.

The West Fargo aquifer system is composed of the West Fargo North aquifer, the West Fargo South aquifer, and the Horace aquifer. The system extends from the vicinity of Argusville, Cass County, to at least as far south as Richland County. The West Fargo North aquifer underlies about 28 $mi^2$ and extends from the vicinity of Argusville to somewhat more than 1 mile south of U.S. Highway 10. It is about 2 miles wide near Harwood and as much as 3.5 miles wide near West Fargo. Mean thickness of the aquifer is about 48 feet. A small buried-valley aquifer about 2 miles north of U.S. Highway 10 and east of West Fargo may hydraulically connect the West Fargo North and the Fargo aquifers.

The West Fargo South aquifer underlies an area of about 15 $mi^2$ and extends from south of U.S. Highway 10 to the Richland county line. The aquifer generally is located from 1 to 2 miles west of Interstate Highway 29 in the northern part and trends southeastward past the highway in the south. It generally is more than 0.5-mile wide but less than 1.5 miles wide. The thickness ranges from less than 5 feet to about 227 feet. Mean thickness is about 75 feet.

The Horace aquifer underlies an area of about 15 $mi^2$ and extends from about 1 mile west of West Fargo to the Richland county line. The aquifer varies in width from about 0.5 mile north of Horace to 1.5 miles near the Richland county line. The aquifer is as much as 217 feet thick, but has a mean thickness of about 115 feet.

The estimated pumpage from all the wells in the area near the city of West Fargo has averaged about 613 million gallons (1,880 acre-ft) annually since 1968, if not longer. Water levels, which were near or above land surface before 1896, had declined to as much as 121.7 feet below land surface in 1981. In the area of intense pumping, the aquifer system has converted from artesian to water-table conditions. At observation well 139-049-06ADB the rate of decline between 1937 and 1969, when the aquifer system at that location converted to water-table conditions, averaged 2.9 ft/yr. Elsewhere, in areas of little or no pumping, the rate of decline was slower; as little as 0.2 ft/yr in observation well 137-049-25CCC in the southern part of the West Fargo South aquifer in southern Cass County. After 1976, water levels declined in observation well 137-049-25CCC at a rate of about 2.1 ft/yr, principally because of pumping about 59.9 million gallons (184 acre-ft) annually from the Cass Rural Water Users, Inc. wells in 137-049-03B.

Annual recharge to the aquifer system was estimated to be about 600 to 650 million gallons (1,800 to 2,000 acre-ft). Annual discharge from the aquifer system was estimated to be about 683 million gallons (2,096 acre-ft). However, both estimates may be too small. Assuming a specific yield of 15 percent, there should be about 131,300 million gallons (404,000 acre-ft) of water that could be obtained from storage in the aquifer system.

Chemical analyses show that water in the West Fargo aquifer system is hard to very hard. Sodium is the dominant cation and generally either bicarbonate or chloride is the dominant anion. Dissolved-solids concentrations in samples collected from the aquifer system ranged from 332 to 2,960 mg/L, bicarbonate concentrations ranged from 198 to 784 mg/L, and chloride concentrations ranged from 25 to 975 mg/L. Dissolved-solids and chloride concentrations generally increased from east to west.

A comparison of samples taken from wells at irregular intervals since 1963 indicates that there generally is no difference in concentrations but there has been a slight decrease in dissolved-solids and sulfate concentrations in water in the West Fargo North aquifer near the Sheyenne River in West Fargo.

The present investigation has indicated a need for more data. The areas of needed investigations are: (1) Leakage through the lake deposits and till; (2) the hydraulic conductivity of the lake deposits and till; (3) the possibility of a hydraulic connection between the Fargo aquifer and the West Fargo North aquifer; (4) the possibility of large quantities of recharge from the west; (5) the configuration of the West Fargo South and Horace aquifers to the south; and (6) the configuration of the Horace aquifer to the north.

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