1972

Groundwater of the Spiritwood Lake area, Stutsman County, North Dakota

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GROUNDWATER OF THE SPIRITWOOD LAKE AREA, STUTSMAN COUNTY, NORTH DAKOTA

by

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Bachelor of Science, University of North Dakota 1965
Master of Science, University of North Dakota 1971

A Dissertation
Submitted to the Faculty
of the
University of North Dakota
in partial fulfillment of the requirements
for the degree of
Doctor of Philosophy

Grand Forks, North Dakota

August
1972

This dissertation submitted by Frank J. Schulte in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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Degree Doctor of Philosophy

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Date July 14, 1972

ACKNOWLEDGMENTS

I am grateful to many individuals and organizations for their assistance and support during this study. All the members of my committee, Lee Clayton, Walter L. Moore, Frank R. Karner, Stephen R. Moran, and Donald P. Naismith are gratefully acknowledged for their useful criticisms, suggestions, and encouragement throughout the course of this project.

I would like to acknowledge the following people for their helpful suggestions and the time they gave to discussing individual aspects of this study: John Cherry, geology department, University of Waterloo, Waterloo, Ontario; Joe S. Downey, U. S. Geological Survey, Grand Forks, North Dakota; Edward J. O'Reilly, chemistry department, University of North Dakota; Art Jacob, Ken Harris, William Bickley, Jr., and Gerald Gronewold, geology department, University of North Dakota.

I would like to thank Mrs. Lorraine Rose for typing the manuscript and Mrs. Lois Baldwin who edited the style of this report.

I would like to thank my wife, Cindy. Without her help and encouragement, this report would not have been possible.

This work was supported in part by the North Dakota Water Resources Research Institute, with funds provided by the U. S. Department of Interior, Office of Water Resources Research, as authorized under the Water Resources Research Act of 1964, public law 88-379. Support for test drilling was furnished by the North Dakota Water Resources Institute, the North Dakota

Geological Survey, and the North Dakota State Water Commission. Laboratory and office space was provided by the University of North Dakota geology department. The United States government granted fellowship assistance in the form of a National Defense Education Act Scholarship so that full time could be devoted to graduate study. Without the support of these institutions and people, this project would not have been possible.

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ABSTRACT

The Spiritwood Lake study area is in a generally undulating to rolling glacial plain 17 miles north and east of Jamestown, North Dakota. Spiritwood Lake is about 50 feet below the surface of the bedrock plain in a former melt-water channel. In the study area, glacial drift unconformably overlies the Pierre Shale, the youngest pre-Pleistocene sediment. The boundary between the two units is marked by a zone of shattered Pierre Shale. The top of this shattered zone forms a plain of moderate relief which probably was the preglacial surface of the study area.

Two large valleys can be distinguished in the bedrock surface of the study area. One valley is 70 feet below the general bedrock surface and was part of a glacial drainage. The second is a channel 200 feet below the bedrock surface and is part of the preglacial drainage.

The Pleistocene sediment of the study area was deposited by glacial, fluvial, lacustrine, and eolian processes. The Pleistocene sediment includes sediment of three facies: till, sand-gravel, and clay-silt.

The potential approach to groundwater was applied to the Spiritwood Lake study. Potential is an expression of the energy of a system. All forms of energy involved in groundwater-flow systems can be expressed in terms of potential. Gravitational, hydrostatic-pressure, velocity, thermal, chemical, and "other" potentials exist for every point in a groundwater-flow system. In the potential approach to groundwater each

potential is expressed in terms of head (energy is expressed by the unit weight of water). This allows the comparison of the various types of energy in a groundwater-flow system. Potentiometric surfaces of the various potentials can be contoured either singularly or collectively. Mathematical models can be applied to the various potentials.

Saturation indices and chemical ratios are useful in groundwater studies, especially where they are used in conjunction with the potential approach.

There are two types of groundwater-flow systems in the Spiritwood Lake area, local and intermediate. The local groundwater-flow systems are between adjacent topographic highs and lows. The local flow systems are mostly in till and do not affect the level of Spiritwood Lake appreciably. The intermediate groundwater-flow system occurs along the zone of shattered Pierre Shale between the undisturbed Pierre Shale and the overlying glacial drift. Water in the intermediate flow system moves from northeast to southwest. The level of Spiritwood Lake is controlled by discharge from the intermediate groundwater-flow system. The time required to transfer a change in hydrodynamic-potential gradient from the recharge to the discharge area of the intermediate groundwater-flow system is indicated by the time lag between the fluctuations in the water level of Spiritwood Lake and changes in precipitation.

CHAPTER I

INTRODUCTION

Purpose

This report is a summary of the groundwater geology of the Spiritwood Lake area in Stutsman County, North Dakota (Figures 1 and 2). Its purpose is twofold. The first purpose of this report is to evaluate the specific groundwater problems of the area. Spiritwood Lake is a fishing and boating lake, and several dozen summer cabins, each with a private dock, occur around the lake. The North Dakota State Game and Fish Department operates a fish hatchery and experiment station on the north side of the lake. In recent years, the size of the lake has increased, causing destruction of property and vegetation around the lake. One purpose of this study was to determine if the level of the lake can be stabilized and if the stabilization would harm the fish hatchery or lower the future recreational value of the lake.

Solving the lake-level problem involved three steps. The first step was an examination of the geology and groundwater of the area to determine the groundwater-flow systems and the permeability of the sediment. The second step was to determine the relationship between the lake, the surface drainage, and the groundwater. The third step included the recommendation of the most economic solution to the problem.

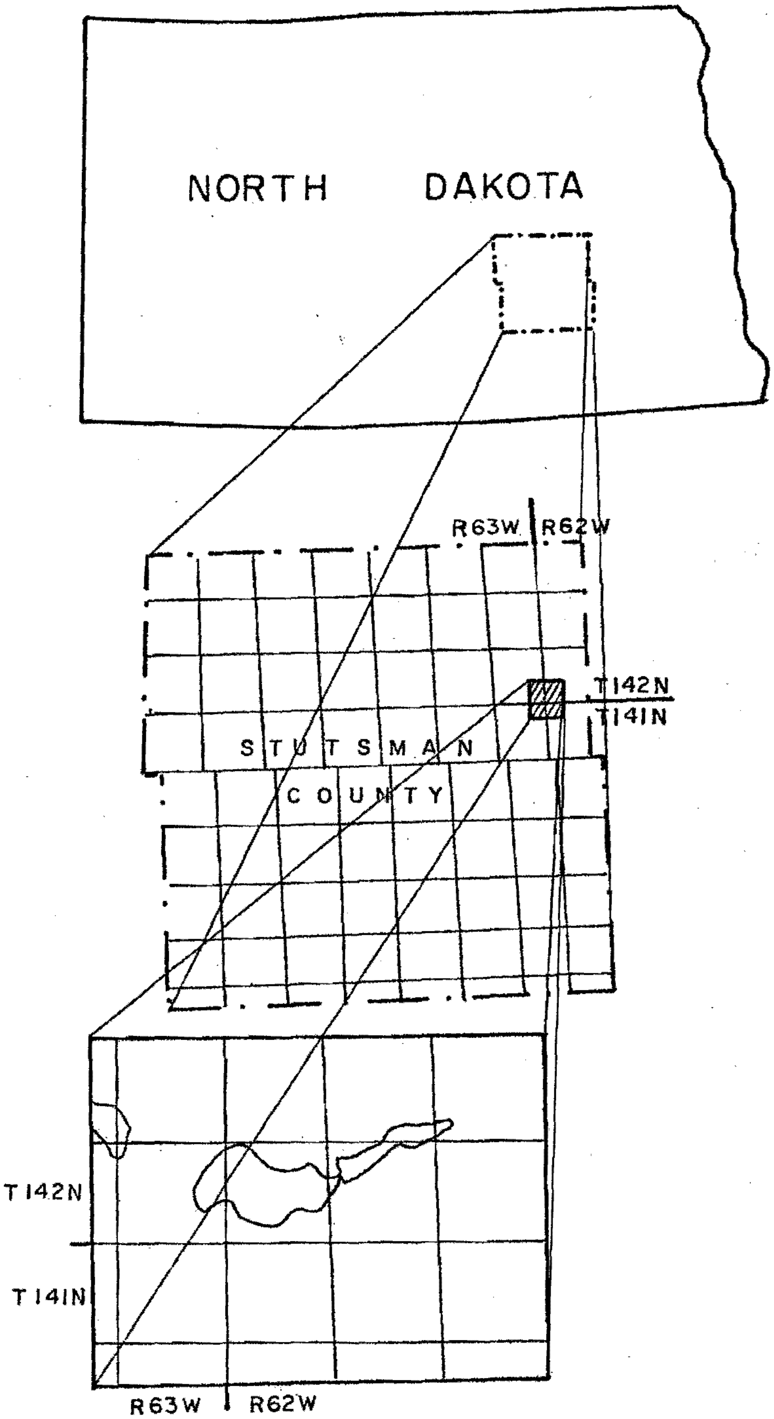

Fig. 1.--Map showing the location of the Spiritwood Lake study area.

Fig. 2.--Photograph of Spiritwood Lake and a small lake northeast of Spiritwood Lake. The photograph was taken looking east.

The second purpose of the report is to offer a solution to a more general problem. Because water is so important in North Dakota, it is not surprising that individuals and agencies have spent large amounts of time and money to obtain information about the groundwater of the state. Federal and state agencies have compiled groundwater inventories and reports for most of the cities and counties in the state. This information is incomplete, however. The inventories represent groundwater in a static state, while in fact groundwater is in a dynamic state. The second purpose of the study was to evaluate the groundwater of the area as a dynamic system and to develop approaches to dynamic groundwater studies that could be applied to other areas. Special attention was given to techniques that could use information already available.

Topography

The area is generally an undulating to rolling glacial plain with less than 150 feet of total surface relief and from 20 to 80 feet of relief per square mile (Figure 3). The drainage is largely nonintegrated; small sloughs are abundant (Figure 4). Spiritwood Lake is about 50 feet below the surface of the glacial plain in a former melt-water channel. The lake has a maximum depth of 14.5 m and an average depth of 8.0 m (Figure 5). The volume of the lake is 2.27×10^7 m^3, 94 percent of which is less than 10 m from the surface. The surface area of the lake is 2.83×10^6 m^2 (Wolf, 1967, p. 2).

Climate

The climate of the Spiritwood Lake area is subhumid and continental, with warm summers and cold winters. Summer temperatures greater than 90° F are common and winter cold waves, with temperatures of -20° F, may

Fig. 4.--Photograph looking across the east end of Spiritwood Lake and the Kensal Moraine. Note the poorly integrated drainage and many small sloughs.

Fig. 3.--Photograph showing the rolling topography of the study area north and west of Spiritwood Lake.

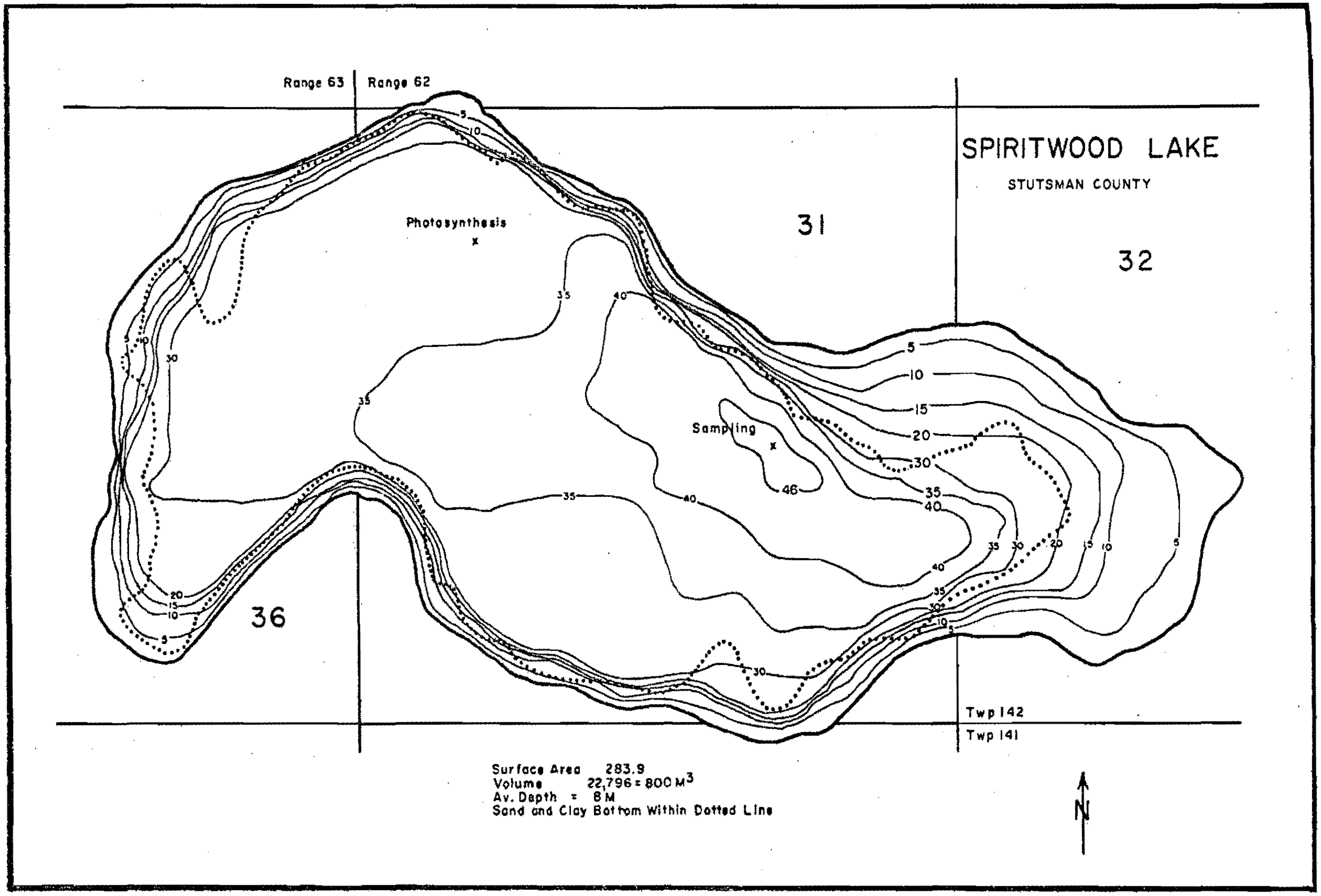

Fig. 5.--Depth contour map of Spiritwood Lake modified from Comita and Wolf (1967, p. 78).

last for extended periods. At the Jamestown Airport, the closest permanent weather station, the mean monthly temperatures for January and July average 7.3° F and 69.0° F over a 20 year period (U.S. Department of Commerce, 1955, p. 34). The Jamestown area has an average annual temperature range of 61.7° F. The lowest temperature recorded at Jamestown is -42° F; the highest is 118° F. The maximum temperature range is 160° F (U.S. Department of Commerce, 1955, p. 37).

At the Jamestown Airport, the average annual precipitation over a 20 year period is 18.7 inches (U.S. Department of Commerce, 1955, p. 15). Between 55 and 60 percent of this precipitation fell during the months of May, June, July, and August. Large deviations from the average annual precipitation occur from year to year and between areas in the same year. Only 6.91 inches of precipitation fell in 1935, while in 1950, 25.84 inches fell at the Jamestown Airport. In the same year, 1950, only 18.34 inches of precipitation fell at the Jamestown hospital, less than 3 miles south of the airport (U.S. Department of Commerce, 1955, p. 15).

Although summer is the period of highest precipitation, most of the surface runoff enters Spiritwood Lake in the spring. The summers are comparatively short, but are filled with numerous long, cloudless days. The summer precipitation not absorbed by the soil or added to the groundwater is lost in evapotranspiration. Little is left as surface runoff. The mean annual snowfall recorded at the Jamestown Airport is 37.5 inches (U.S. Department of Commerce, 1955, p. 33). In the winter, all the soil in the area and the lake itself are frozen, and little of this moisture is added to the soil. With the spring melt a large part of the winter's precipitation becomes surface runoff.

Soil

Haploboralls are present over most of the study area. Some calciaquills however, occur in the poorly drained sections of the area. Figure 6 is a soil map of the study area. The first name on the soil map is the predominant soil in the unit. The second name is another soil type common in the unit but in areas too small to be mapped separately. Table 1 lists the names and distinguishing properties of the soil types found in the area and mapped on Figure 6.

Vegetation

The predominant vegetation of the study area is prairie grassland. Trees occur along lakes and streams, and marsh vegetation occurs in the poorly drained areas. Most of the land is now used for pasture, small grains, and hay. In places, shelter belts have been planted to protect the area from wind erosion.

Spiritwood Lake itself is surrounded by trees and shrubs (Figure 7). Green ash, box elder, and chokecherry predominate along the hill sides. Cottonwood, peach-leaved willows, and aspen occur at lower levels, near the lake shore. Dogwood, black current, poison ivy, and juneberry occur both on the hill sides and at lower levels. The prairie south of the lake is almost a pure stand of Kentucky bluegrass (Wolf, 1967, p. 2).

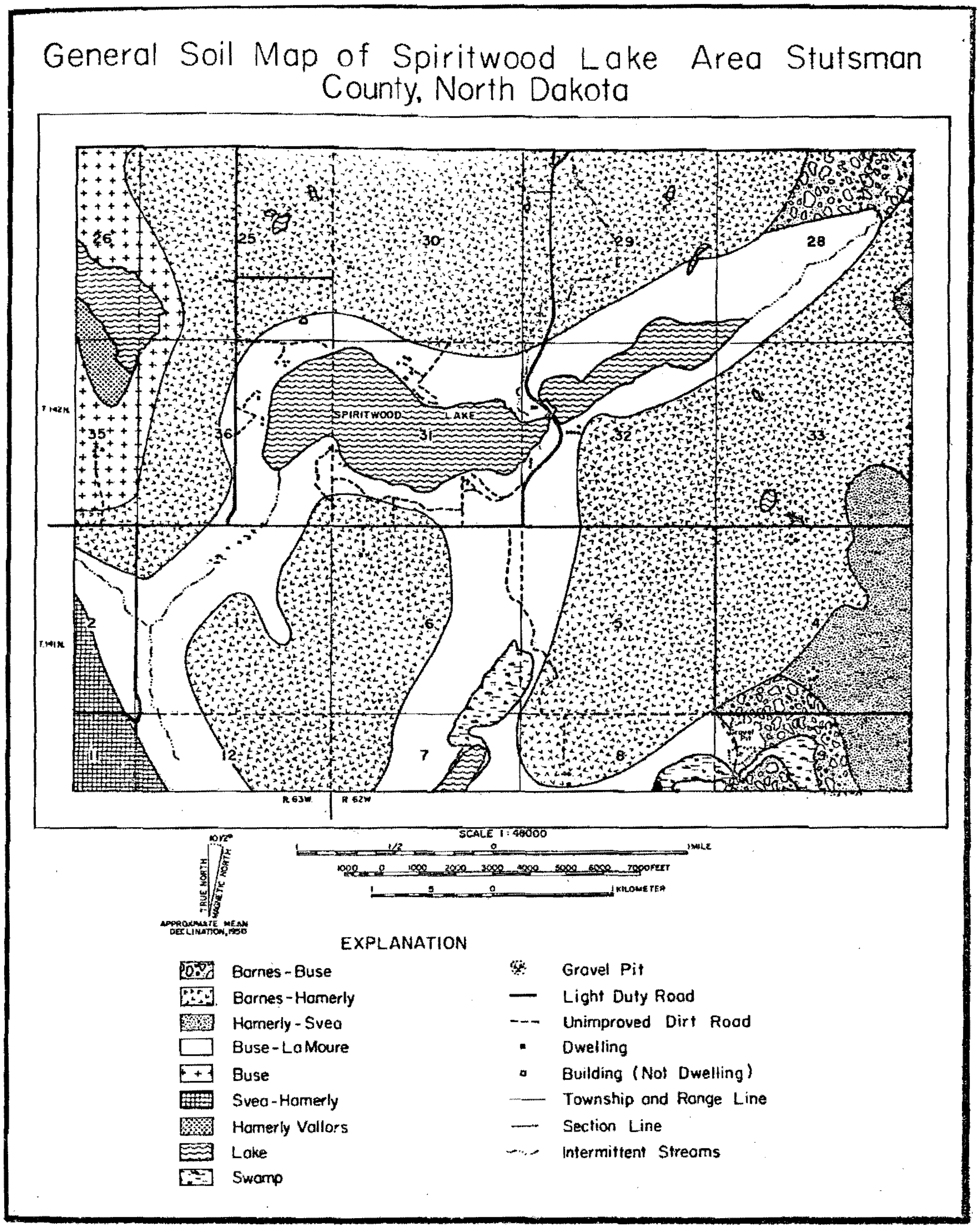

Fig. 6.--General soil map of the Spiritwood Lake study area, modified from the 1963 general soil map of Stutsman County, compiled by the Agricultural Experiment Station, North Dakota State University.

TABLE 1

NAMES AND DISTINGUISHING PROPERTIES OF THE SOIL TYPES FOUND IN THE SPIRITWOOD LAKE STUDY AREA

Property	Barnes	Buse	Hamerly	Lamoure	Svea	Vallers
Parent Material	till	till	till	alluvium	till	till
Texture	clay loam	loam	clay loam	loam	clay loam	clay loam
Slope	3-8%	10-20%	1-5%	0-2%	0-4%	0-2%
Drainage	well drained	excessively drained	poorly drained	poorly drained	moderately well drained	poorly drained
Group Name	Chernozen	Regosol	Solonchak	Humic Gley or Alluvial	Chernozen	Solonchak
7th Approximation Group Name	Haploborall	Haploborall	Calciaquall	Haplaquall	Haploborall	Calciaquall
Source	Omodt and others, 1968	Omodt and others, 1968	Omodt and others, 1968	Patterson and others, 1968	Omodt and others, 1968	Omodt and others, 1968

Fig. 7.--Photograph of the vegetation along the southeast shore of Spiritwood Lake. In the background is Sevenmile Coulee and the Kensal Moraine.

CHAPTER II

GEOLOGY

Pre-Pleistocene Stratigraphy

Introduction

Pleistocene sediment covers the surface of most of the Spiritwood Lake study area. Subsurface information about the Pleistocene deposits and the underlying Pierre Shale was obtained largely from shallow test holes. Some information about the pre-Pleistocene sediment of the area is available from the logs of deep wells and from published geologic reports. Most of the information in the following discussion is from Anderson (1971), Winters (1963), Hansen (1956), Towse (1952), Kline (1942), and Laird (1941) and from North Dakota geological Survey oil well circulars for wells in Stutsman County.

A diagramatic cross section of the stratigraphic units beneath Stutsman County is shown in Figure 8. The study area is located near well D. In Stutsman County, most pre-Pleistocene units dip and thicken to the west-northwest into the Williston Basin.

Precambrian Stratigraphy

The top of the Precambrian is about 2,900 feet below the surface of the study area, at an elevation of 1,428 feet below sea level. Little is known about the composition of the Precambrian rock beneath the study area. Test holes in Stutsman County list the composition of the

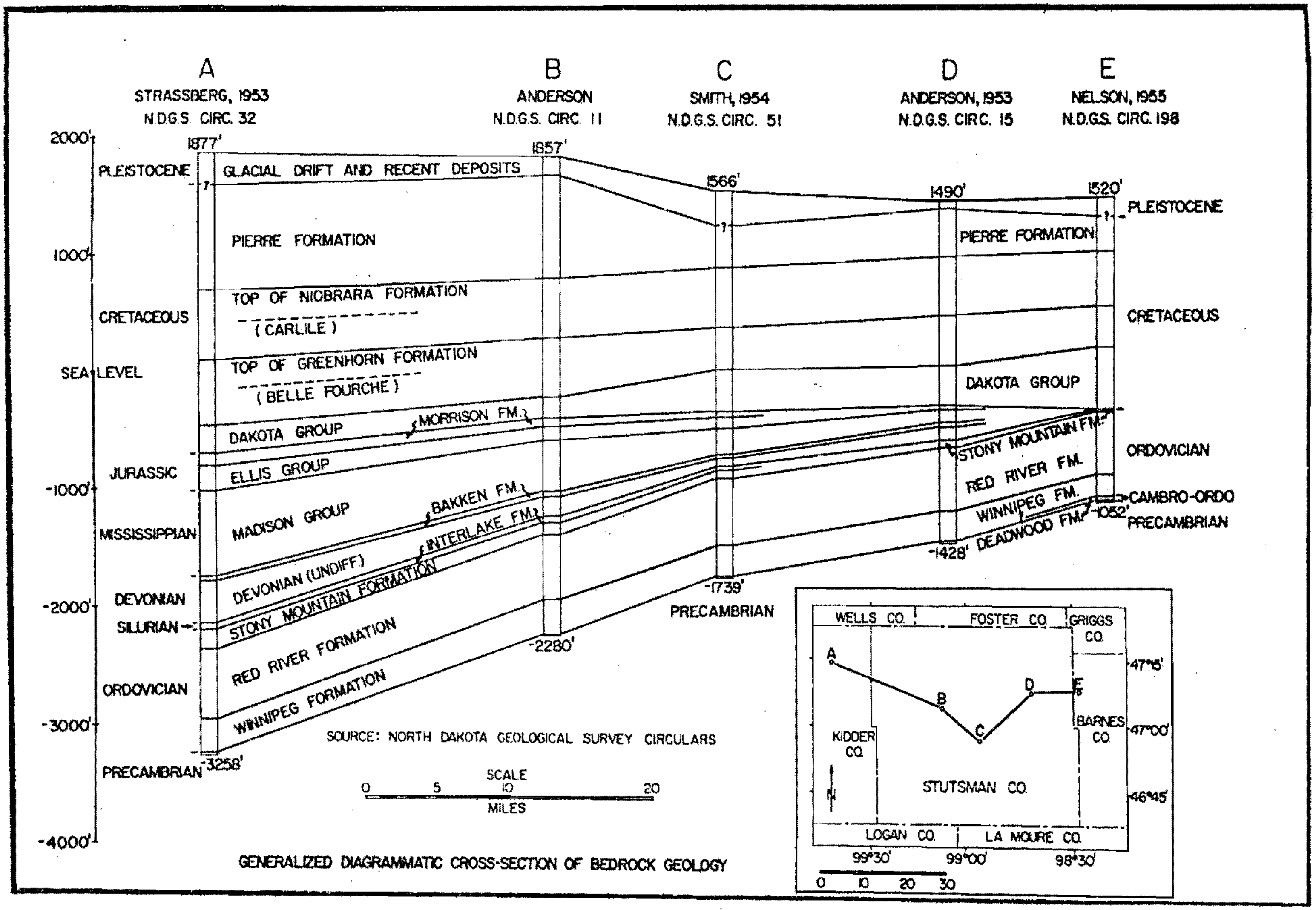

Fig. 8.--Generalized diagramatic cross section of the bedrock geology of Stutsman County, North Dakota (from Winters, 1963, p. 10).

as granite. It is assumed that rocks of a similar composition underlie the study area.

Paleozoic Stratigraphy

About 1,250 feet of Paleozoic rock underlies the study area. The Winnipeg Formation is believed to lie directly over Precambrian rock. The Winnipeg Formation is Ordovician in age and is generally a gray to green shale with interbedded quartz sandstone. The Deadwood Formation, of Cambrian and Ordovician age, may lie between the Winnipeg Formation and the Precambrian rocks. Nelson (1955) recognized this formation in western Barnes County, but it is not believed to extend into the study area. The Deadwood Formation is generally a pale reddish, brown, medium-grained, glauconitic sandstone with interbedded green shale.

Above the Winnipeg Formation are the Red River and Stony Mountain Formations, both of Ordovician age. The Red River Formation consists of yellow to brownish black limestone and dolomite. The Stony Mountain Formation is a light-colored, shaly limestone or dolomite. Lying on the top of the Stony Mountain are light-colored undifferentiated carbonates of Devonian age. Above the carbonates is the Bakken Formation, a black carbonaceous shale of Mississippian age. At the top of the Paleozoic sequence is the Madison Group. This group consists mostly of white to gray limestone and dolomite of Mississippian age.

Mesozoic Stratigraphy

The Mesozoic sediment is about 1,100 feet thick beneath the study area. The oldest Mesozoic rocks belong to the Ellis Group. This group is Jurassic in age and overlies the Madison Group unconformably. Ellis Group consists of two formations. The Piper, the lowest formation, is a dense limestone with some shale and anhydrite. The Swift-Rierdon, the upper formation, consists mostly of varicolored shale and sandstone. The Dakota Group, of Cretaceous age, is composed of varied sand and shale. In the study area, the Dakota Group is divided into four units. In ascending order, they are the Lakota, Skull Creek, Muddy, and Mowry Formations. The Dakota Group is an important aquifer in parts of North Dakota (Willard, 1909).

The Colorado Group (not listed in Figure 8) overlies the Dakota Group. The rocks of the Colorado Group are shale and limy calcareous shale with a few interbedded bentonite beds. In the study area, the group consists of four formations: the Belle Fouche, Greenhorn, Carlile, and the Niobrara Formations.

From 350 to 400 feet of Pierre Shale lies above the Colorado Group in the area. The Pierre Shale is a member of the Montana Group and is upper Cretaceous in age. It is the youngest pre-Pleistocene rock unit occurring in the area. The Pierre Shale is generally a siliceous or calcareous, olive-gray to black shale with a few thin beds of bentonite in some parts of the formation. A complete description of the Pierre Shale and its members in North Dakota is given in Gill and Cobban (1965).

Pre-Pleistocene Surficial Geology

The Pierre Shale is the only pre-Pleistocene rock unit directly underlying the glacial drift of the study area. The Pierre Shale outcrops in two locations in the area (Figure 9). One location is along a road cut on the north side of the east-west road just south of Spiritwood Lake in the SW¼ SW¼ SE¼ sec. 36, T. 142 N., R. 63 W. The second

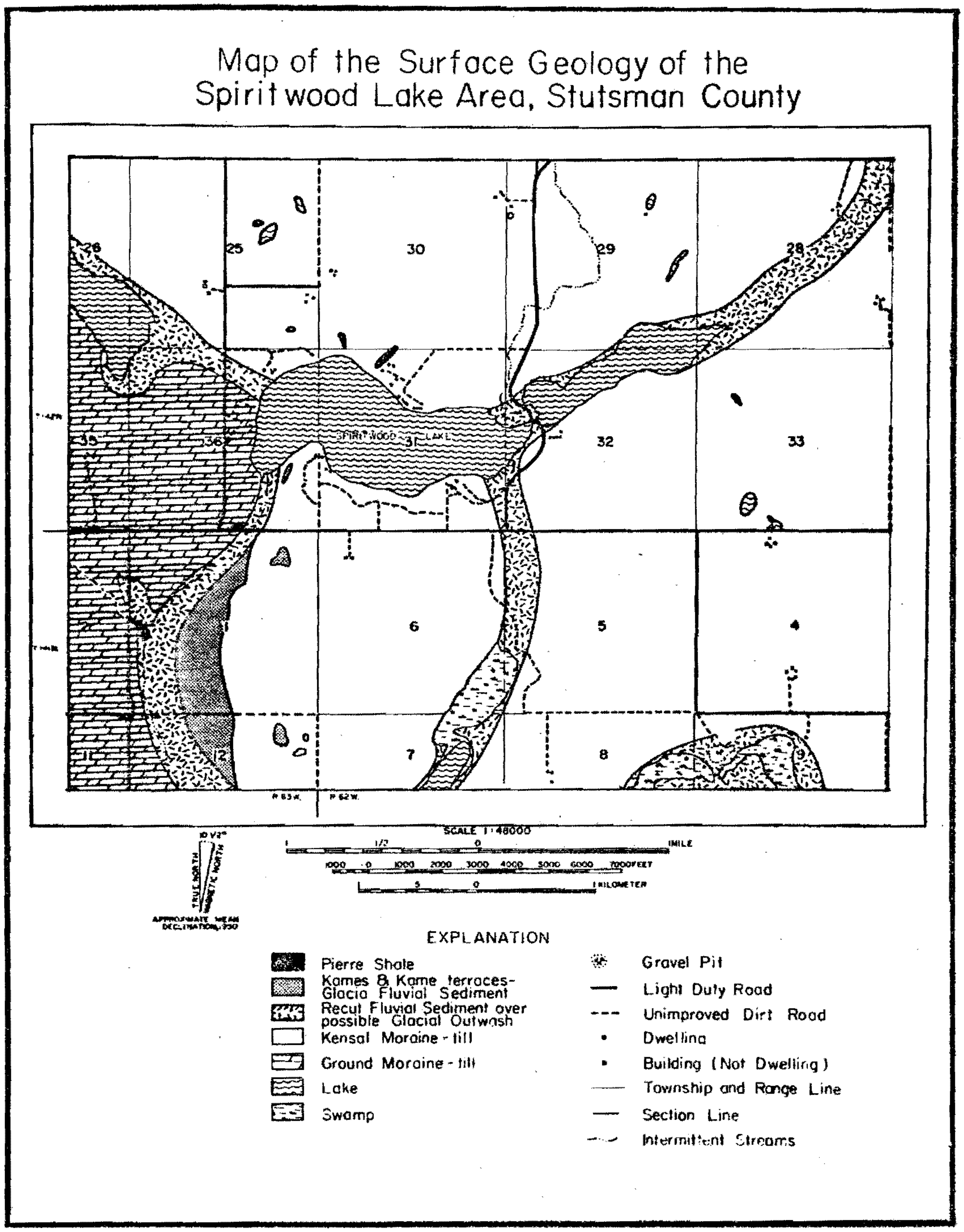

Fig. 9.--Map of the surficial geology of the Spiritwood Lake study area modified from the map of surficial geology of Stutsman County, North Dakota (Winters, 1963, Plate I).

location is on the north side of Spiritwood Lake in the NW¼ NE¼ NW¼ sec. 31, T. 142 N., R. 62 W. Information was obtained from other Pierre outcrops of the surrounding area, from test holes drilled for this project (the lithologic logs are given in Appendix B), and from the logs of Huxley and Petri (1963) and Kresl (1956).

At the two surface exposures in the study area, the Pierre Shale is a dense, massive, noncalcareous shale. When fresh its color is dark gray to black; when weathered it breaks up into thin plates that are light gray when dry and dark gray when wet. In both exposures the shale is highly fractured and the larger fractures are stained with iron oxide. A few iron-oxide concretions and fish scales were found in the exposure north of Spiritwood Lake.

There are no bentonite beds (yellow clay) in the Pierre exposures of the study area. However, bentonite does occur in the Pierre outcrops just west of the area. According to Winters (1963, p. 15),

> Kresl (1956) recognized five bentonite beds. They range from a fraction of an inch to 5 inches in thickness and are found within the shale along the west wall of the James River valley in the SW¼ sec. 35, T. 142 N., R. 64 W. In addition, one bentonite bed about 2 inches thick, is present along the west wall of the James River valley in the SE¼ sec. 23, T. 140 N., R. 64 W., just north of Jamestown. The bentonite is yellow to light tan; its color is in sharp contrast to that of the shale.

Jointing in the exposures of the Pierre in the area was not consistent enough to establish jointing patterns. However, Winters determined three fracture systems in the Pierre along the east side of the Jamestown reservoir 200 feet north of the dam. "The dominant joint system strikes N 40°E and dips 66°S. The second and third joint system of similar magnitude strikes N 90°E and N 40°W and dips 71°N and 72°S, respectively" (Winters, 1963, p. 13).

The contact between Pierre Shale and the overlying till is exposed at only one point in the study area, the Pierre outcrop north of Spiritwood Lake. Here, a 6-inch bed of gravel lies just above the Pierre. The shale, directly underlying the gravel, is badly fractured and shows signs of weathering. This is believed to be characteristic of the Pierre-till contact throughout the area. In his study of Stutsman County, Winters (1963, p. 16) found that a transition zone of weathered shale marks the contact in most exposures where drift overlies Pierre Shale. This transition zone may be several feet thick. According to Winters (1963, p. 14),

> in the SW¼ sec. 25, T. 143 N., R. 64 W., the bedding in the upper part of the 22-foot exposure of weathered shale exhibits severe contortions. Shale in the lower part of the same outcrop is not deformed. The contortions most likely result from forces exerted by the glacier as ice moved over the area.

In subsurface, the Pierre Shale was examined from an elevation of 1,200 feet up to the base of the overlying glacial drift. Lithologic log WRI 71-15 (Appendix B) is typical of the Pierre in the subsurface of the study area.

In the subsurface, the Pierre Shale is predominantly dark gray to black, noncalcareous, and similar to the shale exposed at the surface. Fine laminations can be distinguished in some samples. A zone of bentonite beds occurs at an elevation of about 1,270 feet throughout the study area. This zone dips at low angles to the west. The bentonite is yellow to light gray and occurs in beds from 1 to 2 inches thick. At an elevation of 1,300 feet the Pierre is characterized by a 10-foot zone of highly fractured shale with 2- to 3-foot lenses of fine to very fine, well sorted, quartz sand. This zone will be referred to in the remainder of this report as the Pierre shattered zone.

The Pierre Shale, underlying the Spiritwood Lake area is thought to be part of the Odanah Member (Tovell, 1948; Gill and Cobban, 1965). This stratigraphic position is tentative and is based on lithology and on the location of the study area with respect to a described section of Pierre along the Sheyenne River near Valley City (Gill and Cobban, 1965, p. 17).

According to Winters (1963, p. 14), "the Pierre in Stutsman County dips to the west-northwest 5 to 10 feet per mile in conformance with regional structure." The Pierre in the study area probably has a similar dip.

Bedrock Topography

Figure 10 is a topographic map of the bedrock surface in the Spiritwood Lake study area. This map was compiled from the lithologic logs in Appendix B and from the test-hole and well data compiled by Huxel and Petri (1963). Elevation control for the area varies from good to very poor. Information is especially sketchy along the west side of the area.

The bedrock surface of the area approximates a plain with moderate topographic relief. The top of the plain lies from 1,400 to 1,500 feet above sea leve; maximum relief is about 300 feet. The contours of the bedrock surface indicate two long linear depressions or valleys in the top of the bedrock of the area. A shallow valley runs northwest-southeast across the center of the area. The bottom of this valley is as deep as 70 feet below the plain surface (about 1,390 feet above sea level). A deeper bedrock valley runs northeast-southwest across the east side of the area. This valley is as deep as 200 feet below the plain surface (about 1,250 feet above sea level). The two valleys intersect just southeast of Spiritwood Lake.

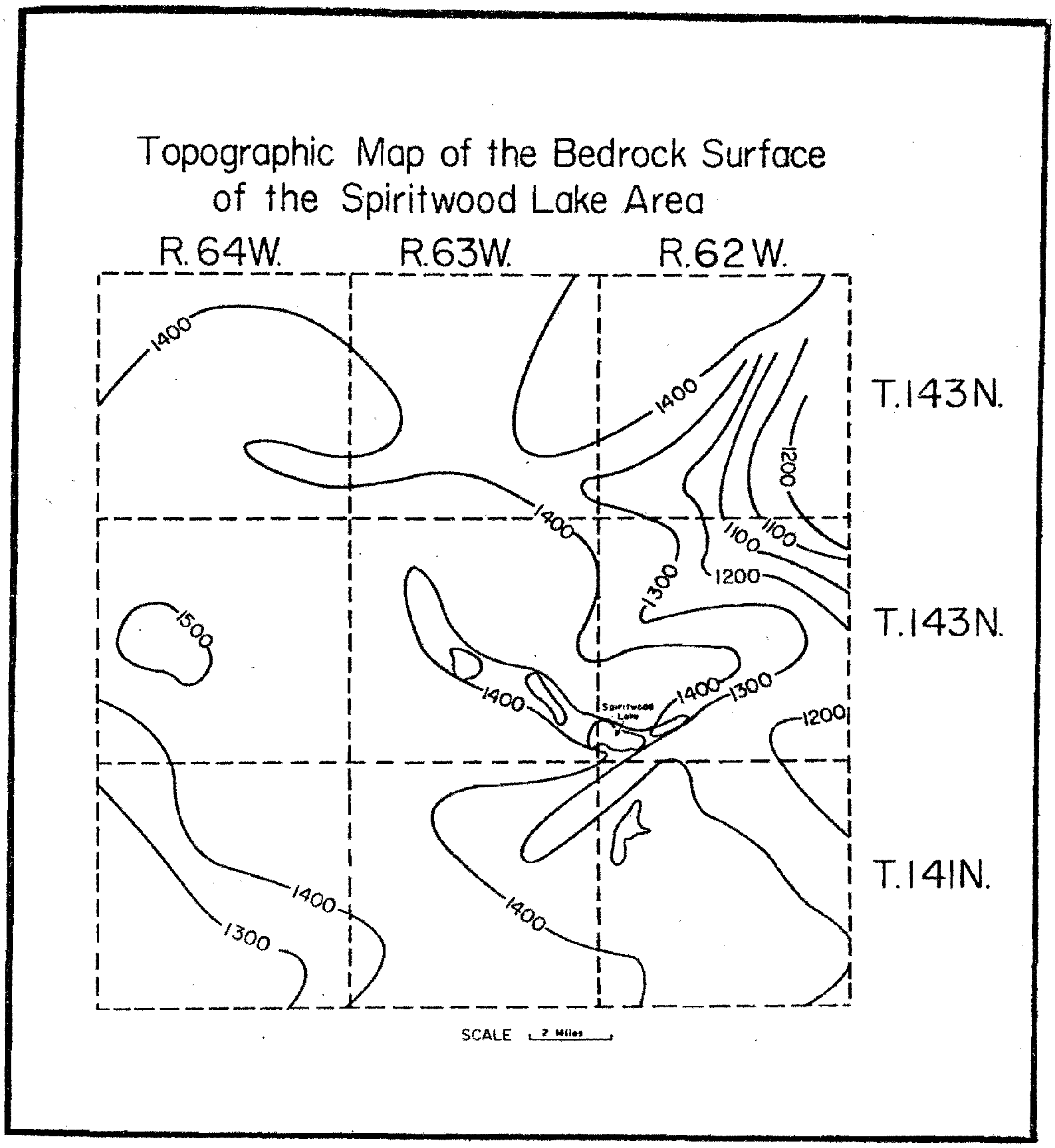

Fig. 10.--Topographic map of the bedrock surface in the Spiritwood Lake area.

The topographic map of the bedrock surface in the study area fits well with the bedrock surface topography of the rest of Stutsman County. According to Winters (1963, p. 15),

> the bedrock surface of the county consists of an extensive plain which is interrupted by separated bedrock highs along the west and northwest borders of the county and which is dissected by deep valleys cut into its surface. The plain has an altitude of about 1400 feet to 1500 feet above sea level.

Pleistocene Stratigraphy

General

Surface exposures and test-hole information (Appendix B) is the source of most of the information in the following discussion of the Pleistocene sediment in the area. Supplementary information was obtained from Winters (1963), Huxel and Petri (1963), and Bluemle (1971b).

The thickness of the Pleistocene sediment in the study area ranges from 0 to 200 feet. It is thinnest in the southeast part of the study area and is thickest over the deep bedrock valley along the east side of the area (Figure 10). Pleistocene sediment can be divided into three distinct facies: till, undifferentiated sand and gravel, and undifferentiated silt and clay.

Till Facies

Till in the Spiritwood area is typically a dense, compact, poorly sorted sediment with particles varying in size from clay to large boulders. An average particle-size distribution for the till is 35 percent clay, 30 percent silt, 30 percent sand, and 5 percent gravel. The size distribution of the till varies little over long distances. When fresh, the till is olive gray to grayish black. In surface exposures and in the subsurface above the water table, the till oxidizes to a yellowish brown. Normally the till is calcareous. Most of the particles in the till are shale, limestone, dolomite, igneous, and metamorphic rock fragments.

Scattered through the till are numerous gravel, sand, silt, and clay lenses. These lenses range from poorly sorted to well sorted and are composed of particles of varied composition. Commonly the lenses are less than 3 feet thick. One test hole intersected 3 feet of clean sand, and another hole 10 feet away encountered only till.

Stratigraphic evidence indicates that glaciers advanced across North Dakota several times. Several glaciers probably passed over the Spiritwood Lake area. Undoubtedly more than one glacial advance is represented in the till of the area. However, separate till lithologies could not be distinguished.

Sand-Gravel Facies

Two types of sand and gravel deposits occur in the area. One is the previously discussed lenses of sand and gravel. The second type of deposit occurs in long, narrow bodies from 3 to 30 feet thick, commonly in surface valleys. The sand and gravel of both types ranges from poorly sorted to well sorted. Individual grains are generally subangular to subrounded. Pebbles of carbonate rock and coarse crystalline igneous rock make up most of the gravel-sized grains, while quartz and carbonate fragments make up most of the sand-sized grains.

Almost all of the long, narrow sand and gravel deposits are fluvial in origin. Individual sand and gravel deposits may be fluvial deposits from preglacial, proglacial, interglacial, or postglacial river systems. Most of the deposits are believed to be proglacial fluvial deposits. No preglacial gravel was found, but some may exist in the deep bedrock valley underlying the east side of the study area.

The sand and gravel lenses in the till are thought to be proglacial and interglacial deposits incorporated into the till during glaciation.

Clay-Silt Facies

The clay-silt facies occurs in the surface valleys and low sections of the area. It was also observed between tills in a exposure on the south side of Spiritwood Lake (sec. 31, T. 142 N., R. 62 W.). The clay-silt facies was not distinguished below till in any of the test holes, but it may be present. It was hard to distinguish from till with low sand and gravel content in the samples recovered in drilling. The clay-silt facies of the area is predominantly silt or clay with some sand and an occasional pebble. It is black or gray, and it is usually calcareous. In some areas the facies has fine laminations, but in most locations the sediment is structureless. The clay and silt is badly contorted in the exposure south of Spiritwood Lake.

Much of the laminated sediment is lacustrine and was deposited before the last glacial advance (Spiritwood Lake exposure) or after glaciation in the topographic depressions left by the ice. Much of the nonlaminated sediment is fluvial overbank sediment deposited along proglacial and postglacial drainage channels.

Pleistocene Surface Geology

Figure 9 is a map of the surface geology of the study area. The terminology is that used by Winters (1963, Plate I) and generally represents genetic interpretation. A discussion of the glacial features of Stutsman County can be found in Winters (1963).

Kensal Moraine

The Kensal Moraine was formed by a southwesterly advancing ice sheet (Lemke and Colten, 1958, p. 58). The Kensal Moraine occurs in Stutsman County from north of Kensal, south-southeast across the county, to east of the town of Spiritwood. Over half the surface of the study area is comprised of the moraine.

The Kensal Moraine is from 3 to 5 miles wide. The distal side is generally well defined whereas the proximal side is more subdued and grades laterally into washboard moraine and ground moraine. The crest is not well defined and consists of linear belts of hills separated by many closed depressions (Figure 11). The altitude of the moraine is about 1,500 feet, and the maximum relief is approximately 200 feet. Local relief averages about 35 feet per square mile (Winters, 1963, p. 62).

Ground Moraine

Ground moraine consists of flat or relatively flat lying till and does not have transverse lineations. The ground moraine in the area is part of a larger area of ground moraine which stretches west to the Missouri Escarpment and covers much of central Stutsman County (Winters, 1963).

The ground moraine in the study area has a low undulating surface. The highest point is 1,516 feet and average relief is 20 to 30 feet per square mile. Drainage is better developed than in the Kensal Moraine but poor when compared with other areas.

Fig. 12.--Aerial photograph of the area around Spiritwood Lake. The photograph shows the surface expression of the Pleistocene melt-water drainage channels.

Most of the ground moraine is composed largely of till. Some lenses of sand and gravel occur in the till, and thin zones of clay and silt are found in closed depressions and along drainage channels.

Valley Outwash

A complex system of melt-water channels has been cut across the central third of Stutsman County. These channels were formed by melt water flowing southeast along the front of an advancing ice sheet. They are distinguished by their surface expression and thick linear deposits of outwash gravel. Included in the complex are Sevenmile Coulee, the James River, their Pleistocene tributaries, and several melt-water channels lying between the two drainage systems (Winters, 1963, p. 75).

Three melt-water channels occur in the study area (Figure 12). The largest channel runs along the margin of the Kensal Moraine. Long Lake, Spiritwood Lake, and Sevenmile Lake all lie in this channel.

A second channel is shorter than the first and forms a cutoff of the first channel between the west end of Spiritwood Lake and the middle of Sevenmile Lake. A third melt-water channel lies west of the second and runs from the south end of Long Lake to Sevenmile Coulee, just west and south of Sevenmile Lake.

The melt-water channel along the edge of the Kensal Moraine is the deepest and probably the oldest of the three channels. The bottom of this channel is cut at least 60 feet into the underlying bedrock. The bottom of the melt-water channel appears as a shallow bedrock valley in Figure 10. The other two melt-water channels are not as deep. They do however, cut into the bedrock.

Fig. 11.--Photograph ~~west~~ east across the Kensal Moraine. Spiritwood Lake appears in the lower left corner.

The till facies, sand-gravel facies, and silt-clay facies are all found in the melt-water channels of the study area. Several feet of sand and gravel lies along the bottom of the largest melt-water channel and has been reworked along the beach of Spiritwood Lake. The outwash gravel near the surface, is mapped on Figure 9.

Till occurs in the melt-water channel along the Kensal Moraine and in parts of the other two channels in the area. Till dams block the largest melt-water channel in several places, and both Long Lake and Spiritwood Lake are formed behind till dams. In places the till in the melt-water channels is 50 to 70 feet thick.

The silt-clay facies is found in the melt-water channels both at the surface and in the subsurface. At the surface the silt-clay facies occur as postglacial overbank and lacustrine sediment. In the subsurface silt and clay occur between beds of till in at least one location.

Pleistocene History

Preglacial Setting

The topography of the bedrock surface indicates the Spiritwood Lake area before glaciation was a plain with moderate topographic relief. Topographic highs of 300 to 400 feet rose above the plain, and wide rounded valleys of an integrated drainage system were cut below the plain to depths of more than 300 feet, but most of the area was relatively flat. The fractured zone now occurring at the top of the Pierre Shale is believed to represent the remains of a surface with a deeply weathered zone. Paleosols were not distinguished in the test holes of the study area. However, Bluemle (1972) stated that paleosols have been found at the surface of the Pierre in the surrounding areas.

The concentration of test holes in the Spiritwood area makes the area one of the best locations in the state for distinguishing bedrock valleys cut by preglacial drainage from valleys cut by glacial drainage. The deep bedrock valley on the eastern side of the study area is believed to be preglacial (Figure 13). Water in this valley is thought to have flowed northeast. It was probably a tributary of the preglacial valley containing the Spiritwood Aquifer (Huxel, 1961). The intersection of the two valleys points north and indicates that the water from the two valleys flowed in that direction.

North of the intersection of the two valleys, the water of the combined drainage system is believed to have flowed northwest to the present position of the upper part of the Sheyenne valley. From there it turned northwest through what is now Devils Lake and then north into Canada, as shown in Figure 13.

The location of this preglacial drainage system is based on the topographic maps of the bedrock surface by Bluemle (1971a), Huxel (1961) and the topographic map shown in Figure 10. The interpretation arrived at seems to agree with the findings elsewhere in North Dakota. Colton, Lemke, and Lindvall (1963) compiled the works of Alden (1932), Meneley, Christianson, and Kupsch (1957), Lemke (1960), and Howard (1960) into a map that shows what is known about the preglacial drainage of North Dakota. The location of the assumed system would fit well in this preglacial drainage map. The map shows all the preglacial drainage of the state flowing north. In light of this, the north flowing drainage from

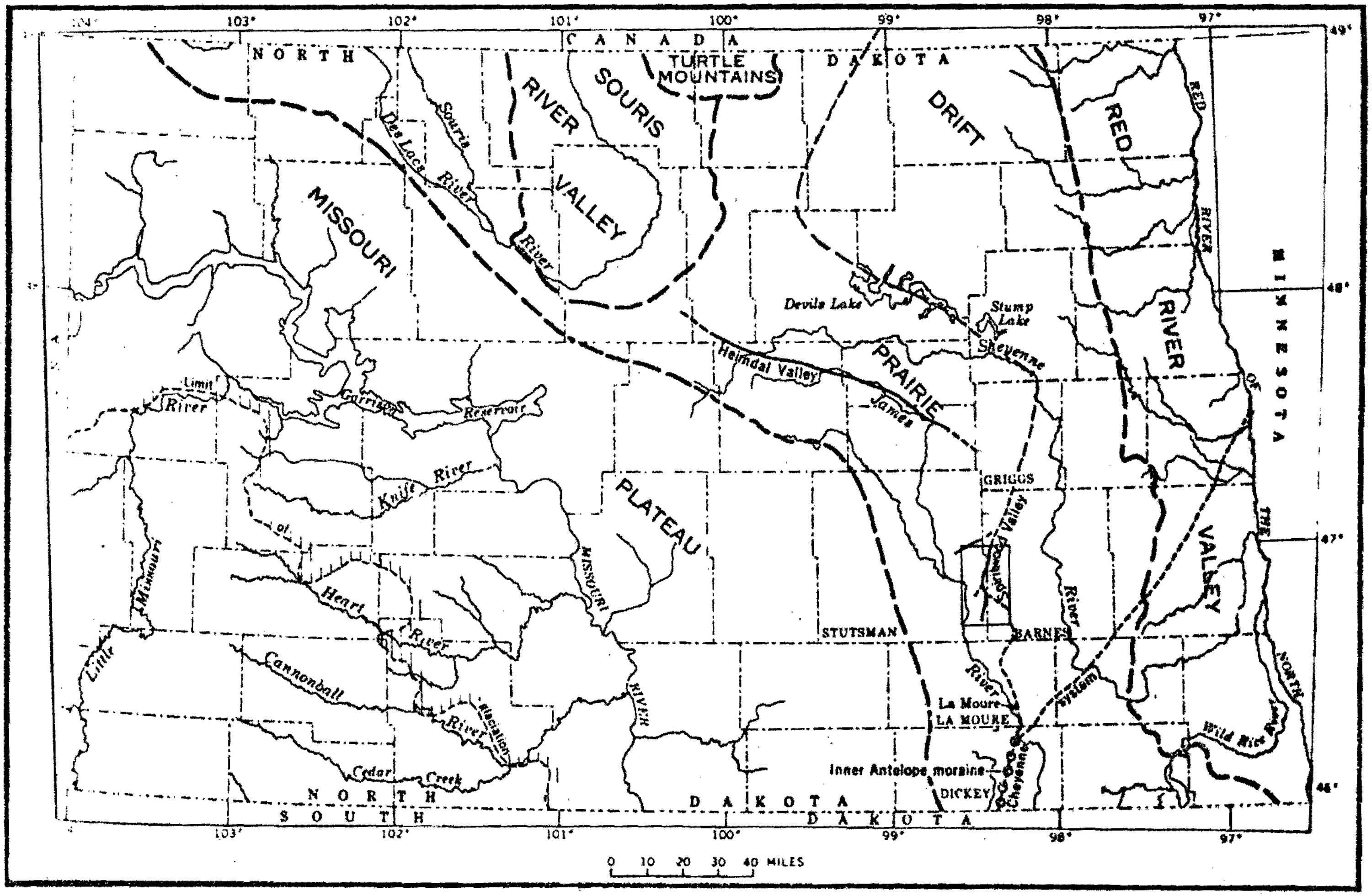

Fig. 13.--Map showing the relationship of the Spiritwood Lake preglacial valley to other buried valleys in the region (modified from Simpson, 1929 and Huxel, 1961).

the study area seems reasonable. This drainage may well be a tributary of the preglacial Cannonball River of south-central North Dakota.

Glacial History

Numerous glaciers advanced across North Dakota during the Pleistocene and many of them probably passed over the Spiritwood Lake study area. However, the records of most of these advances have been lost completely or require better techniques to distinguish than were used for this study. Only the history of the last advances can be deciphered from the surface of the study area.

The early glaciers advancing across the study area removed most of the weathered surface of the Pierre and filled in the lower parts of the preglacial drinage channels with glacial sediment. In the study area the low areas of preglacial drainage are filled with till. In other areas glaciofluvial gravel and lake sediment commonly fill the valleys. Each successive glacial advance distorted at least part of the till and fluvial sediment left in earlier glacial advances. This distorting is responsible for the large number of sand and gravel lenses in the till of the area.

The last glaciation of the study area probably occurred about 14,000 years ago. At this time an ice sheet advanced to a position near the present-day location of the Kensal Moraine. Here the ice sheet remained stationary for an extended period. At this time most of the Kensal Moraine was deposited and the large melt-water channel close to the distal side of the moraine was cut through the drift and deep into the bedrock surface (Figure 12). Later, the ice sheet advanced over this melt-water channel and moved forward in small advances to the present-day James River. At each advance, the melt-water channels in front of the glacier were covered by ice, and new channels developed farther west in front of the ice. The other two melt-water channels in the study area were formed during these small advances. Finally, the ice melted back to a position behind the Kensal Moraine.

The ice advanced over the deep melt-water channel in front of the moraine, because till in the channels occurs over lacustrine sediment, which in turn overlies till. Fluvial sand and gravel occur lower in the section just above the bedrock. Each of the till sheets is thought to represent advances of the glacier over the melt-water channel. The lacustrine sediment is believed to represent a lake formed in the channel when the glacier was behind the Kensal Moraine. The second and any later advances of ice over the Kensal Moraine were probably minor, and the ice may not have advanced more than a few hundred yards beyond the moraine.

After the minor readvances of the glacier, the ice margin finally retreated from the area leaving it much as it appears today.

CHAPTER III

GROUNDWATER THEORY

Introduction

The theory of groundwater movement has developed rather recently. In 1923 O. E. Meinzer published two papers, The Occurrence of Groundwater in the United States with Discussion of Principles (Meinzer, 1923a) and Outline of Groundwater Hydrology with Definitions (Meinzer, 1923b). These served as the basic reference for groundwater studies for the next 40 years.

In 1940, M. King Hubbert published The Theory of Groundwater Motion (Hubbert, 1940). This paper was the first presentation of the physical laws of steady-state groundwater flow within a comprehensive mathematical framework. This paper was, for the most part, ignored until the 1960's.

Among the first significant additions to Hubbert's work were two papers by Toth (1962, 1963). These papers presented a theoretical approach to compliment field studies. They established the basic concept that groundwater-flow patterns could be obtained mathematically by the solution of standard boundary-value problems.

Since Toth's work, many mathematical models of continuous-flow groundwater systems have been proposed. The usefulness of these models has been demonstrated for areas ranging in size from thousands of square miles to less than a square mile (Meyboom, 1963, 1966a, 1967a, 1967b; Maxey, 1968; Williams, 1968; Freeze, 1969a, 1971; Hitchon, 1969a, 1969b).

Interest in groundwater chemistry paralleled the development of groundwater movement theory. In 1955, Chebotarev published a paper in which he used the chemical analysis of several thousand water samples to show that groundwater tends to change composition in a predictable way along its flow path. This was the first of the recent groundwater chemistry studies.

Brown (1963) elaborated on the ways chemistry can be used in studying hydrogeology. Water chemistry was used as the primary means of determining groundwater-flow direction by Back (1960) and Charron (1965a) and as a secondary indicator by Meyboom (1966a) and Toth (1968).

Chemical parameters of groundwater have been computed by Freeze (1969b), Hagmaier (1971), and Schoeller (1959). Ion activities, equilibrium constants, and saturation indices have been used in groundwater studies to distinguish groundwater sources and to determine relationships between groundwater and the sediment through which it flows (Back, 1961, 1963; Barnes and Back, 1964; Robertson, 1964; van Everdinger, 1969; Back and Hanshaw, 1970; Cherry, in press). Wigley (1971) used ionic pairing to explain anomalous saturation indices in natural waters.

Interest in groundwater temperature has lagged behind groundwater movement and groundwater chemistry studies. The differential equation for the simultaneous transfer of heat and fluid was developed by Stallman (1960). Parsons (1970) used this equation to design a hypothetical flow-system model that incorporated water temperature gradients. Only a few individuals have made studies of the effect of groundwater on the temperature of associated material (Cartwright, 1968, 1970; Birman, 1969; Kremar and Masin, 1970).

The development of the theory of groundwater movement, chemistry, and temperature and the application of this theory to specific areas has left many unsolved problems. More and more geologists are seeing a need for a unified approach to groundwater that will use both physical and chemical properties of groundwater. Because all the physical and chemical properties of groundwater can be expressed in terms of energy, a total-energy approach to groundwater seems to be needed. An attempt to develop such an approach is made in the following pages.

Terminology

The terminology used in groundwater studies tends to be inconsistent. For this reason, some of the terms and concepts are defined here as they are used in this report.

Groundwater-Flow Terminology

Flow System.--A flow system is defined by Toth (1963, p. 4806) as

> a set of flow lines in which any two flow lines adjacent at one point of the flow region remain adjacent through the whole region; they can be intersected anywhere by an uninterrupted surface across which flow takes place in one direction.

Length and relationship to topography can be used to define three types of flow systems: local, intermediate, and regional.

Local Flow System.--A local flow system is a system in which groundwater flows from a topographic high to an adjacent low and has a flow path from a few feet to several thousand feet.

Intermediate Flow System.--An intermediate flow system is a system in which groundwater flows from a topographic high to a lower part of the region and has a flow path from several thousand feet to a few miles.

Regional Flow System.--A regional flow system is a system in which groundwater flows from the highest topographic features to the lowest parts of a region and has a flow path from a few miles to several hundred miles.

Flow Components.--Groundwater flows in three-dimensional space. Its flow may be defined by three directional components. The flow components are the longitudinal component, which is perpendicular to a divide, river, or other designated feature, the vertical component, which is on a straight line extending to the center of the earth, and the lateral component, which is normal to the plane formed by the longitudinal and vertical components. The three components can be resolved into a total flow vector, a horizontal component, and a flow resultant (Meyboom, van Everdinger, and Freeze, 1966).

Total Flow Vector.--The total flow vector is the direction of groundwater flow in three-dimensional space. It is the vector sum of the horizontal flow component and the flow resultant.

Horizontal Flow Component.--The horizontal flow component is the direction of groundwater flow in the two-dimensional space of a plane perpendicular to a line through the center of the earth. It may be approximated by a map view of a potentiometric surface.

Flow Resultant.--The flow resultant is the direction of groundwater flow in the two-dimensional space of a plane through the center of the earth. It may be approximated by a cross section of the groundwater flow field. For homogenous, isotropic conditions, a cross section of the flow field may be constructed by contouring values of potential in the plane of the section and drawing flow resultants at right angles to the isopotential lines. Under anisotrophic conditions the isopotential lines and flow resultants are refracted at a permeability interface according to the tangent law (Hubbert, 1940, p. 943). The flow resultants must be corrected for distortion on a vertical exaggerated section (van Everdinger, 1963).

Static Head.--The static head is the height above a standard datum of the column of water that can be supported by the static pressure head and is a measure of fluid hydrodynamic potential energy. Head, when used alone, is understood to mean static head (Lohman and others, 1972).

Total Head.--The total head of a liquid at a given point is the sum of elevation head, pressure head, and velocity head. It is equal to the static head plus the velocity head of the fluid (Lohman and others, 1972).

Potentiometric Surface.--The potentiometric surface is a surface through the static heads of some specific plane below the ground surface.

> As related to an aquifer it is defined by the levels to which water will rise in tightly cased wells. Where the head varies appreciably with depth in the aquifer, a potentiometric surface is meaningful only if it describes the static head along a particular specified surface or stratum in that aquifer (Lohman and others, 1972, p. 11).

Potentiometric surface is used in place of the older term "piezometric surface."

Water Table.--The water table is the plane in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the groundwater just far enough to hold standing water (Lohman and others, 1972, p. 14).

Permeability.--Permeability (or hydrologic conductivity) is a measure of the relative ease with which a medium can transmit a fluid. Its units are defined by Darcy's Law (Hubbert, 1940, p. 819). Permeability is a property of both the fluid and the medium. Permeability is measured in units of length per unit time.

Intrinsic Permeability.--Intrinsic permeability is a measure of the relative ease with which a porous medium can transmit a liquid. It is a property of the medium alone and is independent of the nature of the liquid or the force causing movement (Lohman and others, 1972, p. 9). Intrinsic permeability is measured in units of length squared.

Recharge.--Recharge is the addition of water to the groundwater-flow system by moving water through the unsaturated zone to the water table. A recharge area is an area where groundwater flows downward away from the water table.

Discharge.--Discharge is the loss of water from the groundwater-flow system by means of stream baseflow, seepage, or evapotranspiration. A discharge area is an area where the direction of groundwater flow is upward toward the water table.

Groundwater-Chemistry Terminology

Concentration Terms.--The chemical-concentration terms used in this report are "parts per million," "equivalents per million," "molarity," and "activity." Molarity and activity are used just as they are defined in any standard chemical reference. Equivalents per million is the normality of a solution multiplied by 1,000. Parts per million is the concentration of dissolved matter, by weight, in a million parts, by weight, of solution.

Chemical Ratio.--A chemical ratio is a number computed from the quantitative relationship between the chemical constituents of a water sample. An example is the number obtained by dividing the calcium ion concentration of a water sample by the sodium ion concentration. There are an infinite number of chemical ratios each of which has its own particular formula.

Hydrochemical Facies.--A hydrochemical facies is a mass of water within a groundwater-flow system that may be distinguished on the basis of its chemical characteristics from other water masses in the system. In this study hydrochemical facies will only be used when referring to the classification of hydrochemical facies used by Back (1960). This classification uses percentage values computed from equivalents per million of the anions and cations in solution.

> The following examples represent the general scheme of the classification: (1) "bicarbonate water" describes water in which the total anions are composed of at least 90 percent bicarbonate; (2) double terms, such as "bicarbonate-sulfate," describe water in which the total anions are composed of at least 50 percent but less than 90 percent of the first-named ion and at least 10 percent but less than 50 percent of the second-named ion; (3) the double term, "calcium-magnesium," describes water in which the total cations are composed of at least 90 percent calcium and magnesium; and (4) the double term, "calcium-sodium," represents water in which the total cations are composed of at least 50 percent but less than 90 percent calcium and magnesium and at least 10 percent but less than 50 percent sodium (Hagmaier, 1971, p. 26).

Saturation Indices.--The saturation indices are defined (van Everdinger, 1969, p. 1425) by the equation

$$SI_i = \log Q_i - \log K_i, \qquad (1)$$

where SI_i = the saturation index of the solution for the compound i,

Q_i = the ion-activity product of the groundwater for the compound i, and

K_i = the equilibrium constant for the compound in saturation (at the temperature of the groundwater).

The saturation index is an indication of how close water is to being saturated with a particular compound. A saturation index of 1 indicates that water is saturated; a saturation index of less than 1 indicates the water is undersaturated; and a saturation index of greater than 1 indicates the water is supersaturated.

Groundwater-Potential Terminology

The forces that act on groundwater may be described by a vector field. This field is composed of all the diverse facies that act on water (Remson, Hornberger, and Molz, 1971, p. 10). When these facies are balanced, the groundwater is in a static state and no motion occurs. When these forces do not balance, the finite resultant forces cause the movement of mass or the transfer of energy or both. Because force is a vector, the resultant of a number of forces must be found by adding forces according to the law of vector addition. This is troublesome. It can be avoided by introducing the concept of potentials. Potentials are scalar and can be added algebraically.

Potential.--The potential of a system is the total energy required to move the system from an arbitrary zero datum to the state at which the system exists.

Potential Difference.--If the potential of state A is greater than state B, then the potential difference between the two states is defined as the amount of energy per unit quantity that must be expanded to move the system from state A to state B. Potential difference is a scalar quantity.

Gravitational Potential.--Gravitational potential is the energy per unit quantity required to move a mass or volume of groundwater from the zero datum to the level at which the water exists. If gravitational potential is given in units of energy per unit weight of water, the gravitational potential can be called "position head."

Hydrostatic-Pressure Potential.--Hydrostatic-pressure potential is the energy per unit quantity required at a point in the groundwater system to support the weight of the overlying water column. If the hydrostatic-pressure potential is given in units of energy per unit weight of water, the hydrostatic-pressure potential is the same as the pressure head. The hydrostatic-pressure potential is atmospheric at the water table. Pressure potential is equal to the hydrostatic-pressure potential plus the atmospheric-pressure potential.

Velocity Potential.--The velocity potential is the energy per unit quantity in water that is in the form of kinetic energy of motion. If the velocity potential is given in units of energy per unit weight of water, the gravitational potential can be called "velocity head."

Thermal Potential.--Thermal potential is the energy per unit quantity required to heat a mass or volume of water from a standard temperature datum to the temperature at which the water exists.

Chemical Potential.--Chemical potential is the energy per unit quantity required to change the chemical constituents of groundwater from some standard state to the state in which they exist in the field. If the chemical potential of pure water is arbitrarily set at zero and if the other chemical constituents of groundwater are assumed to have zero chemical potential in their standard state, chemical potential of the water is approximated by the Gibbs free energy of the dissolved solids in the groundwater.

Groundwater Flow

Groundwater flows from areas of high potential to areas of low potential. The potential gradient is commonly derived from topographic differences and the driving force is generally gravity. The purpose of this section is to summarize the theory of groundwater flow.

Hydrodynamic Potential

The hydrodynamic potential of a point in a groundwater-flow system is the sum of the point's gravitational potential, hydrostatic-pressure potential, and velocity potential. It is important because the difference in hydrodynamic potential between points is responsible for almost all groundwater flow. If the density of water is assumed to remain constant, the hydrodynamic potential can be derived from the Bernoulli Equation.

The Bernoulli Equation is a very commonly used modified form of the energy equation for incompressable fluids. For any point P in the groundwater flow system, the Bernoulli Equation may be written as

$$\Phi = g\ Z + \frac{P - Po}{\rho} + \frac{v^2}{2}, \qquad (2)$$

where Φ = hydrodynamic potential at point P,

g = gravitational acceleration,

Z = elevation of point P above a standard horizontal datum (usually sea level),

p = pore pressure at point P,

p_o = atmospheric pressure,

ρ = density of water, and

v = velocity of water at point P.

In this equation gZ is the gravitational potential, $\frac{p - p_o}{\rho}$ is the hydrostatic-pressure potential, and $\frac{v^2}{2}$ is the velocity potential at point P. All of the potentials are in energy units.

If equation 2 is divided by g, the Bernoulli Equation becomes

[illegible]

$$\frac{\Phi}{g} = Z + \frac{p - p_o}{\gamma} + \frac{v^2}{2g}\,, \tag{3}$$

where γ = unit weight of water.

order of 10^{-20} [illegible]

The units of equation 3 are energy per unit weight of water or head (linear units).

If a piezometer is placed at point P, the water will rise to a height (h) above the standard datum. The hydrodynamic head, h, of point P is equal to Φ/g and so is simply the hydrodynamic potential at point P expressed in energy per unit weight of water.

Darcy's Law

Henry Darcy discovered that the saturated flow of water through a column of soil is directly proportional to the head difference and inversely proportional to the length of the column (Davis and De Wiest, 1966, p. 86). The results of his experiments are applied to groundwater movement in the form of Darcy's Law. Darcy's Law is stated below for flow in the x direction of an x, y, and z coordinate system in a homogeneous medium:

$$V_x = -K_x \frac{d\Phi}{dx}, \tag{4}$$

where V_x = seepage velocity in the x direction,

K_x = permeability in the x directions, and

$\frac{d\Phi}{dx}$ = change in hydraulic potential over the linear distance x or hydraulic potential gradient in the x direction (hydrodynamic potential is expressed in linear dimensions).

The negative sign is present in equation 4 because flow occurs in the direction of decreasing potential. A similar equation could be written for seepage velocity in the x, y, and z directions of the three-dimensional coordinate system.

Darcy's Law does not seem to hold for saturated clay or where the potential gradient $\left(\frac{d\Phi}{dt}\right)$ is very large. However, recent investigations by Swartzendruber (1962) and Olsen (1966) suggest that Darcy's Law is a special case of a complicated relationship between fluids and the media through which they flow. A mathematical expression for this relationship has not yet been obtained.

Continuity Equation and Laplace Equation

The continuity equation is a statement of the law of conservation of matter. The equation states that for any system the difference between the mass entering the system and the mass leaving the system is equal to the change in the mass being stored in the system. For fluid flow through a porous medium, the commonly used form of the continuity equation is

$$\frac{d\,(\rho V_x)}{dx} + \frac{d\,(\rho V_y)}{dy} + \frac{d\,(\rho V_z)}{dz} = -F\ \frac{d\,(\rho)}{dt}\ , \qquad (5)$$

where V_x, V_y, V_z = velocity of the fluid in the x, y, and z coordinate directions,

ρ = density of the fluid, and

t = time.

If the density of the fluid (ρ) remains constant, equation 5 becomes

$$\frac{d\ V_x}{dx} + \frac{d\ V_y}{dy} + \frac{d\ V_z}{dx} = \underset{\sim}{F}\ \frac{d\rho}{dt}\ . \tag{6}$$

For steady state conditions, the right side of equation 6 is zero, and the continuity equation becomes

$$\frac{d\ V_x}{dx} + \frac{d\ V_y}{dy} + \frac{d\ V_z}{dz} = 0 \tag{7}$$

The continuity equation in this form is combined with equation 4 (Darcy's Law) to obtain the Laplace Equation:

$$\frac{d^2\ \Phi}{dx^2} + \frac{d^2\ \Phi}{dy^2} + \frac{d^2\ \Phi}{dz^2} = 0. \tag{8}$$

The Laplace Equation describes the spacial distribution of hydrodynamic potential for isotropic and homogeneous conditions. The Laplace Equation and the continuity equation are important in groundwater-flow studies because they form the basis upon which all mathematical models of groundwater-flow systems are built.

Groundwater-Flow Models

The present groundwater-flow models are an outgrowth of the models developed in the early 1960's. At this time, groundwater models were developed independently by Toth and Meyboom. Toth (1963) developed a mathematical model for regional groundwater flow by using the Laplace Equation for isotropic, homogenous sediment and assuming ideal boundary conditions. Meyboom (1963) produced a descriptive model of the groundwater-flow systems in the semi-arid prairie of Saskatchewan, Canada. Meyboom's model is based on field observations. Both models have been refined and expanded considerably in later studies.

Toth's (1962, 1963) theoretical model of groundwater flow is valuable for two reasons. First Toth showed that in the same area, local, intermediate, and regional flow systems could be superimposed on one another (Figure 14). Second, Toth developed a mathematical approach to modeling groundwater-flow systems. Although his own model was based on ideal assumptions, later studies have used his approach to build mathematical models of the more complicated aspects of groundwater flow. With the introduction of digital computors, and finite difference approximations the solution of such complicated problems as stratigraphic pinchouts, heterogeneous sediment, nonisotropic conditions, irregular water tables, and three-dimensional modeling have been approached.

Freeze and Witherspoon (1966, 1967, 1968) and Freeze (1969a) added a new dimension to the Toth model with their research on the theoretical analysis of groundwater flow and their use of digital computors to construct and evaluate models. Freeze (1971) built a three-dimensional groundwater-flow model that can evaluate nonsteady flow through a heterogeneous, nonisotropic medium. This model is limited only by the size of the computor available and can be used to evaluate quantitatively the groundwater flow in any size basin.

Meyboom's (1963) "prairie profile" was specifically designed for the prairie regions of western Canada. However, the generalizations underlying the model hold for other areas, such as North Dakota, where similar conditions prevail. According to Meyboom's (1963, p. 9) definition,

> . . . the Prairie Profile consists of a central topographic high bounded at either side by an area of lower elevation. Geologically the profile is made up of two layers of

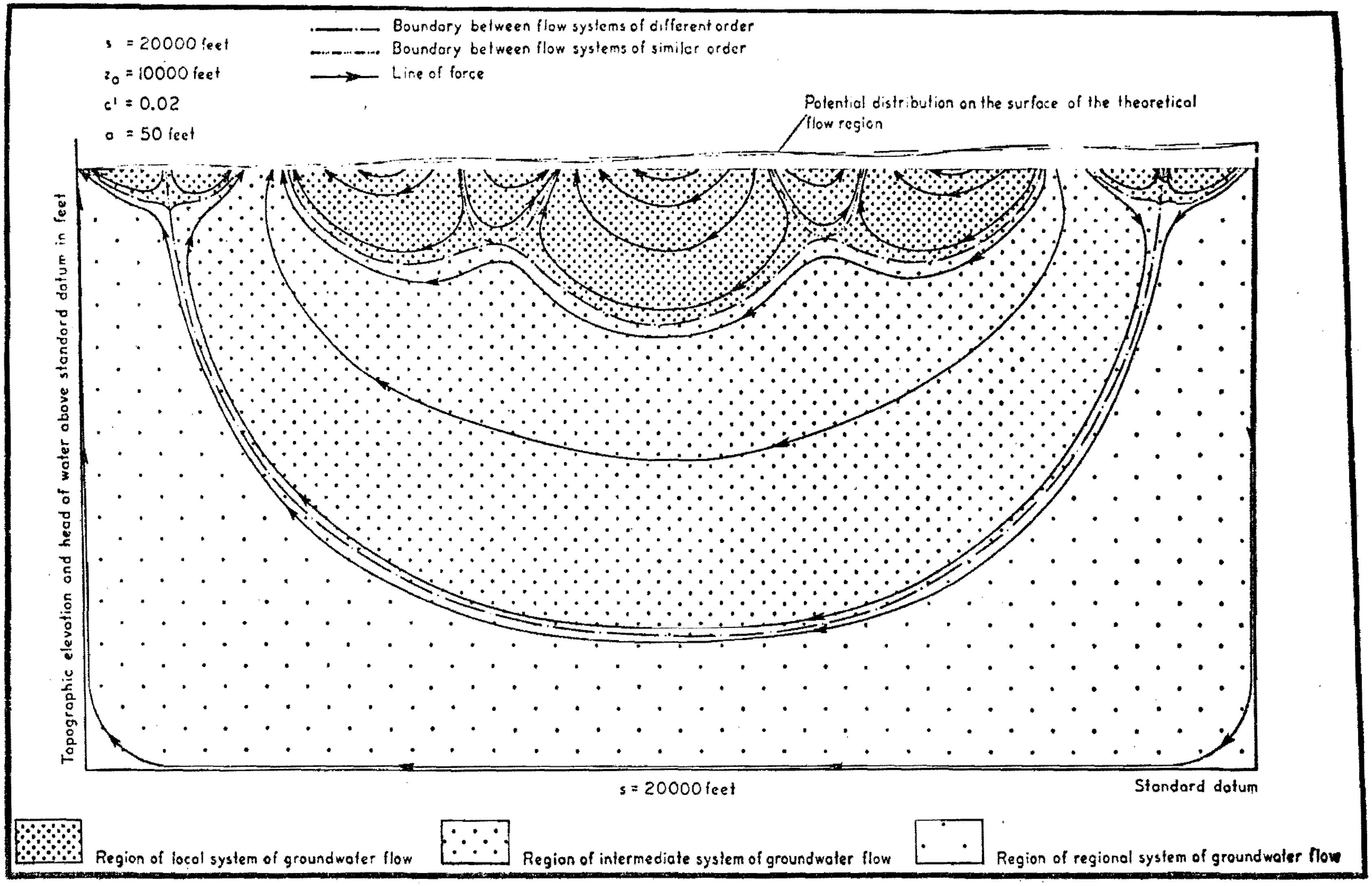

Fig. 14.--Theoretical flow pattern and boundaries between different flow systems (from Toth, 1963, p. 4807).

> different permeability, the upper layer having the lower permeability. Through the profile is a steady flow of groundwater from the area of recharge to the area of discharge. The ratio of permeabilities is such that groundwater flow is essentially downward through the material of low permeability and lateral and upward through the underlying more permeable layer. The potential distribution in the profile is governed by the differential equation of Laplace.

The "prairie-profile" model in Figure 15 shows a topographic high surrounded by areas of low relief and the large-scale regional flow system that results.

The only major point of disagreement between Toth's and Meyboom's models is whether unconfined groundwater-flow systems can extend across high-elevation divides and the valleys of large rivers. Meyboom (1963, p. 27) cites field evidence that indicates that large-scale flow systems do cross these features. Toth's models indicate that they should not.

Generally the combined picture of Meyboom's "prairie profile" and the theoretical models by Toth give a good description of unconfined, regional, groundwater-flow systems (Hagmaier, 1971, p. 34). Concepts of both models are used in most recent groundwater-flow studies.

Groundwater Chemistry

The chemical composition of groundwater depends on the composition of the water as it enters the ground, the chemical environment in the surface soil, the composition of the sediment through which the water flows, the rate at which the water moves through the ground, and the length of time the water is in the flow system. The purpose of this section is to summarize the known groundwater-chemistry theory and postulate how the groundwater-chemistry theory fits in the general concept of groundwater potential.

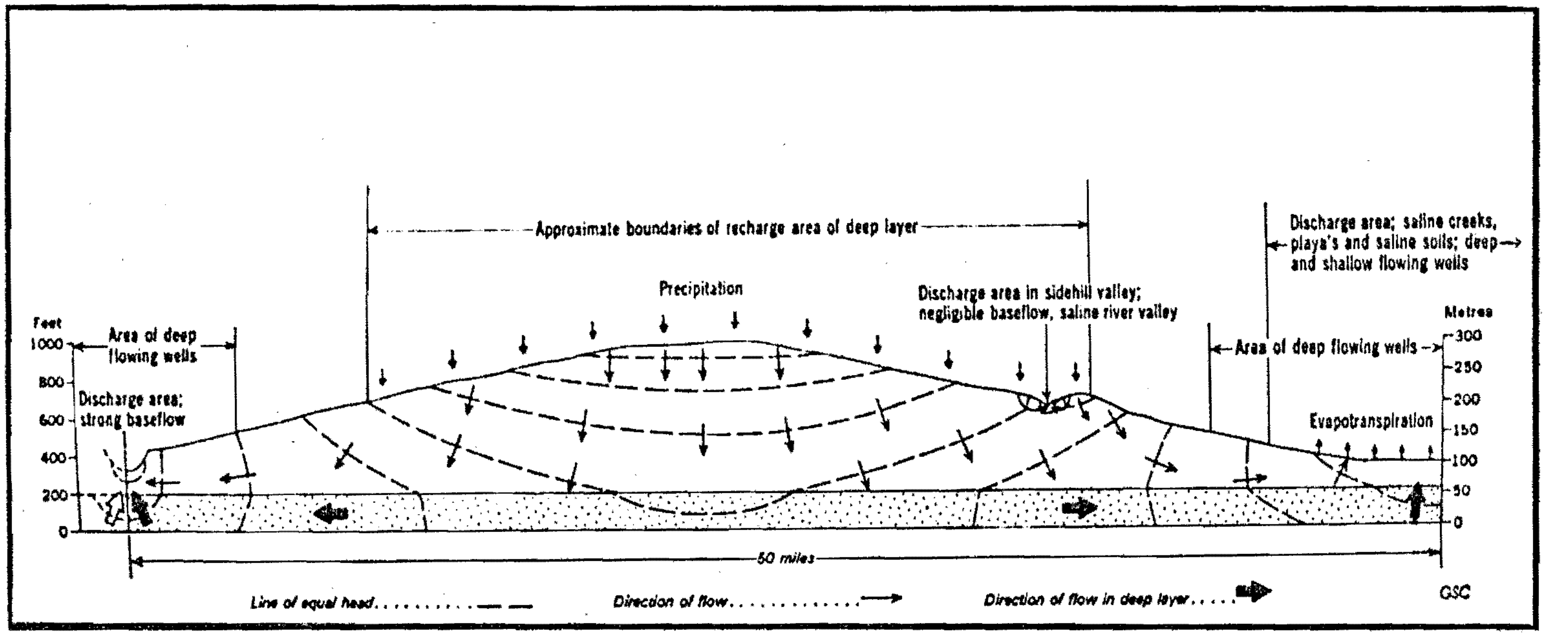

Fig. 15.--The "prairie profile" (from Meyboom, 1963, p. 27).

Chebotarev Sequence

Chebotarev (1955) used the solubility products of common ions and the chemical analysis of several thousand water samples from numerous groundwater-flow systems to demonstrate that the composition of groundwater tends to become more saline along its flow path from recharge to discharge areas. This model predicts the predominant ions in the groundwater along an individual groundwater flow path from recharge to discharge. The sequence of the hydrochemical facies (Figure 16) is

$$HCO_3^- \rightarrow HCO_3^- + SO_4^{--} \rightarrow SO_4^{--} \rightarrow SO_4^{--} + Cl^- \rightarrow Cl^-$$

The length of time the groundwater is in the flow system, in part determines the concentration of the soluble ions, with the oldest water containing the greatest concentration of chloride and total dissolved solids.

The hydrochemical model is for sediment that is typically composed largely of silicate minerals. It emphasizes the importance of residual time. According to the model, the development of the hydrochemical facies is directly related to the time the water is in the sediment and only slightly related to the minerological framework of the sediment through which the water travels. For example, in a local system, the water should be bicarbonate rich, intermediate-flow system should contain both bicarbonate and sulfate facies, and regional-flow systems should have bicarbonate and chloride facies. Observations by Michel (1965) in West Germany and by Charron (1965b) in the Winnipeg, Manitoba, area indicate the size of the flow system does determine the prevailing hydrochemical facies as much or more than the minerological composition of the sediment containing the groundwater.

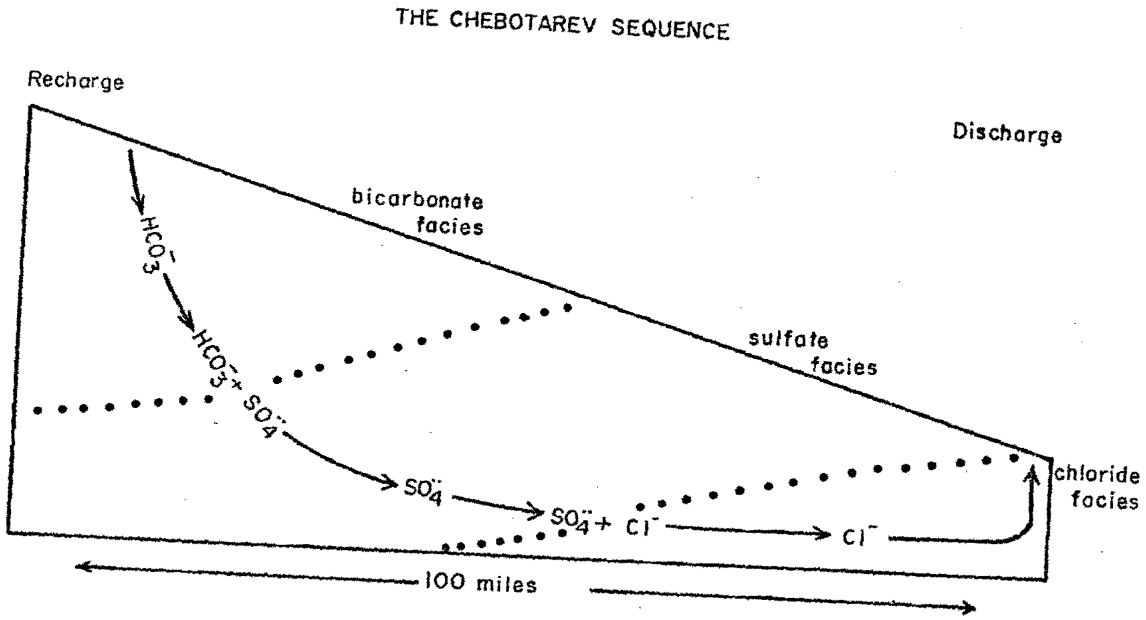

Fig. 16.--Hydrochemical model for regional groundwater flow systems (from Hagmaier, 1971, p. 34).

Distinct from the chemical facies of Chebotarev's hydrochemical model are the large-scale geographic zonations of hydrochemistry. According to Meyboom (1966b),

> it can be shown theoretically (Schoeller, 1959) that the continental distribution of hydrochemical facies, particularly in recharge areas, is a function of climate. This fact was demonstrate for the European part of the U.S.S.R. by Garmanov (Schoeller, 1959), for northern Africa by Schoeller (1959) and for western Canada by Meyboom (1967c). Briefly, the relation of all of these regions is as follows: the recharge areas of regions with abundant to moderate precipitation are characterized by calcium and magnesium bicarbonate waters, recharge areas in zones with low precipitation contain sodium-sulphate waters, whereas desert regions commonly have sodium-chloride waters.

Chemical Ratios

A chemical ratio is the numerical relationship between specified ions in the water of a particular part of the groundwater-flow system. They are usually dimensionless. The chemical ratios are a function of the chemical composition of the groundwater only. However, they may indicate the groundwater's history and the composition of the sediment through which the groundwater passed. If the ratios are to be useful, they summarize the characteristics of the water into a few easily compared values. Chemical ratios are useful in distinguishing the age and chemical facies of a water sample, differentiating the waters of separate flow systems, determining the relationship between flow systems, and determining the history of the water in a particular flow system.

Chebotarev (1955), Schoeller (1959), Todd (1959), Freeze (1969a), Hamilton (1970), and Hagmaier (1971) are a few of those who used chemical ratios in their study of groundwater. The most commonly used ratios are ion percentages (the part of the total cation or anion concentration of a water sample composed of a particular cation or anion). The use of ion percentages allows meaningful comparison of ion concentrations of water samples over a large range of total dissolved solids. Chemical ratios of the major cations and anions are used to determine chemical facies. Other ratios distinguish the waters of particular aquifers and areas. The chemical ratios used in this report and the formulas used to calculate them are given in Appendix A.

Saturation and Base-Exchange Indices

A saturation index or a base-exchange index is a numerical relationship between the chemical composition of groundwater and the composition of the material through which the water flows. Base-exchange indices were first used by Schoeller (1959). Back (1963), van Everdinger (1969), and Cherry (in press) are among those who used saturation indices in groundwater studies.

Saturation indices are a function of the ion-activity products and equilibrium constants of soluble compounds and are defined by equation 1 of this chapter. They are a numerical indication of how close a water sample is to being saturated with the ions which form particular compounds. The larger the number, the more saturated the water. Saturation indices suggest the history and maturity of groundwater and may be used to predict how the water will change along its flow path.

A saturation index may be computed for any compound that is soluble in groundwater. However, indices are usually computed only for the common carbonates and sulfates. The procedures and equations used to compute the saturation indices for $CaCO_3$, $CaMg(CO_3)_2$, and $CaSO_4$ are given in Appendix A.

Base-exchange indices are numerical indicators of the relationship between clay sediment and groundwater. One base-exchange index is a measure of the ease with which magnesium and calcium in groundwater could be replaced by sodium and potassium from clays. The other is a measure of the ease with which the reverse exchange could occur. Large base-exchange values indicate ease of replacement.

Chemical Potential

The chemical potential of a solution is the energy that must be subtracted or added to the solution to change its chemical constituents from some standard state to the state at which the constituents exist in solution. The chemical potential of a solution can be stated by the equation

$$\Delta\Phi_t = X_1\Delta E_i + X_2\Delta E_2 + \cdots + X_i\Delta E_i \ , \qquad (9)$$

where $\Delta\Phi_t$ = total chemical potential of the solution,

X_1, X_2, X_i = mole fraction of the constituents in solution, and

ΔE_1, ΔE_2, ΔE_i = difference in energy per mole between the standard state of each constituent and the state of the constituent in solution.

If the standard state of H_2O is considered liquid at 298.2° K (25° C) and 1 atmosphere of pressure and if the standard state for the other chemical constituents of groundwater is considered crystaline solid at 0° K and an entropy of zero, at 1 atmosphere of pressure and 298.2° K the chemical potential of groundwater is approximated by the standard-state Gibbs free energy of the non-H_2O chemical constituents of groundwater:

$$\Phi_{298.2} = X_1\Delta F_1^o + X_2\Delta F_2^o + \cdots X_i\Delta F_i^o , \qquad (10)$$

where $\Phi_{298.2}$ = chemical potential of the groundwater at 298.2° K and

ΔF_1^o, ΔF_2^o, ΔF_i^o = Gibbs free energy per mole of the non-H_2O chemical constituents of groundwater at standard conditions (1 atmosphere pressure and 298.2° K).

The chemical potential of groundwater at temperatures other than 298.2° K are approximated by the Gibbs free energy of the non-H_2O constituents at which the water occurs. Energy variations resulting from changes in water temperature and pressure are not included in chemical potential but are part of the thermal and hydrostatic-pressure potentials. The Gibbs free energy of chemical substances at conditions other than standard are obtained with the formula

$$\Delta F = \Delta H^o - \Delta S T, \tag{11}$$

where ΔF = Gibbs free energy of the chemical constituent at temperature T,

ΔH^o = enthalpy of the chemical constituent at standard conditions,

ΔS = rate of entropy change between 298.2° K and temperature T, and

T = temperature of the groundwater in degrees Centigrade plus 273.2.

For groundwater, ΔS can be assumed constant over the small temperature range between 25° C and the temperature of the water. If this assumption is made, then ΔS is obtained from the formula

$$\Delta S = \frac{\Delta H^o - \Delta F^o}{T}, \tag{12}$$

where ΔF^o = Gibbs free energy of the chemical constituents at 298.2° K,

ΔH^o = enthalpy of the chemical constituents at 298.2° K, and

T = standard temperature, 298.2° K.

The standard-state Gibbs free energy and standard enthalpy for the chemical constituents of groundwater can be obtained from various chemical references. The free energy and enthalpy values used in this report are listed in Appendix A. If Gibbs-free-energy values are used to compute the chemical potential of a sample of groundwater, either all the chemical constituents of the water must be determined or the assumption must be made that the constituents not determined make up an insignificant part of the total sample.

Usually free energy, enthalpy, and entropy values have been given in kilocalories or calories. Chemical potential can be expressed by using units of energy per unit weight of water.

Groundwater Temperature

Temperature variations in groundwater were not really considered much before the 1960's. In the last 10 years more temperature studies have appeared but still little is known about the temperature variations of groundwater. The purpose of this section is to discuss what is known of groundwater temperature theory and the concept of thermal potential.

Hydrothermal Flow Systems

Stallman (1960) developed a differential equation for the simultaneous transfer of heat and fluid. His basic equation is

$$\frac{D^2T}{dx^2} + \frac{D^2T}{dy^2} + \frac{d^2T}{dz^2} - \frac{c_w\rho_w}{k} \left(\frac{d\ (v_xT)}{dx} + \frac{d\ (v_yT)}{dy} + \frac{d\ (v_2T)}{dz} \right) = \frac{1}{\beta}\ \frac{dT}{dt} \qquad (13)$$

where t = time since heat or water flow started,

T = temperature at any point in time, t,

x, y, z = cartesian coordinates,

v = velocity of fluid flow with the direction of flow specified by the subscripts x, y, and z,

β = thermal diffusivity,

c_w = specific heat of water,

k = thermal conductivity of the rock-fluid complex, and

ρ_w = density of water.

Parsons (1970) used this equation to design a theoretical flow system that incorporates thermal gradients. Parsons' flow system was used by Cartwright (1970) to describe the redistribution of geothermal heat by shallow aquifers.

Meyboom (1966a) states that

> recently, Kohout (1965) advanced a new hypothesis concerning cyclic flow of salt water related to geothermal heating in southern Florida. He postulated that geothermal heating, together with the loss of dissolved solids through dispersion would decrease the density of very deep groundwater in Florida (3,000 feet below sea level) to the extent that there would be a difference in pressure head of almost 11 feet between the top and bottom of the water column. This difference would be sufficient to cause migration of deep groundwater towards higher regions, where it would become incorporated in the tail-end of a hydrodynamic flow system by which it would be discharged into the sea.

Elder (1965) gives an account of groundwater discharge in the thermal areas of New Zealand. He lists four essential elements of a hydrothermal flow system. They are a heat source, a recharge system, a recirculation system, and a surface discharge system. Elder combines these to construct a "pipe model" in which he unifies a hydrothermal flow system with a hydrodynamic system.

The effect of horizontal flow on thermally-induced convection currents is discussed by Pratts (1966).

Thermal Potential

The thermal potential of groundwater is a measure of the heat energy in the water. It must be measured from some stated datum. Absolute thermal potential is measured from 0° K. This is not practical for most groundwater studies and should probably not be used unless both the liquid and solid phase of water is present in the system. The datum for this study was taken at 273.2° K, the lowest temperature at which the liquid phase of water is stable at 1 atmosphere pressure.

The thermal potential of groundwater can be obtained from the formula

$$\Phi T = \int_{To}^{T} (C) dT, \qquad (14)$$

where Φ_T = thermal potential,

T = temperature of the water,

T_o = temperature datum, and

C = specific heat of the groundwater.

If the specific heat of the groundwater is constant over the temperature range from T to T_o, then equation 14 can be written

$$\Phi_T = C \int_{T_o}^{T} dT. \qquad (15)$$

Integrating equation 15 gives

$$\Phi_T = C\ (T - T_o). \qquad (16)$$

If the groundwater has a low concentration of total dissolved solids (less than 8,000 ppm) the heat capacity of the groundwater is closely approximated by the specific heat at constant volume (C_V) for pure water. If this substitution is made, the thermal potential of groundwater can be computed with the formula

$$\Phi_T = C_v\ (T - T_o). \qquad (17)$$

Groundwater Potential

The need for a unified approach to the study of groundwater has been noted by several individuals. Cherry (1970) stated that a unified energy approach to groundwater was the most needed concept in hydrogeology. Back and Hanshaw (in press) feel that one of the "fundamental tasks required to achieve the ultimate goal of hydrogeology is to understand the controls of energy distribution and transformation within aquifer systems." It is then the hydrologist's role to bring together into one concept "the fluctes and forces of the chemical reaction, of the hydrodynamic flow paths, and of heat." Maxey (1969, p. 145) states that

> aquifer systems have been studied by three separate methods of analysis: (1) hydrodynamic, utilizing a distributed potential system; (2) hydrochemical, using parameters of water quality; and (3) hydrothermal, using distribution and gradients of temperature. The various approaches have been dictated largely by the specialized training and experience of the individual research worker. However, the complexity of present hydrologic problems now requires bringing together the various aspects into a single concept of a functioning system.

The concept of potential provides the means to create a unified approach to all forms of energy.

Energy is a thermodynamic function and so is a property of state and is not affected by how the state is reached. Energy is a scalar quality and can be arithmetically added. Potential as defined earlier is a measure of the energy of state.

The total potential of a point P in a groundwater-flow system can be expressed by the formula

$$\Phi_g = \Phi_{hp} + \Phi_v + \Phi_e + \Phi_c + \Phi_t + \Phi_o, \qquad (18)$$

where Φ_g = total potential of the groundwater at point P,

Φ_{hp} = hydrostatic-pressure potential at point P,

Φ_v = velocity potential of the groundwater at point P,

Φ_e = gravitational potential of point P,

Φ_c = chemical potential of the groundwater at point P,

Φ_t = thermal potential of the groundwater at point P, and

Φ_o = other potentials of the groundwater at point P.

The computation of hydrostatic pressure, velocity, elevation, chemical, and thermal potentials was discussed earlier. "Other potentials" (Φ_o) is the sum of all the positive and negative potentials that affect a point in the groundwater-flow system but are not included in the other five potentials listed above. Included in the "other potentials" are the osmotic-pressure potential of Back and Hanshaw (1965) and the absorption potential of Remson, Hornberger, and Molz (1971). "Other potentials" are not well understood at this time and can not be evaluated accurately. It is hoped that future studies will be able to break "other potentials" into component potentials and evaluate them accurately.

"Total potential" and its component potentials can be expressed as head. Because of this, potentiometric surfaces can be contoured for the potentials, either singularly or collectively, just as for hydrodynamic potential. Potentials can be used with the Laplace Equation as follows:

$$\frac{d^2\,\Phi}{dx^2} + \frac{d^2\,\Phi}{dy^2} + \frac{d^2\,\Phi}{dz^2} = 0, \qquad (19)$$

where Φ = total potential, velocity potential, pressure potential, elevation potential, chemical potential, thermal potential, other potentials, or a combination of potentials.

Existing mathematical models for groundwater flow can be adapted for potentials. Once the boundaries of the potentials have been established and defined mathematically, digital computors and difference equations can be applied to potential models.

Potential Approach

The first law of thermodynamics states that energy is neither created or destroyed. Matter can be written as a function of energy. For a particular system, such as a groundwater-flow system, this means that energy can be added to the system, energy can be subtracted from the system, or energy can be changed in form within the system. There are no other alternatives.

Energy, including matter, can be added to the system in the form of energy of recharge, heat, and energy of chemical reaction by the material through which it flows. This additional energy will increase the value of one or more potentials of the system. Energy, including matter, can be subtracted from the system by energy of discharge, heat loss, or energy of chemical reactions with the sediment through which it moves. This loss of energy decreases the value of one or more of the potentials of the system.

Energy can be changed in form within the system in any number of ways. This change increases or decreases the value of two or more potentials of the system.

Taking the three possibilities together, any change affecting the system is reflected in the various potentials of the system.

At the present time "total potential" can not be computed for a point in the groundwater-flow system. It can be approximated by the sum of the hydrostatic-pressure, gravitational, velocity, chemical, and thermal potentials of the point. However, the potential approach to groundwater does create a unified approach to groundwater, which keeps each phase of the groundwater system in prospective with the rest of the system. In addition, it increases the ease with which the energy changes within the system can be compared and correlated. Additional work in defining the "other potentials" and their relationship to the total system will help to clarify this approach and make it possible to compute "total potential" for a point in the groundwater-flow system.

CHAPTER IV

GROUNDWATER OF THE SPIRITWOOD LAKE AREA

The purpose of this chapter is to evaluate the groundwater of the Spiritwood Lake area and the relationship between groundwater and the water level in Spiritwood Lake.

Previous Work

A study of the geology and water resources of Stutsman County (including the Spiritwood Lake area) was made in the early 1960's. The results of this study are published in a three-part bulletin: Geology (Winters, 1963), Groundwater Basic Data (Huxel and Petri, 1963), and Groundwater and Its Chemical Quality (Huxel and Petri, 1965). The study was reconnaissance and did little more than identify the aquifers of the county. A few test holes were drilled near Spiritwood Lake.

Several agencies have determined the chemical composition of groundwater and surface-water samples from several locations within a few miles of Spiritwood Lake. The results of these chemical analysis, the names of the agencies that made the determination, and the location where the water was collected are given in Appendices C and D.

Field and Laboratory Studies

The groundwater of the Spiritwood Lake area was assumed to be a dynamic system in which the groundwater moves along potential gradients from areas of recharge to areas of discharge. The configuration of the groundwater flow systems in the study area was determined from (1) the location of recharge and discharge areas in the vicinity of Spiritwood Lake, (2) the hydrostatic-pressure potential at a few selected points in the groundwater-flow system, (3) the composition, physical properties, and stratigraphy of the sediment the groundwater flows through, (4) the chemical composition and physical properties of the groundwater and surface-water of the study area, and (5) the topography and surface relief of the area around Spiritwood Lake.

Three assumptions were made in determining the configuration of the groundwater-flow systems of the study area. First, the sediments were assumed to be homogeneous unless there was evidence to the contrary. Second, conditions of steady-state flow were assumed in all groundwater-flow systems of the area. Third, the Pierre Shale was assumed to form an almost impermeable boundary at some depth below the study area; the groundwater in the local and intermediate flow systems was therefore assumed to be unaffected by the regional flow system in the sediment below the Pierre.

Piezometers

A piezometer is an installation designed to measure the hydrostatic-pressure potential at a specific point in a groundwater-flow system. The theory of piezometers and the type of piezometers available is given in Appendix A. Casagrade-type standpipe piezometers were installed in the Spiritwood Lake area. The design of the piezometers and the procedures followed in installing them in the study area is given in Appendix A.

Approach

The configuration of the groundwater-flow systems in the Spiritwood Lake area could be obtained from the static-pressure potentials of a large number of points in the groundwater-flow systems of the area. However, the cost of drilling and installing piezometers for this type of project could be several hundred thousand dollars. The inexpensive field installations used for this project are designed to approximate the results of the more expensive projects.

The general relationship between the flow systems in the Spiritwood Lake area was obtained from piezometers installed in key points in the groundwater-flow systems. These key points were determined from the geology and topography of the study area and from surface indicators of groundwater flow. A concentration of piezometers was used to obtain a detailed picture of the groundwater-flow systems at one site in the study area. The generalizations from this site were then used with geologic, topographic, and chemical information to fill in the details of the groundwater-flow systems in the rest of the study area.

Field Studies

Fifty-six piezometers were installed to depths ranging from 15 to 260 feet in the Spiritwood Lake study area. Those piezometers not destroyed by vandalism are shown in Figure 17. The piezometers are distributed in the study area as singles or in nests of two, three, or four piezometers (Figure 18, and 19). In a piezometer nest, each piezometer is at a different depth and measures the hydrostatic-pressure potential of a particular point in the groundwater of the area.

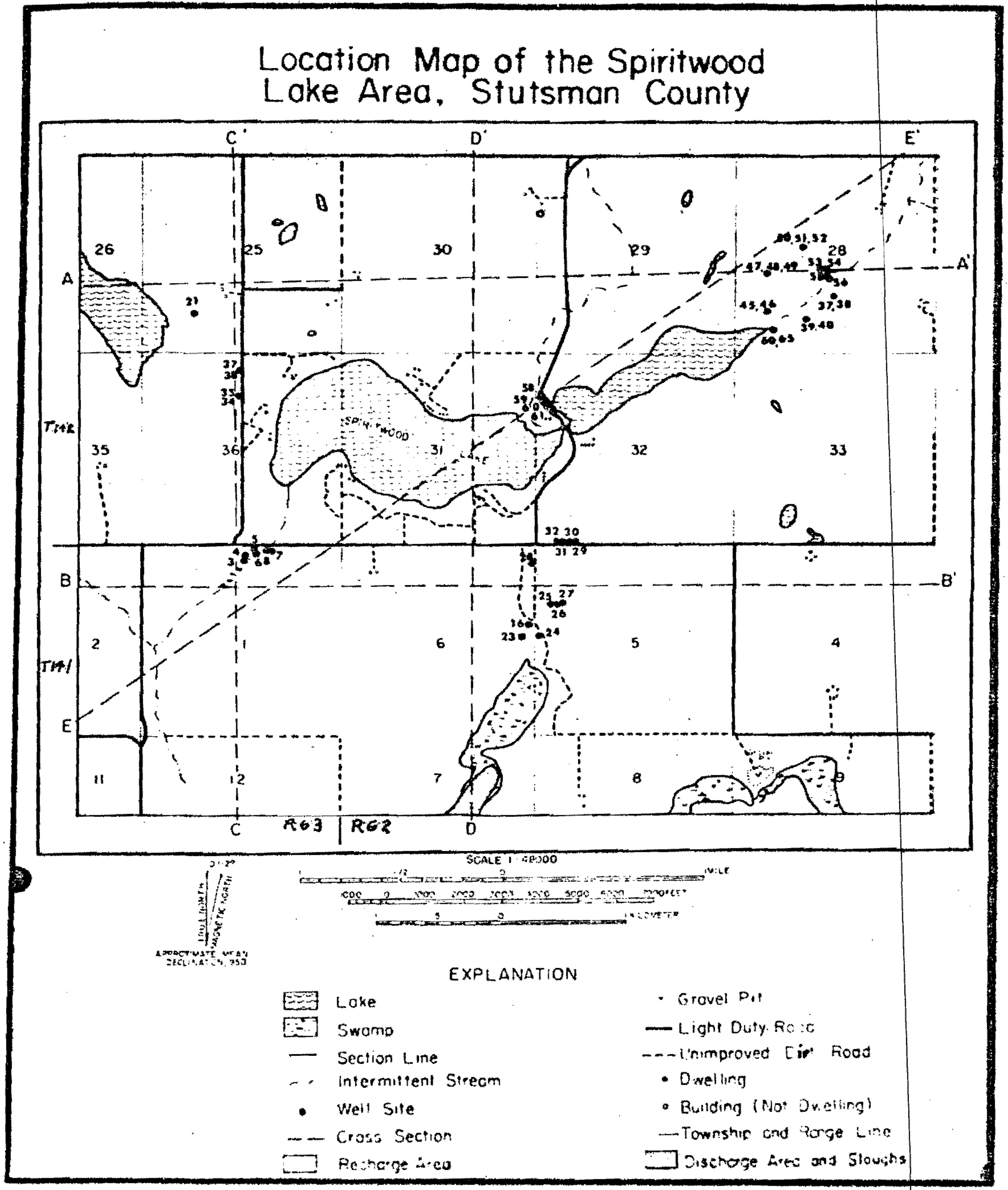

Fig. 17.--Location map of the piezometers in the Spiritwood Lake study area.

Fig. 19.--Photograph of a piezometer nest north and east of Spiritwood Lake (NE¼ NW¼ SW¼ sec. 28, T. 142 N., R. 62 W.).

Fig. 18.--Photograph of a piezometer nest north and east of Spiritwood Lake (NE¼ SW¼ SW¼ sec. 28, T. 142 N., R. 62 W.).

The hydrostatic-pressure potential, temperature, and pH were determined for the water from each of the piezometers in the study area. In addition, water samples were collected for later chemical analysis. The procedures used to collect water samples and measure the physical characteristics of the groundwater are given in Appendix A.

Laboratory Methods

The samples of groundwater and surface-water collected in this study were analyzed for all the major cations and anions and many of the minor ones. The analytical procedures used, the ions determined, and the reliability of the results are discussed in detail in Appendix A.

Three computor programs, CHEM D, CHEM A, and CHEM E, were developed to process the chemical and physical data obtained in the field and chemical analysis part of the study. Computor program CHEM D calculates the hydrostatic-pressure potential of each piezometer. For each water sample analyzed, it determines the concentration of the chemical constituents in parts per million, and equivalents per million, and computes a number of chemical ratios that characterize groundwaters and surface-waters. CHEM A is designed to compute the $CaCO_3$, $CaMg(CO_3)_2$, and $CaSO_4$ saturation indices, ion activities, and molar concentrations of each of the analyzed water samples. CHEM E is designed to compute the Gibbs free energy of the analyzed chemical constituents of each water sample. The three computor programs and the procedures and equations used in the programs are discussed in detail in Appendix A. The data output from the three programs is contained in Appendices C through K.

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Groundwater Flow

The sections of the study area where recharge and discharge occurs are shown on Figure 20. The recharge and discharge areas are a result of the local and intermediate groundwater-flow systems of the study area.

Local groundwater-flow systems occur in the glacial drift. This type of flow system occurs between topographic highs and lows. Figure 21 shows the direction of flow of the local groundwater-flow systems in the Spiritwood Lake area.

An intermediate groundwater-flow system occurs along the contact between the Pierre Shale and the overlying glacial drift and in the upper part of the Pierre Shale. Water in the intermediate flow system moves from the northeast to the southwest (Figure 22).

Figures 23, 24, 25, 26, and 27 show the patterns of groundwater movement in the Spiritwood Lake area. The hydrodynamic equipotential lines on these cross sections are those formed by the combined intermediate and local groundwater-flow systems.

Local Flow Systems

Numerous local groundwater-flow systems occur in the glacial drift. The configuration of these flow systems is controlled by the permeability and topographic relief of the glacial drift.

Laboratory permeabilities were not determined for the sediment. However, approximate permeabilities were estimated from the texture and composition of the sediment.

The longitudinal and lateral laboratory permeabilities for the till in the Spiritwood Lake area ranges from 1×10^{-8} to 1×10^{-9} m/s.

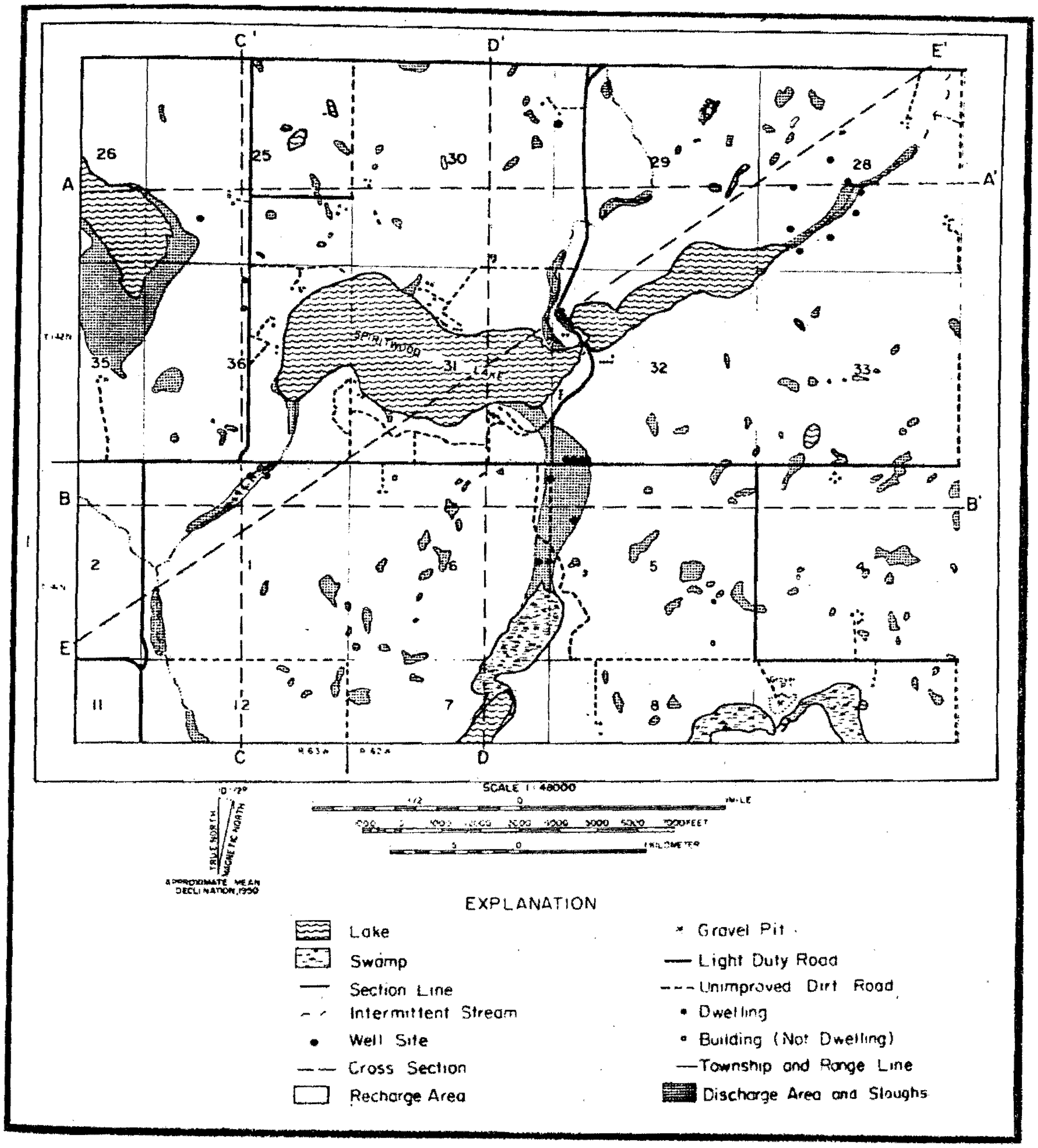

Fig. 20.--Map showing the recharge and discharge areas. Recharge areas are in white, discharge areas are marked with swamp symbol or with parallel dots.

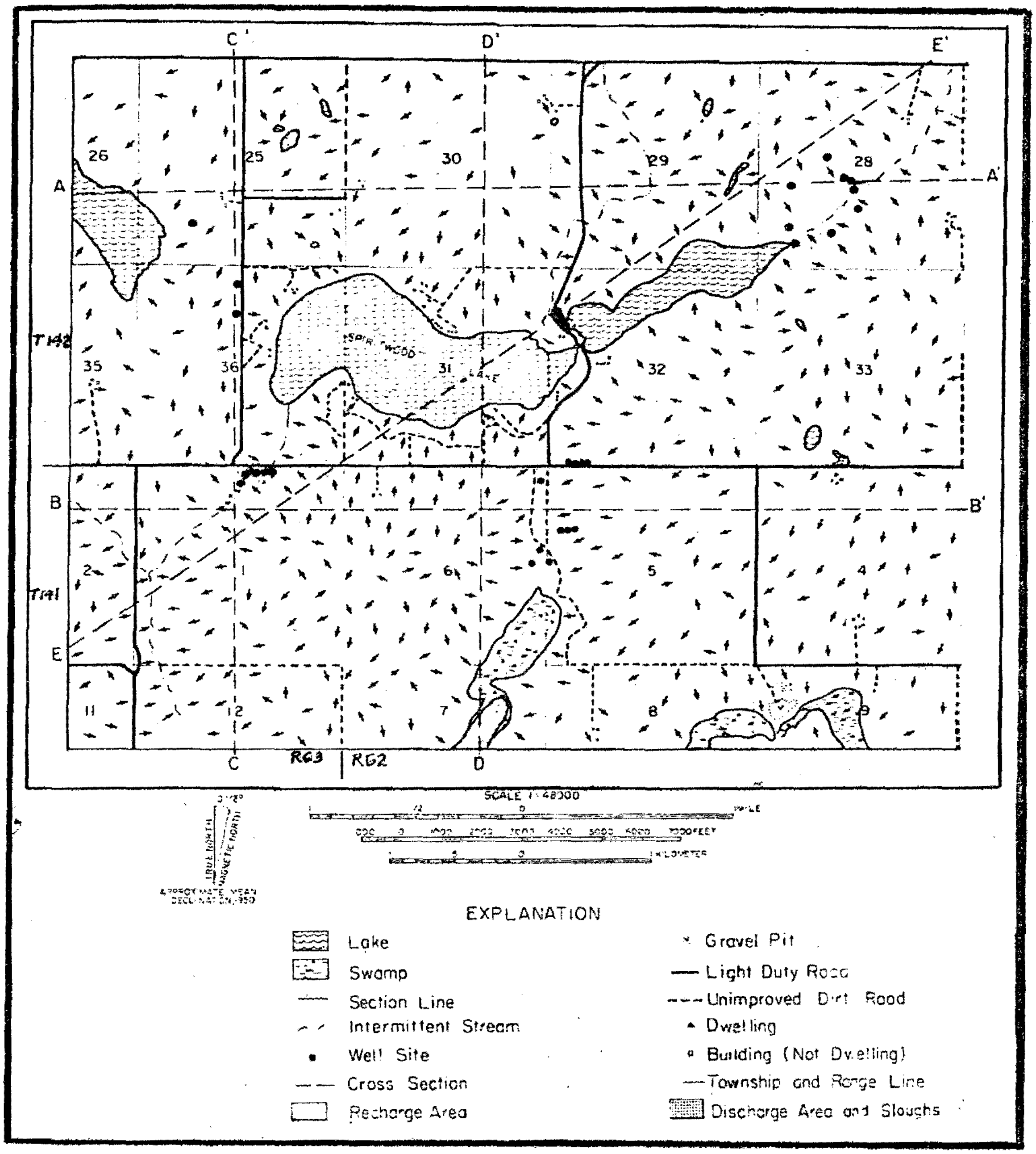

Fig. 21.--Map showing the pattern of the local groundwater-flow systems in the Spiritwood Lake area. The arrows show the direction of groundwater flow.

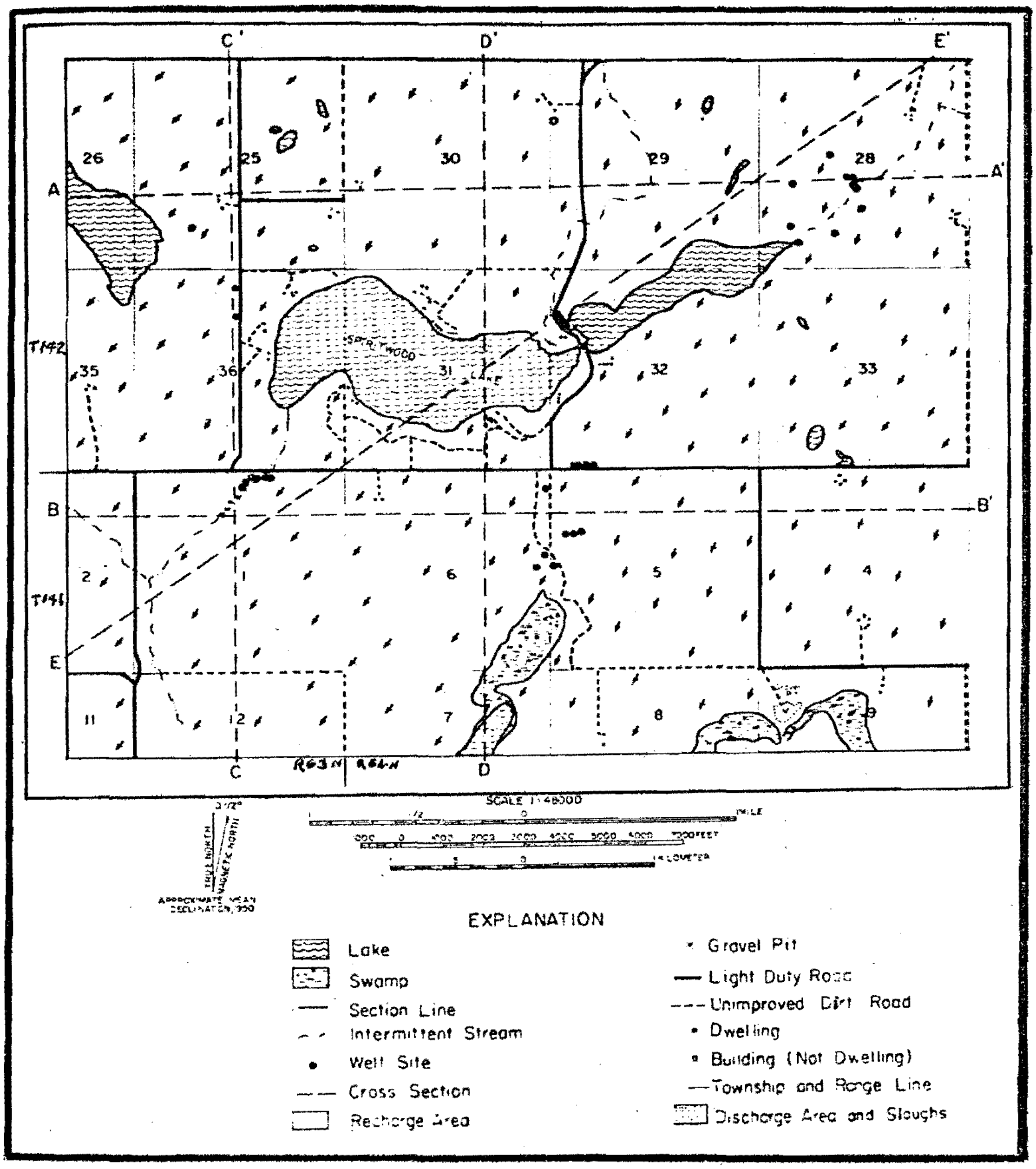

Fig. 22.--Map showing the pattern of the intermediate groundwater-flow system in the Spiritwood Lake area. The arrows show the direction of groundwater flow.

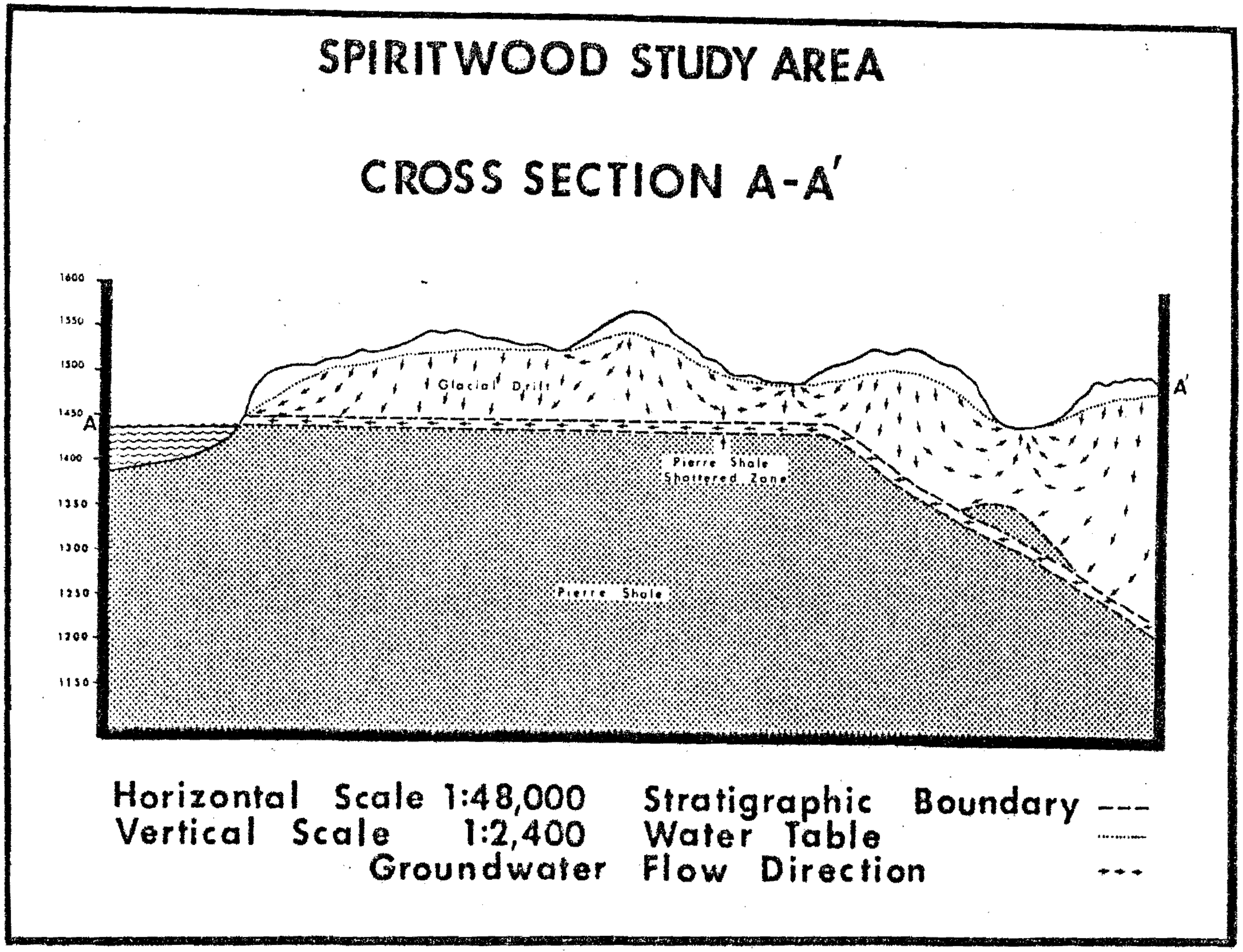

Fig. 23.--Pattern of groundwater flow in a cross section through the Spiritwood Lake area. The cross section is along line A-A' in Figure 17.

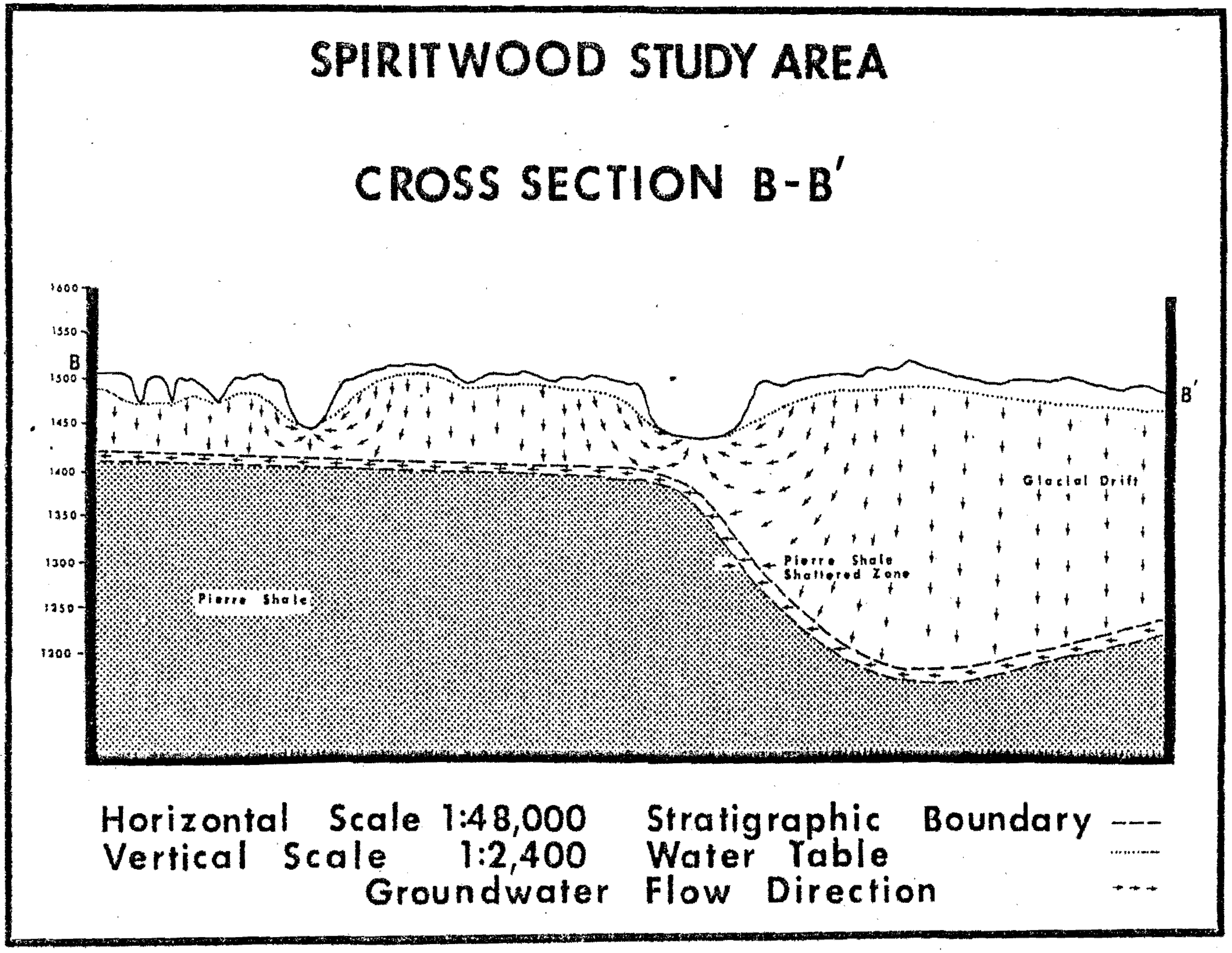

Fig. 24.--Pattern of groundwater flow in a cross section through the Spiritwood Lake area. The cross section is along B-B' in Figure 17.

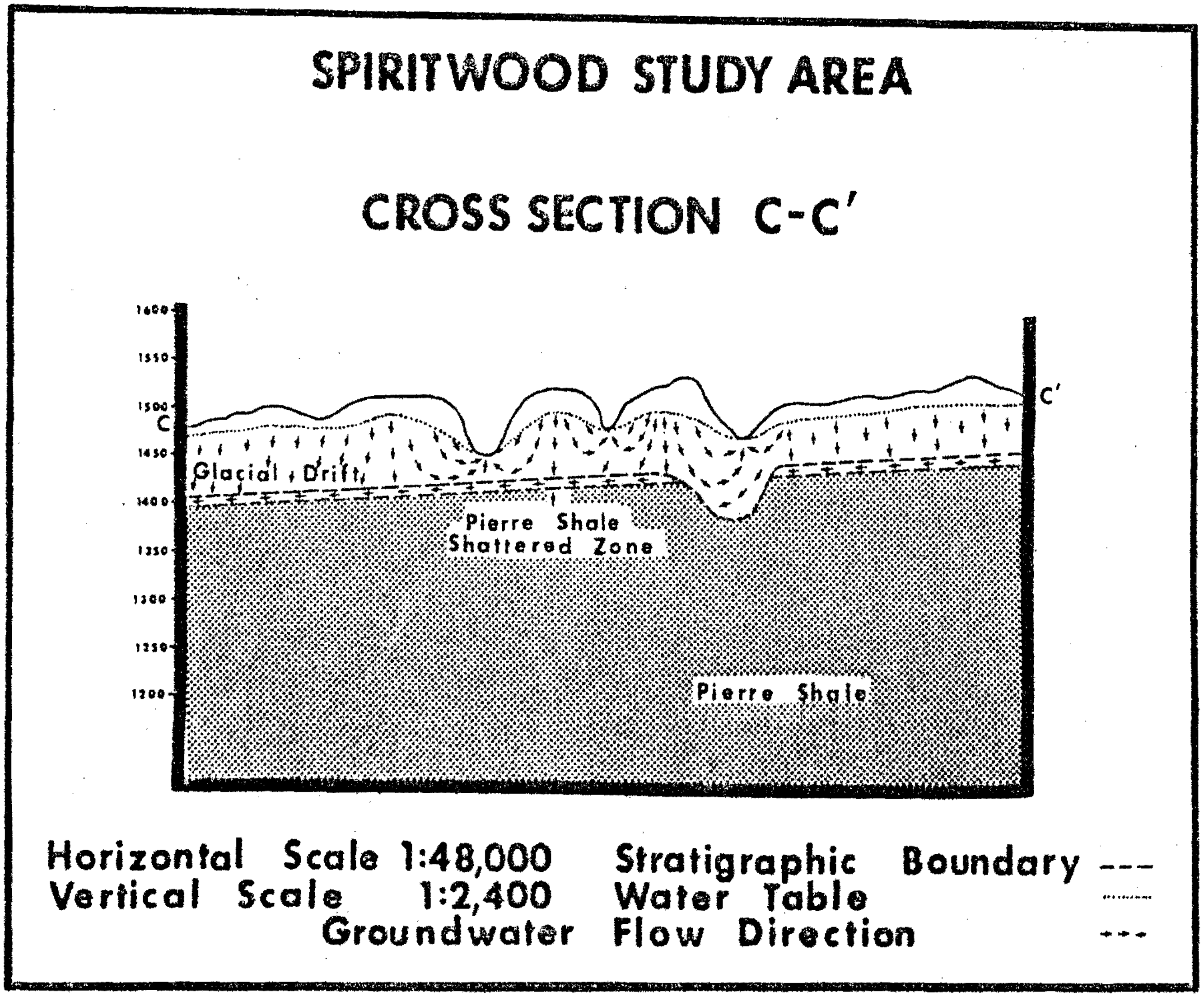

Fig. 25.--Pattern of groundwater flow in a cross section through the Spiritwood Lake area. The cross section is along line C-C' in Figure 17.

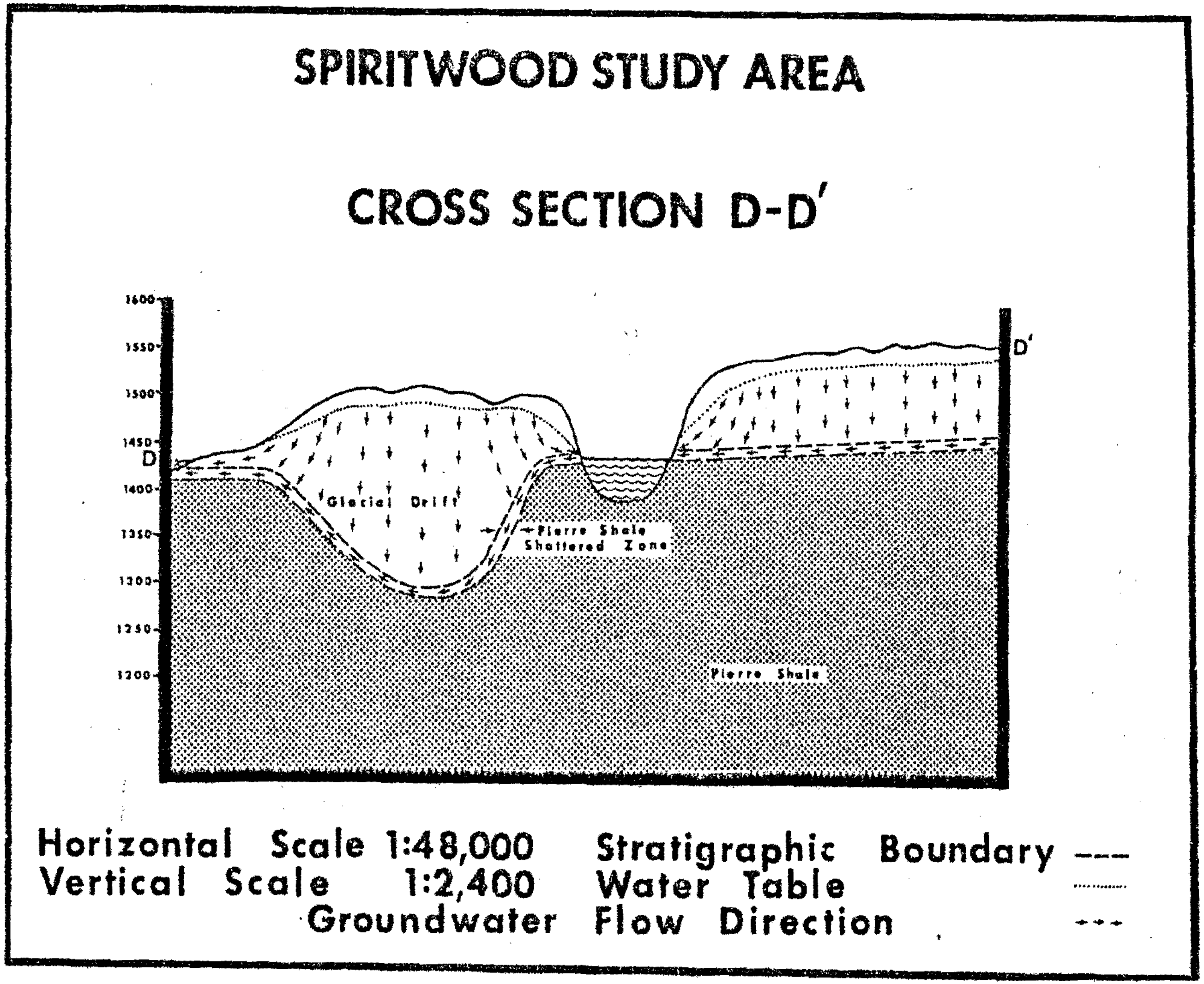

Fig. 26.--Pattern of groundwater flow in a cross section through the Spiritwood Lake area. The cross section is along D-D' in Figure 17.

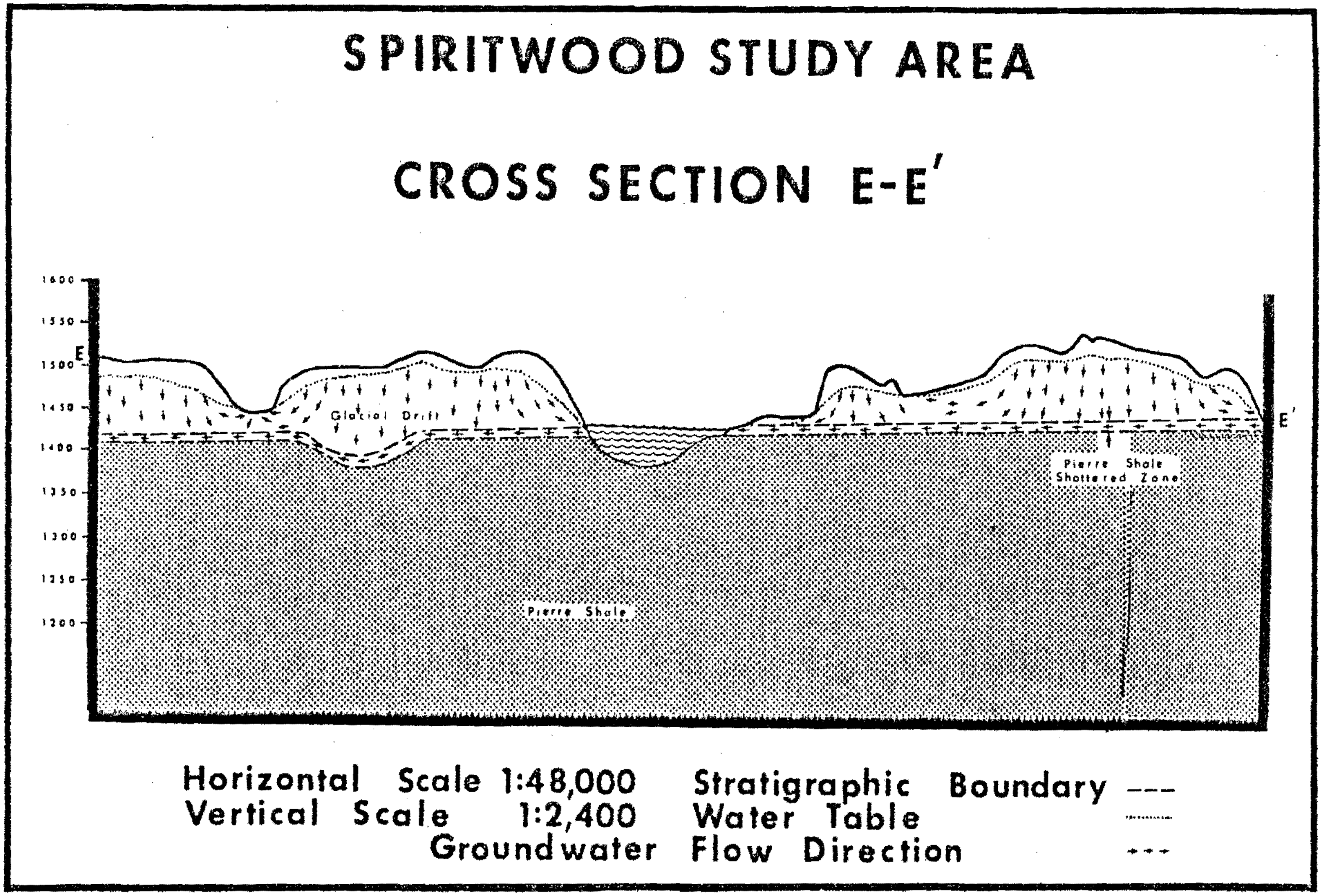

Fig. 27.--Pattern of groundwater flow in a cross section through the Spiritwood Lake area. The cross section is along E-E' in Figure 17.

The vertical permeability of the till is an order of magnitude higher. Fracturing increases the field permeability of the till to a range of 1×10^{-6} to 1×10^{-7} m/s. These figures are similar to the permeabilities given for the tills of Rolette County, North Dakota (Deal, in press). The small bodies of lake sediment scattered throughout the study area have permeabilities similar to that of the till.

The sand and gravel that occurs as lenses in the till or as glacially associated fluvial deposits has a laboratory permeability range of 1×10^{-4} to 1×10^{-2} m/s. The large permeability range depends on the amount of silt and clay mixed with the coarser particles. The vertical permeability of the sand and gravel is generally lower than the lateral and longitudinal permeability, but the difference is not as great as in tills. Field permeabilities are close to the laboratory permeabilities of the sand and gravel.

The direction of water movement in the local groundwater-flow system is dependent on topography and varies from flow system to flow system and within flow systems. The hydrodynamic-potential gradient of the flow systems varies from 0 to 0.1 m/m. Usually the lateral and vertical components of flow are larger than the longitudinal component. The potentiometric surface that forms the water table is a subdued replica of the topography, slightly modified in areas of high permeability.

Some of the water in the local flow systems is delivered to the intermediate groundwater-flow system of the area. Most of the flow, however, discharges at the surface. Only the local groundwater-flow systems directly adjacent to the melt-water channel containing Spiritwood Lake discharge into the lake.

Intermediate Flow System

The groundwater of an intermediate flow system moves through the study area. Most of the flow in this system moves through a zone of shattered shale and clean fine sand. This zone forms the upper 15 feet of the Pierre Shale in most of the area. In at least one location, slumping on the preglacial surface has placed several feet of unshattered Pierre Shale above this shattered zone.

The laboratory permeabilities of the Pierre Shale shattered zone range from 1×10^{-9} to 1×10^{-2} m/s. The lower permeability zones are shale, and the zones of high permeability are sand. Permeabilities in the longitudinal, lateral, and vertical directions are of the same order of magnitude. Field permeabilities for the shattered zone in the Pierre Shale is nearly 1×10^{-3} m/s.

The laboratory permeability of the Pierre Shale below the shattered zone ranges from 1×10^{-11} to 1×10^{-9} m/s. Small fractures in the shale increase the field permeability of the shale, but not enough to carry more than a small fraction of the intermediate groundwater flow of the study area. For this reason, the intermediate flow system is believed to be confined to the shattered zone between glacial drift and the unfractured Pierre Shale.

The plane that forms the bedrock surface of the Spiritwood Lake area is dissected by two drainage networks. These networks are noted and described in the geology section of this report. The melt-water channel system parallel to the Kensal Moraine is the youngest of the two networks (Figure 12). This channel, containing Spiritwood Lake, is cut below the shattered zone in the Pierre Shale. The line of intersection between the melt-water channel and the shattered zone is marked by a series of seeps discharging from the intermediate groundwater-flow system into the channel containing Spiritwood Lake.

The oldest of the two drainage networks dissecting the bedrock surface is the buried preglacial drainage network. One large channel of the network cuts through the study area south and east of Spiritwood Lake (Figure 13). If the Pierre shattered zone marks the preglacial surface of the Pierre Shale, as postulated in the geology section, the buried preglacial drainage valley is the same age as the shattered zone, and the zone follows the bedrock surface of the buried valley. There is some evidence that the shattered zone in the Pierre Shale is at least partially interrupted along the sides of the buried preglacial valley by large-scale slumping. The slumping is probably associated with one of the first advances of ice across the study area.

The direction of water movement in the intermediate groundwater-flow system is from northeast to southwest as shown in Figure 22. Piezometers indicate the intermediate flow system of the area has a hydrodynamic-potential gradient of roughly 10 feet per mile southeast of Spiritwood Lake. The potential gradient of the flow system is believed to be slightly lower in the rest of the study area. The horizontal flow component (the vector sum of the longitudinal and lateral flow components) of the intermediate groundwater-flow system is an order of magnitude greater than the vertical-flow component in the Spiritwood Lake study area.

On the basis of the response time of Spiritwood Lake, the topographic configuration of the bedrock surface, and the characteristics of the Pierre Shale shattered zone, most of the water in the intermediate groundwater-flow system is believed to enter the system in an area about 10 miles from Spiritwood Lake.

The occurrence of periods of high precipitation and low precipitation is somewhat cyclic in North Dakota. Residents of the study area have noted that the water levels of Spiritwood Lake and the other two lakes in in the same melt-water channel lag behind these precipitation cycles by about 5 years. (Water level records are not available for Spiritwood Lake or the other two lakes.) This lag is assumed to be caused by variations in the flow rate of the intermediate groundwater-flow system in the area. The local groundwater-flow systems add little water to the lakes and variations in surface-water flow would have a more immediate affect.

If the shattered zone at the top of the Pierre Shale is continuous north and east of the study area, if the permeability of the shattered zone in the study area is representative, and if the hydrodynamic-potential gradient of the intermediate flow system is assumed to be 20 to 30 feet per mile, computations using Darcy's Law show that water in the intermediate groundwater-flow system travels about 10 miles in 5 years. If the thickness of the zone of shattered Pierre in the area is representative and if the shattered zone is intersected all along the melt-water channel containing Spiritwood Lake, a comparison of the change in volume of the lakes and the rate of groundwater flow through the shattered Pierre Shale shows that a change in hydrodynamic-potential gradient of 5 feet per mile would account for all the water level fluctuations of the three associated lakes. The three lakes in the melt-water channel are connected by a thick highly permeable gravel. Groundwater moves through this gravel to keep the lakes about the same level.

A topographic map of the bedrock surface (Bluemle, 1971a) shows a high area 8 to 15 miles north and east and 100 to 200 feet above Spiritwood Lake. Recharge into the intermediate flow system of the area is believed to take place along the slopes of this bedrock high. The source of the groundwater is seepage from local groundwater-flow systems.

Fluctuations in the level of Spiritwood Lake are believed to occur in the following way. The rate of recharge of the intermediate groundwater-flow system fluctuates with time. Recharge increases in periods of high precipitation and decreases in periods of low precipitation. Changes in hydrodynamic potential in the discharge area reflect these rate changes.

If hydrodynamic-potential change could be transmitted instantaneously, the potential gradient of the flow system would distribute the fluctuations over the length of the groundwater-flow path and a change in hydrodynamic potential gradient would immediately increase or decrease the rate of discharge.

Hydrodynamic-potential changes in a groundwater-flow system do not take place instantaneously, however. The transfer of the potential is limited by the rate of water movement and will travel only as fast as the permeability of the sediment and the potential gradient will allow. This is the reason for the lag time the water levels in piezometers require to react to fluctuations in hydrodynamic potential in sediment of low permeability and the time required for the water table to return to normal after a pump test.

In the Spiritwood Lake area during periods of high precipitation the rate of recharge into the intermediate flow system of the area increases. This increases the hydrodynamic potential of the recharge area, which in turn increases the hydrodynamic-potential gradient and groundwater-flow velocity at the recharge end of the flow system. The increased potential gradient moves down the flow system as fast as the increased velocity can transfer the additional volume of groundwater.

The increased potential gradient remains constant in the recharge area until the rate of recharge changes. If the rate of discharge decreases, the potential gradient in the recharge area decreases and a lower hydrodynamic-potential gradient migrates from the recharge to the discharge areas of the flow system. The result of periodic fluctuations in recharge rate will be periodic fluctuations in the discharge rate, offset by the time required to move a change in hydrodynamic-potential gradient through the groundwater-flow system. In the intermediate flow system of the study area this time seems to be about 5 years.

Groundwater Chemistry

Water samples were collected from the Pierre Shale, till, and the fluvial sand and gravel of the Spiritwood Lake area. The distribution of the major cations and anions in water samples from the Pierre Shale is shown in Figure 28. Similar distributions for till and fluvial sand and gravel are represented in Figures 29 and 30 respectively.

Groundwater from the Pierre Shale is characterized by low calcium and magnesium and high sodium concentrations. Two types of anion distributions occur in the Pierre Shale of the study area. The groundwater samples from the unshattered Pierre are rich in chloride and sulfate and also contain a high percentage of bicarbonate. Compared to the till and fluvial sand and gravel of the study area, the nitrate concentration of the groundwater in the Pierre Shale is low. In Stutsman County, the Pierre groundwater is reportedly rich in boron, compared

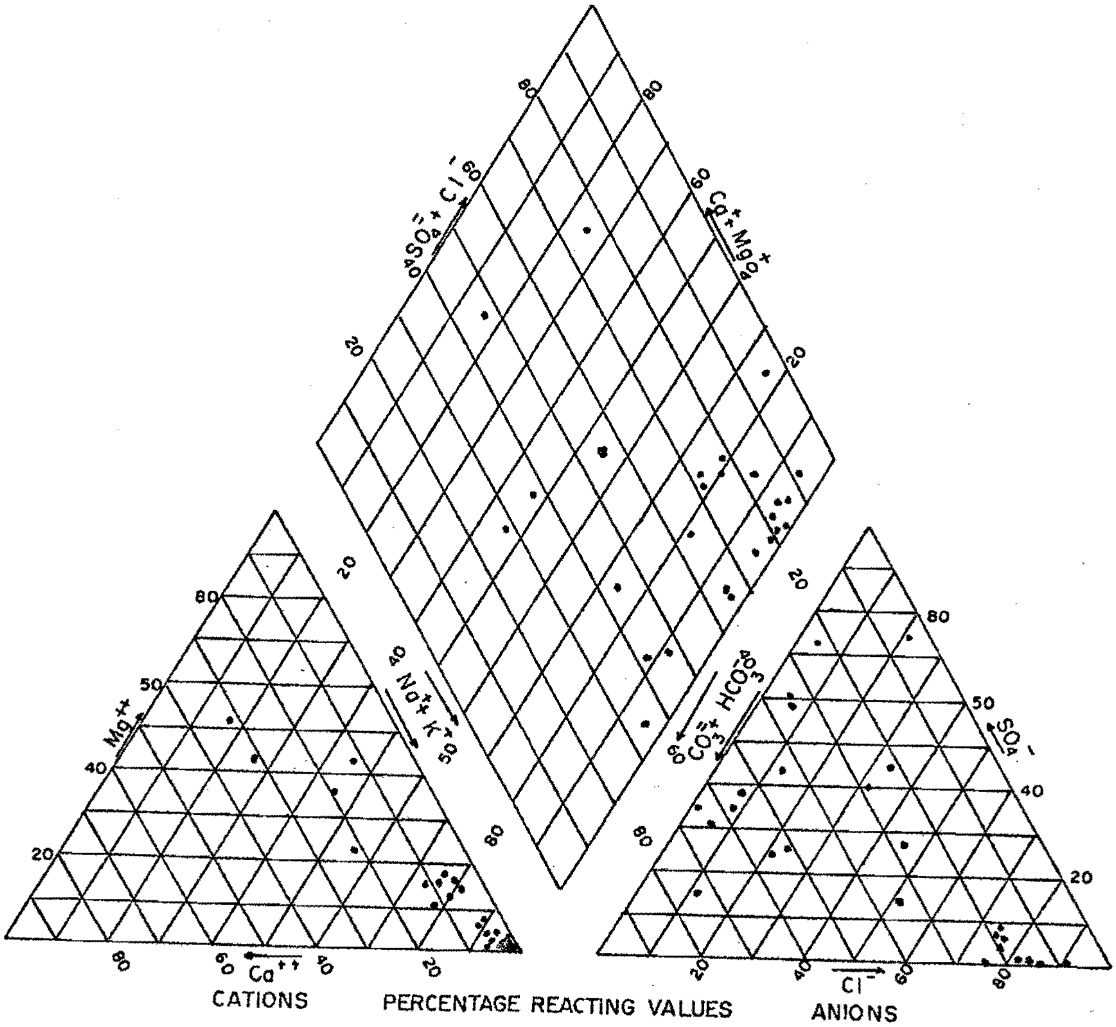

Fig. 28.--Chemical-analysis diagram of the groundwater from the Pierre Shale in the Spiritwood Lake area.

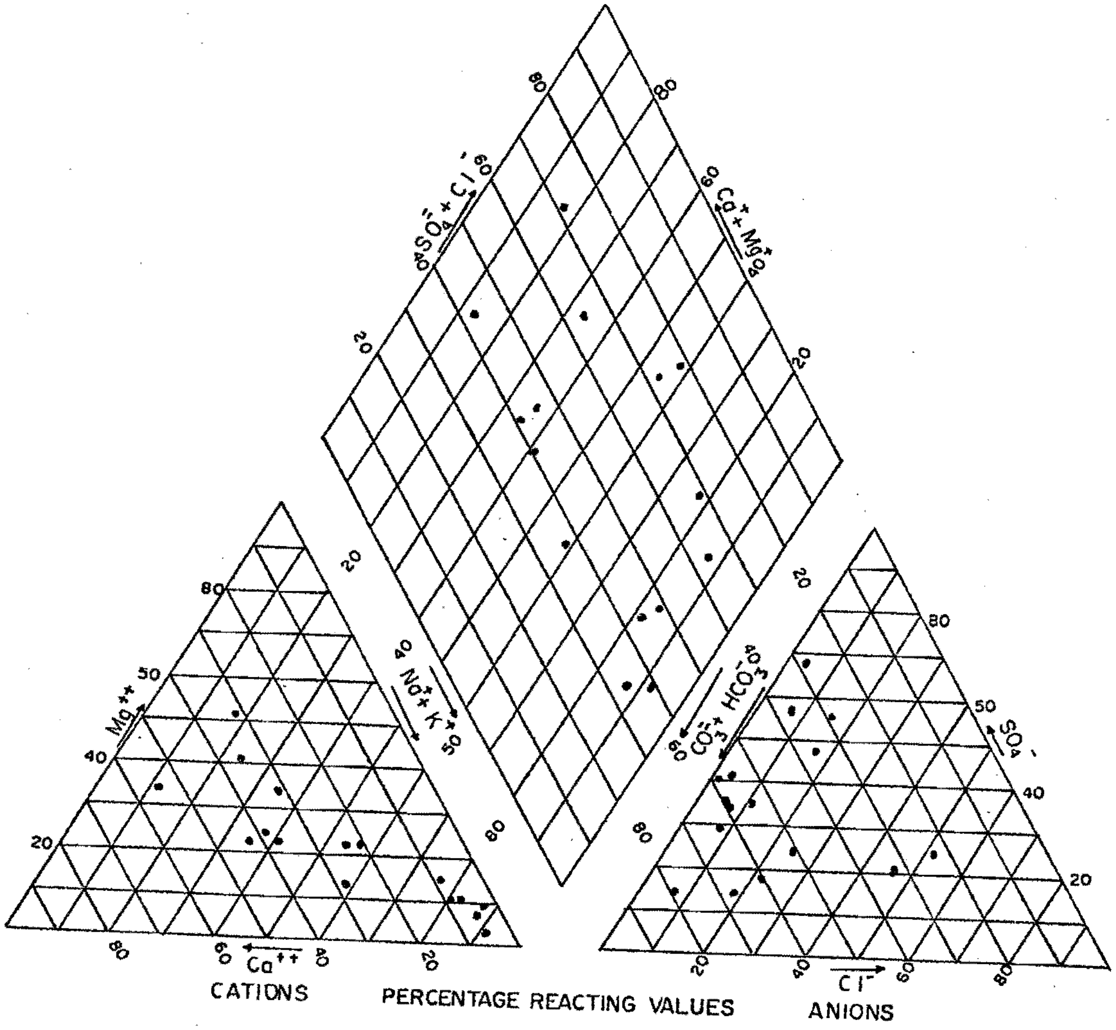

Fig. 29.--Chemical-analysis diagram of the groundwater from till in the Spiritwood Lake area.

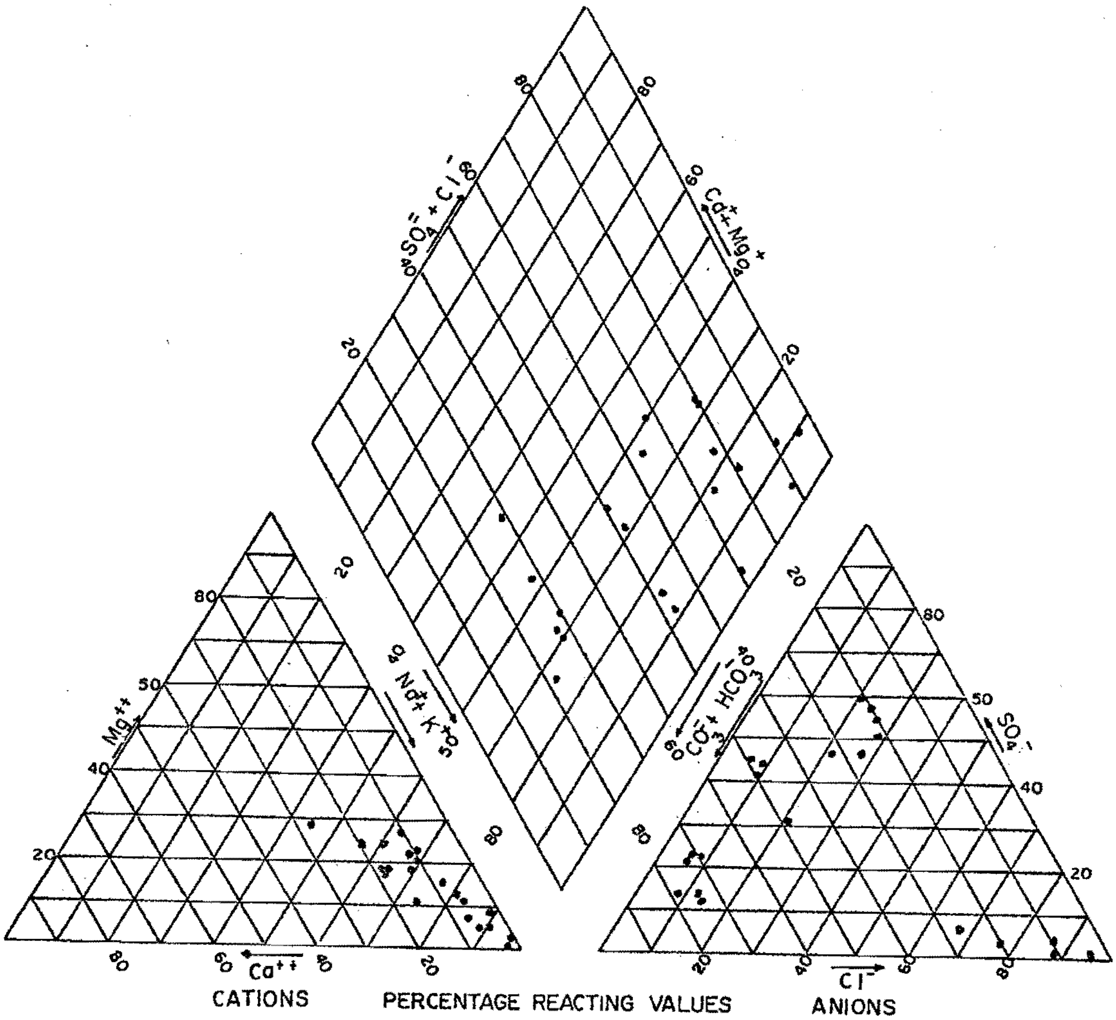

Fig. 30.--Chemical-analysis diagram of the groundwater from the fluvial sand and gravel in the Spiritwood Lake area.

to groundwater in the older Dakota Group and the overlying glacial drift. However, the Pierre does not have the high fluoride concentration characteristic of the Dakota Group rock (Huxel and Petri, 1965, p. 41).

The chemical composition of the groundwater samples from the till and fluvial sand and gravel are similar to the groundwater samples from the shattered zone in the Pierre Shale. The concentration of calcium is commonly higher in the groundwater of the till, whereas the bicarbonate-ion concentration is higher in the groundwater of both the till and fluvial sand and gravel. However, the groundwater of the three units can not be conclusively distinguished by chemical composition.

In a few locations, especially where water samples were taken near the surface, the groundwater samples from the till and fluvial sand and gravel are rich in nitrates and phosphates. The chemical analysis of all water samples used in this study are listed in Appendix D.

Chemical Ratios

The waters of the local and intermediate flow systems in the area can not be distinguished using the chemical ratios computed in this study. If the intermediate-flow system recharges about 10 miles from Spiritwood Lake, if most of the water in the intermediate flow system is derived from local flow systems in the glacial drift, and if the water in the intermediate flow system is in the shattered zone of the Pierre only 5 years, as computed with Darcy's Law, it seems reasonable that the groundwater in the local and intermediate flow systems of the area would be closely related and could not be distinguished by chemical composition or chemical ratios. The chemical ratios computed for the water samples used in this study are listed in Appendix G.

Saturation Indices

Almost all the groundwater samples from till or from fluvial sand and gravel, as well as most of the samples from the shattered Pierre Shale have $CaCO_3$ and $CaMg(CO_3)_2$ saturation indices that are near one which indicates that the water of these samples are nearly saturated with $CaCO_3$ and $CaMg(CO_3)_2$. If these samples are representative of the waters they were collected from, any change in pH, temperature, or chemical composition of the water will cause either precipitation of these compounds from the groundwater or solution of these compounds from the sediment. If the $CaCO_3$ and $CaMg(CO_3)_2$ saturation indices of the study area are typical of glacial drift, saturation index computations may well reveal the reason for some of the irregularities in caliche deposits.

The $CaSO_4$ saturation index of all the groundwater samples was negative, which means that all of the water samples were undersaturated with $CaSO_4$.

The saturation indices of the water samples used in the study are listed in Appendix J.

Chemical Potential

The chemical potential of the groundwater samples collected in this study is variable. However, no consistent pattern could be distinguished in the variation. The area is probably too small and the flow systems too closely related to distinguish meaningful patterns of variation in chemical potential. The chemical potentials computed for the water samples used in this study are given in Appendix K.

Groundwater Temperature

The groundwater temperature in the Spiritwood Lake area is normally from 7° to 8° C. The groundwater temperature for the till and the fluvial sand and gravel seems to be slightly higher than the groundwater temperature for the Pierre Shale. Seasonal changes in surface temperature affect groundwater temperatures down to a depth of 15 to 20 feet.

The thermal potential of the groundwater in the area does not vary appreciably and was not important in understanding the local and intermediate flow systems. Thermal potentials would probably be important in a study of deeper groundwater-flow systems. Huxel and Petri (1965, p. 45) state that in Stutsman County,

> variations of groundwater temperature with well depth were evident. The water from wells less than 20 feet deep varied from 42 to 51° F; from wells 21 to 120 feet deep, 43 to 45° F; and from wells 120 to 340 feet deep, 45 to 49° F. Water from wells penetrating the Dakota Sandstone, at depths of about 1,300 to 2,000 feet is about 73° F. Temperature of the water from the Dakota Sandstone in Barnes County ranged from 68 to 72° F (Kelly, 1964, table 4).

Temperature changes of this magnitude indicate large variations in the thermal potentials in the groundwater-flow system beneath Stutsman County. A study of the regional groundwater-flow systems of the area should include a study of the variation in thermal potential.

Lake Level Control

Spiritwood Lake receives water from precipitation, surface-water flow, discharge from local groundwater-flow systems, and discharge from the intermediate groundwater-flow system. Water is lost from the lake by evapotranspiration, groundwater recharge, and surface-water flow when the lake level is very high. The volume of water added or removed by each of these means is unknown. However, the lag time between the water level in the lake and the periods of high precipitation indicates that the factor controlling the lake level is the rate of discharge from the area's intermediate groundwater-flow system. If this is true, the lake level can be stabilized by creating a surface-water flow from the lake that matches the discharge into the lake. This could be done by digging a channel down Sevenmile Coulee to a depth that would keep the lake at the desired level.

How to artificially control the level of Spiritwood Lake is not a problem. The problem to be considered is whether or not the lake level should be controlled. These three factors must be considered. (1) What affect will draining water from the lake have on the intermediate groundwater-flow system? (2) What affect will draining water from the lake have on the lake level when the lake is low? (3) Do the economic considerations gained in artificially controlling the level of the lake justify the cost of draining the lake and the economic loss caused by the draining.

Spiritwood Lake is a discharge area for the intermediate groundwater-flow system of the study area. Consequently, lowering the lake level would probably have little affect on the intermediate groundwater-flow system.

Artificially controlling the lake level would undoubtedly lower the lake level during periods when the lake is low. The size of the effect is unknown and could only be determined from an accurate water budget of the lake kept over at least 10 years. A guess is that the volume the lake would be reduced during periods of low lake level by about half the volume removed during periods of high lake level.

The economics of artificially maintaining Spiritwood Lake at its present level is questionable. The replacement cost of the summer homes and destroyed vegetation around the lake would probably not be as great as the cost of controlling the lake artificially.

Summer fallowing began in a large scale in the 1950's and 1960's in the Spiritwood Lake area. This markedly increases the recharge into the groundwater-flow systems of the area. The increased recharge should cause the level of Spiritwood Lake to rise steadily in the coming years. It would seem reasonable to let the lake grow until it reaches a level at which surface flow occurs. At this point the level of the lake would be naturally stabilized.

CHAPTER V

SUMMARY OF CONCLUSIONS

The following conclusions were reached in this study.

Geological Conclusions

1. The upper part of the Pierre Shale forms the bedrock surface in the Spiritwood Lake area. The bedrock surface is overlain by 0 to 200 feet of glacial drift.

2. The bedrock surface in the study area forms a plain with moderate topographic relief. Two valleys occur on the bedrock surface. A shallow valley runs northwest-southeast across the center of the study area about 70 feet below the general surface of the bedrock plain. This depression was cut by melt water during one of the last glacial advances through the study area. A deeper bedrock valley runs northeast-southwest about 200 feet below the general surface of the bedrock plain. This valley is part of the preglacial drainage system of the study area.

3. The undisturbed Pierre Shale in the study area is a dense, massive, noncalcareous shale. A semicontinuous, highly permeable zone of shattered Pierre lies between the undisturbed Pierre and the overlying glacial drift of the study area. This shattered zone is believed to mark the preglacial surface of the study area.

4. The glacial drift of the study area includes material of three facies: till, sand-gravel, and clay-silt. The sediment of the till facies was deposited by the action of glacial ice. The sediment of the sand-

gravel facies was deposited by streams. The sediment of the clay-silt facies was deposited by lacustrine, eolian, or fluvial processes.

Groundwater Theory Conclusions

1. Potential is an expression of the energy of a system. All forms of energy involved in groundwater-flow systems can be expressed in terms of potential. The potential approach to groundwater studies allows the comparison of various types of energy contained in a groundwater-flow system. Gravitational, hydrostatic-pressure, velocity, thermal, chemical, and other potentials exist for every point in a groundwater-flow system.

2. Bernoulli's Equation can be used to express the elevation, velocity, and hydrostatic-pressure of any point in a groundwater-flow system in terms of gravitational, velocity, and hydrostatic-pressure potential, respectively.

3. The Gibbs free energy of the non-H_20 constituents of groundwater may be used as an approximation of the chemical potential of the water if the standard datum for water is considered liquid at 25^o C and 1 atmosphere pressure and if the datum for the other chemical constituents of the groundwater is crystaline solid at 0^o K. If these datums are used, the chemical potential of groundwater will usually be negative.

4. The thermal potential of groundwater is equal to the specific heat of the groundwater times the difference in temperature between the groundwater and datum point, if the specific heat of water is constant over this temperature range. Absolute thermal potential is measured from 0^o K.

5. Total potential and its component potentials can be expressed as potential heads. For this reason, potentiometric surfaces can be contoured for the potentials, either singularly or collectively, just as is done for hydrodynamic potentials of groundwater flow.

6. Existing mathematical models for groundwater flow can be adapted for the various potentials or for the total potential. Once potential boundaries have been established and defined, digital computors and difference equations can be applied to potential models.

7. Chemical ratios are numerical relationships between specific ions in the water at a particular point in a groundwater-flow system. Chemical ratios are useful in distinguishing the age and chemical facies of a water sample, differentiating the waters of separate flow systems, and determining the history of the water in a particular flow system. Chemical ratios are especially valuable in studies of regional and larger intermediate groundwater-flow systems.

8. A saturation index is a numerical indication of how close groundwater is to being saturated with the ions that form a particular compound. Saturation indices may suggest the history and maturity of groundwater and may be used to predict how the water will be altered along its flow path.

Study-Area Conclusions

1. Groundwater flow in the Spiritwood Lake area occurs in several local groundwater-flow systems and one associated intermediate groundwater-flow system.

2. The local flow systems occur in the glacial drift of the area and flow from topographically high areas to topographically low areas.

3. The intermediate groundwater-flow system occurs along the zone of shattered Pierre Shale between the undisturbed Pierre and the overlying glacial drift. Water in the intermediate flow system moves from northeast to southwest.

4. The level of Spiritwood Lake is controlled by the discharge from the intermediate groundwater-flow system of the area.

5. In comparison with the intermediate groundwater-flow system, the local groundwater-flow systems do not add an appreciable volume of water to Spiritwood Lake and the two adjacent lakes.

6. The local groundwater-flow systems of the study area and of the area north and east of the study area discharge water into the intermediate groundwater-flow system of the area.

7. The average flow-path length for water in the intermediate groundwater-flow system is believed to be about 10 miles.

8. The time required to transfer a change in the hydrydynamic-potential gradient from the recharge to the discharge area of the intermediate groundwater-flow system is indicated by the time lag between the fluctuations in the water level of Spiritwood Lake and changes in area precipitation.

9. The chemistry of the water in the local groundwater-flow systems of the area is closely related to the chemistry of the water in the intermediate groundwater-flow system.

10. Chemical ratios were not useful in distinguishing the waters of local flow systems from the waters of the intermediate groundwater-flow system.

11. Saturation indices indicate that most of the groundwater in the local and intermediate groundwater-flow systems of the study area are saturated or nearly saturated with $CaCO_3$ and $CaMg(CO_3)_2$.

12. Artificially controlling the level of Spiritwood Lake would not be economically feasible.

APPENDIX A

METHODS USED FOR DATA COLLECTION, WATER ANALYSIS, AND PARAMETER CALCULATION

METHODS USED FOR DATA COLLECTION, WATER ANALYSIS, AND PARAMETER CALCULATION

Location Format

In this study, the format used for location of test wells follows the scheme shown in Figure 31. This system is a modification of the system used by the United States Bureau of Land Management. Each location designation consists of three numerals, separated by hyphens, and three upper-case letters. The first numeral indicates the township north of the area base line. The second numeral indicates the range west of the principal meridian. The third numeral represents the section in which the well is located. The capital letters indicate subdivisions of the section. The first capital letter indicates the quarter section; the second letter indicates the quarter-quarter section; and the third letter indicates the 10 acre subdivision within the quarter-quarter section. The subdivisions of the sections, quarter sections, and quarter-quarter sections are lettered A, B, C, and D in a counter-clockwise direction beginning in the north-east quarter. For example, a well located in the NE¼ of the NW¼ of the SE¼ of sec. 36, t. 141. N., R. 62 W. would be designated 141-62-36DBA.

Drilling and Piezometer Installation Program

Drilling Program

The primary objective in planning the test-drilling program was to obtain the maximum amount of information from the limited funds available. The secondary objective was to develop standard procedures,

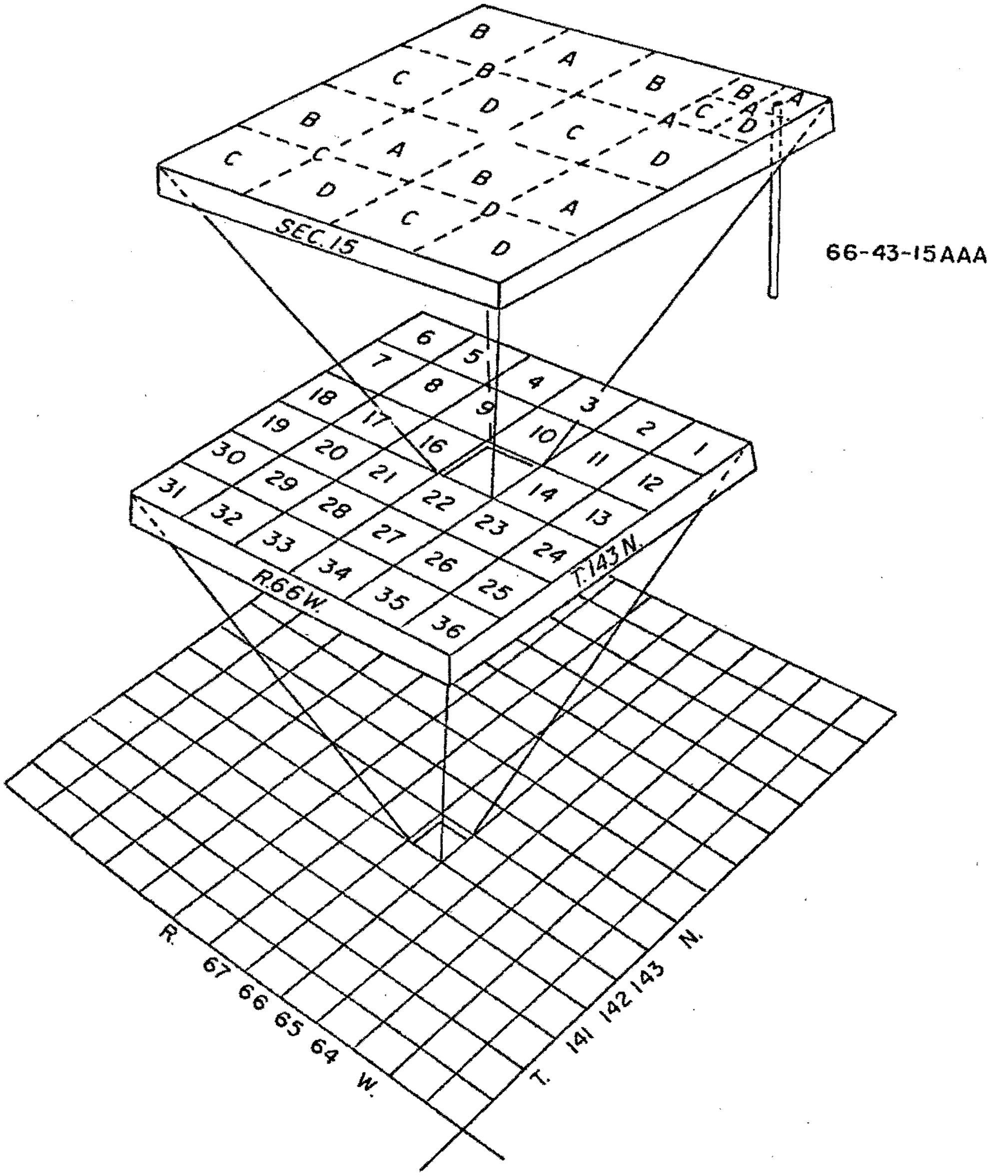

Fig. 31.--Diagram showing the location format.

adapted to North Dakota groundwater conditions, that would deliver a maximum amount of information of an acceptable quality at a moderate cost.

The test-drilling program was divided into two phases. The first phase included the drilling of the holes and the collecting of stratigraphic information. The second phase included the installation of piezometers for the collection of physical and chemical data.

The procedures used in the drilling program for the Spiritwood Lake area are as follows. The first phase began with a preliminary study of the area. This included reading reports and papers, examining aerial photographs, examining soil maps and biological studies of the area, and talking with individuals who were familiar with the area. The data gathered here, in addition to a field investigation of the geology, was used to develop a preliminary evaluation of the geology and groundwater of the Spiritwood area.

The preliminary evaluation was then used to establish a primary test-drilling program. This program was developed to determine the stratigraphy of the area and to establish the general pattern of groundwater flow. This information was then used to update the preliminary evaluation of the geology and groundwater.

After evaluating the area in light of the information obtained in the primary drilling program, a secondary drilling program was developed. This program was designed to accomplish two objectives. The first objective was to answer some of the general stratigraphic and groundwater problems of the study area still remaining after the primary drilling program. Based on the information from the primary drilling program a small section of the study area was chosen for more intensive study. The second objective of the secondary drilling program was to obtain as detailed a control of this small section as the resources available would allow. After the secondary drilling program, a final evaluation of the stratigraphy and groundwater of the area was compiled.

The test wells in the Spiritwood Lake area were made with three different drilling rigs. In the primary drilling program, the shallow holes were made with North Dakota Geological Survey's truck-mounted auger (4 inch diameter). The deep holes were made with a truck-mounted rotary drill belonging to the North Dakota State Water Commission. In the secondary drilling program, the drilling was contracted. The holes were put in place with a large truck-mounted rotary drill owned by the Mann Drilling Company of Garrison, North Dakota.

Sediment samples were collected every 5 feet. These samples were used to compile field descriptions of each stratigraphic unit. Munsell Soil Color Charts were used as references for describing sediment color. Wentworth's (1922) size terminology was used for sediment particles. For coarse samples, the descriptive size terminology of Willman (1942) was used. For fine samples, the descriptive names used were those of Trefethan (1950). Roundness was visually estimated using the black silhouettes of Pettijohn (1949) as a standard. The sorting of the sediment was approximated visually, using the terminology of Trask (1932).

Samples were bagged and marked for further references. The field descriptions of the stratigraphic units are found in Appendix B of this report.

Piezometer Installation

Several kinds of standpipe piezometers of the Casagrande type (Casagrande, 1949) were installed in the Spiritwood Lake area. All holes drilled for the piezometers were 4 inches in diameter. In the primary drilling program, a 1-inch diameter standpipe was used for auger holes, and a 1¼-inch diameter pipe was used for the rotary-drilled holes. In the secondary drilling program 1¼-inch diameter pipe was used for all the piezometers.

The normal procedure used to install piezometers in both the primary and secondary drilling programs was as follows. First, a length of plastic pipe was cut several feet longer than the test hole in which it was to be installed. Then one end of the pipe was plugged, and the lower 3 feet of the pipe above the plugged end was slotted with a hack saw. The slots were made about one third of the way through the pipe and about 3/4 inches apart, with the cuts offset at about 90 degrees. In a few holes in the primary drilling program, 3-foot sand-screens and points were used in place of the slotted pipes. These were used primarily to check the effectiveness of the slotted pipes.

After being slotted, the plastic pipe was inserted into the test hole and packed in place with pea gravel to a depth greater than the length of slotting on the pipe. The gravel-packed part of the hole was then cemented off from the open hole with a mixture of portland cement and pea gravel. This cemented section was normally 4 to 5 feet thick. The rest of the hole was then filled with clay, gravel, and till to a few feet from the surface. The hole settled for a few days and then was cemented up to a few inches above the surface.

After the piezometers were installed, the holes were cleared of as much loose sediment as possible. In the rotary-drilled holes, this was accomplished by pumping water down through the piezometer and then letting water and the sediment it picked up flush around the pipe and spill out at the surface. For the auger holes, this was not possible. The water that accumulated in the auger hole was bailed out. The bailing resulted in the removal of much of the loose sediment.

After the piezometers were cleaned, they were allowed to stand for 3 weeks before use. This was to insure time for the water level in the piezometers to come to equilibrium with the surrounding groundwater. The last step in installing the piezometers was marking and sealing them. In the primary drilling program, the piezometers were marked by placing electric fence posts beside the well. A metal cap over the upper end of the pipe sealed it. In the secondary drilling program, steel fence posts were used to mark the well sites along road ditches. In those areas where livestock might be a problem, the piezometers were protected by a barbed-wire fence. The upper end of all the piezometers in the secondary drilling program were threaded and closed with a 1¼-inch male plug.

Evaluation

General.--The following evaluation of the groundwater drilling program in the Spiritwood Lake area each consist of two parts. The first part is an evaluation of the types of installations used in the primary and secondary drilling programs. The second part is a recommendation for future studies. In the second part, information from the Spiritwood drilling program was combined with information from other studies, using other types of equipment, to make recommendations for future groundwater studies in North Dakota. The drilling methods are considered apart from the actual piezometer installations in the evaluations.

Drilling Methods.--In selecting drilling methods, the major considerations were cost, adaptability of equipment, reliability of stratigraphic information, and the quality of the completed well. Of the various alternatives possible, rotary and auger drilling seemed the most promising. Both were used in the Spiritwood primary drilling program; both were found to have advantages and disadvantages.

The important advantage of the truck-mounted auger as opposed to a rotary-drilling unit is cost. Less equipment and fewer people are needed to efficiently run the auger. The augered holes cost about a fifth as much as the rotary-drilled holes. A second advantage of the auger is that it does not introduce drilling mud into the hole. This was an important consideration where the holes were used to collect water samples or where the holes passed through clays where ion exchange or swelling might markedly change the sediment along the sides of the hole. The third advantage of the auger over the rotary unit is the sediment samples are not mixed with drilling mud as they came to the surface. This makes the samples both easier to describe and easier to decipher.

Offsetting the advantages, there are several disadvantages in using a truck-mounted auger in a drilling program. First, the auger is severely limited in where it can be used. It would not easily penetrate coarse gravel or bouldery till. Even in sediment that is easily drilled, the auger's maximum effective drilling depth is only about 100 feet.

A second disadvantage of the truck-mounted auger is the difficulty in getting representative samples in unconsolidated sediment. The sediment from higher up falls and mixes with that coming up from the bottom of the hole. By the time the sediment reaches the surface, it is hard to tell where the sediment came from. A thin 6-inch sand lense can appear to be 6 or 8 feet thick.

The third disadvantage of using a truck-mounted auger is the difficulty of installing piezometers in auger holes. Unless the auger holes are in very cohesive material such as till, the sides of the hole tend to cave. Many times it is impossible to get the piezometer pipe in place and pack it properly before the sides of the hole cave. Even where the pipe can be placed and packed properly, auger holes do not make good piezometers. There is no effective way to flush the piezometer of the clogging sediment. The two alternatives for cleaning the auger holes are blowing them out with compressed air or bailing them out. Neither procedure is very effective.

In contrast to the augered holes, the shallow, rotary-drilled test holes are very expensive. Comparable drilling costs are approached only for holes over 100 feet deep. In addition, rotary drilling introduces drilling mud and foreign water into the test hole, and the sediment samples are mixed with the drilling mud and water, making them harder to interpret. On the other hand, the rotary-drilling equipment can be used in almost any type of sediment, and even a small rig can drill down to the lowest depths of interest in most groundwater studies. Better stratigraphic sections can be compiled from rotary hole data because the circulating system of the rotary drill makes it easier to determine accurate sample depths. Another advantage is the circulating water in the rotary drilling rig helps to keep the sides of the hole from caving in unconsolidated material. After the piezometer is installed the circulating water can be used to flush out drilling mud and foreign material from the depth at which the piezometer is to draw the water.

Weighing the advantages and disadvantages of both the truck-mounted auger and rotary drill leads to the following two conclusions. First, the truck-mounted auger is satisfactory for groundwater studies only at shallow depths. Second, rotary drilling should be used in groundwater studies if at all possible. Initial costs for rotary drilling are high, but the increased quality of stratigraphic and water chemistry information obtained from the wells makes this the most economical method.

Piezometers.--Four types of piezometers are commonly used in groundwater studies. These are hydraulic piezometers, pneumatic piezometers, electric piezometers, and standpipe piezometers. Each of these uses a particular physical principle to measure pore pressure.

> The hydraulic piezometer is a very specialized device that is used almost exclusively to measure pore pressures in dams or embankments. It consists of a collection chamber made from porous stone connected directly to a pressure gauge. The piezometer tip must be located at an elevation only slightly below that of the pressure gauge. For this reason, its use in hydrogeologic investigations is severely limited (Schwartz, 1969).

The pneumatic piezometer consists of a tube sealed into a point in the groundwater-flow system and two connected pipes leading from the point in the flow system to the ground surface. The tube contains a pressure sensitive valve that opens or closes the connection between the two pipes. In the Warlam and Thomas (1965) pneumatic piezometer, air flows through the outlet pipe as soon as the pressure in the inlet pipe equals the groundwater pore pressure. In another common variety (Laufer and Schober, 1964, p. 643) liquids are used instead of air.

Electric piezometers are becoming increasingly important. The main component of these piezometers is a pressure transducer. This device converts a physical quality such as groundwater pore pressure into an electric signal. The variable inductance transducer is the kind usually used in electric piezometers. The pore pressure at the particular point where the piezometer is installed causes a mechanical deformation of a diaphragm in the transducer. This deformation displaces a primary coil with respect to a secondary coil of the transducer. The induced current in the secondary coil varies with displacement of the primary coil and can be calibrated against known pressures to measure unknown water pressure.

At least three different types of electric piezometers have been designed and are used in groundwater studies. Van Everdinger (1966, p. 70) used a submerged electric piezometer to determine pressures in confined aquifers under the South Saskatchawen Reservoir. Here, the transducers were installed in special housings at the top of a 2-inch standpipe. Wolff and Olsen (1968, p. 839) used an electric piezometer for monitoring rapidly changing water pressure in saturated clay. These differ from the first mentioned electric piezometers in that the transducers are located in the collecting chamber at the bottoms of the test holes. A third variety of electric piezometer is the type used by Lindgren (1966, p. 52). This type is unique because it can be installed at any level in a drill hole. It is sealed in place by simply inflating a rubber bag. This type also incorporates a "flushing line," which permits the piezometer to be calibrated in place by applying a known pressure across the diaphragm.

The fourth and most commonly used type of piezometer is the standpipe piezometer. In its simplest form, this piezometer consists of a pipe or lined borehole with one end at a point in the groundwater and the other at the ground surface. The pore pressure at the bottom of the piezometer is determined by measuring the height of the column of water that can be supported in the standpipe or lined borehole. The standpipe piezometer can be modified from its simplest form by selecting optimal test hole and standpipe diameters. It can be elaborated by putting a pressure gauge at the top of the standpipe for those areas where pore pressure is great enough to lift water over the top of the standpipe and by using continuous recording devices of various types to measure changes in the height of the supported water column. Descriptions of types of standpipe piezometers used are given in Lissey (1967, p. 198), Christiansen (1963), Freeze (1964), and Olsen (1965).

Once the variations of types of piezometers were considered, a choice had to be made as to what type of piezometer would be best suited to the Spiritwood study and to other groundwater studies in the state. Four criteria were used in making the decision. These criteria are reliability, durability, sensitivity, and cost.

Reliability is an indication of how close the measured pore pressure is to the actual pore pressure at the point in the flow system being monitored. Reliability includes the consistency of the measurements, the accuracy of the measurements over an extended period of time, and the fluctuation in the measurements due to other physical factors that can not be corrected for or eliminated.

Durability is an indication of a piezometer installation's ability to resist destruction over extended periods of time. This includes the rate of deterioration of pipes, packing, and measuring equipment, the vulnerability of the installation to vandalism or destruction by natural causes, and the changes in reliability of the installation with time.

Sensitivity is an indication of the time lag between when the pressure at a point in the groundwater system changes and when the piezometer at that point measures the change. Sensitivity is indicated by response time, the time required for a piezometer to register 95 percent of a groundwater pressure change (Gilliland, 1967, p. 10).

Cost is the fourth criteria used to evaluate the different types of piezometers. This criteria is extremely important and, in most projects is the deciding factor. Three types of costs must be considered. They are piezometer building and installation cost, maintainance cost, and information collection cost. The combined cost of these three factors must be considered when evaluating a particular piezometer.

Evaluation of the types of piezometers available, in terms of reliability, durability, sensitivity, and cost, eliminated three of the four commonly used types of piezometers.

The hydraulic piezometers are sensitive, reliable, and durable. However, unless the piezometers are used in the study of the groundwater of a dam, embankment, or similar structure, the cost of hydraulic piezometers makes them prohibitive.

Both the pneumatic and electric piezometers are sensitive to rapid changes in groundwater pore pressure. However, the electric piezometer is hard to keep in adjustment, calibration tends to change with time, and not enough is known about the pneumatic piezometer to make an estimate of its durability. Both the electric piezometer and pneumatic piezometers are expensive to install and maintain. The transducer for the electric piezometer costs from $300 to $500 (Schwartz, 1969). Accurate figures on the cost of pneumatic piezometers are not available but at the present time the piezometers would have to be specially made. Their cost would be close to that of an electric piezometer.

The fourth type of piezometer, the standpipe piezometer, was selected for this project, not because it is ideally suited but because it had the least disadvantages. Standpipe piezometers are reliable, durable, and comparatively low in cost. However, this type of piezometer is slow to react to a change in groundwater pressure, especially in material having a low permeability. The piezometers are especially insensitive to short term fluctuations.

The sensitivity or response time of a standpipe piezometer can be increased by decreasing the diameter of the standpipe and increasing the size of the intake. The intake is the part of the borehole from which the piezometer standpipe draws water. It is usually filled with a porous material and separated from the rest of the hole by an impermeable seal. According to Hvorslev's (1951, p. 12) theory, when the ratio of the "effective length" to the diameter of the intake remains constant, the response time in an open standpipe piezometer is inversely proportional to the diameter of the intake and directly proportional to the diameter of the casing. Table 2 gives the minimum permeability that would be needed to acceptably show the pressure fluctuations of nine different piezometers over four different time periods. The acceptability of the figures given in this table is based on "an arbitrary standard of compatibility" for piezometers (Gilliland, 1967, p. 11). Piezometers

TABLE 2

MINIMUM VALUES OF PERMEABILITY* FOR ACCEPTABLE PERFORMANCE

	Period			
Piezometer	2 min.	1 day	1 week	1 year
D = 6", d = .8"	5×10^{-4}	4×10^{-7}	2×10^{-8}	9×10^{-9}
d = 1¼"	2×10^{-4}	1×10^{-7}	8×10^{-7}	5×10^{-9}
d = 2"	7×10^{-3}	6×10^{-6}	4×10^{-7}	1×10^{-9}
D = 3", d = .8"	4×10^{-4}	2×10^{-7}	1×10^{-8}	8×10^{-9}
d = 1¼"	1×10^{-4}	9×10^{-6}	7×10^{-7}	4×10^{-9}
d = 2"	6×10^{-3}	4×10^{-6}	3×10^{-7}	1×10^{-9}
D = 1", d = .8"	3×10^{-4}	1×10^{-7}	1×10^{-7}	7×10^{-9}
d = 1¼"	9×10^{-3}	7×10^{-6}	6×10^{-7}	3×10^{-9}
d = 2	4×10^{-3}	3×10^{-6}	1×10^{-7}	9×10^{-8}

D is the effective diameter of the water intake.
d is the diameter of the standpipe.
L, the length of the water intake has been fixed at 3'

*The units of permeability are meters per second.

with a time lag of less than a twenty-fifth of the length of the naturally occurring fluctuations in groundwater pressure are acceptable. Such piezometers will have a lag time of no more than 0.04 periods and will receive at least 97 percent of the maximum amplitude of the fluctuation. The pressure fluctuations with periods of 2 minutes, 1 day, 1 week, and 1 year correspond to those produced by earthquakes, evapotranspiration of plants, weekly precipitation, and annual recharge-discharge respectively.

Before beginning the drilling programs in the Spiritwood Lake area, the minimum hydraulic conductivity of the shale and till in the area was estimated to be about 1×10^{-7} m/s. This estimate is believed to be quite accurate. The hydraulic conductivity of similar till in Walsh County, North Dakota, was found to range from 4×10^{-7} m/s to 5×10^{-4} m/s, with lateral permeabilities just slightly higher than vertical permeabilities. The higher permeabilities are not from the till itself but from interbedded sands within the till (Downey, 1972). The laboratory hydraulic conductivity of the shale in the Spiritwood Lake area is as low as 1×10^{-9} m/s. However, fracturing within the shale increased the conductivity of the shale to around 1×10^{-7} m/s. The minimum estimated hydraulic conductivity was used with the values in Table 5 to select piezometer dimensions for the Spiritwood project that would give acceptable response times.

The choice of piezometer sizes was severely limited. The outside diameter of the intake was determined by the bit size of the auger or rotary drilling rig used to make the boreholes. In all cases this was 4 inches. The standpipe of the piezometer is used to collect water samples, down-hole water temperatures, and pH measurements. The inside diameter of the standpipes had to be at least 1 inch in diameter to allow passage of the instruments used to collect this data. The sensitivity and sampling considerations limited the choice of piezometer standpipes to two diameters, 1 inch and 1¼ inch. Pipes of these sizes are readily available. They are large enough to allow the water chemistry instrumentation and sensitive enough to show moderately rapid changes in groundwater pore pressure. Piezometers of these dimensions are sensitive enough to record pressure fluctuations with periods of between 1 day and 1 week.

Normally, the 1-inch standpipe piezometer would be preferable because of its increased sensitivity to pore pressure fluctuations. However, the 1¼-inch diameter pipe is used in the observation wells of the North Dakota State Water Commission and most of the private contractors in North Dakota. Because of the quantity of this type of pipe used, high-quality 1¼-inch plastic pipe is readily available at a reasonable price. In addition, if rotary drilling equipment is used, the North Dakota State Water Commission and most contract drillers have the coupling equipment to connect 1¼-inch plastic pipe to their circulation system. If 1-inch pipe were used, coupling equipment would have to be purchased. For these reasons, 1¼-inch standpipe piezometers have advantages over 1-inch piezometers in North Dakota, especially in small limited-drilling groundwater projects. In large projects, the expense of using 1-inch piezometers would not be as great, and 1-inch standpipes would be preferable.

Once the use of standpipe piezometers was decided and the dimensions of the piezometers selected, piezometer construction in the borehole was considered. Piezometer construction involved three problems.

The first was how to let groundwater seep into the standpipe without filling the pipe with sediment. The second problem was chosing a material to pack between the standpipe and the sides of the hole to allow the groundwater to reach the standpipe and still keep the inlet diameter of the hole at 4 inches (the size of the borehole). The third problem was finding a method of sealing the borehole above the piezometer inlet which would prevent contamination and loss or gain of pore pressure from areas higher in the borehole. The following techniques were used to solve these problems.

Two solutions of the first problem were used in the Spiritwood study. The first was to seal the bottom of the standpipe and then cut slots along the lower 3 feet of the standpipe at half-inch intervals. The second was to use 3-foot, commercially made, sandpoints and screens at the bottom of the standpipes. Both solutions provided acceptable results. The screens let water into the standpipe faster than the slotted pipe section. However, the slotted pipe let water into the standpipe faster than it could be removed, and the extra efficiency of the screens was not needed. The commercial screens are several times as expensive as the slotted pipes. For these reasons, it is recommended that slotted pipes be used in future studies in preference to commercial screens and sandpoints.

The second problem in constructing piezometers, packing the area between the slotted standpipe and the sides of the borehole, was solved with washed pea gravel. Other materials could be used but the pea gravel is effective, cheap, easily obtainable, and easy to handle and work into place. For these reasons, it is ideal for packing the slotted part of the standpipes.

The third problem, sealing the borehole above the piezometer intake, has to be considered whenever standpipe piezometers are installed. Various materials have been used. Christiansen (1963) simply used clay fill. Others used aquagel mud (Schwartz, 1969). Freeze (1964) used small dry clay balls that expand in place, when they contact moisture. More complicated seals are used by the Inland Water Branch of the Canadian Geological Survey (Lissey, 1967, p. 198). An expanding metal basket or retaining ring is brazed to the side of the standpipe of each of their piezometers. Once the piezometer is in place this basket is expanded and filled from the top with concrete to seal the piezometer in place.

In the Spiritwood Lake study, the piezometers were sealed in place with a mixture of portland cement and pea gravel to a depth of about 4 feet. Then the rest of the hole was packed to within a few feet below the surface with fill. The top of the hole was filled in, and a mound around the top of the hole was formed with a mixture of pea gravel and portland cement.

The method used for the Spiritwood Lake study has several advantages. Cement forms a better seal than a clay fill. The method does not require expensive equipment or supplies such as aquagel mud or dry clay balls. The resulting seal is almost as effective as that used by Lissey, but much less expensive. For these reasons, the technique used at Spiritwood Lake is probably the most practical for use in groundwater studies in the state.

Collection of Water Samples

The collection of representative and uncontaminated water samples is necessary if any meaningful interpretation of the water chemistry is to be attempted. The procedures followed by the United States Geological Survey is outlined by Rainwater and Thatcher (1960). Generally their recommendations were followed. In cases where they were not, the alternative procedures used are given below. Water samples were obtained from standpipe piezometers in the study area, from Spiritwood Lake, and from spring-fed stock ponds. The samples were collected in high-density polyethylene bottles with polyethylene-lined backelite screw caps. Before collection, the sample bottles and caps were rinsed with distilled water and labeled with masking tape and pencil. After collection the caps of the sample bottles were screwed down tightly, and then taped with black plastic tape to insure a lasting seal during transportation and storage.

Three types of samplers were used to collect water from the piezometers of the study area. The first sampler used is one designed by John Cherry at the University of Manitoba. This sampler is made from a copper pipe 20 inches long and ½-inch in diameter. The top of the pipe is open. Two holes are punched through the pipe just below the upper rim to attach a cord for raising and lowering the sampler. The bottom of the pipe is fitted with a small metal butterfly valve, which allows water to pass up through the sampler but closes if the water tries to move in the opposite direction. The second type of sampler is an 18-inch plastic pipe, 3/4-inch in diameter. The pipe is open at the top and has a bail cord like that of the copper sampler. The sampler has a series of circular, plastic-coated weights to increase the weight of the sampler. The bottom of the pipe is fitted with a plastic ball valve that works much like the butterfly valve in the copper sampler. The same technique is used to collect water samples with both the copper and plastic samplers. As the sampler is lower into the hole, water passes through the sampler unobstructed. This continues until the sampler reaches the bottom of the hole. At the bottom of the hole the sampler fills with water. As the cord is pulled to draw the sampler back up the standpipe, the water in the sampler attempts to flow back through the bottom of the sampler. This action closes the bottom valve and the water contained in the sampler can then be lifted to the surface where the water is poured into a waiting sample bottle. This process must be repeated several times to fill a sample bottle.

A different principle is used in the third type of water sampler. This sampler is constructed from a 12-inch piece of 3/4-inch plastic pipe. One end of the pipe is left open, and as with the other water samplers, this end is attached to a cord to raise and lower the sampler through the standpipe. The other end of the sampler is closed with a plastic-coated metal cap. The weight of the sampler is increased by a number of plastic-coated lead weights inside the bottom of the sampler. The sampler is dropped into the standpipe of the piezometer and allowed to free fall to the bottom of the hole, trailing the retrieval cord behind it. As long as the sampler is free falling, water will not enter the sampler. However, as soon as the sampler stops it starts to fill with water. The water sample can then be retrieved by pulling it to the surface with the attached cord. This type of sampler is not as reliable as the other two types and was used only as a back up for the other types of water samples.

Water samples were collected from both the free-flowing and non-flowing piezometers in the Spiritwood Lake area. In general, the flowing wells draw water from the Pierre Shale, whereas the nonflowing wells draw water from till or fluvial sediment. For the flowing piezometers, collecting fresh representative water samples was not a problem. The nonflowing piezometers were flushed or bailed out when they were constructed and at the beginning of the summer field season, but they were not bailed before each water sample was collected. Because the piezometer standpipes were plastic and nonreactive to water and the included ions, and because the samples were collected near the perforations at the bottom of the standpipe, most of the water samples are believed to be representative of the groundwater system they were collected from.

Water Level Measurements

In this study, the static water level in a piezometer is considered to represent the hydrodynamic potential at the bottom of the well. The assumption is that the well casing or standpipe of the piezometer does not leak and that the column of water in the standpipe is sealed off from all but the groundwater pore pressure at the bottom of the well. In addition, it assumes that the static water level of the well has completely recovered from any addition or subtraction of water. Because care was taken to insure that the piezometers did not leak and were properly sealed, the first two assumptions are probably valid for almost all the piezometers in the Spiritwood Lake area. No water was added or removed from the nonflowing piezometers for at least a week before static water-level measurements were taken. Almost certainly these piezometers were stabilized to all but the fluctuations within the groundwater system. The flowing wells in the area had less of a chance to recover their static water level.

Consequently, pressures recorded for these wells may be slightly lower than the actual static water level. However, the measured head is believed to be close enough to the actual static head to be as accurate as the elevation and the depth measurements used to calculate hydrodynamic potentiometric surfaces.

Nonflowing Wells

The water level in nonflowing piezometers was measured with a battery operated electric water level indicator (Soiltest model DR-760A). The total head at the bottom of the piezometer was calculated by subtracting the depth from the top of the well to the water level from the elevation of the top of the piezometer.

Flowing Wells

The water pressure at the head of the flowing piezometers in the area was determined with a bourdon pressure gauge. The gauge was attached to the 1¼-inch piezometer standpipes with threaded adapters. The tops of the 1-inch piezometers were not threaded. For these, a rubber packer was attached to the gauge and inserted into the standpipe. The packer was then compressed and expanded to seal into the standpipe by tightening down a nut. This method is explained in detail by Hamilton (1970, p. 128).

After the bourdon pressure gauge was attached to the piezometer standpipe, it was necessary to shut in the standpipe for a period of time in order to obtain a reliable estimate of static water pressure. The shut-in time varied from site to site. Generally, however, the piezometer was shut in until the bourdon pressure gauge stabilized at a constant pressure. Once the gauge stabilized, the pressure was read in pounds per square inch and converted to feet of water. The value obtained was then added to the elevation of the bottom of the piezometer to obtain the hydrodynamic potential head for the point in the flow system at the bottom of the piezometer.

Elevation Determinations

The topographic-map coverage of the Spiritwood Lake area is very good. The whole area is covered in the 1951 edition of the Spiritwood Lake quadrangle in the U. S. Geological Survey 7.5 minute series of topographic maps. Because of the good topographic coverage, the ground elevations of piezometer locations could be determined by interpretation between map contour intervals.

Once the ground elevation of the piezometer was established, the height of the piezometer above ground was added to the ground elevation to determine the elevation of the top of the piezometer. The elevation of the bottom of the piezometer was determined by subtracting the height of the standpipe from the elevation of the top of the piezometer. It is estimated that the values obtained are within 3 feet of the actual elevations at least 90 percent of the time.

Analysis of Water Samples

Temperature, specific conductance, pH, and the concentration of the major cations and anions and many of the minor chemical constituents were determined for 58 water samples from the Spiritwood Lake area. Chemical analysis made by the North Dakota State Water Commission, the United States Geological Survey, and other agencies were used in the evaluation of the water chemistry of the area but are not included in the following discussion of analytical methods.

In the chemical analysis, only water temperature and pH was determined in the field. All water samples were transported to the laboratory for the rest of the chemical determinations. There were undoubtedly some changes in water chemistry between the time of collection and the time of analysis. However, many of the field chemical analytical methods maintain their accuracy only within a limited temperature range, and correction for field analysis of samples is difficult. In addition, many of the procedures used were limited to the laboratory because of the type of equipment needed. Techniques existed for making these determinations in the field but the accuracy of the laboratory methods is so much greater, that advantage of the laboratory methods are believed to offset any changes taking place during transportation to the laboratory. This belief was not tested in this study, but Hamilton (1970) found that no significant change in water samples occurred in their transportation from the field to the laboratory.

Measurement of potentiometric heads and water temperature as well as the chemical analysis of water samples was done at different times during the study. It was felt that for a better comparison of the water in various parts of the groundwater-flow system, the water samples should be collected in as close to the same instant in time as possible. For this reason, most of the chemical analysis and physical measurements recorded and used in this report were collected in a 2-day period in the fall of 1971. The exceptions, recorded here, are water analysis and data collected from piezometers destroyed prior to that time. In these cases, the data used was collected as close to that 2-day period as possible.

The following procedures are described in the order in which the samples were analyzed. The reproducibility of the methods was determined by duplicating the analysis of about 10 percent of the samples. Accuracy of the methods, when given, is based on manual specifications for the instruments used in the determinations.

Water Temperature

Groundwater temperatures were obtained in the field, through the standpipes of established piezometers. Measurements were made with a Whitney portable thermister (model TC-5A) equipped with a 3/4-inch diameter temperature probe and a 200-foot insulated cable. For each temperature reading the probe was lowered to the bottom of the standpipe and allowed to come to equilibrium with the temperature of the groundwater. If the holes were greater than 200 feet, the probe was lowered as far down the hole as possible and allowed to come to equilibrium there. Temperatures were found to vary little with depth within the same piezometer, for depths greater than 150 feet. Once equilibrium was established, the temperature was noted and then the thermister was allowed to stand for 1 to 2 minutes. If the temperature remained constant, that temperature was recorded.

The accuracy of the thermister used is 0.1°C for the range from 0°C to 40°C. The results obtained in the field were reproducible to 0.02°C.

pH

pH measurements were made in the field and again after the water samples had been transported back to the laboratory. In both places a Coleman Precision Portable pH Meter (model 37A) was used with a Coleman

3-472 Tri-Purpose Shielded Glass Electrode and a Coleman 3-711 reference electrode. This instrument was standardized with a 7.0 pH buffered solution each time it was used; it was checked against buffered solutions of between pH 6;0 and pH 10.0. All solutions were corrected for temperature variations with a manual temperature compensator. The Precision Portable pH Meter is accurate to ± 0.005 pH units if the instrument is properly adjusted. Readings are reproducible to ± 0.001 pH units under ideal conditions.

After the pH of all the water samples was determined, both in the field and laboratory, the field and laboratory measurements were compared for each sample. Some changes in pH did occur, especially in water samples with a pH below 8.0. However, in no sample did the change exceed 0.3 pH units, and in most samples the change was considerably smaller. The pH measurements included in this report are those measured in the field. No attempt was made to correct the water chemistry results obtained in the laboratory for changes in pH.

A special downhole cable and probe was designed for use with the Coleman Portable Precision pH Meter to find the pH of groundwater in place. The downhole cable and the circutry for the probe was designed and built by David Krile of Dayton, Ohio. The probe itself was made from a 15-inch by 3/4-inch plastic pipe. The pipe is open on the bottom, has a slot cut on both sides about one-third the way up the pipe, and has a second similar slot about two-thirds the way up. The top of the pipe is filled with and glued to a 4-inch long plastic-coated brass cylinder. A small round vertical hole passes completely through the cylinder to allow three insulated copper wires to pass down into the rest of the plastic pipe. The top of the pipe and cylinder is equipped with a plastic-coated clamp designed to be tightened around the wires by turning two screws. This clamp serves to hold the brass cylinder and plastic pipe in place on the wires.

The three wires that pass down into the pH probe each serve a particular function. The first leads to a thermister hanging near the top slot in the pipe, where water from the hole can pass over it. The second wire leads to a Coleman 3-472 Tri-Purpose Shielded Glass Electrode. This electrode hangs in the probe in such a way that the bottom of the electrode is just inside the slot about two-thirds the distance down the plastic pipe. The slot allows water to come in contact with the end of the glass electrode. The third wire leads to a Coleman 3-711 reference electrode. The pH probe is designed so this electrode hangs about 1 inch above the open bottom of the probe. This lets water into the reference electrode but still protects the electrode from hitting the sides of the hole.

The three wires that pass through the top of the pH probe lead from the probe to a water-tight, insulated, 5-point, male plug. This plug in turn connects to a 200-foot insulated cable, which may be rolled on a small metal spool. The other end of the cable leads to a small box about the size of a match box. This box serves two functions. The first function involves the signal from all three wires leading from the pH probe. The box contains a series of large capacitors. Their function is to shunt off any alternating current passing up through the wires while allowing direct currents to pass through unobstructed. These capacitors help to remove the effects of stray currents picked up along the 200-foot cable. The second function of the box involves only the signal from the thermister in the pH probe. The box contains a simple wheatstone bridge, which uses a variable resistor and a dip meter to balance the resistor in the bridge and measure the temperature of the water at the thermister. This mechanism is capable of measuring temperatures to within 0.5°C, which is adequate for making temperature corrections in the pH meter.

An insulated electrical cable passes from the metal box at the top of the downhole cable to a two-point insulated socket wired into the pH meter. This cable connects the electrodes in the pH probe to the meter. From here, the pH meter is adjusted and read just as it is when used with standard electrodes on 30-inch leads.

Although the downhole cable and probe add considerably to the information obtainable with the pH meter, they add several sources of error. These error sources must be considered to obtain accurate pH information. There are three sources of error. The first is the change of the impedance of the metering system. Normally, the wires connecting the pH electrodes to the meter are about 30 inches long. This relatively short path is increased to over 200 feet when the downhole cable and probe are used rather than the normal electrodes. The increased length the current must travel increases the resistance along the current path and hence increases the overall impedance of the pH metering system. In addition, when the downhole cable and probe are used with the system, the electrodes are completely submerged. Normally, only the ends of the electrodes are submerged. The submergence does not interfere with the functioning of the electrodes but it does change the impedance of the metering system.

The change in impedance of the pH meter system does not pose a major problem as long as it is taken into account. The Coleman

Precision pH Meter is an extremely high impedance system. Compared to the total impedance, the change in impedance when the downhole probe and cable is used is slight, and can be easily adjusted for, when zeroing and standardizing the meter. However, the impedance of the system is changed and the meter must be zeroed and standardized with both the probe and downhole cable connected and the probe completely submerged if the probe and downhole cable are to be used with the system. Otherwise, valid pH readings can not be obtained.

The second source of error is also related to impedance. Because it is such a high impedance system, the pH metering system is easily affected by stray currents. The addition of the 200-foot cable increases the system's susceptability to these currents.

This source of error is taken care of in time. The system includes a series of capacitors to shunt off alternating current. Most stray current are alternating currents. Time is necessary for the capacitors to build up a charge and become effective. For this reason, these procedures should be followed when the downhole cable and probe are used. First, the probe should be submerged in a standard buffer solution and allowed to stand undisturbed for at least 5 minutes. The pH meter should then be zeroed and standardized. The probe should then be lowered to the point where the pH is to be read and left undisturbed for several minutes. Care should be taken that the cable is not touched during this time. Once the probe has come to equilibrium, the pH should be obtained from the meter without disturbing the probe or cable. If the system is disturbed, time will allow the meter to come back to equilibrium. If these procedures are followed consistently pH measurements can usually be taken despite stray currents.

The third source of error is purely mechanical, how to submerge the electrodes of the 15-inch downhole probe in a standard buffer solution to standardize and zero the pH meter. One solution is obvious. Gallons of buffer solution can be carried into the field. This, however, is neither practical nor economical. A moderate amount of the buffer solution can be carried into the field along with a high-density polyethylene graduated cylinder. The pH meter is then standardized by placing the probe in the cylinder and filling the cylinder with solution to above the upper electrode. This method gave acceptable results without introducing large errors into the measurements.

Alkalinity ($HCO_3^- + CO_3$)

Alkalinity, as used in groundwater chemistry, is the capacity of a water to neutralize a strong acid and is primarily a function of the carbonate and bicarbonate in solution (Rainwater and Thatcher, 1960, p. 93). The potentiometeric method was used to determine the alkalinity of water samples in this study. This method consisted of titrating a $5x10^{-2}$ m^3 sample of water with a 0.0231 normal solution of sulfuric acid against a pH meter to end points of pH 8.2, for carbonate, and pH 5.1 to 4.5, for bicarbonate. A pH end point of 5.1 was used for samples with total alkalinity of near $3x10^{-7}$, kg/m^3; an end point of 4.8 was used for samples with a total alkalinity of near $15x10^{-5}$ kg/m^3; and an end point of 4.5 was used for samples with a total alkalinity of near $5x10^{-6}$ kg/m^3 and greater. For samples with total alkalinities between these values, an end point was extrapolated approximately. The total alkalinity, hydroxide carbonate, and bicarbonate was calculated using the procedures given by APHA (1965, p. 52).

The normality of the sulfuric acid was checked periodically against a sodium carbonate standard to insure the acid remained stable. The values determined for alkalinity were reproducible to within ± 2 percent.

Sulfate

The turbidimetric method was used to determine sulfate concentration (APHA, 1965, p. 291). A Fisher photometer (Electrophometer II, model 81) was used to objectively determine the value of light absorbance through a suspension of barium sulfate in the water sample. The absorbance values were determined by passing a light through a blue filter (transmittance range 400 to 475 mm). A light path of 23 mm was used. A suspension of barium sulfate was formed in the sample by adding Sulfaver powder and stirring the mixture for about 5 minutes. (Sulfaver is the trade name for a powdered mixture of barium chloride and several conditioning reagents manufactured by Hach Chemical Company.) A calibration curve was constructed from the absorbance value obtained from the five standard solutions over the range of 0 to 100 ppm. The absorbance of each sample was compared with this curve to determine the amount of sulfate in the sample. Samples containing concentrations of sulfate exceeding the range of the working curve were diluted.

The error involved in the sulfate determination is estimated to be about ± 5 percent and possibly slightly higher in those sample which were diluted. The instrument accuracy was ± 0.5 percent or better in the range of optimum light conditions.

Chloride, Fluoride, and Bromide

In this study selective-ion electrodes were used to determine chloride, fluoride, and bromide ion concentrations. Selective-ion electrodes are similar to the glass electrodes used to determine pH. However, where the glass-electrode, reference-electrode, pH-meter combination measures the hydrogen-ion activity of a solution; the selective-electrode, reference-electrode, pH-meter combination measures the activity of a specific ion or related group of ions. In this study the electrode used to determine chloride was the Coleman Chloride Ion-Selective Electrode (3-802); for fluoride, the Coleman Fluoride Ion-Selective Electrode (3-803); and for bromide, the Coleman Bromide Ion-Selective Electrode (3-801) was used. In all three cases a conventional Calomel electrode was used as a reference, and the negative and positive millivolt scale of a Coleman Precision Portable pH Meter (Model 37A) was used to record the voltages between electrodes.

The electrode-pH meter is used in the following manner to determine ion concentration in the samples. First, standard 1-molar solutions of chloride, fluoride, and bromide is made. The chloride standard solution is made by mixing 1 molecular weight of sodium chloride (reagent quality) with 1×10^{-3} m^3 of distilled, deionized water. Similarly, the fluoride standard is made from sodium fluoride and the bromide standard from potassium bromide. Once 1-molar standard solutions are completed, the 1-molar standards are used to make seven solutions for each ion. These solutions are spaced with a tenfold concentration ratio throughout the range from 1 molar to 1×10^{-6}

molar and are formed by diluting the 1-molar solutions with distilled water at a ratio of 1 to 10. These solutions are then allowed to come to room temperature (regulated at 25°C) and each is measured with the selective ion-electrode, reference-electrode, pH-meter combination to obtain a reading in millivolts. The seven readings obtained for each ion are then used to plot a calibration graph of concentration against millivolts. This process is repeated until consistent graphs are obtained for chloride, bromide, and fluoride. Once consistent graphs are obtained they are used for references in determining the chloride, fluoride, and bromide concentration of each water sample.

Care was taken that water samples were close to 25°C when ion concentrations were determined and that the calibration graphs were checked periodically against a standard solution of known concentration. If this was done, the reproducibility of ion concentrations determined by this method was found to be ± 5 percent or less.

Wet chemical techniques described by Hagmaier (1971, p. 119) were used to determine the ion concentration of chloride and fluoride in several of the water samples previously determined with selective-ion electrodes. The selective-ion determinations compared favorably with the concentrations determined by wet chemical procedures.

Atomic Absorption Determinations

The concentrations of sodium, potassium, magnesium, calcium, maganese, iron, lithium, copper, and strontium in water samples were determined with a Perkin-Elmer (model 403) Atomic Absorption/Flame Emission Spectro-Photometer using a mixture of air and acetylene. Care was taken to follow the instructions given in the Perkin-Elmer instruction manual and Traversy (1971). For each element, the specified current and flow rates were used. Wave lengths were set approximately, using the rating specifications. Usually the wave length had to be adjusted above and below the specified wave length to obtain the maximum power peak. The instrument was calibrated each time it was used, with prepared standards, whose concentrations were in the optimum operating range for the particular element being determined. The instrument was equipped with a direct readout, which would give individual readouts, averages of ten readouts, and averages of one hundred readouts. The average of ten readouts were used for most elements. In cases where the average of ten readouts would not stabilize, average of one hundred was used. The instrument was recalibrated after each ten determinations or when the readouts seemed unstable. For those samples containing ion concentrations greater than the optimum operating range of the machine, dilutions were made at five-fold ratios from 1 part sample, 4 parts double-distilled water to 1 part sample, 624 parts double-distilled water.

The results obtained for all elements, determined with the atomic absorption unit, were reproducible to within ± 1 percent under ideal instrument conditions.

Ortho-Phosphate

The Stanna-Ver method was used to determine the total orthophosphate in water samples. The basis for this method is that in a dilute phosphate solution, ammonium molybdate reacts in an acid medium to form a heteropoly acid, molybdo-phosphoric acid. This in turn is reduced to the intensely colored complex, molybdenum blue, by the reducing agent stannous chloride (APHA, 1965, p. 230). The intensity of the solutions color is related to the concentration of the ortho-phosphate. For each determination of ortho-phosphate, two identical 2.5×10^{-2} m^3 water samples were measured with a 2.5×10^{-2} m^3 graduated cylinder. A 1×10^{-3} m^3 volume of strong ammonium molybdate solution was added to each sample. The sample was then swirled to mix. When the solution was mixed, 1 gm of Stanna-Ver (the trade name for a powder composed mostly of stannous chloride manufactured by the Hach Chemical Company) was added to one of the two water samples. The Stanna-Ver sample was swirled to mix and then allowed to stand 10 minutes to let the blue color develop completely. A Hach AC-DR Colorimeter (model 585) with a phosphate-meter scale and a 5330 color filter was zeroed on the water sample containing only water and ammonium molybdate. The colorimeter was then used to measure the concentration of ortho-phosphate in the sample containing stannous chloride. Once the concentration of total ortho-phosphates was determined, a table in Rainwater and Thatcher (1960, p. 82) was used to determine the concentration of $PO_4^{=}$, $HPO_4^{=}$, and $H_2PO_4^{-}$ ions.

The reproducibility of this procedure for determining phosphate was found to be about ± 8 percent.

Nitrate and Nitrite

Two wet chemical procedures were used to determine the concentrations of nitrate and nitrite in water samples. First, the combined concentration of nitrate and nitrite was determined by the cadium-reduction method. The concentration of nitrite in the sample was determined by the Nitri-Ver method. Then the concentration of nitrate was subtracted from the combined concentration of nitrate and nitrite to compute the concentration of nitrate in the sample.

The procedures followed in both the cadium-reduction method and the Nitri-Ver method are given on page 42 of the Hach Chemical Company catalog (Number 10, 1968). Nitra-Ver and Nitri-Ver, (trade names for powdered reagents produced by the Hach Chemical Company) were used in the determination of nitrite by the Nitri-Ver method. In both determinations, a Hach AD-DR Colorimeter (model 585) with the specified meter scales and color filters was used.

The reproducibility of the procedures used to determine nitrite and nitrate in this study was found to be ± 10 percent.

Error Analysis

Following the procedures of Hamilton (1970), a numerical estimate was made of the error involved in the analysis of water samples in this study. Theoretically, the total equivalent weights of all the cations and anions in solution should balance. Consequently, the difference between the cations and anions determined in the analysis was assumed to approximate the analytical error of the analysis. This is valid if the unanalyzed constituents of the sample represent only an insignificant percentage of the total ions. In this analysis only two common ions, silica and aluminum, were not determined. Neither element is common in an ionized state under normal groundwater conditions. Consequently, the error analysis is thought to be valid for this study.

The values for percent error were determined by the following formula:

$$\text{percent error} = \frac{\text{total cations} - \text{total anions}}{\text{total cations} + \text{total anions}} \times 100,$$

where both cations and anions are expressed in equivalents.

The mean percent error for the 58 samples completely analyzed was 5.3 with a standard deviation of 3.6.

Computation Procedures

Introduction

Three computor programs were developed to utilize the physical and chemical information obtained in the field and laboratory phase of this study. The first program, CHEM D, calculates basic information for water samples. This includes concentration of the ions determined by laboratory analysis, concentrations of combinations of these ions, the total concentration of ions, the percentage of the total concentration composed of each of the ionic constituents or combinations of constituents, and the various chemical parameters used to describe and distinguish groundwater facies and chemical systems. In addition, CHEM D calculates the pore pressure for specific points in the groundwater flow system.

The second computor program, CHEM A, calculates the molar concentration of each of twenty ionic constituents of a water sample, the activity for each of these ions, the total ionic strength of the water, and the $CaSO_4$, $CaCO_3$, and $CaMg(CO_3)_2$ saturation indices (SI).

The third computor program, CHEM E, calculates the molarity of the water samples, the free energy and enthalpy of the samples, and the free energy and enthalpy per molecular weight for each of the water samples.

Several types of data input is used by the three programs. The first type is ion concentration. The analyzed constituents of the water samples are included in the input data of all three programs. For this study, the computor input data included the samples discussed above plus samples analyzed by the North Dakota State Water Commission, the North Dakota State Game and Fish Department, and the U.S. Geological Survey. The concentration of all the chemical constituents in the input data is expressed in parts per million (ppm).

The second type of input data is the physical properties of the water, measured at the time and place of collection. Examples of this type are water temperature, pH, and specific conductivity.

The third type of input data used in the programs is supplementary information about the source of the water samples. Examples of this type of data are geographic location of the sampling site (usually a piezometer), surface elevation of the sampling site, depth below the surface of the sampling site, date of the sample collection, stratigraphic unit the sample was collected from, and the institute or individual who collected the sample.

CHEM D Computor Program

Data Input.--CHEM D, the basic-data program, is designed to read up to seventeen physical-data items, twenty-one ionic concentrations, and three computation factors for each water sample. This information for each water sample is arranged on seven consecutive computor cards. The items of physical data and their card and space locations are listed in Table 3. The twenty-one chemical constituents are listed in Table 4. The three computation factors, P1COR, P2COR, and P3COR are located in spaces 6 to 15, 16 to 25, and 26 to 35 respectively on card 4 of the data input. Additional format instructions are included in the CHEM D program.

TABLE 3

KEY TO FORMAT LOCATION OF PHYSICAL DATA

Abbreviation	Definition	Program Symbol	Location Format Card	Location Format Spaces
WELL NO.	number assigned to source of water (usually a piezometer)	NX	1	2-5
LOCATION	geographic location of well	LT,LR,LS SL1,S12,SL3	1	6-19
E.T.W.	feet of elevation at the top of the well casing	EW	1	27-36
WELL D.	depth of the well in feet, measured from the top of the well casing	DW	1	47-56
D.T.W.	distance in feet from the top of the well casing to the water level in the well. Negative values indicate pressure head at top of well casing in feet of head	DTW	1	37-46
TEMP.	temperature of water in degrees Centigrade at the time the sample was collected	TEMP	2	6-15
PH	negative logarithm of the hydrogen-ion concentration	PH	2	36-45
S.C.	specific conductance of water measured in micromhos	SC	2	16-25
T. ALK.	total alkalinity of water sample measured in parts per million $CaCO_3$	TA	2	26-35
SOURCE	geologic material or source of water	NS	1	20-26
ANAL.	party who collected and analyzed the sample	NANAL	7	36-45
DATE	date water samples were collected	NDATE	7	46-50

TABLE 4

CHEMICAL CONSTITUENTS INCLUDED IN THE INPUT DATA FOR COMPUTOR PROGRAMS CHEM D, CHEM A, AND CHEM E. INCLUDED ARE PROPERTIES OF THE CONSTITUENTS AND THEIR LOCATION FORMAT

Valance	Element or Ion	Common form in groundwater	Molecular weight	Symbol	Format Location Card	Format Location Spaces
2	Calcium	Ca^{++}	40.080	CA	3	6-15
2	Magnesium	Mg^{++}	24.305	MG	3	16-25
2	Manganese	Mn^{++}	54.938	MN	3	46-55
1	Sodium	Na^{+}	22.990	NA	3	26-35
1	Potassium	K^{+}	39.100	K	3	36-45
2	Iron	Fe^{++}	55.840	FE	3	56-65
2	Strontium	Sr^{++}	87.620	SR	5	36-45
2	Copper	Cu^{++}	63.546	CU	5	46-55
1	Lithium	Li^{+}	6.941	LI	5	56-65
1	Bicarbonate	HCO_3^{-}	61.077	HCO3	6	6-15
2	Carbonate	$CO_3^{=}$	59.997	CO3	6	16-25
2	Sulfate	$SO_4^{=}$	96.056	SO4	4	6-15
1	Chloride	Cl^{-}	35.453	CL	4	16-25
1	Phosphate	$H_2PO_4^{-}$	96.986	P1		
2		$HPO_4^{=}$	95.978	P2 } P	5	26-35
3		PO_4	94.970	P3		
1	Bromide	Br	79.904	BR	4	36-45
1	Nitrite	NO_2^{-}	46.005	NO2	5	16-25
1	Nitrate	NO_3^{-}	62.004	NO3	5	6-15
1	Fluoride	F^{-}	18.998	F	4	26-35
0	Boron	H_3BO_3	10.810	B	6	46-55
0	Aluminum	$Al(OH)_3$	26.982	AL	6	36-45
0	Silica	H_4SiO_4	28.080	SI	6	26-35

All chemical concentrations are listed in units of parts per million in the computor input deck. The computation factors are listed in percentages. The physical data is listed in the units indicated in Table 3.

Care must be taken to insure that each item of data is in its proper location. The card input for the CHEM D program is designed to substitute zero into all data locations left blank. This innovation allows the program to process water samples for which all the input data not available. If data is misplaced, the zeroing process may allow the program to work, but erroneous answers will result.

Computations.--There are three phases of the computation stage of CHEM D. The first phase is a preparation phase. In this phase, the elevation of the sampling site and the hydrodynamic potentiometric surface above the sampling point is determined, the concentration of the three phosphate ions is calculated, and the form of the chemical constituents in the water is established.

The lowest point in a piezometer is considered the collecting point for the water sample. The elevation of this point is computed in the CHEM D program by subtracting the depth of the well from the elevation of the well head. The elevation of the potentiometric surface is determined by subtracting the depth to water measured from the top of the piezometer. The elevation of the top of the piezometer, the depth to water, and the depth of the well are all included in the input data from the CHEM D program.

Only the total concentration of phosphate is included in the data input for the CHEM D program. The concentration of the three common phosphate ions, $H_2PO_4^-$, $HPO_4^=$, and PO_4^{-3} are determined in the program. To make these calculations, three computation factors are included in the data input for each water sample. These factors are from Reiman, Neuss, and Niaman (1942, p. 523) and represent the percent fraction of the total phosphate concentration of each of the three phosphate ions. They are determined by the pH and temperature of the water at the time the water sample was collected. These factors are multiplied by the total concentration of phosphate ions in each water sample, to determine the concentration of the ions $H_2PO_4^-$, $HPO_4^=$, and PO_4^{-3}.

Each of the chemical constituents in the CHEM D data input has one or more forms that occur in natural groundwater and surface water. The common forms of the twenty-three chemical constituents are listed in Table 4. Only the ferrous ion is listed for ion because "the ferric ion is slightly soluble only at pH values less than 5" (APHA, 1965, p. 155). The common forms of aluminum, silica, and boron in aqueous solutions are considered to be the compounds $Al(OH)_3$, H_4SiO_4, and H_3BO_3. H_4SiO_4 disassociates only in very acidic solutions which are not commonly found in groundwater (Krauskopf, 1967, p. 115). $Al(OH)_3$ and H_3BO_3 do not disassociate appreciably in normal groundwater and surface water (Weast, 1972, p. D-121). The forms of the other ions are commonly accepted and can be found in any standard chemistry text.

The second computation phase for CHEM D is an equivalent-unit phase. In this phase, ion concentrations are computed in equivalents per million, compound concentrations in parts per million, ion percentages, and compound percentages.

The CHEM D program is designed to compute concentrations in equivalents per million for the twenty chemical constituents in ionic form listed in Table 4. Equivalents per million are calculated using the formula

$$E_i = \frac{C_i V_i}{W_i} ,$$

where E_i = concentration of the ion in equivalents per million,

C_i = concentration of the ion i in parts per million (from the data input deck),

V_i = valance of the ion i (listed in Table 4), and

W_i = molecular weight of ion i (listed in Table 4).

The concentration of the compounds H_4SiO_4, $Al(OH)_3$, and H_3BO_3, in parts per million is computed by CHEM D using the formula

$$C_j = \frac{C_i W_i}{W_j} ,$$

where C_j = concentration of the compound j in parts per million,

C_i = concentration of the element i in parts per million (Si, Al, or B) from the input data deck,

W_j = molecular weight of the compound j computed from the molecular weight of the elements, and

W_i = molecular weight of the element i.

Ion and compound percentages for twenty-three constituents of each water sample are obtained in the CHEM D program using the formula

$$P_i = \frac{E_i}{\sum_{i=1}^{k} E_i} ,$$

where P_i = the percentage of the cations, anion, or compound i,

E_i = the cation or anion i equivalents per million or the compound i in parts per million, and

k = the total number of cations, anions, or compounds included in the chemical constituents.

Commonly in surface-water and groundwater studies, the concentration of only the major ions, Ca^{++}, Mg^{++} K^{+}, Na^{+}, $SO_4^{=}$, HCO_3^{-}, $CO_3^{=}$, and Cl^{-} are determined. Percentages of the major ions were determined so the samples could be easily compared with samples in other studies analyzed only for major ions. The formulas used in the calculations are given in Table 5. All concentrations are in equivalents per million.

The third computation phase for CHEM D is a chemical-parameter phase. It includes the calculation of the chemical parameters used by Freeze (1969a, p. 220), the chemical parameters used by Hagmaier (1971, p. 153), and additional parameters thought to be important in comparing and describing the chemistry of water samples.

All of the chemical parameters calculated by CHEM D, the formulas used to calculate the parameters, the addresses of the parameters in the program, and the dimensions of the parameters are given in Table 6, Table 7, and Table 8 of this report. Ratios AXX to PXX2 have been adapted from those suggested by Schoeller (1959) and Chebotarev (1955). Ratios PXX2 and HXX are from Todd (1959). The base exchange indices are from Schoeller (1959). All ions are used in equivalents per million. Chemical expressions are used for all ions and compounds. All ion concentrations are expressed in equivalents per million unless otherwise indicated.

Data Printout.--The printout for the CHEM D program is designed to fit on standard 8½-inch by 11-inch pages with room for a 1½-inch left-hand margin and a 1-inch margin at the top, bottom, and right-hand side. Each full page of printout has column headings and well numbers for each

TABLE 5

THE EQUATIONS FROM THE CHEM D COMPUTOR PROGRAM USED TO DETERMINE PERCENTAGES OF MAJOR IONS

Parameter Name	Program Address	Equation used to Calculate Parameter
PXCL	PXCL	$\mathrm{PXCL} = \frac{\mathrm{Cl}^-}{\mathrm{Cl}^- + \mathrm{SO}_4^- + \mathrm{HCO}_3^- + \mathrm{CO}_3^=}$
PXSO4	PXSO4	$\mathrm{PXSO4} = \frac{\mathrm{SO4}^=}{\mathrm{Cl}^- + \mathrm{SO}_4^- + \mathrm{HCO}_3^- + \mathrm{CO}_3^=}$
PXHCO3	PXHCO3	$\mathrm{PXHCO3} = \frac{\mathrm{HCO}_3}{\mathrm{Cl}^- + \mathrm{SO}_4^= + \mathrm{HCO}_3^- + \mathrm{CO}_3^=}$
PXCO3	PXCO3	$\mathrm{PXCO3} = \frac{\mathrm{CO}_3^=}{\mathrm{Cl}^- + \mathrm{SO}_4^= + \mathrm{HCO}_3^- + \mathrm{CO}_3^=}$
PXCA	PXCA	$\mathrm{PXCA} = \frac{\mathrm{Ca}^{++}}{\mathrm{Ca}^{++} + \mathrm{Mg}^{++} + \mathrm{K}^+ + \mathrm{Na}^+}$
PXMG	PXMG	$\mathrm{PXMG} = \frac{\mathrm{Mg}^{++}}{\mathrm{Ca}^{++} + \mathrm{Mg}^{++} + \mathrm{K}^+ + \mathrm{Na}^+}$
PXK	PXK	$\mathrm{PXK} = \frac{\mathrm{K}^+}{\mathrm{Ca}^{++} + \mathrm{Mg}^{++} + \mathrm{K}^+ + \mathrm{Na}^+}$
PXNA	PXNA	$\mathrm{PXNA} = \frac{\mathrm{Na}^+}{\mathrm{Ca}^{++} + \mathrm{Mg}^{++} + \mathrm{K}^+ + \mathrm{Na}^+}$
PXCM	PXCM	$\mathrm{PXCM} = \frac{\mathrm{Ca}^{++} + \mathrm{Mg}^{++}}{\mathrm{Ca}^{++} + \mathrm{Mg}^{++} + \mathrm{K}^+ + \mathrm{Na}^+}$
PXKN	PXKN	$\mathrm{PXKN} = \frac{\mathrm{K}^+ + \mathrm{Na}^+}{\mathrm{Ca}^{++} + \mathrm{Mg}^{++} + \mathrm{K}^+ + \mathrm{Na}^+}$
PXSC	PXSC	$\mathrm{PXSC} = \frac{\mathrm{Cl}^- + \mathrm{SO}_4^=}{\mathrm{Cl}^- + \mathrm{SO}_4^= + \mathrm{HCO}_3^= + \mathrm{CO}_3^-}$
PXHC	PXHC	$\mathrm{PXHC} = \frac{\mathrm{HCO3}^- + \mathrm{CO}_3^=}{\mathrm{Cl}^- + \mathrm{SO}_4^= + \mathrm{HCO}_3^- + \mathrm{CO}_3^=}$

TABLE 6

FREEZE'S CHEMICAL PARAMETERS AND THE EQUATIONS, FROM THE CHEM D COMPUTOR PROGRAM, USED IN THEIR DETERMINATION

Parameter Name	Program Address	Equation used to Calculate Parameters	Parameter Dimensions
SO/SOC	AXX	$AAX = \frac{SO_4^{=}}{SO_4^{=} + Cl^{-}}$	Non-dimensional
SO/SOHCC	BXX	$BXX = \frac{SO_4^{=}}{SO_4^{=} + HCO_3^{-} + CO_3^{=}}$	Non-dimensional
HC/HC + C	CXX	$CXX = \frac{HCO_3^{-}}{HCO_3^{-} + Cl^{-}}$	Non-dimensional
M/M +CA	DXX	$DXX = \frac{Mg^{++}}{Mg^{++} + Ca^{++}}$	Non-dimensional
NK/NKCL	EXX	$EXX = \frac{Na^{+} + K^{+}}{Na^{+} + K^{+} + Cl^{-}}$	Non-dimensional
C + M/CMS	FXX	$FXX = \frac{Ca^{++} + Mg^{++}}{Ca^{++} + Mg^{++} + SO_4^{=}}$	Non-dimensional
(Percent Sodium	PXX2	$PXX2 = \frac{Na^{+} + K^{+}}{Na^{+} + K^{+} + Ca^{++} + Mg^{++}}$	Non-dimensional
S.A.R. (Sodium Absorption)	HXX	$HXX = \frac{Na^{+}}{\left[\frac{Ca^{++} + Mg^{++}}{2}\right]^{\frac{1}{2}}}$	Non-dimensional
B.E.R.I. (Base exchange index, Mg^{++} and Ca^{++} for Na^{+} and K^{+})	PXX	$PXX = \frac{Cl - (Na^{+} + K^{+})}{SO_4^{=} + HCO_3^{-} + NO_3^{-}}$	Non-dimensional
B.E.R.I. (Base exchange index, Na^{+} and K^{+} for Mg^{++} and Ca^{+})	QXX	$QXX = \frac{Cl^{-} - (Na^{+} + K^{+})}{Cl^{-}}$	Non-dimensional
$CL + F + NO_3$	CLX	$CLX = Cl^{-} + F^{-} + NO_3^{-}$	Equivalents per million

TABLE 7

HAGMAIER'S CHEMICAL PARAMETERS AND THE EQUATIONS, FROM THE CHEM D COMPUTOR PROGRAM, USED IN THEIR DETERMINATION

Parameter Name	Program Address	Equation used to Calculate Parameter	Parameter Dimension
CA/NA	AA	$AA = \frac{Ca^{++}}{Na^{++}}$	Non-dimensional
CA/MG	AB	$AB = \frac{Ca^{++}}{Mg^{++}}$	Non-dimensional
CL/NA	AC	$AC = \frac{Cl^{-}}{Na^{+}}$	Non-dimensional
SO4/NA	AD	$AD = \frac{SO_4^{=}}{Na^{+}}$	Non-dimensional
HCO3/NA	AF	$AF = \frac{HCO_3^{-}}{Na^{+}}$	Non-dimensional
F/CL	AG	$AG = \frac{F^{-}}{Cl^{-}}$	Non-dimensional
K/F	AH	$AH = \frac{K^{+}}{F^{-}}$	Non-dimensional
CA/HCO3	AI	$AI = \frac{Ca^{++}}{HCO_3^{-}}$	Non-dimensional
SO4/HCO3	AJ	$AJ = \frac{SO_4^{=}}{HCO_3^{-}}$	Non-dimensional
T.D.S. (Total Dissolved Solids)	TDS	$TDS = \Sigma C_i$ $i = 23$, all chemical constituents determined	Parts per million
TOT. H. (Total hardness)	THRD	$THRD = \frac{(Ca^{++} + Mg^{++}) \times 100.077}{2.0}$	Parts per million $CaCO_3$

TABLE 7--Continued

Parameter Name	Program Address	Equation used to Calculate Parameter	Parameter Dimension
TANI	TANI	$TANI = \Sigma E_i$ i = all ions	Equivalents per million
TANI/TDS	AK	$AK = \frac{TANI}{TDS}$	Non-dimensional
THRD/TDS	AN	$AN = \frac{THRD}{TDS}$	Non-dimensional
TCAT	TCAT	$TCAT = \Sigma E_i$ i = all cations	Equivalents per million
NA + K	PX11	$PX11 = \frac{K^+ + Na^+}{TCAT}$	Non-dimensional
CA + MG	PX12	$PX12 = \frac{Ca^{++} + Mg^{++}}{TCAT}$	Non-dimensional
SO_4 + CL	PX13	$PX13 = \frac{SO_4 + Cl^-}{TANI}$	Non-dimensional
HCO3 + CO3	PX14	$PX14 = \frac{HCO_3^- + CO_3^=}{TANI}$	Non-dimensional

TABLE 8

CHEMICAL PARAMETERS AND THE EQUATIONS, FROM THE CHEM D COMPUTOR PROGRAM, USED IN THEIR DETERMINATION

Parameter Name	Program Address	Equation used to Calculate Parameter	Parameter Dimension
TOTA	PX6	$PX6 = Cl^- + SO_4^= + HCO_3^- + CO_3^=$	Equivalents per million
TOTC	PX7	$PX7 = Ca^{++} + Mg^{++} + K^+ + Na^+$	Equivalents per million
TPPM	PX8	$PX8 = AD(OH)^3 + H_4SiO_4 + B_3BO_3$	Parts per million
TOTP	PX9	$PX9 = H_2PO_4^- + HPO_4^= + PO_4^{-3}$	Equivalents per million
TOTN	PX10	$PX10 = NO_2^- + NO_3^-$	Equivalents per million
C+F+B+N3	GXX	$GXX = Cl^- + F^- + Br^- + NO_3^-$	Equivalents per million
CL+F+BR	PX5	$PX5 = Cl^- + F^- + Br^-$	Equivalents per million
XION	XION	$XION = \sum_{i=1}^{c} E_i$	Equivalents per million
TCAT	TCAT	$TCAT = \sum_{i=1}^{c} E_i$	Equivalents per million
TANI	TANI	$TANI = \sum_{i=1}^{a} E_i$	Equivalents per million
ATCAT	ATCAT	$ATCAT = \sum_{i=1}^{c} C_i$	Parts per million

TABLE 8--Continued

Parameter Name	Program Address	Equation used to Calculate Parameters	Parameter Dimension
ATANI	ATANI	$\mathrm{ATANI} = \sum_{i=1}^{a} C_i$	Parts per million
PTCAT	PTCAT	$\mathrm{PTCAT} = \frac{\mathrm{TCAT}}{\mathrm{XION}}$	Non-dimensional
PTANI	PTANI	$\mathrm{PTANI} = \frac{\mathrm{TANI}}{\mathrm{XION}}$	Non-dimensional
CM/ION	PXXL	$\mathrm{PXX1} = \frac{Na^{+} + K^{+}}{\mathrm{XION}}$	Non-dimensional
CM/ION	PXX2	$\mathrm{PXX2} = \frac{Ca^{++} + Mg^{++}}{\mathrm{XION}}$	Non-dimensional
SC/ION	PXX3	$\mathrm{PXX3} = \frac{SO_4^{=} + Cl^{-}}{\mathrm{XION}}$	Non-dimensional
HC/ION	PXX4	$\mathrm{PXX4} = \frac{HCO_3^{-} + CO_3^{=}}{\mathrm{XION}}$	Non-dimensional
RBC/ION	PXX5	$\mathrm{PXX5} = \frac{F^{-} + B^{-} + Cl^{-}}{\mathrm{XION}}$	Non-dimensional

E_i = concentration in equivalents per million
C_i = concentration in parts per million
k = the cations and anions considered in CHEM D
c = the 9 cations considered in CHEM D
a = the 11 anions considered in CHEM D

of the fifty-two samples. Partial pages are arranged similarly but with fewer numbers and shorter data columns.

The input water data and the data computed in the program is arranged in Appendices C through G of this report. The title page of each appendix includes definitions and explanations of the parameters and symbols. The CHEM D program is filed in the Geology Library at the University of North Dakota, Grand Forks.

CHEM A Computor Program

Data Input.--The input data for CHEM A is only slightly different from that used for CHEM D. Both programs use the same seven-card input deck for each water sample. The position of the information is identical for the two programs. However, CHEM A uses only the well numbers, the temperature, and the concentrations of the twenty chemical constituents occurring in ionic form under normal surface-water and groundwater conditions (see Table 4). An additional data set proceeds the water sample data of CHEM A. This data set contains values for (α^o) Effective Diameter (Klotz, 1950, p. 331) and the constant A and B of the Debye-Huckel expression (Manov and others, 1943, p. 1765) for each of the twenty ions mentioned above. The information included in the data input as a set of twenty-one cards at the beginning of the deck.

Computations.--The computations of CHEM A are in the following order. For each sample, the program begins with the concentration in parts per million of twenty chemical constituents. From these concentrations, the molarity of the water for each of the ions is determined. The molarity, in turn, is used to determine the activity of each ion.

Finally ion-activities are used to determine the $CaCO_3$, $CcMg(CO_3)_2$, and $CaSO_4$ saturation indices of the sample.

Molarity of the twenty ions is found in CHEM A with the formula

$$M_i = \frac{C_i \times 10^{-3}}{W_i} ,$$

where M_i = molarity of the ion i in moles per liter times a thousand,

C_i = concentration of the ion i in parts per million, and

W_i = molecular weight of the ion (listed in Table 4).

To obtain the activity of the ions, the ionic strength of the solution was calculated first using the formula of Lewis and Randall (1961):

$$I = \tfrac{1}{2} \sum_{i=1}^{k} M_i V_i^2 ,$$

where I = ionic strength,

V_i = valance of the ion i, and

k = number of ions being considered.

The ion-activity coefficients for the ions are determined in CHEM A from the Debye-Hückel expression

$$-\log\gamma_i = \frac{A\ V_i^2\ I}{1 + \alpha^o\ I}$$

where γ_i = the ion-activity coefficient for ion i,

A = a quantity dependent on the temperature and characteristics of the solution (from the input data),

B = a quantity dependent on the temperature and characteristics of the solution (from the input data), and

α^o = a quantity with a value dependent on the "effective diameter" of the ion in solution (from the input data).

The ion activity is then obtained by the formula

$$a_i = M_i \gamma_i,$$

where a_i = the activity of the ion i.

The last part of the CHEM A program is a calculation of the $CaCO_3$, $CaMg(CO_3)_2$, and $CaSO_4$ saturation indices of each water sample. A saturation index is a gauge of how close a solution is to being saturated with the component ions of a particular compound. For example, the $CaCO_3$ saturation index is a comparison of the concentration of Ca^{++} and $CO_3^{=}$ in water with the concentration of these ions, at saturation, indicated by the $CaCO_3$ equilibrium constant K for the water.

The saturation index is defined by the equation

$$SI_i = \log Q_i - \log K_i,$$

where SI_i = the saturation index of the solution for the compound i,

Q_i = the ion-activity product of the water sample for the compound i, and

K_i = the equilibrium constant for the compound in solution (at the temperature of the solution).

Values for the ion-activity product (Q) for $CaCO_3$, $CaMg(CO_3)_2$, and $CaSO_4$ are determined in CHEM A with the following equations from van Everdinger (1969, p. 1426):

$$\log Q_{CaCO_3} = \log [Ca^{++}] + \log [HCO_3^{-}],$$

$$-\log [H^+] + \log K_{HCO3^-},$$

$$\log Q_{CaMg(CO_3)_2} = \log [Ca^{++}] + \log [Mg^{++}],$$

$$-\log [H^+] + 2 \log [HCO_3^{-}] + 2 \log K_{HCO_3^-}, \text{ and}$$

$$\log Q_{CaSO_4} = \log [Ca^{++}] + \log [SO_4^{=}].$$

The square brackets indicate that ion-activity rather than molar concentration is used for the inclosed ion. The $-\log [H^+]$ in the equations, is considered to be the pH of the water sample at the time of collection. This is possible because the glass-electrode, pH-meter, reference-electrode combination measures ion activity rather than molar concentrations (Moore, 1962, p. 400). $K_{HCO_3^-}$ is obtained by interpolation from the data of Harned and Scholes (1941), included in Table 3.2 of Garrels and Christ (1965, p. 89). For water temperatures of less than 5°C or greater than 10°C, values of $K_{HCO_3^-}$ are included in the input data for CHEM A. For water temperatures between 5°C and 10°C, which includes all the water samples collected in the study, $K_{HCO_3^-}$ is determined by the formula

$$-\log K_{HCO_3^-} = 6.52 - 0.1\ (T_c - 5),$$

where T_c = temperature of the water sample at the time of collection in degrees Centigrade.

This is a straight line interpolation of the values given in Garrels and Christ for 5°C and 10°C.

Values for $\log K_{CaCO_3}$ for temperature between 0 and 80°C are given in Garrels and Christ (1965, p. 89). The K_{CaCO_3} values used in CHEM A are obtained in a similar way, using the formula

$$-\log K_{CaCO_3} = 8.09 + .012\ (T_c^{\circ} - 5)$$

for water temperatures between 5 and 10°C. A value of -16.82 is used for $K_{CaMg(CO_3)_2}$ at 25°C (Barnes and Back, 1964). The value of standard K_{CaSO_4} used in CHEM A is derived from the free energy ΔF_r^{o} for the reaction

$$Ca_{aq}^{++} + SO_{4\ aq}^{=} \qquad CaSO_{4\ S}\ .$$

ΔF_r^{o} for the reaction is calculated using the formula

$$\Delta F_r^{o} = \Sigma F^{o}\ (\text{products}) - \Sigma F^{o}\ (\text{reactants}),$$

where F^o = the free energy of the chemical constituents at 25°C (the values are given in Table 9).

K_{CaCO_4} can then be obtained using the relationship in Krauskopf (1967, p. 657),

$$\log K = \frac{\Delta F_r^o}{1.364}$$

Values of K_{CaSO_4} and $K_{CaMg(CO_3)_2}$ for the temperature of the water samples are derived from the 25°C. equilibrium values by using Van't Hoff's equation in the form

$$2.303 \log \frac{K_{T2}}{K_{25^o}} = \frac{\Delta H_r^o}{R} \left(\frac{1}{T_2} - \frac{1}{T_1} \right),$$

where K_{T2} = the equilibrium constant for the compound at the temperature of the water sample,

K_{25^o} = the equilibrium constant for the compound at 25°C,

ΔH_r^o = the standard heat of reaction obtained

R = the gas constant (1.98726 calories per degree-mole),

T_2 = the absolute temperature of the water sample, and

T_1 = absolute temperature of 25°C (298.16°K).

The assumption is made that ΔH_r^o is constant over the range of temperatures involved.

Data Printout.--The printout for CHEM A is arranged in the same format as CHEM D. The molarities, activities, and saturation indices of each water sample is arranged in Appendices H through J of this report. The title page of each appendix includes the definitions and explanations of the parameters and symbols used. The CHEM A program is filed in the Geology Library at the University of North Dakota, Grand Forks.

TABLE 9

FREE ENERGY, ENTHALPY, AND ENTROPY VALUES OBTAINED FROM VARIOUS SOURCES

Form	Formula	ΔF^o	ΔH^o	S^o	Source
aq	Ca^{++}	-132.2	-129.8	13.2	Latimer, 1952
aq	Mg^{++}	-108.8	-111.52	-32.7	Langmuir, 1965
aq	Mn^{++}	- 54.4	- 53.3	-20.0	Latimer, 1952
aq	Na^+	- 62.5	- 60.0	14.0	Kelley and King, 1961
aq	K^+	- 67.3	- 60.0	24.2	Kelley, 1962
aq	Fe^{++}	- 20.3	- 21.0	-27.1	Latimer, 1952
aq	Sr^{++}	-133.2	-130.4	- 9.4	Latimer, 1952
aq	Cu^{++}	15.5	14.5	-26.5	Kelley and King, 1961
aq	Li^+	- 70.22	- 66.55	3.4	Rossini and others, 1952
aq	HCO_3^-	-140.31	-165.18	22.7	Latimer, 1952
aq	$CO_3^=$	-126.22	-161.63	-12.7	Latimer, 1952
aq	$SO_4^=$	-177.34	-216.9	4.4	Kelley and King, 1961
aq	Cl^-	- 31.35	- 40.02	13.2	Latimer, 1952
aq	$H_2PO_4^-$	-271.3	-311.3	21.3	Rossini and others, 1952
aq	$HPO_4^=$	-261.5	-310.4	- 8.6	Rossini and others, 1952
aq	$PO_4^=$	-245.1	-306.9	-52.0	Rossini and others, 1952
aq	Br^-	- 24.574	- 28.90	19.29	Rossini and others, 1952
aq	NO_2^-	- 8.25	- 25.4	29.9	Latimer, 1952
aq	NO_3^-	- 26.4	- 49.4	35.0	Latimer, 1952
aq	F^-	- 66.08	- 78.66	- 2.3	Latimer, 1952
aq	Al^{+3}	-115.0	-125.4	-74.9	Latimer, 1952
aq	H_4SiO_4	-312.9	-349.1	78.0	Siever, 1957
L	H_2O	- 56.69	- 68.32	16.72	Kubaschewski and Evens, 1958
aq	H^+	0	0	0	Garrel and Christ, 1965
aq	OH^-	- 37.60	- 54.96	- 2.52	Latimer, 1952
S	$CaMg(CO_3)_2$	-518.7	-557.6	37.1	Robie, 1959
S	$CaSO_4$	-315.56	-342.42	25.5	Rossini and others, 1952

ΔF^o = Free energy in kilocalories per mole
ΔH^o = Enthalpy in kilocalories per mole
S^o = Entropy in calories per mole-degree
aq = Aqueous solution
L = Liquid
S = Solid crystaline

CHEM E Computor Program

Data Input.--The data input for the CHEM E program is similar to that used by CHEM A. The same seven card data set is used for each water sample, and the same information is used from this data set. However, the data proceeding the water-sample data differs. This data set contains the standard free-energy and enthalpy values for the twenty chemical constituents in ionic form from the water samples. This information is given in Table 9.

Computations.--The computations in the CHEM E are in the following order. The program begins with the concentration of twenty ions, in parts per million, for each water sample. From this the program calculates the molar concentration for each of the ions. The molar concentrations, with the temperature the sample was collected at, and the free-energy and enthalpy values in Table 9 are used to compute free energy and enthalpy quantities for the sample.

The ionic molar concentrations are determined in the CHEM E program by the same procedures used in CHEM A. The standard free energy and enthalpy in the input data are then used to determine the free energy of each ion at water-sample temperature. This is accomplished in two steps. First, the Gibbs free-energy function (Sheehan, 1970, p. 191) is used to find the rate of entropy change. The equation used in CHEM E for each ion

$$\Delta S_i = \frac{\Delta H_i^o - \Delta F_i^o}{.001\ T_i^o} ,$$

where ΔS_i = the rate of entropy change for ion i (in calories per degree-mole),

ΔH_i = the standard enthalpy of ion i (in kilocalories per mole, from input data, listed in Table 9),

ΔF_i^o = the standard free energy of ion i (in kilocalories per mole from input data, listed in Table 9),

T_i = temperature at standard conditions (298.16 K), and

i = each of the twenty ions considered in CHEM E.

Then, the free energy of each ion, at water-sample temperature, is computed by assuming that the enthalpy of the ion is constant over the limited temperature range involved and using the equation

$$\Delta F_i = \Delta H_i^o - T_i \, \Delta S_i \, ,$$

where ΔF_i = the free energy of the ion i at water-sample temperature (in kilocalories per mole) and

T_i = the absolute water sample temperature of the ion i (water-sample temperature in degrees Centigrade plus 273.16).

After the free energy, enthalpy, and molar concentrations of each ion was determined, this information was used by the program to compute the total free energy, enthalpy, and molarity of the ions for each sample. The following equations were used in these calculations:

$$F_T = \sum_{i=1}^{k} \Delta F_i ,$$

$$H_T^o = \sum_{i=1}^{k} \Delta H_i^o , \text{ and}$$

$$M_T = \sum_{i=1}^{k} M_i ,$$

where ΔF_T = the total free energy in all the ions of the sample (in kilocalories per mole),

ΔH_T^o = the total enthalpy of all the ions of the sample (in kilocalories per mole),

M_T = the total molar concentration of all the ions in the sample (in moles),

M_i = molar concentration of the ion i, and

k = the total number of ions in the water sample.

Free energy and enthalpy per mole was obtained using the following equations:

$$\Delta F_{mole} = \frac{\Delta F_T}{M_T} \text{ and}$$

$$\Delta H_{mole} = \frac{\Delta H_T}{M_T} ,$$

where ΔF_{mole} = free energy per mole of ion concentration, and

ΔH_{mole} = enthalpy per mole of ion concentration.

Data Printout.--The printout for CHEM E is arranged in the same format as CHEM D. The free energy, enthalpy, and molarity values for each water sample are arranged in Appendix I. The title page of the appendix includes the definitions and explanations for the symbols and parameter used within. The CHEM E program is filed in the Geology Library at the University of North Dakota, Grand Forks.

APPENDIX B

LITHOLOGIC LOGS OF TEST HOLES IN THE SPIRITWOOD LAKE AREA, STUTSMAN COUNTY, NORTH DAKOTA

142-62-28CCA
NDSWC 5454

Elevation: 1,444 feet

Well Number: 64

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Sand; fine to very coarse grained; slightly gravelly, clayey; angular to subrounded; mostly quartz; oxidized	5	1-6
Clay; very silty, sandy; grayish black; moderately cohesive; plastic; moderately calcareous; overbank sediment	5	6-11
Gravel; fine to coarse; sandy; angular to subrounded; poor to fair sorting; mostly carbonate pebbles, some granitic pebbles; takes water readily	5	11-16

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 13 to 16 feet, in gravel. A 3-foot number-18 screen was set and packed in place with pea gravel. The rest of the pipe was cemeneted in place with a mixture of portland cement and pea gravel.

141-62-5BCC
NDSWC 5455
[illegible]

Elevation: 1,437 feet

Well Number: 23

	Thickness (feet)	Depth (feet)
Glacial Drift		
Clay; silty, sandy; dark brown to black; topsoil	1	0-1
Clay; silty, slightly sandy, pebbly; dark yellowish brown; slightly to moderately cohesive; slightly plastic; oxidized; till	6	1-7
Clay; silty, slightly sandy, pebbly; a few cobbles and boulders; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	39	7-46
Gravel; fine to medium; sandy; angular to subangular; poorly sorted; mostly granitic and carbonate pebbles; a few shale pebbles	½	46-46½
Clay; silty, slightly sandy, pebbly; olive gray; moderately cohesive; moderately plastic; calcareous; till	6½	46½-53
Boulder; approximately ½ foot in diameter; granitic	½	53-53½
Pierre Shale		
Shale; slightly clayey; siliceous; grayish black; noncalcareous; fine laminations	6½	53½-60

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 55 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-62-5BCC
NDSWC 5457

Elevation: 1,441 feet

Well Number: 62

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Sand; very coarse grained; slightly gravelly clayey; subangular; poorly sorted; mostly quartz and carbonate grains; oxidized	6	1-7
Glacial Drift		
Clay; silty, slightly sand, pebbly; dark yellowish brown; slightly cohesive; plastic; oxidized; till	7	7-14
Clay; silty, slightly sandy, pebby; a few cobbles; olive gray; moderately cohesive; moderately plastic; calcareous; till	26	14-40

No piezometer was set in this hole. This was a duplication of well number 16.

142-62-28CCA
NDSWC 5458
N 922

Elevation: 1,444 feet

Well Number: 41

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey; sandy; brownish black; topsoil	1	0-1
Sand; fine to very coarse grained; slightly gravelly, clayey; angular to subrounded; mostly quartz; oxidized	5	1-6
Clay; very silty, sandy; grayish black; moderately cohesive; plastic; moderately calcareous; overbank sediment	5	6-11
Gravel; fine to coarse; sandy; angular to subrounded; poorly to fairly sorted; mostly carbonate with some granitic pebbles; takes water readily	5	11-16
Glacial Drift		
Clay; silty, slightly sandy, pebbly; olive gray; cohesive; moderately plastic; calcareous; till	151	16-167
Pierre Shale		
Shale; siliceous, grayish black; noncalcareous; moderately indurated; bentonitic; bedded	3	167-170

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 168 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CAA
NDSWC 5459
N937

Elevation: 1,445 feet

Well Number: 56

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Sand; fine to very coarse grained; silty, clayey; angular to subrounded; fair sorting; mostly quartz, some carbonate, granitic, and shale grains; oxidized	5	1-6
Clay; very silty, moderately sandy; dark gray to brownish black; slightly cohesive; plastic; calcareous; laminated	5	6-11
Sand; fine to very coarse grained; silty, slightly gravelly lower 3 to 4 feet of section; angular to subrounded; fair sorting; mostly quartz, some carbonate, granitic and shale grains	13	11-24
Glacial Drift		
Clay; silty, slightly sandy, pebbly; olive gray; moderately cohesive; moderately plastic; calcareous; till	93	24-117
Pierre Shale		
Shale; siliceous; grayish black; noncalcareous; bedded; moderately indurated; bentonitic	3	117-120

A plastic pipe, 1¼ inch in diameter, was set on a piezometer at a depth of 117 feet, at the contact between the Pierre Shale and the till unit. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-63-36ADA
NDSWC 5460

Elevation: 1,488 feet

Well Number: 20

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Clay; moderately silty, sandy, pebbly; occasional cobbles and boulders; dusky yellow to moderate yellowish brown; moderately cohesive; moderately plastic; oxidized; till	44	1-45
Gravel; fine to coarse; slightly sandy; angular to subrounded; fair sorting; mostly carbonate (limestone and dolostone) and shale pebbles; some granitic, sandstone, siltstone, and lignite pebbles	12	45-57
Sand; very fine to medium grained; subangular to subrounded; moderately well sorted; mostly quartz and carbonate pebbles; small percent of shale and lignite pebbles	10	57-67
Silt; moderately clayey; dark gray; slightly to moderately cohesive; plastic; calcareous	28	67-95
Gravel; fine to coarse; clayey, silty; poorly sorted; angular to subrounded; mostly shale, some carbonate and granitic pebbles	3	95-98
Pierre Shale		
Shale; siliceous; grayish black; noncalcareous; bedded; bentonitic; moderately indurated	2	98-100

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 60 feet, in gravel. A 3-foot, number-12 screen was set and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-63-36AAA
NDSWC 5461

Elevation: 1,463 feet

Well Number: 21

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Clay; silty, sandy, pebbly; dusky yellow to moderate yellowish brown; moderately cohesive; moderately plastic; oxidized; till	31	1-32
Gravel; fine to coarse; slightly sandy; angular to subrounded; poorly sorted mostly shale and carbonate pebbles; some granitic, siltstone, and sandstone pebbles; oxidized throughout	6	32-38
Pierre Shale		
Shale; siliceous; grayish black; noncalcareous; moderately indurated; bedded	12	38-50

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 38 feet, just above the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-63-25CCB
NDSWC 5462

Elevation: 1,452 feet

Well Number: 63

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Clay; silty, sandy, pebbly; occasional cobbles and boulders; moderately yellowish brown; moderately cohesive; moderately plastic; oxidized; till	8	1-9
Clay; silty, pebbly; olive gray; moderately cohesive; moderately plastic; calcareous; occasional gravel lenses in lower 6 feet of section; till	19	9-28
Pierre Shale		
Shale; siliceous; grayish black; moderately indurated; noncalcareous; bedded	12	28-40

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 30 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-63-1AAB
NDGS 69-1

Elevation: 1,450 feet

Well Number: 3

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Clay; silty; dark brown to black; topsoil	1	0-1
Silt; clayey, sandy; dark brown; slightly cohesive; slightly plastic; calcareous	4	1-5
Sand; fine to very fine; subangular to subrounded; well sorted; dark brown; mostly quartz grains	4	5-9
Sand; fine to medium; subangular to subrounded; poorly sorted; dark brown; mostly quartz and carbonate grains	2	9-11
Gravel; fine to coarse; subangular to subrounded; poorly sorted; dark brown; mostly granitic, quartz and carbonate pebbles, some shale pebbles	7	11-18
Glacial Drift		
Clay; silty, slightly sandy, pebbly; a few cobbles; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	4	18-22
Pierre Shale		
Shale; clayey; siliceous; grayish black; noncalcareous	1	22-23

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 22 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-63-1ABB
NDGS 69-2

Elevation: 1,453 feet

Well Number: 4

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Clay; silty; dark brown to black; topsoil	1	0-1
Silt; clayey, sandy; dark brown; slightly cohesive; slightly plastic; calcareous	3	1-4
Sand; fine to very fine; subangular to subrounded; well sorted; dark brown; mostly quartz grains	6½	5-10½
Gravel; fine to coarse; sandy; subangular to to subrounded; dark brown; mostly granitic and carbonate pebbles, some quartz and shale pebbles	5½	10½-16

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 16 feet in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-63-1ABB
NDGS 69-3

Elevation: 1,453 feet

Well Number: 5

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; dark brown to black; topsoil	1	0-1
Silt and clay; dark brown; slightly to moderately cohesive; slightly plastic	12	1-13
Glacial Drift		
Clay; silty, slightly sandy, pebbly; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	9	13-22
Gravel; fine to coarse; abundant sand and silt; subangular to subrounded; poorly sorted; dark brown; mostly granitic and carbonate pebbles, some others	6	22-28
Pierre Shale		
Shale; clayey; siliceous; grayish black; noncalcareous; fine laminations	2	31-33

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 31 feet in the till above the Pierre Shale contact. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-63-1ABB
NDGS 69-4

Elevation: 1,450 feet

Well Number: 6

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; dark brown to black; topsoil	1	0-1
Silt and clay; dark brown; slightly to moderately cohesive; slightly plastic	12	1-13
Glacial Drift		
Clay; silty, slightly sandy, pebbly; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	9	13-22

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 22 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-63-1ABA
NDGS 69-5
[illegible]

Elevation: 1,453 feet

Well Number: 7

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clay; dark brown to black; topsoil	1	0-1
Silt; clayey, sandy; dark brown; moderately cohesive; slightly plastic; calcareous; few fine laminations	13	1-14
Sand; very fine to fine; subangular to subrounded; fair sorting; gray; mostly quartz grains with some carbonate grains	26	14-40
Glacial Drift		
Clay; silty, slightly sandy, pebbly; a few cobbles and boulders; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	16	40-56
Pierre Shale		
Shale; slightly clayey, siliceous; grayish black; noncalcareous; fine laminations	1	56-57

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 57 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-63-1ABA
NDGS 69-6
N876

Elevation: 1,453 feet

Well Number: 8

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clay, dark brown to black; topsoil	1	0-1
Silt; clayey, sandy; dark brown; moderately cohesive; slightly plastic; calcareous; few fine laminations	13	1-14
Sand; very fine to fine; subangular to subrounded; fair sorting; gray; mostly quartz grains, some carbonate grains	3	14-17

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 17 feet, in the sand. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-62-5AAA
NDGS 69-7
N 9-7

Elevation: 1,439 feet

Well Number: 28

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; dark brown to black; topsoil	1	0-1
Clay; silty, slightly sandy, pebbly; yellowish brown; moderately cohesive; slightly plastic; oxidized; till	4	1-5
Clay; silty, slightly sandy, pebbly; olive gray; moderately cohesive; slightly plastic; calcareous; till	44	5-49

The hole caved in to within 20 feet of the surface. A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 20 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-32CCD
NDGS 69-8

Elevation: 1,442 feet

Well Number: 29

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Silt and clay; dark yellowish brown; slightly cohesive; slightly plastic; oxidized	6	1-7
Glacial Drift		
Clay; silty, some sand and pebbles; grayish black; moderately cohesive; moderately plastic; calcareous; till	12	7-19
Clay; very sandy, silty; olive gray; slightly cohesive; slightly plastic; calcareous till	26	19-45
Clay; silty, sandy; a few pebbles and cobbles; olive gray; moderately cohesive; slightly plastic; calcareous; till	11	45-56
Pierre Shale		
Shale; slightly clayey; siliceous; grayish black; noncalcareous	3	56-59

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 59 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-32CCD
NDGS 69-9

Elevation: 1,441 feet

Well Number: 30

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Silt and clay; dark yellowish brown; slightly cohesive; slightly plastic; oxidized	6	1-7
Glacial Drift		
Clay; silty, some sand and pebbles, grayish black; moderately cohesive; moderately plastic; calcareous; till	12	7-19
Clay; very sandy, silty; olive gray; slightly cohesive; slightly plastic; calcareous; till	15	19-34

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 34 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-32CCC
NDGS 69-10
N3

Elevation: 1,441 feet

Well Number: 31

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Silt and clay; dark yellowish brown; slightly cohesive; slightly plastic; oxidized	6	1-7
Glacial Drift		
Clay; silty, some sand and pebbles; grayish black; moderately cohesive; moderately plastic; calcareous; till	12	7-19

The hole caved in to within 10 feet of the surface. A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 10 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-32CCC
NDGS 69-11

Elevation: 1,440 feet

Well Number: 31

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Silt and clay; dark yellowish brown; slightly cohesive; slightly plastic; oxidized	2½	1-3½
Gravel; fine to coarse; subangular to subrounded; very poorly sorted; abundance of clay and silt; dark yellowish brown; mostly granitic pebbles	3	3½-6½
Sand; fine to medium; subangular to subrounded; very poorly sorted; abundance of silt and clay; gray; quartz grains with some carbonate grains	3	6½-9½
Glacial Drift		
Clay; silty, some sand and pebbles; grayish black; moderately cohesive; slightly plastic; calcareous; till	9½	9½-19

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 19 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-62-5BCB
NDGS 69-12
N 21

Elevation: 1,444 feet

Well Number: 27

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Clay; silty, sandy; dark brown to black; topsoil	1	0-1
Gravel; fine to medium; sandy, clayey; subrounded to subangular; poorly sorted; mostly granitic and carbonate pebbles	3	1-4
Silt; sandy, clayey; gray; slightly cohesive; slightly plastic; calcareous	15	4-19
Sand; clayey, silty; subangular to subrounded; poorly sorted; dark gray; quartz and carbonate pebbles with a few others	7	19-26
Glacial Drift		
Clay; sandy, silt, slightly pebbly; olive gray; slightly cohesive; slightly plastic; calcareous; till	21	26-47

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 46 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-62-5BCB
NDGS 69-13

Elevation: 1,444 feet

Well Number: 25

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Clay; silty, sandy; dark brown to black; topsoil	1	0-1
Gravel; fine to medium; sandy, clayey; subangular to subrounded; poorly sorted; gray; mostly granitic and carbonate pebbles	3	1-4
Silt; sandy, clayey; gray; slightly cohesive; slightly plastic; calcareous	15	4-19
Sand; clayey, silty; subangular to subrounded; poorly sorted; dark gray; quartz and carbonate pebbles	7	19-26
Glacial Drift		
Clay; sandy, silty, slightly pebbly; olive gray; slightly plastic; calcareous; till	3	26-29

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 29 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-62-5BCC
NDGS 69-14
[illegible]

Elevation: 1,444 feet

Well Number: 26

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Clay; silty, sandy; dark brown to black; topsoil	1	0-1
Gravel; fine to medium; sandy, clayey; subangular to subrounded; poorly sorted; mostly granitic and carbonate pebbles	3	1-4
Silt; sandy, clayey; gray; slightly cohesive; slightly plastic; calcareous	12	4-16

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 16 feet, in the silt. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-63-36AAA
NDGS 69-15

Elevation: 1,463 feet

Well Number: 19

	Thickness (feet)	Depth (feet)
Glacial Drift		
Clay; silty, sandy; brownish black; topsoil	1	0-1
Clay; silty, sandy, slightly pebbly; dark yellowish brown; moderately cohesive; slightly plastic; oxidized; till	26	1-27
Gravel; medium to very coarse; sandy; subangular to subrounded; poorly sorted; mostly granitic and carbonate pebbles	4	27-31

The drill could not get through the gravel section. A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 31 feet, in the gravel. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-63-36AAA
NDGS 69-16

Elevation: 1,463 feet

Well Number: 22

	Thickness (feet)	Depth (feet)
Glacial Drift		
Clay; silty, sandy; brownish black; topsoil	1	0-1
Clay; silty, sandy, pebbly; a few cobbles and boulders; dark yellowish brown; moderately cohesive; slightly plastic, oxidized; till	30	1-31
Gravel; coarse to very coarse; sandy; subangular to subrounded; poorly sorted; mostly granitic and carbonate pebbles	3	31-34

The drill could not get through the gravel section. A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 31 feet, in the gravel. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CCA
NDGS 69-17
N922

Elevation: 1,444 feet

Well Number: 42

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Clay; silty, sandy; brownish black; topsoil	1	0-1
Clay; very silty, sandy; grayish black; moderately cohesive; slightly plastic; overbank sediment	12½	1-13½
Gravel; medium to coarse; subangular to subrounded; poorly sorted; mostly granitic and carbonate pebbles	5	13½-18½
Sand; fine to medium; angular to subrounded; gray; mostly quartz grains with some carbonate grains	9½	18½-28
Gravel; medium to coarse; sandy; angular to subrounded; poorly sorted; gray; large boulders; mostly quartz with some carbonate pebbles	25	28-53

The drill was stopped by a boulder at 53 feet. A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 53 feet, in the gravel. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CCA
NDGS 69-18
N [illegible]

Elevation: 1,443 feet

Well Number: 65

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Sand; silty, clayey; dark brown to black; topsoil	1	0-1
Sand; fine to medium; clayey; subangular to subrounded; fair sorting; yellowish brown; mostly quartz grains with a few carbonate grains	20	1-21
Gravel; fine to medium; clayey; subangular to subrounded; fair to poor sorting; gray; mostly quartz with a few carbonate pebbles	13	21-34

The drill was stopped by a boulder at a depth of 34 feet. The hole caved in to within 20 feet of the surface. A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 20 feet, in the gravel. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CAA
NDGS 69-19
N 92

Elevation: 1,445 feet

Well Number: 66

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Sand; silty; dark brown to black; topsoil	1	0-1
Sand; fine to medium; subangular to subrounded; fair sorting; yellowish brown; mostly quartz grains	13	1-14
Gravel; fine to medium; subangular to subrounded; fair sorting; yellowish brown; mostly quartz and carbonate pebbles	3	14-17

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 17 feet, in the gravel. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CAA
NDGS 69-20

Elevation: 1,445 feet

Well Number: 67

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Sand; silty; dark brown to black; topsoil	1	0-1
Sand; fine to medium; subangular to subrounded; fair sorting; yellowish brown; mostly quartz grains	3	1-4
Silt and clay; grayish black; moderately cohesive; slightly plastic; calcareous	6	4-10
Sand; fine to medium, subangular to subrounded; fair sorting; gray; mostly quartz grains	3	10-13
Gravel; fine to medium; sandy; angular to subrounded; poor to fair sorting; gray; mostly granitic pebbles with some carbonate pebbles	6	13-19

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 19 feet, in the gravel. The bottom 3 feet of the pipe was packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

141-62-6ADA
NDGS 69-21
N902

Elevation: 1,441 feet

Well Number: 16

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Sand; silty; dark brown to black; topsoil	1	0-1
Sand; fine to medium; subangular to subrounded fair sorting; yellowish brown; mostly quartz grains	18	1-19
Silt and clay; very silty, sandy; grayish black; moderately cohesive; slightly plastic; calcareous	51	19-70
Sand; fine to medium; subangular to subrounded; fair sorting; gray; most quartz grains	14	70-84

A plastic pipe, 1 inch in diameter, was set as a piezometer at a depth of 84 feet, in the sand. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-63-36AAD
WRI 71-1

Elevation: 1,488 feet

Well Number: 34

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; dark brown to black; topsoil	1	0-1
Clay; silty, sandy, slightly pebbly; dark yellowish brown; slightly to moderately cohesive; slightly plastic; oxidized; till	34	1-35
Sand; fine to coarse; dark brown; fair to well sorted; subangular to subrounded; mostly quartz and carbonate grains	1	35-36
Clay; silty, sandy, slightly pebbly; some large cobbles; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	14	36-50
Gravel; fine to medium; sandy; angular to subangular; poorly sorted; mostly granitic and carbonate pebbles	10	50-60
Clay; slightly sandy, silty; grayish black; moderately cohesive; plastic; slightly calcareous; overbank	10	60-70
Silt; clayey, slightly sandy; few pebbles; olive gray to grayish black; slightly to moderately cohesive; moderately plastic; calcareous; till	28	70-98
Gravel; fine to coarse grained; sandy; angular to subangular; poorly sorted; mostly granitic and carbonate pebbles with a few shale pebbles	3	98-101
Pierre Shale		
Shale; slightly clayey; siliceous; grayish black; noncalcareous; fine laminations	9	101-110

A plastic pipe, 1¼ inch in diameter, was set and lost. A second hole was drilled to the same depth, and a plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 110 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-63-36AAD
WRI 71-2

Elevation: 1,488 feet

Well Number: 35

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; dark brown to black; topsoil	1	0-1
Clay; silty, sandy, slightly pebbly; dark yellowish brown; slightly to moderately cohesive; slightly plastic; oxidized; till	34	1-35
Sand; fine to medium; dark brown; fair to well sorted; subangular to subrounded; mostly quartz and carbonate pebbles	1	35-36
Clay; silty, sandy, slightly pebbly; some large cobbles; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	14	36-50
Gravel; fine to medium; sandy; angular to subangular, poorly sorted; mostly granitic and carbonate pebbles	10	50-60

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 60 feet, in the gravel. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-63-36AAA
WRI 71-3
N 317

Elevation: 1,463 feet

Well Number: 33

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; dark brown to black; topsoil	1	0-1
Clay; sandy, silty; a few pebbles, cobbles, and boulders; dark yellowish brown; slightly to moderately cohesive; slightly plastic; oxidized; till	19	1-20
Clay; sandy, silty; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	10	20-30
Gravel; fine to coarse; very sandy; angular to subangular; poorly sorted; mostly quartz, carbonate, and granitic pebbles; slightly calcareous	9	30-39

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 37 feet, in the gravel. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-63-36AAA
WRI 71-4

N 917

Elevation: 1,463 feet

Well Number: 36

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; dark brown to black; topsoil	1	0-1
Clay; sandy, silty; a few pebbles, cobbles, and boulders; dark yellowish brown; slightly to moderately cohesive; moderately plastic; calcareous; till	19	1-20
Clay; sandy, silty; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	10	20-30
Gravel; fine to coarse; very sandy; angular to subangular; poor to fair sorting; mostly quartz, carbonate, and granitic pebbles	9	30-39
Pierre Shale		
Shale; slightly clayey, siliceous; grayish black; noncalcareous; fine laminations; bentonite beds up to 1 inch thick	11	39-50

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 50 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CAA
WRI 71-5
N 427

Elevation: 1,452 feet

Well Number: 53

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Clay; silty, slightly sandy, pebbly; dark yellowish brown; slightly to moderately cohesive; slightly plastic; oxidized; till	19	1-20
Silt; clayey, slightly sandy; some pebbles, cobbles, and boulders; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	40	20-60
Clay; silty, slightly sandy, pebbly; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	50	60-110
Pierre Shale		
Shale; slightly clayey; siliceous; grayish black; noncalcareous; fine laminations; fish tooth and white flecks at 111 feet	15	110-125

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 125 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CAA
WRI 71-6

Elevation: 1,452 feet

Well Number: 54

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Clay; silty, moderately to slightly sandy; dark yellowish brown; moderately cohesive; slightly plastic; oxidized; till	19	1-20
Sand; fine to medium; slightly silty, clayey; subangular to subrounded; poorly sorted; yellowish brown; mostly quartz and carbonate grains	1½	20-21½
Clay; silty, sandy; few pebbles and cobbles; olive gray; moderately cohesive; slightly plastic; calcareous; till	23½	21½-45

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 45 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CAA
WRI 71-7
N-727

Elevation: 1,445 feet

Well Number: 55

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Clay; very silty, sandy; dark yellowish brown; slightly cohesive; plastic; oxidized; overbank sediment	14	1-15
Silt; sandy, clayey; poorly sorted; grayish black; slightly cohesive; slightly plastic; calcareous; a few small laminations	25	15-40
Sand; fine to coarse; clayey, silty; poor to fair sorting; angular to subrounded; grayish black; mostly quartz and carbonate grains	20	40-60
Glacial Drift		
Clay; sandy, silty; few pebbles and cobbles; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	10	60-70

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 50 feet, in sand. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CCA
WRI 71-8
A-43-

Elevation: 1,443 feet

Well Number: 44

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Sand; fine to coarse; angular to subrounded; poorly sorted; yellowish brown; mostly quartz and carbonate grains; oxidized	5	1-6
Silt; clayey, sandy; yellowish brown; slightly cohesive; slightly plastic; few laminations; overbank sediment	12	6-18
Gravel; fine to very coarse; slightly sandy; subangular to subrounded; fair to good sorting; yellowish brown; mostly carbonate, quartz, and granitic pebbles	12	18-30
Sand; fine to coarse; silty, clayey; subangular to subrounded; very poor sorting; grayish black; mostly carbonate, quartz, and granitic pebbles	8	30-38
Glacial Drift		
Clay; silty, sandy; few pebbles and cobbles; olive gray; moderately cohesive; slightly plastic; calcareous; till	2	38-40

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 38 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28BDC
WRI 71-9
N [illegible]

Elevation: 1,528 feet

Well Number: 50

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; sandy, clayey; dark brown to black; topsoil	1	0-1
Clay; silty, sandy, pebbly; a few cobbles and boulders; dark yellowish brown; moderately cohesive; slightly to moderately plastic; oxidized; till	19	1-20
Clay; sandy; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	14	20-34
Sand; fine to very fine; subangular to subrounded; well sorted; gray; mostly quartz and a few carbonate pebbles	5	34-39
Clay; silty, sandy; a few pebbles and cobbles; olive gray; moderately cohesive; slightly plastic; calcareous; till	19	39-58
Sand; fine to medium; subangular to subrounded; poorly sorted; gray; mostly quartz and carbonate grains	1	58-59
Gravel; fine to very coarse; angular to subrounded; poorly sorted; dark gray; mostly granitic and carbonate pebbles; a few shale, sandstone, and quartz pebbles	8	59-67
Silt; clayey, sandy, pebbly; a few cobbles and boulders; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	33	67-100
Clay; silty, sandy, pebbly; a few small sand inclusions; olive gray; moderately cohesive; moderately plastic; calcareous; till	55	100-155
Pierre Shale		
Shale; slightly to moderately clayey; siliceous; grayish black; noncalcareous; bentonite beds about 2 inches thick at about 160 feet, below that no bentonite beds	15	155-170

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 170 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28~~DBC~~
WRI 71-10
N926

Elevation: 1,528 feet

Well Number: 51

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; sandy, clayey; dark brown to black, topsoil	1	0-1
Clay; silty, sandy, pebbly; a few cobbles and boulders; dark yellowish brown; moderately cohesive; slightly to moderately plastic; oxidized; till	19	1-20
Clay; silty, sandy; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	40	20-60
Sand; fine to very fine; subangular to subrounded; well sorted; gray; mostly quartz plus a few carbonate grains	1½	60-61½
Clay; silty, sandy; a few pebbles and cobbles; olive gray; moderately cohesive; slightly plastic; calcareous; till	46½	61½-108
Sand; fine to medium; subangular to subrounded; poorly sorted; dark gray to black; mostly shale and a few carbonate and quartz grains	1	108-109
Clay; silty, sandy; a few pebbles and cobbles; olive gray; slightly cohesive; slightly plastic; calcareous; till	1	109-110

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 110 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28BDC
WRI 71-11
N 2-26

Elevation: 1,528 feet

Well Number: 52

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; sandy, clayey; dark brown to black; topsoil	1	0-1
Clay; silty, sandy, pebbly; a few cobbles and boulders; dark yellowish brown; moderately cohesive; slightly to moderately plastic; calcareous; till	19	1-20
Clay; silty, sandy; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	22	20-42
Sand; fine to very coarse; subangular to subrounded; well sorted to poorly sorted; gray; mostly quartz and carbonate grains with a few shale grains	5	42-47
Clay; silty, sandy; a few pebbles and cobbles; olive gray; moderately cohesive; slightly plastic; calcareous; till	23	47-70

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 70 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CBA
WRI 71-12
A-425

Elevation: 1,528 feet

Well Number: 47

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; few pebbles; brownish black; topsoil	1	0-1
Clay; silty, sandy, pebbly; a few cobbles and boulders; dark yellowish brown; moderately cohesive; slightly plastic; oxidized; till	24	1-25
Clay; silty, sandy, pebbly; slightly to moderately cohesive; slightly plastic; calcareous; till	25	25-50
Silt; clayey, very sandy; few pebbles, cobbles, and boulders; sand increased downward; olive gray; slightly cohesive; slightly plastic; calcareous; till	45	50-95
Sand; clayey, silty; a few pebbles and cobbles; as much as 60 percent of till is sand; olive gray; slightly cohesive; slightly plastic; calcareous; two 1-foot lenses of sand at 110 feet and 112 feet; till	45	95-140
Clay; sandy, silty, pebbly; a few cobbles; olive green; slightly cohesive; slightly plastic; calcareous; till	80	140-220
Pierre Shale		
Shale; slightly clayey, siliceous; grayish black; noncalcareous; two beds of bentonite 1 to 2 inches thick; fine laminations	5	220-225
Shale; crushed shale fragments, mixed with a fine sand; gray to grayish black; shale slightly clayey; siliceous; noncalcareous; sand grains mostly quartz	5	225-230
Shale; slightly clayey; siliceous; grayish black; noncalcareous; no bentonite; scattered fine laminations	10	230-240

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 240 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CBA
WRI 71-13
[illegible]

Elevation: 1,527 feet

Well Number: 48

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; few pebbles; brownish black; topsoil	1	0-1
Clay; silty, sandy, pebbly; a few cobbles and boulders; dark yellowish brown; moderately cohesive; slightly plastic; oxidized; till	24	1-25
Clay; silty, sandy, pebbly; a few cobbles and boulders; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	21	25-46
Sand; fine to coarse grained; silty; subangular to subrounded; very poorly sorted; gray; mostly quartz	12	46-58

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 58 feet, in the sand. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CBA
WRI 71-14

Elevation: 1,526 feet

Well Number: 49

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; a few pebbles; brownish black; topsoil	1	0-1
Clay; silty, sandy, pebbly; a few cobbles and boulders; dark yellowish brown; moderately cohesive; slightly plastic; oxidized; till	24	1-25
Clay; silty, sandy, pebbly; a few cobbles and boulders; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	32	25-57
Sand; fine to medium; subangular to subrounded; well sorted; gray; mostly quartz plus some carbonate grains	1	57-58
Clay; silty, slightly sandy; a few pebbles cobbles, and boulders; olive gray; moderately cohesive; slightly to moderately plastic; calcareous; till	62	58-120

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 120 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CCA
WRI 71-15
N 934

Elevation: 1,456 feet

Well Number: 59

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Clay and silt; slightly sandy; dark yellowish brown; slightly cohesive; slightly plastic; oxidized; overbank sediment	6	1-7
Gravel; fine to coarse; sandy, slightly silty and clayey; subangular to subrounded; poorly sorted; yellowish brown; mostly granitic and carbonate pebbles; oxidized	5	7-12
Gravel; fine to coarse; sandy, slightly silty and clayey; subangular to subrounded; poorly sorted; gray; mostly granitic and carbonate pebbles	8	12-20
Glacial Drift		
Clay; silty, slightly sandy; some pebbles and a few cobbles and boulders; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	15	20-35
Sand; fine to medium; silty, clayey; angular to subrounded; very poorly sorted; very dark gray; abundance of shale grains; some quartz and carbonate grains; calcareous	20	35-55
Clay; silty, sandy; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; slightly to moderately plastic; calcareous; till	45	55-100
Clay; silty, sandy, pebbly; a few cobbles; olive gray; moderately cohesive; slightly plastic; calcareous; most of the pebbles and cobbles are shale, a few pieces of lignite particles are common; till	50	100-150
Pierre Shale		
Shale; slightly clayey; siliceous; grayish black; noncalcareous; fine laminations	15	150-165
Shale; slightly clayey; siliceous; grayish black; sand lenses 2 to 3 feet thick; sand very fine, mostly quartz; angular to subrounded; well sorted; gray; noncalcareous	15	165-180
Shale; clayey; siliceous; very dark brown; noncalcareous	5	180-185

142-62-28CCA
WRI 71-15
N 934

Elevation: 1,456 feet

Well Number: 59

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt; clayey, sandy; brownish black; topsoil	1	0-1
Clay and silt; slightly sandy; dark yellowish brown; slightly cohesive; slightly plastic; oxidized; overbank sediment	6	1-7
Gravel; fine to coarse; sandy, slightly silty and clayey; subangular to subrounded; poorly sorted; yellowish brown; mostly granitic and carbonate pebbles; oxidized	5	7-12
Gravel; fine to coarse; sandy, slightly silty and clayey; subangular to subrounded; poorly sorted; gray; mostly granitic and carbonate pebbles	8	12-20
Glacial Drift		
Clay; silty, slightly sandy; some pebbles and a few cobbles and boulders; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	15	20-35
Sand; fine to medium; silty, clayey; angular to subrounded; very poorly sorted; very dark gray; abundance of shale grains; some quartz and carbonate grains; calcareous	20	35-55
Clay; silty, sandy; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; slightly to moderately plastic; calcareous; till	45	55-100
Clay; silty, sandy, pebbly; a few cobbles; olive gray; moderately cohesive; slightly plastic; calcareous; most of the pebbles and cobbles are shale, a few pieces of lignite particles are common; till	50	100-150
Pierre Shale		
Shale; slightly clayey; siliceous; grayish black; noncalcareous; fine laminations	15	150-165
Shale; slightly clayey; siliceous; grayish black; sand lenses 2 to 3 feet thick; sand very fine, mostly quartz; angular to subrounded; well sorted; gray; noncalcareous	15	165-180
Shale; clayey; siliceous; very dark brown; noncalcareous	5	180-185

142-62-28
WRI 71-15
Cont.

	Thickness (feet)	Depth (feet)
Shale; clayey; siliceous; very dark brown bentonite beds 1 inch to 2 inches thick	15	185-200
Shale; slightly clayey, siliceous; grayish black; noncalcareous; fine laminations	60	200-260

A plastic pipe was set in the top of this hole to vent the flow of water while the hole was being cemented. No piezometer was placed in the hole.

142-~~64~~-28CCA
WRI 71-16
N924

Elevation: 1,457 feet

Well Number: 45

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt, clayey, sandy; brownish black; topsoil	1	0-1
Clay and silt; slightly sandy; dark yellowish brown; slightly cohesive; slightly plastic; oxidized; overbank	6	1-7
Gravel; fine to coarse; sandy, slightly silty and clayey; subangular to subrounded; poorly sorted; yellowish brown; mostly granitic and carbonate pebbles; oxidized	5	7-12
Gravel; fine to coarse; sandy, slightly silty and clayey; subangular to subrounded; poorly sorted; gray; mostly granitic and carbonate pebbles	8	12-20
Glacial Drift		
Clay; slightly sandy, pebbly; a few cobbles and boulders; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	15	20-35
Sand; fine to medium; silty and clayey; angular to subrounded; very poorly sorted; abundance of shale grains, some quartz and carbonate grains; calcareous	20	35-55
Clay; silty, sandy; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; slightly to moderately plastic; calcareous; till	45	55-100
Clay; silty, sandy, pebbly; a few cobbles; olive gray; moderately cohesive; slightly plastic; calcareous; most of the pebbles and cobbles are shale, lignite is common; till	50	100-150
Pierre Shale		
Shale; slightly clayey; siliceous; grayish black; noncalcareous; fine laminations	15	150-165
Shale; slightly clayey; siliceous; grayish black; sand lenses 1 to 3 feet thick; sand is very fine, mostly quartz; gray; well sorted; subangular to subrounded; noncalcareous	15	165-180

63
142-~~64~~-28
WRI 71-16
Cont.

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 180 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CCA
WRI 71-17
N 724

Elevation: 1,457 feet

Well Number: 46

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Silt, clayey, sandy; brownish black; topsoil	1	0-1
Clay and silt; slightly sandy; dark yellowish brown; slightly cohesive; slightly plastic; oxidized; overbank	6	1-7
Gravel; fine to coarse; slightly silty and clayey; subangular to subrounded; poorly sorted; yellowish brown; mostly granitic and carbonate pebbles; oxidized	5	7-12
Gravel; fine to coarse; slightly silty and clayey; subangular to subrounded; poorly sorted; gray; mostly granitic and carbonate pebbles	8	12-20
Glacial Drift		
Clay; silty, slightly sandy, pebbly; a few cobbles and boulders; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	15	20-35
Sand; fine to medium; silty, clayey; angular to subrounded; very poorly sorted; very dark gray; abundance of shale with some quartz and carbonate grains; calcareous	20	35-55
Clay; silty, sandy; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	5	55-60

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 60 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CDB
WRI 71-18
N [illegible]

Elevation: 1,458 feet

Well Number: 40

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Sand; silty, clayey; brownish black; topsoil	1	0-1
Sand; fine to medium; subangular to subrounded; poorly sorted; yellowish brown; mostly quartz and carbonate grains; oxidized	5	1-6
Glacial Deposits		
Clay; silty, sandy; a few pebbles; dark yellowish brown; moderately cohesive; slightly plastic; oxidized; till	10	6-16
Clay; silty, sandy; a few pebbles; olive gray; moderately cohesive; slightly plastic; calcareous; till	42	16-58
Sand; fine to medium; silty, clayey; subangular to subrounded; poorly sorted; gray; mostly quartz and carbonate grains	1	58-59
Silt; clayey, sandy; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	21	59-80
Sand; fine to medium; subangular to subrounded; poorly to well sorted; gray; mostly quartz and carbonate grains	5	80-85
Clay; silty, slightly sandy; a few pebbles; olive gray; moderately cohesive; slightly plastic; calcareous; till	75	85-160
Clay; silty, sandy; a few pebbles and cobbles; olive gray; moderately cohesive; moderately plastic; very compact; calcareous; till	45	160-205
Pierre Shale		
Shale; clayey; siliceous; grayish black; noncalcareous	5	205-210

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 210 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CDB
WRI 71-19

Elevation: 1,458 feet

Well Number: 39

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Sand; silty, clayey; brownish black; topsoil	1	0-1
Sand; fine to medium; subangular to subrounded; poorly sorted; yellowish brown; mostly quartz and carbonate grains; oxidized	5	1-6
Glacial Deposits		
Clay; silty, sandy, a few pebbles; dark yellowish brown; moderately cohesive; slightly plastic; oxidized; till	10	6-16
Clay; silty, sandy, a few pebbles; olive gray; moderately cohesive; slightly plastic; calcareous; till	42	16-58
Sand; fine to medium; silty, clayey; subangular to subrounded; poorly sorted; gray; mostly quartz and carbonate grains	1	58-59
Silt; clayey, sandy; a few pebbles and cobbles; olive gray; slightly to moderately cohesive; moderately plastic; calcareous; till	21	59-80
Sand; fine to medium; subangular to subrounded; poorly to well sorted; gray; mostly quartz and carbonate grains	5	80-85

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 85 feet, in the sand. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-28CAD
WRI 71-21
N 930

Elevation: 1,459 feet

Well Number: 38

	Thickness (feet)	Depth (feet)
Fluvial Deposits		
Sand; silt, clay; dark brown to black; topsoil	1	0-1
Sand; fine to medium; clayey; angular to subrounded; poorly sorted; yellowish brown; very dirty sand; mostly quartz and carbonate grains with a few shale grains; oxidized	4	1-5
Clay; silty, slightly sandy; a few pebbles and cobbles; dark yellowish brown; slightly to moderately cohesive; slightly plastic; oxidized; till	10	5-15
Clay; silty, sandy, pebbly; a few cobbles and boulders; olive gray; moderately cohesive; slightly plastic; calcareous; till	9	15-24
Sand; fine to medium; subangular to subrounded; well sorted; gray; mostly quartz and carbonate grains	3	24-27
Clay; silty, sandy, pebbly; a few pebbles and cobbles; olive gray; moderately cohesive; slightly plastic; calcareous; till	53	27-80

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 80 feet, in the till. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-32BBC
WRI 71-22
[illegible]

Elevation: 1,481 feet

Well Number: 58

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; dark brown; topsoil; poorly developed	½	0-½
Sand; fine to coarse; clayey; subangular to subrounded; very poorly sorted; yellowish brown; very dirty; oxidized	4½	½-5
Clay; silty, sandy, pebbly; a few cobbles and boulders; dark yellowish brown; slightly cohesive; slightly plastic; oxidized; till	14	5-19
Clay; silty, sandy; a few pebbles, cobbles, and boulders; olive gray; moderately cohesive; slightly plastic; calcareous; till	26	19-45
Sand; fine to coarse; few pebbles; angular subrounded; poorly sorted; gray; mostly quartz and carbonate grains	2	45-47
Clay; silty, sandy, very pebbly; a few cobbles and boulders; olive gray; moderately cohesive; slightly plastic; calcareous; till	16	47-63
Pierre Shale		
Shale; slightly clayey; siliceous; grayish black; noncalcareous; fine laminations	6½	63-69½

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 60 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

142-62-32BBC
WRI 71-23
N 929

Elevation: 1,475 feet

Well Number: 59

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; clayey, sandy; dark brown; topsoil; poorly developed	½	0-½
Clay; silty, sandy, pebbly; a few cobbles and boulders; dark yellowish brown; slightly cohesive; slightly plastic; oxidized; till	14½	½-15
Gravel; coarse to medium; sandy; subangular to subrounded; poor sorting; light yellowish brown; mostly granitic pebbles with a few carbonate, sandstone and shale pebbles	5	15-20

Hole was stopped at the boulder pavement because of drilling problems.

142-62-32BBC
WRI 71-24

N429

Elevation: 1,471 feet

Well Number: 60

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; sandy, clayey; a few pebbles and and cobbles; dark brown; topsoil; poorly developed	½	0-½
Sand; clayey, silty; abundance of cobbles and boulders; slightly cohesive; slightly plastic; dark yellowish brown; oxidized; till	19½	½-20

Hole stopped at boulder pavement because of drilling problems.

142-62-32BBC
WRI 71-25

N 929

Elevation: 1,461 feet

Well Number: 61

	Thickness (feet)	Depth (feet)
Glacial Drift		
Silt; sandy, clayey; dark brown; poorly developed; topsoil	½	0-½
Clay; silty, sandy, pebbly; a few cobbles and boulders; dark yellowish brown; slightly cohesive; slightly plastic; oxidized; till	19½	½-20
Clay; silty, sandy, pebbly; a few cobbles and boulders; olive gray; slightly to moderately cohesive; slightly plastic; calcareous; till	20	20-40
Pierre Shale		
Shale; slightly clayey; siliceous; grayish black; noncalcareous; fine laminations	20	40-60

A plastic pipe, 1¼ inch in diameter, was set as a piezometer at a depth of 60 feet, in the Pierre Shale. The bottom 3 feet of the pipe was slotted and packed in place with pea gravel. The rest of the pipe was cemented in place with a mixture of portland cement and pea gravel.

APPENDIX C

PHYSICAL WELL DATA

PHYSICAL WELL DATA

Explanations of the headings used on pages to are given below.

WELL NO.	number assigned to source of water (usually a piezometer).
LOCATION	geographical location of well. (See Figure 31)
E.T.W.	elevation in feet of the top of well casing.
WELL D.	depth of the well in feet measured from the top of the well casing.
D.T.W.	distance in feet from the top of the well casing to the water level in the well. Negative values indicate pressure head at top of well casing in feet of head.
S.W.L.	static water level in well measured in feet of head above sea level.
E.B.W.	elevation above sea level of bottom of the well measured in feet.
TEMP.	temperature of water in degrees Centigrade at the time the same was collected.
PH	negative logarithm of the hydrogen-ion concentration.
S.C.	specific conductance of water measured in micromhos.
T.D.S.	total dissolved solids measured in parts per million.
T. ALK.	total alkalinity of water sample measured in parts per million $CaCO_3$.
TOT. H.	total hardness of water sample measured in parts per million $CaCO_3$.
SOURCE	geological material or source of water

in water sample
Pierre Shale = 1
Till = 2
Fluvial gravels = 3
Lake = 4
Others = 5

ANAL. party who collected and analyzed sample
Frank Schulte = 1
N. Dak. Water Commission = 2
N. Dak. Game and Fish = 3
N. Dak. State University = 4
U.S. Geological Survey = 5
University of N. Dak. Biology Dept. = 6

DATE date water samples were collected.
First two digits = day
Second two digits = month
Third two digits = year

WELL NO.	LOCATION	E.T.W.	WELL D.	D.T.W.	S.W.L.
1	142-62-32BCA	1435.00	0.0	0.0	1435.00
2	142-62-31DBD	1435.00	0.0	0.0	1435.00
3	141-63- 1ABB	1450.00	23.00	4.20	1445.80
4	141-63- 1ABB	1453.00	16.00	4.50	1448.50
5	141-63- 1ABB	1453.00	33.00	4.40	1448.60
6	141-63- 1ABB	1450.00	22.00	2.40	1447.60
7	141-63- 1ABA	1453.00	57.00	2.30	1450.70
8	141-63- 1ABA	1453.00	17.00	2.20	1450.80
9	142-62-32CCD	1442.00	9.00	2.20	1439.80
10	141-62-32CCD	1441.00	10.00	1.90	1439.10
11	142-62-32CCC	1441.00	34.00	3.10	1437.90
12	142-62-32CCC	1440.00	59.00	4.50	1435.50
13	141-62- 5BCB	1444.00	29.00	4.40	1439.60
14	141-62- 5BCC	1444.00	47.00	12.20	1431.80
15	141-62- 5BCC	144.00	16.00	2.30	141.70
16	141-62- 6ADA	1441.00	84.00	2.00	1439.00
17	141-62- 6ADD	1438.00	120.00	4.70	1433.30
18	141-62- 5AAA	1441.00	49.00	2.00	1439.00
19	142-63-36AAA	1463.00	31.00	28.20	1434.80
20	142-63-36ADA	1488.00	100.00	41.60	1446.40
21	142-63-36AAA	1463.00	50.00	28.30	1434.70
22	142-36-36AAA	1463.00	34.00	28.10	1434.90
23	141-62- 5BCC	1437.00	60.00	0.60	1436.40
24	141-62- 6ADD	1438.00	120.00	4.30	1433.70
25	141-62- 5BCB	1444.00	29.00	4.40	1439.60
26	141-62- 5BCC	1444.00	16.00	2.30	1441.70
27	141-62- 5BCC	1444.00	47.00	3.50	1440.50
28	141-62- 1AAA	1441.00	49.00	2.40	1438.60
29	142-62-32CCD	1442.00	19.00	1.80	1440.20
30	141-62-32CCD	1441.00	10.00	1.20	1439.80
31	142-62-32CCC	1441.00	34.00	1.60	1439.40
32	142-62-32CCC	1440.00	59.00	1.20	1438.80
33	142-63-36AAA	1463.00	39.00	28.10	1434.90
34	142-63-36AAD	1488.00	110.00	41.50	1446.50
35	142-63-36AAD	1488.00	60.00	41.60	1446.40
36	142-63-36AAA	1463.00	60.00	28.20	1434.80
37	142-62-28CAD	1459.00	200.00	-1.20	1460.20
38	142-62-28CAD	1459.00	80.00	9.80	1449.20
39	142-62-28CDB	1458.00	85.00	6.80	1451.20
40	142-62-28CDB	1458.00	210.00	-1.20	1459.20
41	142-62-28CCA	1444.00	170.00	0.20	1443.80
42	142-62-28CCA	1444.00	53.00	6.90	1437.10
43	142-62-29DDD	1436.00	0.0	0.0	1436.00
44	142-62-28CCA	1443.00	40.00	7.20	1435.80
45	142-62-28CCA	1457.00	180.00	-4.10	1461.10
46	142-62-28CCA	1457.00	60.00	3.20	1453.80
47	142-62-28CBA	1528.00	240.00	27.20	1500.80
48	142-62-28CBA	1527.00	58.00	29.40	1497.60
49	142-62-28CBA	1526.00	120.00	29.10	1496.90
50	142-62-28BDC	1528.00	170.00	19.70	1508.30
51	142-62-28BDC	1528.00	110.00	16.20	1511.80
52	142-62-28BDC	1528.00	70.00	9.70	1518.30

WELL NO.	LOCATION	E.T.W.	WELL D.	D.T.W.	S.W.L.
53	142-62-28CAA	1452.00	125.00	-1.20	1453.20
54	142-62-28CAA	1452.00	45.00	24.80	1427.20
55	142-62-28CAA	1445.00	70.00	4.60	1440.40
56	142-62-28CAA	1445.00	220.00	-0.20	1445.20
57	142-62-28DBB	1438.00	0.0	0.0	1438.00
58	142-62-32BBC	1481.00	60.00	24.70	1456.30
65	141-62-31AAA	0.0	0.0	0.0	0.0
68	140-63-24BBB	0.0	130.00	0.0	0.0
69	140-64-23BCD	0.0	1572.00	0.0	0.0
70	140-64-25BCD	0.0	30.00	0.0	0.0
71	140-64-25BCC	0.0	87.00	0.0	0.0
72	140-64-25BCC	0.0	57.00	0.0	0.0
73	140-64-25CCC	0.0	1450.00	0.0	0.0
74	140-64-25ACC	0.0	1487.00	0.0	0.0
75	140-64-30CCB	0.0	240.00	0.0	0.0
76	141-62- 8ACC	0.0	0.0	0.0	0.0
77	142-62- 7BBA	0.0	35.00	0.0	0.0
78	142-62-28ABD	0.0	30.00	0.0	0.0
79	142-63-18AAA	0.0	65.00	0.0	0.0
80	142-64-18CCC	0.0	135.00	0.0	0.0
81	142-64-18CCC	0.0	200.00	0.0	0.0
82	143-64- 4ACC	0.0	30.00	0.0	0.0
83	144-62-16CCB	0.0	35.00	0.0	0.0
84	142-65-20BAA	0.0	90.00	0.0	0.0
85	140-63- 5BCB	0.0	80.00	0.0	0.0
86	140-63- 5BCB	0.0	80.00	0.0	0.0
87	140-62-24BBA	0.0	216.00	0.0	0.0

WELL NO.	E.B.W.	TEMP.	PH	S.C.	T.D.S.
1	1435.00	6.25	7.071	8000.0	3334.94
2	1435.00	6.15	6.989	2980.0	2209.08
3	1427.00	9.00	8.121	890.0	523.12
4	1437.00	9.12	8.056	660.0	470.04
5	1420.00	9.14	8.046	940.0	750.56
6	1428.00	9.11	7.900	930.0	694.24
7	1396.00	9.05	8.076	1450.0	1154.47
8	1436.00	9.12	8.041	1490.0	1209.46
9	1433.00	8.40	8.929	8000.0	5836.17
10	1431.00	7.90	8.380	1030.0	906.57
11	1407.00	8.20	7.791	920.0	736.97
12	1381.00	8.48	8.024	1160.0	825.12
13	1415.00	8.78	8.126	740.0	593.98
14	1397.00	8.81	7.966	1850.0	1341.21
15	128.00	7.94	8.032	1800.0	1087.93
16	1357.00	8.40	8.359	1620.0	1423.90
17	1318.00	9.21	8.195	1920.0	1319.66
18	1392.00	9.01	8.535	5400.0	3505.46
19	1432.00	8.51	7.488	780.0	586.02
20	1388.00	8.20	7.924	720.0	593.02
21	1413.00	8.40	8.362	2850.0	2308.35
22	1429.00	8.10	8.299	840.0	535.56
23	1377.00	7.86	8.209	1780.0	1497.40
24	1318.00	8.00	7.810	1460.0	1065.54
25	1415.00	8.01	8.284	1700.0	1264.49
26	1428.00	6.95	7.846	1180.0	849.55
27	1397.00	7.10	7.889	1500.0	1364.54
28	1392.00	7.00	6.835	1850.0	1065.62
29	1423.00	6.65	7.856	750.0	562.54
30	1431.00	7.00	6.886	720.0	434.09
31	1407.00	6.40	7.436	750.0	553.60
32	1381.00	6.61	7.734	1380.0	1036.68
33	1424.00	6.18	8.155	790.0	612.61
34	1378.00	6.36	8.612	2120.0	1310.27
35	1428.00	6.82	8.331	760.0	429.64
36	1403.00	6.70	7.844	1840.0	2122.96
37	1259.00	7.38	8.705	5500.0	3555.89
38	1379.00	6.68	8.622	2460.0	2074.52
39	1373.00	6.70	7.986	8000.0	6905.00
40	1248.00	7.60	8.468	3510.0	2765.76
41	1274.00	7.90	7.848	8000.0	4394.54
42	1391.00	7.20	7.362	2600.0	1821.33
43	1436.00	6.00	7.826	2080.0	1539.44
44	1403.00	6.04	8.435	2910.0	2083.21
45	1277.00	7.90	8.880	3500.0	2684.97
46	1397.00	7.30	7.938	2240.0	1781.20
47	1288.00	7.60	7.768	2480.0	1936.96
48	1469.00	6.78	8.396	1780.0	1392.74
49	1406.00	7.14	8.259	2210.0	882.15
50	1358.00	7.69	8.364	2210.0	1198.51
51	1418.00	7.18	7.211	2400.0	1954.20
52	1458.00	7.30	7.950	2200.0	1105.86

WELL NO.	E.B.W.	TEMP.	PH	S.C.	T.D.S.
53	1327.00	7.48	8.874	3550.0	2734.72
54	1407.00	6.60	8.013	2950.0	1877.05
55	1375.00	7.06	8.319	2410.0	1759.86
56	1225.00	7.06	8.525	3400.0	2476.42
57	1438.00	6.59	7.684	2080.0	1602.12
58	1421.00	6.59	7.969	700.0	369.35
65	0.0	9.00	8.600	0.0	490.30
68	-130.00	7.78	7.800	1800.0	1658.81
69	-1572.00	20.00	7.600	3250.0	2455.60
70	-30.00	0.0	7.900	0.0	1076.19
71	-87.00	7.22	7.200	1240.0	1113.59
72	-57.00	8.89	7.200	1100.0	1013.54
73	-1450.00	22.78	7.800	3380.0	2525.40
74	-1487.00	0.0	0.0	0.0	2557.53
75	-240.00	7.78	7.700	5440.0	3560.28
76	0.0	8.89	7.400	1090.0	1046.31
77	-35.00	6.67	7.300	22300.0	2119.24
78	-30.00	6.67	7.500	18700.0	1576.29
79	-65.00	6.67	7.500	9220.0	888.58
80	-135.00	8.33	7.200	23000.0	1987.94
81	-200.00	7.22	7.700	72400.0	4583.62
82	-30.00	6.67	7.500	19600.0	1579.91
83	-35.00	6.11	7.300	40100.0	3911.55
84	-90.00	7.22	7.900	12000.0	7310.09
85	-80.00	6.67	7.900	3070.0	2538.58
86	-80.00	8.89	7.600	3150.0	2609.05
87	-216.00	5.56	7.600	1160.0	1094.82

WELL NO.	T. ALK.	TOT. H.	SOURCE	ANAL.	DATE
1	3290.71	5.65	5	1	131071
2	381.55	578.92	4	1	131071
3	192.03	325.04	1	1	121071
4	119.15	200.15	3	1	121071
5	247.36	217.32	1	1	121071
6	192.22	256.48	3	1	121071
7	194.92	153.26	1	1	121071
8	252.57	355.21	3	1	121071
9	506.87	134.24	2	1	150970
10	298.84	75.31	2	1	150970
11	277.44	153.16	2	1	150970
12	140.94	398.87	1	1	150970
13	219.02	153.18	2	1	150970
14	520.56	96.02	3	1	150970
15	383.48	153.29	3	1	121071
16	372.10	122.83	3	1	121071
17	299.26	210.60	1	1	121071
18	809.95	52.89	2	1	150970
19	320.05	169.27	2	1	150970
20	299.23	125.21	2	1	150970
21	104.11	394.10	1	1	150970
22	266.06	145.67	2	1	150970
23	544.85	99.54	1	1	121071
24	296.53	192.92	1	1	121071
25	472.17	139.16	2	1	121071
26	319.86	110.05	3	1	121071
27	698.13	103.43	3	1	121071
28	93.51	93.51	2	1	121071
29	308.09	186.81	2	1	121071
30	254.69	215.20	3	1	121071
31	293.44	109.37	2	1	121071
32	432.26	74.82	1	1	121071
33	314.46	209.90	1	1	131071
34	283.41	431.19	2	1	131071
35	224.42	197.53	1	1	131071
36	337.21	267.70	2	1	131071
37	542.15	137.17	1	1	131071
38	307.71	328.13	2	1	131071
39	250.64	455.43	2	1	131071
40	406.42	171.05	1	1	131071
41	530.39	116.94	1	1	131071
42	327.95	507.60	3	1	131071
43	402.95	505.31	5	1	131071
44	273.00	212.60	3	1	131071
45	454.82	48.03	1	1	131071
46	294.60	380.67	2	1	131071
47	334.12	287.00	1	1	131071
48	216.13	290.75	2	1	131071
49	284.96	384.47	2	1	131071
50	227.89	270.09	1	1	131071
51	391.19	273.18	2	1	131071
52	273.58	398.98	2	1	131071

WELL NO.	T. ALK.	TOT. H.	SOURCE	ANAL.	DATE
53	440.55	45.27	1	1	131071
54	171.40	451.07	2	1	131071
55	299.80	216.12	2	1	131071
56	447.49	85.32	1	1	131071
57	311.37	327.76	5	1	131071
58	66.71	82.76	1	1	131071
65	0.0	250.62	4	3	0
68	0.0	53.10	1	2	20659
69	0.0	329.02	6	2	170462
70	0.0	374.71	3	2	140621
71	0.0	436.87	3	2	20659
72	0.0	401.30	3	2	20659
73	0.0	198.09	6	2	150662
74	0.0	237.03	6	6	140621
75	0.0	125.19	1	2	20659
76	0.0	573.67	3	2	290959
77	0.0	1321.98	2	2	280959
78	0.0	934.57	2	2	280959
79	0.0	343.65	2	2	280959
80	0.0	705.88	2	2	0
81	0.0	349.87	1	2	280959
82	0.0	803.82	2	2	280959
83	0.0	2571.03	2	2	280959
84	0.0	474.19	1	2	290959
85	0.0	97.81	1	2	20659
86	120.00	120.20	1	2	20659
87	0.0	270.36	3	2	61060

APPENDIX D

CHEMICAL DATA

CHEMICAL DATA

Explanations of the headings used on pages to are given below.

WELL NO.	number assigned to source of water (usually a piezometer).
CA	calcium concentration in parts per million.
MG	magnesium concentration in parts per million.
MN	manganese concentration in parts per million.
NA	sodium concentration in parts per million.
K	potassium concentration in parts per million.
SI	silica concentration in parts per million.
FE	iron concentration in parts per million.
SR	strontium concentration in parts per million.
CU	copper concentration in parts per million.
LI	lithium concentration in parts per million.
HCO3	bicarbonate concentration in parts per million.
CO3	carbonate concentration in parts per million.
CL	chloride concentration in parts per million.
F	fluoride concentration in parts per million.
BR	bromide concentration in parts per million.

H2PO4	phosphate concentration as $H_2PO_4^-$ in parts per million.
HPO4	phosphate concentration as $HPO_4^=$ in parts per million.
PO4	phosphate concentration as PO_4^{-3} in parts per million.
NO2	nitrite concentration in parts per million.
NO3	nitrate concentration in parts per million.
B	boron concentration in parts per million.
ATCAT	total cations in parts per million.
ATANI	total anions in parts per million.
SO4	total sulfate concentration in parts per million.
AL	total aluminum concentration in parts per million.

WELL NO.	CA	MG	MN	NA	K
1	1.85	0.25	0.15	6.10	5.00
2	21.60	127.50	0.03	301.25	57.75
3	48.55	49.50	0.05	31.00	2.25
4	31.10	29.75	0.01	18.00	2.25
5	40.45	28.25	0.02	116.25	4.50
6	49.95	32.00	0.04	59.00	5.25
7	26.75	21.00	0.16	261.25	11.00
8	73.00	42.00	0.01	188.75	6.45
9	8.00	27.75	0.11	1950.00	29.75
10	6.25	14.50	0.11	272.50	9.45
11	19.70	25.25	0.02	156.25	8.50
12	65.75	57.00	0.02	56.00	7.60
13	16.00	27.50	0.04	116.25	8.60
14	23.45	9.10	0.05	493.75	12.00
15	26.35	21.25	0.02	330.00	16.60
16	14.15	21.25	0.06	371.25	18.65
17	27.45	34.50	0.04	307.50	20.00
18	7.00	8.60	0.05	1193.75	16.75
19	31.10	22.25	0.04	107.50	8.75
20	20.05	18.25	0.02	130.00	9.45
21	42.40	70.00	0.19	606.25	13.50
22	16.70	25.25	0.03	131.25	9.75
23	20.90	11.50	0.01	475.00	11.40
24	31.50	27.75	0.14	226.25	21.05
25	27.70	17.00	0.03	322.50	25.00
26	21.40	13.75	0.02	212.50	16.40
27	18.75	13.75	0.07	321.25	19.95
28	21.95	9.40	0.20	315.00	11.30
29	35.65	23.75	0.03	62.75	8.70
30	39.60	28.25	0.07	27.75	7.55
31	25.25	11.25	0.02	137.50	8.50
32	11.00	11.50	0.03	267.50	9.75
33	18.10	40.00	0.04	74.50	6.05
34	65.50	65.00	0.02	268.75	36.00
35	26.75	31.75	0.05	60.50	11.15
36	37.95	42.00	0.14	562.50	19.25
37	26.90	17.00	0.19	1037.50	19.25
38	46.90	51.25	0.26	493.75	24.50
39	86.75	58.00	0.02	1837.50	25.75
40	29.75	23.50	0.14	743.75	17.15
41	18.80	17.00	0.09	1293.75	21.45
42	97.75	64.00	1.01	288.75	41.75
43	25.10	107.50	0.58	238.75	35.50
44	33.20	31.50	0.15	330.00	20.90
45	8.60	6.45	0.03	825.00	11.10
46	78.25	45.00	0.02	328.75	20.10
47	32.90	49.75	0.17	500.00	24.00
48	39.35	46.75	0.11	267.50	16.10
49	74.00	48.50	0.06	332.50	18.15
50	30.25	47.25	0.05	500.00	30.25
51	31.90	47.00	0.09	518.75	26.50
52	77.75	49.75	0.48	330.00	21.50

WELL NO.	CA	MG	MN	NA	K
53	5.35	7.75	0.04	812.50	13.50
54	93.25	53.00	0.06	346.25	22.35
55	29.25	34.75	0.08	556.25	12.55
56	17.35	10.20	0.04	756.25	13.25
57	46.75	51.25	0.04	337.50	9.75
58	17.15	9.70	0.12	130.00	6.55
65	47.60	32.00	0.0	7.00	0.0
68	15.00	3.80	0.05	425.00	5.50
69	79.00	32.00	0.20	637.00	14.00
70	94.00	34.00	0.0	123.00	0.0
71	109.00	40.00	1.10	115.00	6.40
72	103.00	35.00	1.00	94.00	6.90
73	48.00	19.00	0.23	705.00	12.00
74	57.00	23.00	0.0	707.00	0.0
75	32.00	11.00	0.01	1130.00	11.00
76	144.00	52.00	0.0	32.00	6.60
77	259.00	164.00	2.50	81.00	10.00
78	183.00	116.00	22.00	71.00	5.40
79	103.00	21.00	0.54	75.00	4.70
80	192.00	55.00	2.10	277.00	11.00
81	89.00	31.00	0.42	1460.00	18.00
82	190.00	80.00	0.0	127.00	6.00
83	469.00	340.00	0.0	168.00	15.00
84	119.00	43.00	0.24	2520.00	26.00
85	24.00	9.20	0.0	692.00	8.70
86	30.00	11.00	0.13	709.00	9.80
87	72.00	22.00	0.0	164.00	9.80

WELL NO.	SI	AL	FE	SR	CU
1	0.0	0.0	0.17	0.06	0.11
2	0.0	0.0	0.05	0.23	0.05
3	0.0	0.0	0.03	0.18	0.04
4	0.0	0.0	0.02	0.10	0.03
5	0.0	0.0	0.11	0.01	0.06
6	0.0	0.0	0.08	0.22	0.03
7	0.0	0.0	0.08	0.16	0.04
8	0.0	0.0	0.10	0.41	0.06
9	0.0	0.0	0.13	0.44	0.03
10	0.0	0.0	0.26	0.12	0.02
11	0.0	0.0	0.08	0.18	0.06
12	0.0	0.0	0.01	0.61	0.03
13	0.0	0.0	0.08	0.24	0.02
14	0.0	0.0	0.0	0.19	0.02
15	0.0	0.0	0.10	0.33	0.04
16	0.0	0.0	0.10	0.23	0.01
17	0.0	0.0	0.08	0.37	0.05
18	0.0	0.0	0.0	0.28	0.02
19	0.0	0.0	0.01	0.18	0.0
20	0.0	0.0	0.16	0.14	0.03
21	0.0	0.0	0.12	0.59	0.03
22	0.0	0.0	0.07	0.08	0.04
23	0.0	0.0	0.11	0.20	0.05
24	0.0	0.0	0.09	0.17	0.05
25	0.0	0.0	0.07	0.28	0.03
26	0.0	0.0	0.13	0.02	0.03
27	0.0	0.0	0.02	0.20	0.02
28	0.0	0.0	0.01	0.27	0.03
29	0.0	0.0	0.02	0.30	0.03
30	0.0	0.0	0.04	0.29	0.02
31	0.0	0.0	0.08	0.22	0.02
32	0.0	0.0	0.03	0.11	0.03
33	0.0	0.0	0.11	0.13	0.04
34	0.0	0.0	0.04	0.65	0.06
35	0.0	0.0	0.09	0.28	0.19
36	0.0	0.0	0.06	0.58	0.04
37	0.0	0.0	0.04	0.38	0.03
38	0.0	0.0	0.06	0.74	0.09
39	0.0	0.0	0.14	2.21	0.03
40	0.0	0.0	0.07	0.12	0.05
41	0.0	0.0	0.06	0.45	0.02
42	0.0	0.0	0.10	1.01	0.04
43	0.0	0.0	0.10	0.25	0.08
44	0.0	0.0	0.10	0.50	0.04
45	0.0	0.0	0.14	0.0	0.07
46	0.0	0.0	0.14	0.70	0.05
47	0.0	0.0	0.06	0.48	0.09
48	0.0	0.0	0.04	0.68	0.05
49	0.0	0.0	0.0	0.87	0.05
50	0.0	0.0	0.10	0.52	0.04
51	0.0	0.0	0.11	0.16	0.06
52	0.0	0.0	0.03	0.81	0.03

WELL NO.	SI	AL	FE	SR	CU
53	0.0	0.0	0.0	0.14	0.02
54	0.0	0.0	0.06	1.22	0.02
55	0.0	0.0	0.02	0.43	0.01
56	0.0	0.0	0.05	0.21	0.02
57	0.0	0.0	0.14	0.38	0.06
58	0.0	0.0	0.12	0.17	0.03
65	0.0	0.0	0.0	0.0	0.0
68	29.00	0.0	0.06	0.0	0.0
69	11.00	0.0	2.70	0.0	0.0
70	32.00	0.0	0.97	0.0	0.0
71	28.00	0.0	4.30	0.0	0.0
72	27.00	0.0	4.60	0.0	0.0
73	11.00	0.0	0.85	0.0	0.0
74	19.00	0.0	1.50	0.0	0.0
75	28.00	0.0	0.29	0.0	0.0
76	27.00	0.0	0.03	0.0	0.0
77	27.00	0.0	0.47	0.0	0.0
78	22.00	0.0	0.02	0.0	0.0
79	28.00	0.0	0.23	0.0	0.0
80	28.00	0.0	4.80	0.0	0.0
81	26.00	0.0	6.00	0.0	0.0
82	26.00	0.0	0.03	0.0	0.0
83	27.00	0.0	0.08	0.0	0.0
84	26.00	0.0	4.60	0.0	0.0
85	29.00	0.0	0.0	0.0	0.0
86	29.00	0.0	0.01	0.0	0.0
87	31.00	0.0	1.80	0.0	0.0

WELL NO.	LI	HCO3	CO3	SO4	CL
1	0.08	3282.99	7.72	3.00	15.27
2	2.86	342.90	38.65	1095.00	216.55
3	0.38	161.95	30.08	148.00	47.93
4	0.32	96.39	22.76	222.00	44.38
5	1.14	167.16	80.20	251.00	56.80
6	0.51	146.34	45.88	320.00	29.11
7	1.24	149.04	45.88	610.00	24.14
8	0.95	179.69	72.88	615.00	24.14
9	2.66	347.23	159.64	29.00	3266.00
10	3.89	260.28	38.56	255.00	39.05
11	0.70	246.98	30.46	226.00	19.88
12	0.60	94.66	46.28	475.00	18.82
13	0.63	171.60	47.42	172.00	29.11
14	2.00	422.24	98.32	152.00	124.25
15	1.56	310.60	72.88	178.00	124.25
16	1.48	279.94	92.16	480.00	127.80
17	1.06	249.52	49.74	270.00	355.00
18	3.01	680.39	129.56	72.00	1384.50
19	0.82	288.81	31.24	63.00	29.47
20	0.66	236.77	62.46	90.00	19.17
21	2.57	96.41	7.70	1215.00	248.50
22	0.58	219.78	46.28	49.00	31.60
23	1.34	447.67	97.18	250.00	173.95
24	0.78	260.67	35.86	178.00	276.90
25	1.09	429.37	42.80	255.00	127.80
26	0.74	234.26	85.60	245.00	11.01
27	1.62	625.25	72.88	143.00	131.35
28	0.55	73.47	20.04	32.00	550.25
29	0.45	244.85	63.24	96.00	19.17
30	0.27	219.61	35.08	40.00	14.56
31	0.45	231.74	61.70	49.00	20.59
32	3.05	358.62	73.64	248.00	47.93
33	0.56	264.72	49.74	135.00	19.17
34	1.72	202.43	80.98	420.00	145.55
35	0.66	167.36	57.06	46.00	24.14
36	1.92	294.41	42.80	895.00	220.10
37	2.02	411.43	130.72	17.00	1881.50
38	1.39	188.17	119.54	805.00	333.70
39	3.17	193.58	57.06	8.00	4615.00
40	1.82	302.70	103.72	183.00	1349.00
41	2.35	437.47	92.92	12.00	2485.00
42	1.30	236.95	91.00	380.00	568.00
43	1.45	361.31	41.64	515.00	177.50
44	1.41	231.36	41.64	390.00	994.00
45	1.90	362.66	92.16	195.00	1171.50
46	1.26	248.32	46.28	740.00	266.25
47	1.20	292.10	42.02	630.00	355.00
48	1.25	154.43	61.70	615.00	184.60
49	0.90	204.76	80.20	90.00	25.56
50	1.35	161.57	66.32	76.00	241.40
51	1.26	336.43	54.76	640.00	291.10
52	1.23	233.48	40.10	51.00	291.10

WELL NO.	LI	HCO3	CO3	SO4	CL
53	1.11	322.95	117.60	165.00	1278.00
54	2.14	144.80	26.60	290.00	887.50
55	1.04	246.20	53.60	285.00	532.50
56	1.45	308.29	139.20	47.00	1171.50
57	1.03	253.53	57.84	650.00	184.60
58	0.24	54.37	12.34	85.00	49.70
65	0.0	365.00	0.0	27.90	8.00
68	0.0	760.00	0.0	320.00	11.00
69	0.0	284.00	0.0	1140.00	213.00
70	0.0	476.00	0.0	212.00	26.00
71	0.0	462.00	0.0	222.00	52.00
72	0.0	450.00	0.0	191.00	31.00
73	0.0	344.00	0.0	1090.00	247.00
74	0.0	378.00	0.0	1050.00	276.00
75	0.0	835.00	0.0	0.80	1420.00
76	0.0	462.00	0.0	247.00	9.20
77	0.0	452.00	0.0	1030.00	21.00
78	0.0	404.00	0.0	455.00	150.00
79	0.0	420.00	0.0	156.00	10.00
80	0.0	755.00	0.0	385.00	200.00
81	0.0	764.00	0.0	39.00	2070.00
82	0.0	347.00	0.0	361.00	167.00
83	0.0	400.00	0.0	2120.00	110.00
84	0.0	604.00	0.0	18.00	3860.00
85	0.0	686.00	0.0	928.00	63.00
86	0.0	680.00	0.0	950.00	87.00
87	0.0	494.00	0.0	181.00	37.00

WELL NO.	F	BR	NO2	NO3	B
1	0.26	1.84	1.0000	1.09	0.0
2	0.48	1.48	0.0130	2.09	0.0
3	0.40	0.76	0.0090	1.59	0.0
4	0.40	0.88	0.0070	1.19	0.0
5	0.33	0.96	0.0090	2.99	0.0
6	0.41	0.66	0.0280	4.27	0.0
7	0.41	0.54	0.0070	2.39	0.0
8	0.55	0.76	0.0140	3.99	0.0
9	0.84	7.67	0.0100	5.79	0.0
10	0.74	1.04	0.0	4.80	0.0
11	0.46	0.54	0.0070	1.69	0.0
12	0.34	0.39	0.0120	1.69	0.0
13	0.48	0.77	0.0120	2.99	0.0
14	0.51	0.76	0.0060	2.09	0.0
15	0.67	1.04	0.0130	3.89	0.0
16	0.55	0.96	0.0110	12.79	0.0
17	0.59	1.76	0.0100	1.69	0.0
18	0.67	4.40	0.0110	3.09	0.0
19	0.49	0.66	0.0070	1.59	0.0
20	0.49	0.67	0.0080	4.39	0.0
21	0.41	1.48	0.0	3.20	0.0
22	0.59	0.77	0.0130	3.09	0.0
23	0.49	1.32	0.0090	4.69	0.0
24	0.53	3.12	0.0070	0.89	0.0
25	0.65	1.12	0.0090	7.19	0.0
26	0.65	2.16	0.0070	2.89	0.0
27	1.01	2.32	0.0310	1.47	0.0
28	0.29	4.16	0.0080	14.89	0.0
29	0.52	0.76	0.0080	3.79	0.0
30	0.28	0.31	0.0270	17.27	0.0
31	0.54	0.96	0.0120	3.19	0.0
32	0.54	0.96	0.0070	3.69	0.0
33	0.51	0.56	0.0080	2.99	0.0
34	0.65	1.32	0.0130	11.79	0.0
35	0.59	0.66	0.0060	1.79	0.0
36	0.67	1.48	0.0100	3.79	0.0
37	0.74	7.35	0.0080	2.09	0.0
38	0.61	2.48	0.0080	5.39	0.0
39	0.53	7.67	3.5500	5.85	0.0
40	0.65	5.19	0.0900	4.51	0.0
41	0.55	5.75	0.0090	3.59	0.0
42	0.44	4.63	0.0130	29.89	0.0
43	0.26	2.24	26.0000	4.00	0.0
44	0.48	2.80	0.0060	4.39	0.0
45	0.78	3.60	0.0240	3.88	0.0
46	0.59	1.68	0.0100	2.89	0.0
47	0.44	2.08	0.0060	4.89	0.0
48	0.53	1.36	0.0130	2.89	0.0
49	0.54	1.48	0.0070	3.79	0.0
50	0.55	1.36	0.0070	33.69	0.0
51	0.44	3.28	0.0140	1.89	0.0
52	0.54	2.88	0.0080	3.79	0.0

WELL NO.	F	BR	NO2	NO3	B
53	0.76	3.40	0.0110	5.19	0.0
54	0.46	2.88	0.0090	5.19	0.0
55	0.51	2.48	0.0140	4.79	0.0
56	0.61	3.27	0.0070	3.99	0.0
57	0.48	1.36	0.0080	4.79	0.0
58	0.34	0.76	0.0100	1.99	0.0
65	0.20	0.0	0.0	2.60	0.0
68	0.60	0.0	0.0	3.10	2.70
69	2.30	0.0	0.0	0.60	2.30
70	0.0	0.0	0.0	0.70	0.0
71	0.20	0.0	0.0	3.30	0.43
72	0.20	0.0	0.0	2.60	0.32
73	2.40	0.0	0.0	0.40	3.30
74	0.0	0.0	0.0	0.0	0.0
75	0.20	0.0	0.0	0.70	4.10
76	0.30	0.0	0.0	0.20	0.10
77	0.20	0.0	0.0	5.40	0.22
78	0.20	0.0	0.0	93.00	0.24
79	0.50	0.0	0.0	0.80	0.17
80	0.20	0.0	0.0	6.00	0.70
81	0.30	0.0	0.0	0.90	2.80
82	0.20	0.0	0.0	210.00	0.47
83	0.40	0.0	0.0	195.00	0.29
84	0.20	0.0	0.0	0.90	4.40
85	0.40	0.0	0.0	8.00	3.50
86	0.40	0.0	0.0	9.00	4.10
87	0.10	0.0	0.0	5.30	0.30

WELL NO.	H2PO4	HPO4	PO4	ATCAT	ATANI
1	2.81	5.19	0.0	13.77	3321.17
2	0.24	0.36	0.0	511.32	1697.76
3	0.02	0.40	0.0	131.98	391.14
4	0.01	0.44	0.0	81.58	388.46
5	0.02	0.30	0.0	190.79	559.77
6	0.03	0.43	0.0	147.08	547.16
7	0.02	0.36	0.0	321.68	832.79
8	0.04	0.67	0.0	311.73	897.73
9	0.01	1.11	0.0	2018.87	3817.30
10	0.0	0.0	0.0	307.10	599.47
11	0.02	0.19	0.0	210.74	526.23
12	0.02	0.29	0.0	187.62	637.50
13	0.01	0.23	0.0	169.36	424.62
14	0.03	0.44	0.0	540.56	800.65
15	0.02	0.32	0.0	396.25	691.68
16	0.06	2.45	0.0	427.18	996.72
17	0.01	0.29	0.0	391.05	928.61
18	0.02	1.36	0.0	1229.46	2276.00
19	0.02	0.08	0.0	170.65	415.37
20	0.02	0.28	0.0	178.76	414.26
21	0.0	0.0	0.0	735.65	1572.70
22	0.02	0.67	0.0	183.75	351.81
23	0.06	1.52	0.0	520.51	976.89
24	0.15	1.63	0.0	307.78	757.76
25	0.21	6.64	0.0	393.70	870.79
26	0.23	2.75	0.0	264.99	584.56
27	0.84	10.76	0.0	375.63	988.91
28	5.71	6.09	0.0	358.71	706.91
29	0.19	2.33	0.0	131.68	430.86
30	1.41	1.70	0.0	103.84	330.25
31	0.47	2.11	0.0	183.29	370.31
32	0.03	0.26	0.0	303.00	733.68
33	0.01	0.37	0.0	139.53	473.08
34	0.14	9.66	0.0	437.74	872.53
35	0.02	0.59	0.0	131.42	298.22
36	0.02	0.24	0.0	664.44	1458.52
37	0.02	1.72	0.0	1103.31	2452.58
38	0.01	0.67	0.0	618.94	1455.58
39	0.01	0.20	0.0	2013.57	4891.43
40	0.01	0.54	0.0	816.35	1949.41
41	0.26	3.02	0.0	1353.97	3040.57
42	3.09	11.61	0.0	495.71	1325.62
43	0.18	2.00	0.0	409.31	1130.13
44	0.01	0.72	0.0	417.80	1665.41
45	0.02	2.06	0.0	853.29	1831.68
46	0.06	0.85	0.0	474.27	1306.93
47	0.20	1.57	0.0	608.65	1328.31
48	0.01	0.38	0.0	371.83	1020.91
49	0.02	0.76	0.0	475.03	407.12
50	0.19	7.61	0.0	609.81	588.70
51	0.13	0.33	0.0	625.83	1328.37
52	0.09	1.29	0.0	481.58	624.28

WELL NO.	H2PO4	HPO4	PO4	ATCAT	ATANI
53	0.01	1.39	0.0	840.41	1894.31
54	0.07	1.19	0.0	518.35	1358.70
55	0.01	0.38	0.0	634.38	1125.48
56	0.06	3.67	0.0	798.82	1677.60
57	0.28	2.33	0.0	446.90	1155.22
58	0.05	0.71	0.0	164.08	205.27
65	0.0	0.0	0.0	86.60	403.70
68	0.0	0.0	0.0	449.41	1094.70
69	0.0	0.0	0.0	764.90	1639.90
70	0.0	0.0	0.0	251.97	714.70
71	0.0	0.0	0.0	275.80	739.50
72	0.0	0.0	0.0	244.50	674.80
73	0.0	0.0	0.0	785.08	1683.80
74	0.0	0.0	0.0	788.50	1704.00
75	0.0	0.0	0.0	1184.30	2256.70
76	0.0	0.0	0.0	234.63	718.70
77	0.0	0.0	0.0	516.97	1508.60
78	0.0	0.0	0.0	397.42	1102.20
79	0.0	0.0	0.0	204.47	587.30
80	0.0	0.0	0.0	541.90	1346.20
81	0.0	0.0	0.0	1604.42	2874.20
82	0.0	0.0	0.0	403.03	1085.20
83	0.0	0.0	0.0	992.08	2825.40
84	0.0	0.0	0.0	2712.84	4483.10
85	0.0	0.0	0.0	733.90	1685.40
86	0.0	0.0	0.0	759.94	1726.40
87	0.0	0.0	0.0	269.60	717.40

APPENDIX E

CHEMICAL DATA (NORMALITY)

CHEMICAL DATA (NORMALITY)

Explanations of the headings used on pages to are given below.

WELL NO.	number assigned to source of water (usually a piezometer).
ECA	normality of calcium ion in equivalents per million.
EMG	normality of magnesium ion in equivalents per million.
EMN	normality of manganese ion in equivalents per million.
ENA	normality of sodium ion in equivalents per million.
EK	normality of potassium ion in equivalents per million.
EFE	normality of iron ion in equivalents per million.
ESR	normality of strontium ion in equivalents per million.
ECU	normality of copper ion in equivalents per million.
ELI	normality of lithium ion in equivalents per million.
EHCO3	normality of bicarbonate in equivalents per million.
ECO3	normality of carbonate ion in equivalents per million.
ESO4	normality of sulfate ion in equivalents per million.
ECL	normality of chloride ion in equivalents per million.
EF	normality of fluoride ion in equivalents per million.

EPI	normality of phosphate ion ($H_2PO_4^-$) in equivalents per million.
EP2	normality of phosphate ion ($HPO_4^=$) in equivalents per million.
EP3	normality of phosphate ion (PO_4^{-3}) in equivalents per million.
ENO2	normality of nitrite ion in equivalents per million.
ENO3	normality of nitrate ion in equivalents per million.
EAL	concentration of $AL(OH)_3$ in parts per million.
ESIO4	concentration of H_4SIO_4 in parts per million.
EB	concentration of H_3BO_3 in parts per million.
TCAT	total normality of the cations in equivalents per million.
TANI	total normality of the anions in equivalents per million.
EBR	normality of bromide ion in equivalents per million.

WELL NO.	ECA	EMG	EMN	ENA	EK
1	0.092	0.021	0.005	0.265	0.128
2	1.078	10.492	0.001	13.104	1.477
3	2.423	4.073	0.002	1.348	0.058
4	1.552	2.448	0.000	0.783	0.058
5	2.018	2.325	0.001	5.057	0.115
6	2.493	2.633	0.001	2.566	0.134
7	1.335	1.728	0.006	11.364	0.281
8	3.643	3.456	0.000	8.210	0.165
9	0.399	2.283	0.004	84.820	0.761
10	0.312	1.193	0.004	11.853	0.242
11	0.983	2.078	0.001	6.796	0.217
12	3.281	4.690	0.001	2.436	0.194
13	0.798	2.263	0.001	5.057	0.220
14	1.170	0.749	0.002	21.477	0.307
15	1.315	1.749	0.001	14.354	0.425
16	0.706	1.749	0.002	16.148	0.477
17	1.370	2.839	0.001	13.376	0.512
18	0.349	0.708	0.002	51.925	0.428
19	1.552	1.831	0.001	4.676	0.224
20	1.000	1.502	0.001	5.655	0.242
21	2.116	5.760	0.007	26.370	0.345
22	0.833	2.078	0.001	5.709	0.249
23	1.043	0.946	0.000	20.661	0.292
24	1.572	2.283	0.005	9.841	0.538
25	1.382	1.399	0.001	14.028	0.639
26	1.068	1.131	0.001	9.243	0.419
27	0.936	1.131	0.003	13.974	0.510
28	1.095	0.774	0.007	13.702	0.289
29	1.779	1.954	0.001	2.729	0.223
30	1.976	2.325	0.003	1.207	0.193
31	1.260	0.926	0.001	5.981	0.217
32	0.549	0.946	0.001	11.636	0.249
33	0.903	3.292	0.001	3.241	0.155
34	3.268	5.349	0.001	11.690	0.921
35	1.335	2.613	0.002	2.632	0.285
36	1.894	3.456	0.005	24.467	0.492
37	1.342	1.399	0.007	45.129	0.492
38	2.340	4.217	0.009	21.477	0.627
39	4.329	4.773	0.001	79.927	0.659
40	1.485	1.934	0.005	32.351	0.439
41	0.938	1.399	0.003	56.275	0.549
42	4.878	5.266	0.037	12.560	1.068
43	1.252	8.846	0.021	10.385	0.908
44	1.657	2.592	0.005	14.354	0.535
45	0.429	0.531	0.001	35.885	0.284
46	3.905	3.703	0.001	14.300	0.514
47	1.642	4.094	0.006	21.749	0.614
48	1.964	3.847	0.004	11.636	0.412
49	3.693	3.991	0.002	14.463	0.464
50	1.509	3.888	0.002	21.749	0.774
51	1.592	3.868	0.003	22.564	0.678
52	3.880	4.094	0.017	14.354	0.550

WELL NO.	ECA	EMG	EMN	ENA	EK
53	0.267	0.638	0.001	35.342	0.345
54	4.653	4.361	0.002	15.061	0.572
55	1.460	2.859	0.003	24.196	0.321
56	0.866	0.839	0.001	32.895	0.339
57	2.333	4.217	0.001	14.680	0.249
58	0.856	0.798	0.004	5.655	0.168
65	2.375	2.633	0.0	0.304	0.0
68	0.749	0.313	0.002	18.486	0.141
69	3.942	2.633	0.007	27.708	0.358
70	4.691	2.798	0.0	5.350	0.0
71	5.439	3.292	0.040	5.002	0.164
72	5.140	2.880	0.036	4.089	0.176
73	2.395	1.563	0.008	30.666	0.307
74	2.844	1.893	0.0	30.753	0.0
75	1.597	0.905	0.000	49.152	0.281
76	7.186	4.279	0.0	1.392	0.169
77	12.924	13.495	0.091	3.523	0.256
78	9.132	9.545	0.801	3.088	0.138
79	5.140	1.728	0.020	3.262	0.120
80	9.581	4.526	0.076	12.049	0.281
81	4.441	2.551	0.015	63.506	0.460
82	9.481	6.583	0.0	5.524	0.153
83	23.403	27.978	0.0	7.308	0.384
84	5.938	3.538	0.009	109.614	0.665
85	1.198	0.757	0.0	30.100	0.223
86	1.497	0.905	0.005	30.840	0.251
87	3.593	1.810	0.0	7.134	0.251

WELL NO.	EFE	ESR	ECU	ELI	EHCO3
1	0.006	0.001	0.003	0.012	53.752
2	0.002	0.005	0.002	0.412	5.614
3	0.001	0.004	0.001	0.055	2.652
4	0.001	0.002	0.001	0.046	1.578
5	0.004	0.000	0.002	0.164	2.737
6	0.003	0.005	0.001	0.073	2.396
7	0.003	0.004	0.001	0.179	2.440
8	0.004	0.009	0.002	0.137	2.942
9	0.005	0.010	0.001	0.383	5.685
10	0.009	0.003	0.001	0.560	4.262
11	0.003	0.004	0.002	0.101	4.044
12	0.000	0.014	0.001	0.086	1.550
13	0.003	0.005	0.001	0.091	2.810
14	0.0	0.004	0.001	0.288	6.913
15	0.004	0.008	0.001	0.225	5.085
16	0.004	0.005	0.000	0.213	4.583
17	0.003	0.008	0.002	0.153	4.085
18	0.0	0.006	0.001	0.434	11.140
19	0.000	0.004	0.0	0.118	4.729
20	0.006	0.003	0.001	0.095	3.877
21	0.004	0.013	0.001	0.370	1.578
22	0.003	0.002	0.001	0.084	3.598
23	0.004	0.005	0.002	0.193	7.330
24	0.003	0.004	0.002	0.112	4.268
25	0.003	0.006	0.001	0.157	7.030
26	0.005	0.000	0.001	0.107	3.835
27	0.001	0.005	0.001	0.233	10.237
28	0.000	0.006	0.001	0.079	1.203
29	0.001	0.007	0.001	0.065	4.009
30	0.001	0.007	0.001	0.039	3.596
31	0.003	0.005	0.001	0.065	3.794
32	0.001	0.003	0.001	0.439	5.872
33	0.004	0.003	0.001	0.081	4.334
34	0.001	0.015	0.002	0.248	3.314
35	0.003	0.006	0.006	0.095	2.740
36	0.002	0.013	0.001	0.277	4.820
37	0.001	0.009	0.001	0.291	6.736
38	0.002	0.017	0.003	0.200	3.081
39	0.005	0.050	0.001	0.457	3.169
40	0.003	0.003	0.002	0.262	4.956
41	0.002	0.010	0.001	0.339	7.163
42	0.004	0.023	0.001	0.187	3.880
43	0.004	0.006	0.003	0.209	5.916
44	0.004	0.011	0.001	0.203	3.788
45	0.005	0.0	0.002	0.274	5.938
46	0.005	0.016	0.002	0.182	4.066
47	0.002	0.011	0.003	0.173	4.782
48	0.001	0.016	0.002	0.180	2.528
49	0.0	0.020	0.002	0.130	3.352
50	0.004	0.012	0.001	0.194	2.645
51	0.004	0.004	0.002	0.182	5.508
52	0.001	0.018	0.001	0.177	3.823

WELL NO.	EFE	ESR	ECU	ELI	EHCO3
53	0.0	0.003	0.001	0.160	5.288
54	0.002	0.028	0.001	0.308	2.371
55	0.001	0.010	0.000	0.150	4.031
56	0.002	0.005	0.001	0.209	5.048
57	0.005	0.009	0.002	0.148	4.151
58	0.004	0.004	0.001	0.035	0.890
65	0.0	0.0	0.0	0.0	5.976
68	0.002	0.0	0.0	0.0	12.443
69	0.097	0.0	0.0	0.0	4.650
70	0.035	0.0	0.0	0.0	7.793
71	0.154	0.0	0.0	0.0	7.564
72	0.165	0.0	0.0	0.0	7.368
73	0.030	0.0	0.0	0.0	5.632
74	0.054	0.0	0.0	0.0	6.189
75	0.010	0.0	0.0	0.0	13.671
76	0.001	0.0	0.0	0.0	7.564
77	0.017	0.0	0.0	0.0	7.400
78	0.001	0.0	0.0	0.0	6.615
79	0.008	0.0	0.0	0.0	6.877
80	0.172	0.0	0.0	0.0	12.361
81	0.215	0.0	0.0	0.0	12.509
82	0.001	0.0	0.0	0.0	5.681
83	0.003	0.0	0.0	0.0	6.549
84	0.165	0.0	0.0	0.0	9.889
85	0.0	0.0	0.0	0.0	11.232
86	0.000	0.0	0.0	0.0	11.133
87	0.064	0.0	0.0	0.0	8.088

WELL NO.	ECO3	ESO4	ECL	EF	EBR
1	0.257	0.062	0.431	0.014	0.023
2	1.288	22.799	6.108	0.025	0.019
3	1.003	3.082	1.352	0.021	0.010
4	0.759	4.622	1.252	0.021	0.011
5	2.673	5.226	1.602	0.017	0.012
6	1.529	6.663	0.821	0.022	0.008
7	1.529	12.701	0.681	0.022	0.007
8	2.429	12.805	0.681	0.029	0.010
9	5.322	0.604	92.122	0.044	0.096
10	1.285	5.309	1.101	0.039	0.013
11	1.015	4.706	0.561	0.024	0.007
12	1.543	9.890	0.531	0.018	0.005
13	1.581	3.581	0.821	0.025	0.010
14	3.277	3.165	3.505	0.027	0.010
15	2.429	3.706	3.505	0.035	0.013
16	3.072	9.994	3.605	0.029	0.012
17	1.658	5.622	10.013	0.031	0.022
18	4.319	1.499	39.052	0.035	0.055
19	1.041	1.312	0.831	0.026	0.008
20	2.082	1.874	0.541	0.026	0.008
21	0.257	25.298	7.009	0.022	0.019
22	1.543	1.020	0.891	0.031	0.010
23	3.239	5.205	4.906	0.026	0.017
24	1.195	3.706	7.810	0.028	0.039
25	1.427	5.309	3.605	0.034	0.014
26	2.853	5.101	0.311	0.034	0.027
27	2.429	2.977	3.705	0.053	0.029
28	0.668	0.666	15.521	0.015	0.052
29	2.108	1.999	0.541	0.027	0.010
30	1.169	0.833	0.411	0.015	0.004
31	2.057	1.020	0.581	0.028	0.012
32	2.455	5.164	1.352	0.028	0.012
33	1.658	2.811	0.541	0.027	0.007
34	2.699	8.745	4.105	0.034	0.017
35	1.902	0.958	0.681	0.031	0.008
36	1.427	18.635	6.208	0.035	0.019
37	4.358	0.354	53.070	0.039	0.092
38	3.985	16.761	9.412	0.032	0.031
39	1.902	0.167	130.172	0.028	0.096
40	3.458	3.810	38.050	0.034	0.065
41	3.097	0.250	70.093	0.029	0.072
42	3.033	7.912	16.021	0.023	0.058
43	1.388	10.723	5.007	0.014	0.028
44	1.388	8.120	28.037	0.025	0.035
45	3.072	4.060	33.044	0.041	0.045
46	1.543	15.408	7.510	0.031	0.021
47	1.401	13.117	10.013	0.023	0.026
48	2.057	12.805	5.207	0.028	0.017
49	2.673	1.874	0.721	0.028	0.019
50	2.211	1.582	6.809	0.029	0.017
51	1.825	13.326	8.211	0.023	0.041
52	1.337	1.062	8.211	0.028	0.036

WELL NO.	ECO3	ESO4	ECL	EF	EBR
53	3.920	3.435	36.048	0.040	0.043
54	0.887	6.038	25.033	0.024	0.036
55	1.787	5.934	15.020	0.027	0.031
56	4.640	0.979	33.044	0.032	0.041
57	1.928	13.534	5.207	0.025	0.017
58	0.411	1.770	1.402	0.018	0.010
65	0.0	0.581	0.226	0.011	0.0
68	0.0	6.663	0.310	0.032	0.0
69	0.0	23.736	6.008	0.121	0.0
70	0.0	4.414	0.733	0.0	0.0
71	0.0	4.622	1.467	0.011	0.0
72	0.0	3.977	0.874	0.011	0.0
73	0.0	22.695	6.967	0.126	0.0
74	0.0	21.862	7.785	0.0	0.0
75	0.0	0.017	40.053	0.011	0.0
76	0.0	5.143	0.259	0.016	0.0
77	0.0	21.446	0.592	0.011	0.0
78	0.0	9.474	4.231	0.011	0.0
79	0.0	3.248	0.282	0.026	0.0
80	0.0	8.016	5.641	0.011	0.0
81	0.0	0.812	58.387	0.016	0.0
82	0.0	7.516	4.710	0.011	0.0
83	0.0	44.141	3.103	0.021	0.0
84	0.0	0.375	108.877	0.011	0.0
85	0.0	19.322	1.777	0.021	0.0
86	0.0	19.780	2.454	0.021	0.0
87	0.0	3.769	1.044	0.005	0.0

WELL NO.	EP1	EP2	EP3	ENO2	ENO3
1	0.029	0.108	0.0	0.0217	0.018
2	0.002	0.008	0.0	0.0003	0.034
3	0.000	0.008	0.0	0.0002	0.026
4	0.000	0.009	0.0	0.0002	0.019
5	0.000	0.006	0.0	0.0002	0.048
6	0.000	0.009	0.0	0.0006	0.069
7	0.000	0.008	0.0	0.0002	0.039
8	0.000	0.014	0.0	0.0003	0.064
9	0.000	0.023	0.0	0.0002	0.093
10	0.0	0.0	0.0	0.0	0.077
11	0.000	0.004	0.0	0.0002	0.027
12	0.000	0.006	0.0	0.0003	0.027
13	0.000	0.005	0.0	0.0003	0.048
14	0.000	0.009	0.0	0.0001	0.034
15	0.000	0.007	0.0	0.0003	0.063
16	0.001	0.051	0.0	0.0002	0.206
17	0.000	0.006	0.0	0.0002	0.027
18	0.000	0.028	0.0	0.0002	0.050
19	0.000	0.002	0.0	0.0002	0.026
20	0.000	0.006	0.0	0.0002	0.071
21	0.0	0.0	0.0	0.0	0.052
22	0.000	0.014	0.0	0.0003	0.050
23	0.001	0.032	0.0	0.0002	0.076
24	0.002	0.034	0.0	0.0002	0.014
25	0.002	0.138	0.0	0.0002	0.116
26	0.002	0.057	0.0	0.0002	0.047
27	0.009	0.224	0.0	0.0007	0.024
28	0.059	0.127	0.0	0.0002	0.240
29	0.002	0.048	0.0	0.0002	0.061
30	0.015	0.035	0.0	0.0006	0.279
31	0.005	0.044	0.0	0.0003	0.051
32	0.000	0.005	0.0	0.0002	0.060
33	0.000	0.008	0.0	0.0002	0.048
34	0.001	0.201	0.0	0.0003	0.190
35	0.000	0.012	0.0	0.0001	0.029
36	0.000	0.005	0.0	0.0002	0.061
37	0.000	0.036	0.0	0.0002	0.034
38	0.000	0.014	0.0	0.0002	0.087
39	0.000	0.004	0.0	0.0772	0.094
40	0.000	0.011	0.0	0.0020	0.073
41	0.003	0.063	0.0	0.0002	0.058
42	0.032	0.242	0.0	0.0003	0.482
43	0.002	0.042	0.0	0.5652	0.065
44	0.000	0.015	0.0	0.0001	0.071
45	0.000	0.043	0.0	0.0005	0.063
46	0.001	0.018	0.0	0.0002	0.047
47	0.002	0.033	0.0	0.0001	0.079
48	0.000	0.008	0.0	0.0003	0.047
49	0.000	0.016	0.0	0.0002	0.061
50	0.002	0.159	0.0	0.0002	0.543
51	0.001	0.007	0.0	0.0003	0.030
52	0.001	0.027	0.0	0.0002	0.061

WELL NO.	EP1	EP2	EP3	ENO2	ENO3
53	0.000	0.029	0.0	0.0002	0.084
54	0.001	0.025	0.0	0.0002	0.084
55	0.000	0.008	0.0	0.0003	0.077
56	0.001	0.077	0.0	0.0002	0.077
57	0.003	0.048	0.0	0.0002	0.064
58	0.000	0.015	0.0	0.0002	0.077
65	0.0	0.0	0.0	0.0002	0.032
68	0.0	0.0	0.0	0.0	0.042
69	0.0	0.0	0.0	0.0	0.050
70	0.0	0.0	0.0	0.0	0.010
71	0.0	0.0	0.0	0.0	0.011
72	0.0	0.0	0.0	0.0	0.053
73	0.0	0.0	0.0	0.0	0.042
74	0.0	0.0	0.0	0.0	0.006
75	0.0	0.0	0.0	0.0	0.0
76	0.0	0.0	0.0	0.0	0.011
77	0.0	0.0	0.0	0.0	0.003
78	0.0	0.0	0.0	0.0	0.087
79	0.0	0.0	0.0	0.0	1.500
80	0.0	0.0	0.0	0.0	0.013
81	0.0	0.0	0.0	0.0	0.097
82	0.0	0.0	0.0	0.0	0.015
83	0.0	0.0	0.0	0.0	3.387
84	0.0	0.0	0.0	0.0	3.145
85	0.0	0.0	0.0	0.0	0.015
86	0.0	0.0	0.0	0.0	0.129
87	0.0	0.0	0.0	0.0	0.145
					0.085

WELL NO.	EAL	SIO4	EB	TCAT	TANI
1	0.0	0.0	0.0	0.534	54.715
2	0.0	0.0	0.0	26.572	35.898
3	0.0	0.0	0.0	7.965	8.153
4	0.0	0.0	0.0	4.891	8.272
5	0.0	0.0	0.0	9.686	12.323
6	0.0	0.0	0.0	7.910	11.518
7	0.0	0.0	0.0	14.900	17.426
8	0.0	0.0	0.0	15.626	18.975
9	0.0	0.0	0.0	88.667	103.990
10	0.0	0.0	0.0	14.177	12.087
11	0.0	0.0	0.0	10.185	10.388
12	0.0	0.0	0.0	10.704	13.570
13	0.0	0.0	0.0	8.439	8.881
14	0.0	0.0	0.0	23.998	16.940
15	0.0	0.0	0.0	18.080	14.844
16	0.0	0.0	0.0	19.305	21.554
17	0.0	0.0	0.0	18.263	21.465
18	0.0	0.0	0.0	53.853	56.178
19	0.0	0.0	0.0	8.407	7.975
20	0.0	0.0	0.0	8.504	8.485
21	0.0	0.0	0.0	34.987	34.234
22	0.0	0.0	0.0	8.960	7.158
23	0.0	0.0	0.0	23.146	20.831
24	0.0	0.0	0.0	14.361	17.097
25	0.0	0.0	0.0	17.616	17.676
26	0.0	0.0	0.0	11.975	12.268
27	0.0	0.0	0.0	16.793	19.688
28	0.0	0.0	0.0	15.954	18.551
29	0.0	0.0	0.0	6.760	8.805
30	0.0	0.0	0.0	5.751	6.356
31	0.0	0.0	0.0	8.458	7.593
32	0.0	0.0	0.0	13.825	14.948
33	0.0	0.0	0.0	7.680	9.434
34	0.0	0.0	0.0	21.494	19.308
35	0.0	0.0	0.0	6.977	6.362
36	0.0	0.0	0.0	30.608	31.210
37	0.0	0.0	0.0	48.671	64.719
38	0.0	0.0	0.0	28.893	33.404
39	0.0	0.0	0.0	90.201	135.710
40	0.0	0.0	0.0	36.482	50.459
41	0.0	0.0	0.0	59.515	80.827
42	0.0	0.0	0.0	24.024	31.683
43	0.0	0.0	0.0	21.633	23.748
44	0.0	0.0	0.0	19.362	41.480
45	0.0	0.0	0.0	37.411	46.306
46	0.0	0.0	0.0	22.626	28.643
47	0.0	0.0	0.0	28.293	29.477
48	0.0	0.0	0.0	18.060	22.697
49	0.0	0.0	0.0	22.764	8.745
50	0.0	0.0	0.0	28.133	13.998
51	0.0	0.0	0.0	28.896	28.973
52	0.0	0.0	0.0	23.093	14.586

WELL NO.	EAL	SIO4	EB	TCAT	TANI
53	0.0	0.0	0.0	36.757	48.886
54	0.0	0.0	0.0	24.988	34.498
55	0.0	0.0	0.0	28.999	26.915
56	0.0	0.0	0.0	35.157	43.925
57	0.0	0.0	0.0	21.645	24.991
58	0.0	0.0	0.0	7.524	4.548
65	0.0	0.0	0.0	5.313	6.835
68	0.0	99.257	15.443	19.692	19.498
69	0.0	37.649	13.156	34.745	34.525
70	0.0	109.525	0.0	12.873	12.952
71	0.0	95.834	2.460	14.091	13.717
72	0.0	92.412	1.830	12.486	12.271
73	0.0	37.649	18.875	34.970	35.427
74	0.0	65.030	0.0	35.543	35.836
75	0.0	95.834	23.451	51.946	53.763
76	0.0	92.412	0.572	13.026	12.986
77	0.0	92.412	1.258	30.306	29.536
78	0.0	75.298	1.373	22.705	21.830
79	0.0	95.834	0.972	10.278	10.446
80	0.0	95.834	4.004	26.685	26.126
81	0.0	88.989	16.015	71.189	71.738
82	0.0	88.989	2.688	21.743	21.306
83	0.0	92.412	1.659	59.075	56.959
84	0.0	88.989	25.167	119.929	119.166
85	0.0	99.257	20.019	32.277	32.481
86	0.0	99.257	23.451	33.498	33.534
87	0.0	106.102	1.716	12.852	12.991

APPENDIX F

CHEMICAL CONSTITUENT PERCENTAGES

CHEMICAL CONSTITUENT PERCENTAGES

Explanations of the data headings used on pages to are given below.

WELL NO.	number assigned to source of water (usually a piezometer).
PCA	percent of the total cations composed of calcium.
PMG	percent of the total cations composed of magnesium.
PMN	percent of the total cations composed of manganese.
PNA	percent of the total cations composed of sodium.
PK	percent of the total cations composed of potassium.
PFE	percent of the total cations composed of iron.
PSR	percent of the total cations composed of strontium.
PCU	percent of the total cations composed of copper.
PLI	percent of the total cations composed of lithium.
PHCO3	percent of the total anions composed of bicarbonate.
PCO3	percent of the total anions composed of carbonate.
PSO4	percent of the total anions composed of sulfate.
PCL	percent of the total anions composed of chloride.
PF	percent of the total anions composed of fluoride.
PBR	percent of the total anions composed of bromide.

PPI	percent of the total anions composed of phosphate ($H_2PO_4^-$).
PP2	percent of the total anions composed of phosphate ($HPO_4^=$).
PP3	percent of the total anions composed of phosphate (PO_4^{-3}).
PNO2	percent of the total anions composed of nitrite.
PNO3	percent of the total anions composed of nitrate.
PSIO4	percent of the total dissolved solids composed of H_4SIO_4.
PEAL	percent of the total dissolved solids composed of $AL(OH)_3$.
PEB	percent of the total dissolved solids composed of H_3BO_3.
PTCAT	percent of the total equivalents of cations and anions composed of cations.
PTANI	percent of the total equivalents of cations and anions composed of anions.
NA+K	percent of the total cations composed of sodium and potassium.
CA+MG	percent of the total cations composed of calcium and magnesium.
SO4+CL	percent of the total anions composed of sulfate and chloride.
HCO3+CO3	percent of the total anions composed of bicarbonate and carbonate.
CL+F+BR	percent of the total anions composed of chloride, bromide and fluoride.

WELL NO.	PCA	PMG	PMN	PNA	PK
1	17.29	3.85	1.02	49.69	23.95
2	4.06	39.48	0.00	49.31	5.56
3	30.42	51.14	0.02	16.93	0.72
4	31.73	50.05	0.01	16.01	1.18
5	20.84	24.00	0.01	52.21	1.19
6	31.51	33.29	0.02	32.44	1.70
7	8.96	11.60	0.04	76.27	1.89
8	23.31	22.12	0.00	52.54	1.06
9	0.45	2.58	0.00	95.66	0.86
10	2.20	8.42	0.03	83.61	1.70
11	9.65	20.40	0.01	66.73	2.13
12	30.65	43.82	0.01	22.76	1.82
13	9.46	26.81	0.02	59.92	2.61
14	4.88	3.12	0.01	89.50	1.28
15	7.27	9.67	0.00	79.39	2.35
16	3.66	9.06	0.01	83.65	2.47
17	7.50	15.54	0.01	73.24	2.80
18	0.65	1.31	0.00	96.42	0.80
19	18.46	21.78	0.02	55.62	2.66
20	11.76	17.66	0.01	66.49	2.84
21	6.05	16.46	0.02	75.37	0.99
22	9.30	23.19	0.01	63.72	2.78
23	4.51	4.09	0.00	89.27	1.26
24	10.95	15.90	0.04	68.53	3.75
25	7.85	7.94	0.01	79.63	3.63
26	8.92	9.45	0.01	77.19	3.50
27	5.57	6.74	0.02	83.21	3.04
28	6.87	4.85	0.05	85.89	1.81
29	26.32	28.91	0.02	40.38	3.29
30	34.36	40.42	0.04	20.99	3.36
31	14.90	10.94	0.01	70.71	2.57
32	3.97	6.84	0.01	84.16	1.80
33	11.76	42.86	0.02	42.19	2.01
34	15.21	24.88	0.00	54.39	4.28
35	19.13	37.45	0.03	37.72	4.09
36	6.19	11.29	0.02	79.94	1.61
37	2.76	2.87	0.01	92.72	1.01
38	8.10	14.60	0.03	74.33	2.17
39	4.80	5.29	0.00	88.61	0.73
40	4.07	5.30	0.01	88.68	1.20
41	1.58	2.35	0.01	94.56	0.92
42	20.30	21.92	0.15	52.28	4.44
43	5.79	40.89	0.10	48.01	4.20
44	8.56	13.39	0.03	74.13	2.76
45	1.15	1.42	0.00	95.92	0.76
46	17.26	16.37	0.00	63.20	2.27
47	5.80	14.47	0.02	76.87	2.17
48	10.87	21.30	0.02	64.43	2.28
49	16.22	17.53	0.01	63.53	2.04
50	5.37	13.82	0.01	77.31	2.75
51	5.51	13.38	0.01	78.09	2.35
52	16.80	17.73	0.08	62.16	2.38

WELL NO.	PCA	PMG	PMN	PNA	PK
53	0.73	1.73	0.00	96.15	0.94
54	18.62	17.45	0.01	60.27	2.29
55	5.03	9.86	0.01	83.44	1.11
56	2.46	2.39	0.00	93.57	0.96
57	10.78	19.48	0.01	67.82	1.15
58	11.37	10.61	0.06	75.15	2.23
65	44.71	49.56	0.0	5.73	0.0
68	3.80	1.59	0.01	93.88	0.71
69	11.35	7.58	0.02	79.75	1.03
70	36.44	21.73	0.0	41.56	0.0
71	38.60	23.36	0.28	35.50	1.16
72	41.16	23.07	0.29	32.75	1.41
73	6.85	4.47	0.02	87.69	0.88
74	8.00	5.32	0.0	86.52	0.0
75	3.07	1.74	0.00	94.62	0.54
76	55.16	32.85	0.0	10.69	1.30
77	42.65	44.53	0.30	11.63	0.84
78	40.22	42.04	3.53	13.60	0.61
79	50.01	16.81	0.19	31.74	1.17
80	35.90	16.96	0.29	45.15	1.05
81	6.24	3.58	0.02	89.21	0.65
82	43.61	30.28	0.0	25.41	0.71
83	39.62	47.36	0.0	12.37	0.65
84	4.95	2.95	0.01	91.40	0.55
85	3.71	2.35	0.0	93.25	0.69
86	4.47	2.70	0.01	92.07	0.75
87	27.96	14.09	0.0	55.51	1.95

WELL NO.	PFE	PSR	PCU	PLI	PHCO3
1	1.14	0.26	0.65	2.16	98.24
2	0.01	0.02	0.01	1.55	15.64
3	0.01	0.05	0.02	0.69	32.52
4	0.01	0.05	0.02	0.94	19.08
5	0.04	0.00	0.02	1.70	22.21
6	0.04	0.06	0.01	0.93	20.80
7	0.02	0.02	0.01	1.20	14.00
8	0.02	0.06	0.01	0.88	15.50
9	0.01	0.01	0.00	0.43	5.47
10	0.07	0.02	0.00	3.95	35.26
11	0.03	0.04	0.02	0.99	38.93
12	0.00	0.13	0.01	0.81	11.42
13	0.03	0.06	0.01	1.08	31.64
14	0.0	0.02	0.00	1.20	40.81
15	0.02	0.04	0.01	1.24	34.26
16	0.02	0.03	0.00	1.10	21.27
17	0.02	0.05	0.01	0.84	19.03
18	0.0	0.01	0.00	0.81	19.83
19	0.00	0.05	0.0	1.41	59.29
20	0.07	0.04	0.01	1.12	45.69
21	0.01	0.04	0.00	1.06	4.61
22	0.03	0.02	0.01	0.93	50.27
23	0.02	0.02	0.01	0.83	35.19
24	0.02	0.03	0.01	0.78	24.96
25	0.01	0.04	0.01	0.89	39.77
26	0.04	0.00	0.01	0.89	31.26
27	0.00	0.03	0.00	1.39	52.00
28	0.00	0.04	0.01	0.50	6.48
29	0.01	0.10	0.01	0.96	45.53
30	0.02	0.12	0.01	0.68	56.57
31	0.03	0.06	0.01	0.77	49.97
32	0.01	0.02	0.01	3.18	39.28
33	0.05	0.04	0.02	1.05	45.94
34	0.01	0.07	0.01	1.15	17.17
35	0.05	0.09	0.09	1.36	43.07
36	0.01	0.04	0.00	0.90	15.44
37	0.00	0.02	0.00	0.60	10.41
38	0.01	0.06	0.01	0.69	9.22
39	0.01	0.06	0.00	0.51	2.34
40	0.01	0.01	0.00	0.72	9.82
41	0.00	0.02	0.00	0.57	8.86
42	0.01	0.10	0.01	0.78	12.24
43	0.02	0.03	0.01	0.97	24.91
44	0.02	0.06	0.01	1.05	9.13
45	0.01	0.0	0.01	0.73	12.82
46	0.02	0.07	0.01	0.80	14.19
47	0.01	0.04	0.01	0.61	16.22
48	0.01	0.09	0.01	1.00	11.14
49	0.0	0.09	0.01	0.57	38.34
50	0.01	0.04	0.00	0.69	18.90
51	0.01	0.01	0.01	0.63	19.01
52	0.00	0.08	0.00	0.77	26.21

WELL NO.	PFE	PSR	PCU	PLI	PHCO3
53	0.0	0.01	0.00	0.44	10.82
54	0.01	0.11	0.00	1.23	6.87
55	0.00	0.03	0.00	0.52	14.98
56	0.01	0.01	0.00	0.59	11.49
57	0.02	0.04	0.01	0.69	16.61
58	0.06	0.05	0.01	0.46	19.57
65	0.0	0.0	0.0	0.0	87.43
68	0.01	0.0	0.0	0.0	63.82
69	0.28	0.0	0.0	0.0	13.47
70	0.27	0.0	0.0	0.0	60.17
71	1.09	0.0	0.0	0.0	55.14
72	1.32	0.0	0.0	0.0	60.04
73	0.09	0.0	0.0	0.0	15.90
74	0.15	0.0	0.0	0.0	17.27
75	0.02	0.0	0.0	0.0	25.43
76	0.01	0.0	0.0	0.0	58.25
77	0.06	0.0	0.0	0.0	25.06
78	0.00	0.0	0.0	0.0	30.30
79	0.08	0.0	0.0	0.0	65.83
80	0.64	0.0	0.0	0.0	47.31
81	0.30	0.0	0.0	0.0	17.44
82	0.00	0.0	0.0	0.0	26.67
83	0.00	0.0	0.0	0.0	11.50
84	0.14	0.0	0.0	0.0	8.30
85	0.0	0.0	0.0	0.0	34.58
86	0.00	0.0	0.0	0.0	33.20
87	0.50	0.0	0.0	0.0	62.26

WELL NO.	PCO3	PSO4	PCL	PF	PBR
1	0.47	0.11	0.79	0.03	0.04
2	3.59	63.51	17.02	0.07	0.05
3	12.30	37.80	16.58	0.26	0.12
4	9.17	55.88	15.13	0.25	0.13
5	21.70	42.41	13.00	0.14	0.10
6	13.28	57.85	7.13	0.19	0.07
7	8.78	72.88	3.91	0.12	0.04
8	12.80	67.48	3.59	0.15	0.05
9	5.12	0.58	88.59	0.04	0.09
10	10.63	43.93	9.11	0.32	0.11
11	9.77	45.30	5.40	0.23	0.07
12	11.37	72.88	3.91	0.13	0.04
13	17.80	40.33	9.25	0.28	0.11
14	19.35	18.68	20.69	0.16	0.06
15	16.37	24.97	23.61	0.24	0.09
16	14.25	46.37	16.72	0.13	0.06
17	7.72	26.19	46.65	0.14	0.10
18	7.69	2.67	69.51	0.06	0.10
19	13.06	16.45	10.42	0.32	0.10
20	24.54	22.09	6.37	0.30	0.10
21	0.75	73.90	20.47	0.06	0.05
22	21.55	14.25	12.45	0.43	0.13
23	15.55	24.99	23.55	0.12	0.08
24	6.99	21.68	45.68	0.16	0.23
25	8.07	30.04	20.39	0.19	0.08
26	23.26	41.58	2.53	0.28	0.22
27	12.34	15.12	18.82	0.27	0.15
28	3.60	3.59	83.66	0.08	0.28
29	23.94	22.70	6.14	0.31	0.11
30	18.40	13.10	6.46	0.23	0.06
31	27.09	13.44	7.65	0.37	0.16
32	16.42	34.54	9.04	0.19	0.08
33	17.58	29.80	5.73	0.28	0.07
34	13.98	45.29	21.26	0.18	0.09
35	29.90	15.06	10.70	0.49	0.13
36	4.57	59.71	19.89	0.11	0.06
37	6.73	0.55	82.00	0.06	0.14
38	11.93	50.18	28.18	0.10	0.09
39	1.40	0.12	95.92	0.02	0.07
40	6.85	7.55	75.41	0.07	0.13
41	3.83	0.31	86.72	0.04	0.09
42	9.57	24.97	50.57	0.07	0.18
43	5.84	45.15	21.08	0.06	0.12
44	3.35	19.58	67.59	0.06	0.08
45	6.63	8.77	71.36	0.09	0.10
46	5.39	53.79	26.22	0.11	0.07
47	4.75	44.50	33.97	0.08	0.09
48	9.06	56.42	22.94	0.12	0.07
49	30.57	21.43	8.24	0.33	0.21
50	15.79	11.30	48.64	0.21	0.12
51	6.30	45.99	28.34	0.08	0.14
52	9.16	7.28	56.29	0.19	0.25

WELL NO.	PCO3	PSO4	PCL	PF	PBR
53	8.02	7.03	73.74	0.08	0.09
54	2.57	17.50	72.56	0.07	0.10
55	6.64	22.05	55.80	0.10	0.12
56	10.56	2.23	75.23	0.07	0.09
57	7.72	54.15	20.84	0.10	0.07
58	9.04	38.91	30.82	0.39	0.21
65	0.0	8.50	3.30	0.15	0.0
68	0.0	34.17	1.59	0.16	0.0
69	0.0	68.75	17.40	0.35	0.0
70	0.0	34.08	5.66	0.0	0.0
71	0.0	33.70	10.69	0.08	0.0
72	0.0	32.41	7.13	0.09	0.0
73	0.0	64.06	19.67	0.36	0.0
74	0.0	61.01	21.72	0.0	0.0
75	0.0	0.03	74.50	0.02	0.0
76	0.0	39.60	2.00	0.12	0.0
77	0.0	72.61	2.01	0.04	0.0
78	0.0	43.40	19.38	0.05	0.0
79	0.0	31.09	2.70	0.25	0.0
80	0.0	30.68	21.59	0.04	0.0
81	0.0	1.13	81.39	0.02	0.0
82	0.0	35.28	22.11	0.05	0.0
83	0.0	77.50	5.45	0.04	0.0
84	0.0	0.31	91.37	0.01	0.0
85	0.0	59.49	5.47	0.06	0.0
86	0.0	58.99	7.32	0.06	0.0
87	0.0	29.01	8.03	0.04	0.0

WELL NO.	PP1	PP2	PP3	PNO2	PNO3
1	0.05	0.20	0.0	0.04	0.03
2	0.01	0.02	0.0	0.00	0.09
3	0.00	0.10	0.0	0.00	0.31
4	0.00	0.11	0.0	0.00	0.23
5	0.00	0.05	0.0	0.00	0.39
6	0.00	0.08	0.0	0.01	0.60
7	0.00	0.04	0.0	0.00	0.22
8	0.00	0.07	0.0	0.00	0.34
9	0.00	0.02	0.0	0.00	0.09
10	0.0	0.0	0.0	0.0	0.64
11	0.00	0.04	0.0	0.00	0.26
12	0.00	0.05	0.0	0.00	0.20
13	0.00	0.05	0.0	0.00	0.54
14	0.00	0.05	0.0	0.00	0.20
15	0.00	0.05	0.0	0.00	0.42
16	0.00	0.24	0.0	0.00	0.96
17	0.00	0.03	0.0	0.00	0.13
18	0.00	0.05	0.0	0.00	0.09
19	0.00	0.02	0.0	0.00	0.32
20	0.00	0.07	0.0	0.00	0.83
21	0.0	0.0	0.0	0.0	0.15
22	0.00	0.19	0.0	0.00	0.70
23	0.00	0.15	0.0	0.00	0.36
24	0.01	0.20	0.0	0.00	0.08
25	0.01	0.78	0.0	0.00	0.66
26	0.02	0.47	0.0	0.00	0.38
27	0.04	1.14	0.0	0.00	0.12
28	0.32	0.68	0.0	0.00	1.29
29	0.02	0.55	0.0	0.00	0.69
30	0.23	0.56	0.0	0.01	4.38
31	0.06	0.58	0.0	0.00	0.68
32	0.00	0.04	0.0	0.00	0.40
33	0.00	0.08	0.0	0.00	0.51
34	0.01	1.04	0.0	0.00	0.98
35	0.00	0.19	0.0	0.00	0.45
36	0.00	0.02	0.0	0.00	0.20
37	0.00	0.06	0.0	0.00	0.05
38	0.00	0.04	0.0	0.00	0.26
39	0.00	0.00	0.0	0.06	0.07
40	0.00	0.02	0.0	0.00	0.14
41	0.00	0.08	0.0	0.00	0.07
42	0.10	0.76	0.0	0.00	1.52
43	0.01	0.18	0.0	2.38	0.27
44	0.00	0.04	0.0	0.00	0.17
45	0.00	0.09	0.0	0.00	0.13
46	0.00	0.06	0.0	0.00	0.16
47	0.01	0.11	0.0	0.00	0.27
48	0.00	0.04	0.0	0.00	0.21
49	0.00	0.18	0.0	0.00	0.70
50	0.01	1.13	0.0	0.00	3.88
51	0.00	0.02	0.0	0.00	0.10
52	0.01	0.18	0.0	0.00	0.42

WELL NO.	PP1	PP2	PP3	PNO2	PNO3
53	0.00	0.06	0.0	0.00	0.17
54	0.00	0.07	0.0	0.00	0.24
55	0.00	0.03	0.0	0.00	0.29
56	0.00	0.17	0.0	0.00	0.15
57	0.01	0.19	0.0	0.00	0.31
58	0.01	0.33	0.0	0.00	0.71
65	0.0	0.0	0.0	0.0	0.61
68	0.0	0.0	0.0	0.0	0.26
69	0.0	0.0	0.0	0.0	0.03
70	0.0	0.0	0.0	0.0	0.09
71	0.0	0.0	0.0	0.0	0.39
72	0.0	0.0	0.0	0.0	0.34
73	0.0	0.0	0.0	0.0	0.02
74	0.0	0.0	0.0	0.0	0.0
75	0.0	0.0	0.0	0.0	0.02
76	0.0	0.0	0.0	0.0	0.02
77	0.0	0.0	0.0	0.0	0.29
78	0.0	0.0	0.0	0.0	6.87
79	0.0	0.0	0.0	0.0	0.12
80	0.0	0.0	0.0	0.0	0.37
81	0.0	0.0	0.0	0.0	0.02
82	0.0	0.0	0.0	0.0	15.90
83	0.0	0.0	0.0	0.0	5.52
84	0.0	0.0	0.0	0.0	0.01
85	0.0	0.0	0.0	0.0	0.40
86	0.0	0.0	0.0	0.0	0.43
87	0.0	0.0	0.0	0.0	0.66

WELL NO.	PSIO4	PEAL	PEB	PTCAT	PTANI
1	0.0	0.0	0.0	0.97	0.97
2	0.0	0.0	0.0	42.54	42.54
3	0.0	0.0	0.0	49.42	49.42
4	0.0	0.0	0.0	37.16	37.16
5	0.0	0.0	0.0	44.01	44.01
6	0.0	0.0	0.0	40.72	40.72
7	0.0	0.0	0.0	46.09	46.09
8	0.0	0.0	0.0	45.16	45.16
9	0.0	0.0	0.0	46.02	46.02
10	0.0	0.0	0.0	53.98	53.98
11	0.0	0.0	0.0	49.51	49.51
12	0.0	0.0	0.0	44.10	44.10
13	0.0	0.0	0.0	48.72	48.72
14	0.0	0.0	0.0	58.62	58.62
15	0.0	0.0	0.0	54.91	54.91
16	0.0	0.0	0.0	47.25	47.25
17	0.0	0.0	0.0	45.97	45.97
18	0.0	0.0	0.0	48.94	48.94
19	0.0	0.0	0.0	51.32	51.32
20	0.0	0.0	0.0	50.06	50.06
21	0.0	0.0	0.0	50.54	50.54
22	0.0	0.0	0.0	55.59	55.59
23	0.0	0.0	0.0	52.63	52.63
24	0.0	0.0	0.0	45.65	45.65
25	0.0	0.0	0.0	49.92	49.92
26	0.0	0.0	0.0	49.40	49.40
27	0.0	0.0	0.0	46.03	46.03
28	0.0	0.0	0.0	46.24	46.24
29	0.0	0.0	0.0	43.43	43.43
30	0.0	0.0	0.0	47.50	47.50
31	0.0	0.0	0.0	52.70	52.70
32	0.0	0.0	0.0	48.05	48.05
33	0.0	0.0	0.0	44.88	44.88
34	0.0	0.0	0.0	52.68	52.68
35	0.0	0.0	0.0	52.30	52.30
36	0.0	0.0	0.0	49.51	49.51
37	0.0	0.0	0.0	42.92	42.92
38	0.0	0.0	0.0	46.38	46.38
39	0.0	0.0	0.0	39.93	39.93
40	0.0	0.0	0.0	41.96	41.96
41	0.0	0.0	0.0	42.41	42.41
42	0.0	0.0	0.0	43.13	43.13
43	0.0	0.0	0.0	47.67	47.67
44	0.0	0.0	0.0	31.82	31.82
45	0.0	0.0	0.0	44.69	44.69
46	0.0	0.0	0.0	44.13	44.13
47	0.0	0.0	0.0	48.98	48.98
48	0.0	0.0	0.0	44.31	44.31
49	0.0	0.0	0.0	72.25	72.25
50	0.0	0.0	0.0	66.78	66.78
51	0.0	0.0	0.0	49.93	49.93
52	0.0	0.0	0.0	61.29	61.29

WELL NO.	PSIO4	PEAL	PEB	PTCAT	PTANI
53	0.0	0.0	0.0	42.92	42.92
54	0.0	0.0	0.0	42.01	42.01
55	0.0	0.0	0.0	51.86	51.86
56	0.0	0.0	0.0	44.46	44.46
57	0.0	0.0	0.0	46.41	46.41
58	0.0	0.0	0.0	62.33	62.33
65	0.0	0.0	0.0	43.73	43.73
68	5.98	0.0	0.93	50.25	50.25
69	1.53	0.0	0.54	50.16	50.16
70	10.18	0.0	0.0	49.85	49.85
71	8.61	0.0	0.22	50.67	50.67
72	9.12	0.0	0.18	50.43	50.43
73	1.49	0.0	0.75	49.68	49.68
74	2.54	0.0	0.0	49.79	49.79
75	2.69	0.0	0.66	49.14	49.14
76	8.83	0.0	0.05	50.08	50.08
77	4.36	0.0	0.06	50.64	50.64
78	4.78	0.0	0.09	50.98	50.98
79	10.79	0.0	0.11	49.60	49.60
80	4.82	0.0	0.20	50.53	50.53
81	1.94	0.0	0.35	49.81	49.81
82	5.63	0.0	0.17	50.51	50.51
83	2.36	0.0	0.04	50.91	50.91
84	1.22	0.0	0.34	50.16	50.16
85	3.91	0.0	0.79	49.84	49.84
86	3.80	0.0	0.90	49.97	49.97
87	9.69	0.0	0.16	49.73	49.73

WELL NO.	NA+K	CA+MG	SO4+CL	HCO3+CO3	CL+F+BR
1	0.74	0.21	0.01	0.99	0.47
2	0.55	0.44	0.81	0.19	6.15
3	0.18	0.82	0.54	0.45	1.38
4	0.17	0.82	0.71	0.28	1.28
5	0.53	0.45	0.55	0.44	1.63
6	0.34	0.65	0.65	0.34	0.85
7	0.78	0.21	0.77	0.23	0.71
8	0.54	0.45	0.71	0.28	0.72
9	0.97	0.03	0.89	0.11	92.26
10	0.85	0.11	0.53	0.46	1.15
11	0.69	0.30	0.51	0.49	0.59
12	0.25	0.74	0.77	0.23	0.55
13	0.63	0.36	0.50	0.49	0.86
14	0.91	0.08	0.39	0.60	3.54
15	0.82	0.17	0.49	0.51	3.55
16	0.86	0.13	0.63	0.36	3.65
17	0.76	0.23	0.73	0.27	10.07
18	0.97	0.02	0.72	0.28	39.14
19	0.58	0.40	0.27	0.72	0.87
20	0.69	0.29	0.28	0.70	0.57
21	0.76	0.23	0.94	0.05	7.05
22	0.67	0.32	0.27	0.72	0.93
23	0.91	0.09	0.49	0.51	4.95
24	0.72	0.27	0.67	0.32	7.88
25	0.83	0.16	0.50	0.48	3.65
26	0.81	0.18	0.44	0.55	0.37
27	0.86	0.12	0.34	0.64	3.79
28	0.88	0.12	0.87	0.10	15.59
29	0.44	0.55	0.29	0.69	0.58
30	0.24	0.75	0.20	0.75	0.43
31	0.73	0.26	0.21	0.77	0.62
32	0.86	0.11	0.44	0.56	1.39
33	0.44	0.55	0.36	0.64	0.57
34	0.59	0.40	0.67	0.31	4.16
35	0.42	0.57	0.26	0.73	0.72
36	0.82	0.17	0.80	0.20	6.26
37	0.94	0.06	0.83	0.17	53.20
38	0.77	0.23	0.78	0.21	9.48
39	0.89	0.10	0.96	0.04	130.30
40	0.90	0.09	0.83	0.17	38.15
41	0.95	0.04	0.87	0.13	70.19
42	0.57	0.42	0.76	0.22	16.10
43	0.52	0.47	0.66	0.31	5.05
44	0.77	0.22	0.87	0.12	28.10
45	0.97	0.03	0.80	0.19	33.13
46	0.65	0.34	0.80	0.20	7.56
47	0.79	0.20	0.78	0.21	10.06
48	0.67	0.32	0.79	0.20	5.25
49	0.66	0.34	0.30	0.69	0.77
50	0.80	0.19	0.60	0.35	6.85
51	0.80	0.19	0.74	0.25	8.28
52	0.65	0.35	0.64	0.35	8.28

WELL NO.	NA+K	CA+MG	SO4+CL	HCO3+CO3	CL+F+BR
53	0.97	0.02	0.81	0.19	36.13
54	0.63	0.36	0.90	0.09	25.09
55	0.85	0.15	0.78	0.22	15.08
56	0.95	0.05	0.77	0.22	33.12
57	0.69	0.30	0.75	0.24	5.25
58	0.77	0.22	0.70	0.29	1.43
65	0.06	0.94	0.12	0.87	0.24
68	0.95	0.05	0.36	0.64	0.34
69	0.81	0.19	0.86	0.13	6.13
70	0.42	0.58	0.40	0.60	0.73
71	0.37	0.62	0.44	0.55	1.48
72	0.34	0.64	0.40	0.60	0.88
73	0.89	0.11	0.84	0.16	7.09
74	0.87	0.13	0.83	0.17	7.78
75	0.95	0.05	0.75	0.25	40.06
76	0.12	0.88	0.42	0.58	0.28
77	0.12	0.87	0.75	0.25	0.60
78	0.14	0.82	0.63	0.30	4.24
79	0.33	0.67	0.34	0.66	0.31
80	0.46	0.53	0.52	0.47	5.65
81	0.90	0.10	0.83	0.17	58.40
82	0.26	0.74	0.57	0.27	4.72
83	0.13	0.87	0.83	0.11	3.12
84	0.92	0.08	0.92	0.08	108.89
85	0.94	0.06	0.65	0.35	1.80
86	0.93	0.07	0.66	0.33	2.48
87	0.57	0.42	0.37	0.62	1.05

APPENDIX G

CHEMICAL PARAMETERS IN EQUIVALENTS PER MILLION

CHEMICAL PARAMETERS IN EQUIVALENTS PER MILLION

Explanations of the headings used on pages to are given below.

WELL NO.	number assigned to source of water (usually a piezometer).
TOTA	concentration of chloride, sulfate, bicarbonate, and carbonate ions in equivalents per million.
TOTC	concentration of calcium, magnesium, sodium, and potassium ions in equivalents per million.
TPPM	total concentration of H_4SIO_4, $AL(OH)_3$ and H_3BO_3 in parts per million.
TOTP	total concentration of phosphate from $H_2PO_4^-$, HPO_4 and PO_4^{-3} in equivalents per million.
TOTN	total concentration of nitrate and nitrite in equivalents per million.
NK/ION	concentration of sodium and potassium divided by the sum of all cations and anions.
CM/ION	concentration of calcium and magnesium divided by the sum of all the cations and anions.
SC/ION	concentration of sulfate and chloride divided by the sum of all the cations and anions.
HC/ION	concentration of bicarbonate and carbonate divided by the sum of all the cations and anions.
FBC/ION	concentration of fluoride, bromide, and chloride divided by the sum of all the cations and anions.
PXCL	concentration of chloride divided by concentration of chloride, sulfate, bicarbonate, and carbonate.

PXSO4	concentration of sulfate divided by the concentration of chloride, sulfate, bicarbonate, and carbonate.
PXHSO4	concentration of bicarbonate divided by the concentration of chloride, sulfate, bicarbonate, and carbonate.
PXCO3	concentrations of carbonate divided by the concentration of chloride, sulfate, bicarbonate, and carbonate.
PXCA	concentration of calcium divided by the concentration of calcium, magnesium, sodium, and potassium.
PXMG	concentration of magnesium divided by the concentration of calcium, magnesium, sodium, and potassium.
PXNA	concentration of sodium divided by the concentration of calcium, magnesium, sodium, and potassium.
PXK	concentration of potassium divided by the concentration of calcium, magnesium, sodium, and potassium.
PXCM	concentration of calcium and magnesium divided by the concentration of calcium, magnesium, sodium, and potassium.
PXKN	concentration of potassium and sodium divided by the concentration of calcium, magnesium, sodium, and potassium.
PXSC	concentration of sulfate and chloride divided by the concentration of chloride, sulfate, bicarbonate, and carbonate.
PXHC	concentration of bicarbonate and carbonate divided by the concentration of chloride, sulfate, bicarbonate, and carbonate.
CA/NA	concentration of calcium divided by the concentration of sodium.
CA/MG	concentration of calcium divided by the concentration of magnesium.

CL/NA	concentration of chloride divided by the concentration of sodium.
SO4/NA	concentration of sulfate divided by the concentration of sodium.
HCO3/NA	concentration of bicarbonate divided by the concentration of sodium.
F/CL	concentration of fluoride divided by the concentration of chloride.
K/F	concentration of potassium divided by the concentration of fluoride.
CA/HCO3	concentration of calcium divided by the concentration of bicarbonate.
SO4/HCO3	concentration of sulfate divided by the concentration of bicarbonate.
TANI/TDS	concentration of all the anions divided by the total dissolved solids.
TCAT/TDS	concentration of all the cations divided by the total dissolved solids.
THRD/TDS	concentration of total hardness divided by the total dissolved solids.
SO/SOC	concentration of sulfate divided by the concentration of sulfate and chloride.
SO/SOHCC	concentration of sulfate divided by the concentration of sulfate, carbonate, and bicarbonate.
HC/HC+C	concentration of bicarbonate divided by the concentration of bicarbonate and the concentration of chloride.
M/M+CA	concentration of magnesium divided by the concentration of magnesium and calcium.
NK/NKCL	concentration of sodium and potassium divided by the concentration of sodium, potassium, and chloride.
C+M/CMS	concentration of calcium and magnesium divided by the concentration of calcium, magnesium, and sulfate.

C+F+B+N3	concentration of chloride, bromide, fluoride, nitrate, and nitrite.
S.A.R.	sodium absorption ratio (concentration of sodium divided by the square root of the quantity obtained by dividing the calcium and magnesium by two.
B.E.R.1	base exchange index (Mg, Ca in water exchanged for Na, K, in soil). The concentration of chloride less the concentration of sodium and potassium divided by the concentrations of sulfate, bicarbonate, and nitrate.
B.E.R.2	base exchange index (Na, K in water exchanged for Mg and Ca in soil). The concentration of chloride less the concentration of sodium and potassium divided by the concentration of chloride.
CL+F+NO3	concentration of chloride, fluoride, and nitrate.

WELL NO.	TOTA	TOTC	TPPM	TOTP	TOTN
1	54.50	0.51	0.0	0.14	0.04
2	35.81	26.15	0.0	0.01	0.03
3	8.09	7.90	0.0	0.01	0.03
4	8.21	4.84	0.0	0.01	0.02
5	12.24	9.51	0.0	0.01	0.05
6	11.41	7.83	0.0	0.01	0.07
7	17.35	14.71	0.0	0.01	0.04
8	18.86	15.47	0.0	0.01	0.06
9	103.73	88.26	0.0	0.02	0.09
10	11.96	13.60	0.0	0.0	0.08
11	10.33	10.07	0.0	0.00	0.03
12	13.51	10.60	0.0	0.01	0.03
13	8.79	8.34	0.0	0.00	0.05
14	16.86	23.70	0.0	0.01	0.03
15	14.73	17.84	0.0	0.01	0.06
16	21.25	19.08	0.0	0.05	0.21
17	21.38	18.10	0.0	0.01	0.03
18	56.01	53.41	0.0	0.03	0.05
19	7.91	8.28	0.0	0.00	0.03
20	8.37	8.40	0.0	0.01	0.07
21	34.14	34.59	0.0	0.0	0.05
22	7.05	8.87	0.0	0.01	0.05
23	20.68	22.94	0.0	0.03	0.08
24	16.98	14.24	0.0	0.04	0.01
25	17.37	17.45	0.0	0.14	0.12
26	12.10	11.86	0.0	0.06	0.05
27	19.35	16.55	0.0	0.23	0.02
28	18.06	15.86	0.0	0.19	0.24
29	8.66	6.69	0.0	0.05	0.06
30	6.01	5.70	0.0	0.05	0.28
31	7.45	8.38	0.0	0.05	0.05
32	14.84	13.38	0.0	0.01	0.06
33	9.34	7.59	0.0	0.01	0.05
34	18.86	21.23	0.0	0.20	0.19
35	6.28	6.86	0.0	0.01	0.03
36	31.09	30.31	0.0	0.01	0.06
37	64.52	48.36	0.0	0.04	0.03
38	33.24	28.66	0.0	0.01	0.09
39	135.41	89.69	0.0	0.00	0.17
40	50.27	36.21	0.0	0.01	0.07
41	80.60	59.16	0.0	0.07	0.06
42	30.85	23.77	0.0	0.27	0.48
43	23.03	21.39	0.0	0.04	0.63
44	41.33	19.14	0.0	0.02	0.07
45	46.11	37.13	0.0	0.04	0.06
46	28.53	22.42	0.0	0.02	0.05
47	29.31	28.10	0.0	0.03	0.08
48	22.60	17.86	0.0	0.01	0.05
49	8.62	22.61	0.0	0.02	0.06
50	13.25	27.92	0.0	0.16	0.54
51	28.87	28.70	0.0	0.01	0.03
52	14.43	22.88	0.0	0.03	0.06

WELL NO.	TOTA	TOTC	TPPM	TOTP	TOTN
53	48.69	36.59	0.0	0.03	0.08
54	34.33	24.65	0.0	0.03	0.08
55	26.77	28.84	0.0	0.01	0.08
56	43.71	34.94	0.0	0.08	0.06
57	24.82	21.48	0.0	0.05	0.08
58	4.47	7.48	0.0	0.02	0.03
65	6.78	5.31	0.0	0.0	0.04
68	19.42	19.69	114.70	0.0	0.05
69	34.39	34.64	50.80	0.0	0.01
70	12.94	12.84	109.52	0.0	0.01
71	13.65	13.90	98.29	0.0	0.05
72	12.22	12.29	94.24	0.0	0.04
73	35.29	34.93	56.52	0.0	0.01
74	35.84	35.49	65.03	0.0	0.0
75	53.74	51.94	119.29	0.0	0.01
76	12.97	13.03	92.98	0.0	0.00
77	29.44	30.20	93.67	0.0	0.09
78	20.32	21.90	76.67	0.0	1.50
79	10.41	10.25	96.81	0.0	0.01
80	26.02	26.44	99.84	0.0	0.10
81	71.71	70.96	105.00	0.0	0.01
82	17.91	21.74	91.68	0.0	3.39
83	53.79	59.07	94.07	0.0	3.14
84	119.14	119.76	114.16	0.0	0.01
85	32.33	32.28	119.28	0.0	0.13
86	33.37	33.49	122.71	0.0	0.15
87	12.90	12.79	107.82	0.0	0.09

WELL NO.	NK/ION	CM/ION	SC/ION	HC/ION	FBC/ION
1	0.01	0.00	0.01	0.98	0.01
2	0.23	0.19	0.46	0.11	0.10
3	0.09	0.40	0.28	0.23	0.09
4	0.06	0.30	0.45	0.18	0.10
5	0.23	0.20	0.31	0.25	0.07
6	0.14	0.26	0.39	0.20	0.04
7	0.36	0.09	0.41	0.12	0.02
8	0.24	0.21	0.39	0.16	0.02
9	0.44	0.01	0.48	0.06	0.48
10	0.46	0.06	0.24	0.21	0.04
11	0.34	0.15	0.26	0.25	0.03
12	0.11	0.33	0.43	0.13	0.02
13	0.30	0.18	0.25	0.25	0.05
14	0.53	0.05	0.16	0.25	0.09
15	0.45	0.09	0.22	0.23	0.11
16	0.41	0.06	0.33	0.19	0.09
17	0.35	0.11	0.39	0.14	0.25
18	0.48	0.01	0.37	0.14	0.36
19	0.30	0.21	0.13	0.35	0.05
20	0.35	0.15	0.14	0.35	0.03
21	0.39	0.11	0.47	0.03	0.10
22	0.37	0.18	0.12	0.32	0.06
23	0.48	0.05	0.23	0.24	0.11
24	0.33	0.12	0.37	0.17	0.25
25	0.42	0.08	0.25	0.24	0.10
26	0.40	0.09	0.22	0.28	0.02
27	0.40	0.06	0.18	0.35	0.10
28	0.41	0.05	0.47	0.05	0.45
29	0.19	0.24	0.16	0.39	0.04
30	0.12	0.36	0.10	0.39	0.04
31	0.39	0.14	0.10	0.36	0.04
32	0.41	0.05	0.23	0.29	0.05
33	0.20	0.25	0.20	0.35	0.03
34	0.31	0.21	0.31	0.15	0.10
35	0.22	0.30	0.12	0.35	0.05
36	0.40	0.09	0.40	0.10	0.10
37	0.40	0.02	0.47	0.10	0.47
38	0.35	0.11	0.42	0.11	0.15
39	0.36	0.04	0.58	0.02	0.58
40	0.38	0.04	0.48	0.10	0.44
41	0.40	0.02	0.50	0.07	0.50
42	0.24	0.18	0.43	0.12	0.29
43	0.25	0.22	0.35	0.16	0.11
44	0.24	0.07	0.59	0.09	0.46
45	0.43	0.01	0.44	0.11	0.40
46	0.29	0.15	0.45	0.11	0.15
47	0.39	0.10	0.40	0.11	0.17
48	0.30	0.14	0.44	0.11	0.13
49	0.47	0.24	0.08	0.19	0.02
50	0.53	0.13	0.20	0.12	0.16
51	0.40	0.09	0.37	0.13	0.14
52	0.40	0.21	0.25	0.14	0.22

WELL NO.	NK/ION	CM/ION	SC/ION	HC/ION	FBC/ION
53	0.42	0.01	0.46	0.11	0.42
54	0.26	0.15	0.52	0.05	0.42
55	0.44	0.08	0.37	0.10	0.27
56	0.42	0.02	0.43	0.12	0.42
57	0.32	0.14	0.40	0.13	0.11
58	0.48	0.14	0.26	0.11	0.12
65	0.03	0.41	0.07	0.49	0.02
68	0.48	0.03	0.18	0.32	0.01
69	0.41	0.09	0.43	0.07	0.09
70	0.21	0.29	0.20	0.30	0.03
71	0.19	0.31	0.22	0.27	0.05
72	0.17	0.32	0.20	0.30	0.04
73	0.44	0.06	0.42	0.08	0.10
74	0.43	0.07	0.42	0.09	0.11
75	0.47	0.02	0.38	0.13	0.38
76	0.06	0.44	0.21	0.29	0.01
77	0.06	0.44	0.37	0.12	0.01
78	0.07	0.42	0.31	0.15	0.10
79	0.16	0.33	0.17	0.33	0.01
80	0.23	0.27	0.26	0.23	0.11
81	0.45	0.05	0.41	0.09	0.41
82	0.13	0.37	0.28	0.13	0.11
83	0.07	0.44	0.41	0.06	0.03
84	0.46	0.04	0.46	0.04	0.46
85	0.47	0.03	0.33	0.17	0.03
86	0.46	0.04	0.33	0.17	0.04
87	0.29	0.21	0.19	0.31	0.04

WELL NO.	PXCL	PXSO4	PXHCO3	PXCO3	PXCA
1	0.01	0.00	0.99	0.00	0.18
2	0.17	0.64	0.16	0.04	0.04
3	0.17	0.38	0.33	0.12	0.31
4	0.15	0.56	0.19	0.09	0.32
5	0.13	0.43	0.22	0.22	0.21
6	0.07	0.58	0.21	0.13	0.32
7	0.04	0.73	0.14	0.09	0.09
8	0.04	0.68	0.16	0.13	0.24
9	0.89	0.01	0.05	0.05	0.00
10	0.09	0.44	0.36	0.11	0.02
11	0.05	0.46	0.39	0.10	0.10
12	0.04	0.73	0.11	0.11	0.31
13	0.09	0.41	0.32	0.18	0.10
14	0.21	0.19	0.41	0.19	0.05
15	0.24	0.25	0.35	0.16	0.07
16	0.17	0.47	0.22	0.14	0.04
17	0.47	0.26	0.19	0.08	0.08
18	0.70	0.03	0.20	0.08	0.01
19	0.11	0.17	0.60	0.13	0.19
20	0.06	0.22	0.46	0.25	0.12
21	0.21	0.74	0.05	0.01	0.06
22	0.13	0.14	0.51	0.22	0.09
23	0.24	0.25	0.35	0.16	0.05
24	0.46	0.22	0.25	0.07	0.11
25	0.21	0.31	0.40	0.08	0.08
26	0.03	0.42	0.32	0.24	0.09
27	0.19	0.15	0.53	0.13	0.06
28	0.86	0.04	0.07	0.04	0.07
29	0.06	0.23	0.46	0.24	0.27
30	0.07	0.14	0.60	0.19	0.35
31	0.08	0.14	0.51	0.28	0.15
32	0.09	0.35	0.40	0.17	0.04
33	0.06	0.30	0.46	0.18	0.12
34	0.22	0.46	0.18	0.14	0.15
35	0.11	0.15	0.44	0.30	0.19
36	0.20	0.60	0.16	0.05	0.06
37	0.82	0.01	0.10	0.07	0.03
38	0.28	0.50	0.09	0.12	0.08
39	0.96	0.00	0.02	0.01	0.05
40	0.76	0.08	0.10	0.07	0.04
41	0.87	0.00	0.09	0.04	0.02
42	0.52	0.26	0.13	0.10	0.21
43	0.22	0.47	0.26	0.06	0.06
44	0.68	0.20	0.09	0.03	0.09
45	0.72	0.09	0.13	0.07	0.01
46	0.26	0.54	0.14	0.05	0.17
47	0.34	0.45	0.16	0.05	0.06
48	0.23	0.57	0.11	0.09	0.11
49	0.08	0.22	0.39	0.31	0.16
50	0.51	0.12	0.20	0.17	0.05
51	0.28	0.46	0.19	0.06	0.06
52	0.57	0.07	0.26	0.09	0.17

WELL NO.	PXCL	PXSO4	PXHCO3	PXCO3	PXCA
53	0.74	0.07	0.11	0.08	0.01
54	0.73	0.18	0.07	0.03	0.19
55	0.56	0.22	0.15	0.07	0.05
56	0.76	0.02	0.12	0.11	0.02
57	0.21	0.55	0.17	0.08	0.11
58	0.31	0.40	0.20	0.09	0.11
65	0.03	0.09	0.88	0.0	0.45
68	0.02	0.34	0.64	0.0	0.04
69	0.17	0.69	0.14	0.0	0.11
70	0.06	0.34	0.60	0.0	0.37
71	0.11	0.34	0.55	0.0	0.39
72	0.07	0.33	0.60	0.0	0.42
73	0.20	0.64	0.16	0.0	0.07
74	0.22	0.61	0.17	0.0	0.08
75	0.75	0.00	0.25	0.0	0.03
76	0.02	0.40	0.58	0.0	0.55
77	0.02	0.73	0.25	0.0	0.43
78	0.21	0.47	0.33	0.0	0.42
79	0.03	0.31	0.66	0.0	0.50
80	0.22	0.31	0.48	0.0	0.36
81	0.81	0.01	0.17	0.0	0.06
82	0.26	0.42	0.32	0.0	0.44
83	0.06	0.82	0.12	0.0	0.40
84	0.91	0.00	0.08	0.0	0.05
85	0.05	0.60	0.35	0.0	0.04
86	0.07	0.59	0.33	0.0	0.04
87	0.08	0.29	0.63	0.0	0.28

WELL NO.	PXMG	PXNA	PXK	PXCM	PXKN
1	0.04	0.52	0.25	0.22	0.78
2	0.40	0.50	0.06	0.44	0.56
3	0.52	0.17	0.01	0.82	0.18
4	0.51	0.16	0.01	0.83	0.17
5	0.24	0.53	0.01	0.46	0.54
6	0.34	0.33	0.02	0.65	0.35
7	0.12	0.77	0.02	0.21	0.79
8	0.22	0.53	0.01	0.46	0.54
9	0.03	0.96	0.01	0.03	0.97
10	0.09	0.87	0.02	0.11	0.89
11	0.21	0.67	0.02	0.30	0.70
12	0.44	0.23	0.02	0.75	0.25
13	0.27	0.61	0.03	0.37	0.63
14	0.03	0.91	0.01	0.08	0.92
15	0.10	0.80	0.02	0.17	0.83
16	0.09	0.85	0.02	0.13	0.87
17	0.16	0.74	0.03	0.23	0.77
18	0.01	0.97	0.01	0.02	0.98
19	0.22	0.56	0.03	0.41	0.59
20	0.18	0.67	0.03	0.30	0.70
21	0.17	0.76	0.01	0.23	0.77
22	0.23	0.64	0.03	0.33	0.67
23	0.04	0.90	0.01	0.09	0.91
24	0.16	0.69	0.04	0.27	0.73
25	0.08	0.80	0.04	0.16	0.84
26	0.10	0.78	0.04	0.19	0.81
27	0.07	0.84	0.03	0.12	0.88
28	0.05	0.86	0.02	0.12	0.88
29	0.29	0.41	0.03	0.56	0.44
30	0.41	0.21	0.03	0.75	0.25
31	0.11	0.71	0.03	0.26	0.74
32	0.07	0.87	0.02	0.11	0.89
33	0.43	0.43	0.02	0.55	0.45
34	0.25	0.55	0.04	0.41	0.59
35	0.38	0.38	0.04	0.58	0.42
36	0.11	0.81	0.02	0.18	0.82
37	0.03	0.93	0.01	0.06	0.94
38	0.15	0.75	0.02	0.23	0.77
39	0.05	0.89	0.01	0.10	0.90
40	0.05	0.89	0.01	0.09	0.91
41	0.02	0.95	0.01	0.04	0.96
42	0.22	0.53	0.04	0.43	0.57
43	0.41	0.49	0.04	0.47	0.53
44	0.14	0.75	0.03	0.22	0.78
45	0.01	0.97	0.01	0.03	0.97
46	0.17	0.64	0.02	0.34	0.66
47	0.15	0.77	0.02	0.20	0.80
48	0.22	0.65	0.02	0.33	0.67
49	0.18	0.64	0.02	0.34	0.66
50	0.14	0.78	0.03	0.19	0.81
51	0.13	0.79	0.02	0.19	0.81
52	0.18	0.63	0.02	0.35	0.65

WELL NO.	PXMG	PXNA	PXK	PXCM	PXKN
53	0.02	0.97	0.01	0.02	0.98
54	0.18	0.61	0.02	0.37	0.63
55	0.10	0.84	0.01	0.15	0.85
56	0.02	0.94	0.01	0.05	0.95
57	0.20	0.68	0.01	0.30	0.70
58	0.11	0.76	0.02	0.22	0.78
65	0.50	0.06	0.0	0.94	0.06
68	0.02	0.94	0.01	0.05	0.95
69	0.08	0.80	0.01	0.19	0.81
70	0.22	0.42	0.0	0.58	0.42
71	0.24	0.36	0.01	0.63	0.37
72	0.23	0.33	0.01	0.65	0.35
73	0.04	0.88	0.01	0.11	0.89
74	0.05	0.87	0.0	0.13	0.87
75	0.02	0.95	0.01	0.05	0.95
76	0.33	0.11	0.01	0.88	0.12
77	0.45	0.12	0.01	0.87	0.13
78	0.44	0.14	0.01	0.85	0.15
79	0.17	0.32	0.01	0.67	0.33
80	0.17	0.46	0.01	0.53	0.47
81	0.04	0.89	0.01	0.10	0.90
82	0.30	0.25	0.01	0.74	0.26
83	0.47	0.12	0.01	0.87	0.13
84	0.03	0.92	0.01	0.08	0.92
85	0.02	0.93	0.01	0.06	0.94
86	0.03	0.92	0.01	0.07	0.93
87	0.14	0.56	0.02	0.42	0.58

WELL NO.	PXSC	PXHC	CA/NA	CA/MG	CL/NA
1	0.01	0.99	0.35	4.49	1.62
2	0.81	0.19	0.08	0.10	0.47
3	0.55	0.45	1.80	0.59	1.00
4	0.72	0.28	1.98	0.63	1.60
5	0.56	0.44	0.40	0.87	0.32
6	0.66	0.34	0.97	0.95	0.32
7	0.77	0.23	0.12	0.77	0.06
8	0.72	0.28	0.44	1.05	0.08
9	0.89	0.11	0.00	0.17	1.09
10	0.54	0.46	0.03	0.26	0.09
11	0.51	0.49	0.14	0.47	0.08
12	0.77	0.23	1.35	0.70	0.22
13	0.50	0.50	0.16	0.35	0.16
14	0.40	0.60	0.05	1.56	0.16
15	0.49	0.51	0.09	0.75	0.24
16	0.64	0.36	0.04	0.40	0.22
17	0.73	0.27	0.10	0.48	0.75
18	0.72	0.28	0.01	0.49	0.75
19	0.27	0.73	0.33	0.85	0.18
20	0.29	0.71	0.18	0.67	0.10
21	0.95	0.05	0.08	0.37	0.27
22	0.27	0.73	0.15	0.40	0.16
23	0.49	0.51	0.05	1.10	0.24
24	0.68	0.32	0.16	0.69	0.79
25	0.51	0.49	0.10	0.99	0.26
26	0.45	0.55	0.12	0.94	0.03
27	0.35	0.65	0.07	0.83	0.27
28	0.90	0.10	0.08	1.42	1.13
29	0.29	0.71	0.65	0.91	0.20
30	0.21	0.79	1.64	0.85	0.34
31	0.21	0.79	0.21	1.36	0.10
32	0.44	0.56	0.05	0.58	0.12
33	0.36	0.64	0.28	0.27	0.17
34	0.68	0.32	0.28	0.61	0.35
35	0.26	0.74	0.51	0.51	0.26
36	0.80	0.20	0.08	0.55	0.25
37	0.83	0.17	0.03	0.96	1.18
38	0.79	0.21	0.11	0.55	0.44
39	0.96	0.04	0.05	0.91	1.63
40	0.83	0.17	0.05	0.77	1.18
41	0.87	0.13	0.02	0.67	1.25
42	0.78	0.22	0.39	0.93	1.28
43	0.68	0.32	0.12	0.14	0.48
44	0.87	0.13	0.12	0.64	1.95
45	0.80	0.20	0.01	0.81	0.92
46	0.80	0.20	0.27	1.05	0.53
47	0.79	0.21	0.08	0.40	0.46
48	0.80	0.20	0.17	0.51	0.45
49	0.30	0.70	0.26	0.93	0.05
50	0.63	0.37	0.07	0.39	0.31
51	0.75	0.25	0.07	0.41	0.36
52	0.64	0.36	0.27	0.95	0.57

WELL NO.	PXSC	PXHC	CA/NA	CA/MG	CL/NA
53	0.81	0.19	0.01	0.42	1.02
54	0.91	0.09	0.31	1.07	1.66
55	0.78	0.22	0.06	0.51	0.62
56	0.78	0.22	0.03	1.03	1.00
57	0.76	0.24	0.16	0.55	0.35
58	0.71	0.29	0.15	1.07	0.25
65	0.12	0.88	7.80	0.90	0.74
68	0.36	0.64	0.04	2.39	0.02
69	0.86	0.14	0.14	1.50	0.22
70	0.40	0.60	0.88	1.68	0.14
71	0.45	0.55	1.09	1.65	0.29
72	0.40	0.60	1.26	1.78	0.21
73	0.84	0.16	0.08	1.53	0.23
74	0.83	0.17	0.09	1.50	0.25
75	0.75	0.25	0.03	1.76	0.81
76	0.42	0.58	5.16	1.68	0.19
77	0.75	0.25	3.67	0.96	0.17
78	0.67	0.33	2.96	0.96	1.37
79	0.34	0.66	1.58	2.97	0.09
80	0.52	0.48	0.80	2.12	0.47
81	0.83	0.17	0.07	1.74	0.92
82	0.68	0.32	1.72	1.44	0.85
83	0.88	0.12	3.20	0.84	0.42
84	0.92	0.08	0.05	1.68	0.99
85	0.65	0.35	0.04	1.58	0.06
86	0.67	0.33	0.05	1.65	0.08
87	0.37	0.63	0.50	1.98	0.15

WELL NO.	SO4/NA	HCO3/NA	F/CL	K/F	CA/HCO3
1	0.24	202.58	0.03	9.34	0.00
2	1.74	0.43	0.00	58.46	0.19
3	2.29	1.97	0.02	2.73	0.91
4	5.90	2.02	0.02	2.73	0.98
5	1.03	0.54	0.01	6.63	0.74
6	2.60	0.93	0.03	6.22	1.04
7	1.12	0.21	0.03	13.04	0.55
8	1.56	0.36	0.04	5.70	1.24
9	0.01	0.07	0.00	17.21	0.07
10	0.45	0.36	0.04	6.20	0.07
11	0.69	0.59	0.04	8.98	0.24
12	4.06	0.64	0.03	10.86	2.12
13	0.71	0.56	0.03	8.71	0.28
14	0.15	0.32	0.01	11.43	0.17
15	0.26	0.35	0.01	12.04	0.26
16	0.62	0.28	0.01	16.48	0.15
17	0.42	0.31	0.00	16.47	0.34
18	0.03	0.21	0.00	12.15	0.03
19	0.28	1.01	0.03	8.68	0.33
20	0.33	0.69	0.05	9.37	0.26
21	0.96	0.06	0.00	16.00	1.34
22	0.18	0.63	0.03	8.03	0.23
23	0.25	0.35	0.01	11.30	0.14
24	0.38	0.43	0.00	19.30	0.37
25	0.38	0.50	0.01	18.69	0.20
26	0.55	0.41	0.11	12.26	0.28
27	0.21	0.73	0.01	9.60	0.09
28	0.05	0.09	0.00	18.93	0.91
29	0.73	1.47	0.05	8.13	0.44
30	0.69	2.98	0.04	13.10	0.55
31	0.17	0.63	0.05	7.65	0.33
32	0.44	0.50	0.02	8.77	0.09
33	0.87	1.34	0.05	5.76	0.21
34	0.75	0.28	0.01	26.91	0.99
35	0.36	1.04	0.05	9.18	0.49
36	0.76	0.20	0.01	13.96	0.39
37	0.01	0.15	0.00	12.64	0.20
38	0.78	0.14	0.00	19.52	0.76
39	0.00	0.04	0.00	23.61	1.37
40	0.12	0.15	0.00	12.82	0.30
41	0.00	0.13	0.00	18.95	0.13
42	0.63	0.31	0.00	46.10	1.26
43	1.03	0.57	0.00	66.34	0.21
44	0.57	0.26	0.00	21.16	0.44
45	0.11	0.17	0.00	6.91	0.07
46	1.08	0.28	0.00	16.55	0.96
47	0.60	0.22	0.00	26.50	0.34
48	1.10	0.22	0.01	14.76	0.78
49	0.13	0.23	0.04	16.33	1.10
50	0.07	0.12	0.00	26.72	0.57
51	0.59	0.24	0.00	29.26	0.29
52	0.07	0.27	0.00	19.35	1.01

WELL NO.	SO4/NA	HCO3/NA	F/CL	K/F	CA/HCO3
53	0.10	0.15	0.00	8.63	0.05
54	0.40	0.16	0.00	23.61	1.96
55	0.25	0.17	0.00	11.96	0.36
56	0.03	0.15	0.00	10.55	0.17
57	0.92	0.28	0.00	9.87	0.56
58	0.31	0.16	0.01	9.36	0.96
65	1.91	19.63	0.05	0.0	0.40
68	0.36	0.67	0.10	4.45	0.06
69	0.86	0.17	0.02	2.96	0.85
70	0.83	1.46	0.0	0.0	0.60
71	0.92	1.51	0.01	15.55	0.72
72	0.97	1.80	0.01	16.76	0.70
73	0.74	0.18	0.02	2.43	0.43
74	0.71	0.20	0.0	0.0	0.46
75	0.00	0.28	0.00	26.72	0.12
76	3.69	5.43	0.06	10.69	0.95
77	6.09	2.10	0.02	24.29	1.75
78	3.07	2.14	0.00	13.12	1.38
79	1.00	2.11	0.09	4.57	0.75
80	0.67	1.03	0.00	26.72	0.78
81	0.01	0.20	0.00	29.15	0.36
82	1.36	1.03	0.00	14.58	1.67
83	6.04	0.90	0.01	18.22	3.57
84	0.00	0.09	0.00	63.17	0.60
85	0.64	0.37	0.01	10.57	0.11
86	0.64	0.36	0.01	11.90	0.13
87	0.53	1.13	0.01	47.62	0.44

WELL NO.	SO4/HCO3	TANI/TDS	TCAT/TDS	THRD/TDS	SO/SOC
1	0.00	0.02	0.00	0.00	0.13
2	4.06	0.02	0.01	0.26	0.79
3	1.16	0.02	0.02	0.62	0.70
4	2.93	0.02	0.01	0.43	0.79
5	1.91	0.02	0.01	0.29	0.77
6	2.78	0.02	0.01	0.37	0.89
7	5.20	0.02	0.01	0.13	0.95
8	4.35	0.02	0.01	0.29	0.95
9	0.11	0.02	0.02	0.02	0.01
10	1.25	0.01	0.02	0.08	0.83
11	1.16	0.01	0.01	0.21	0.89
12	6.38	0.02	0.01	0.48	0.95
13	1.27	0.01	0.01	0.26	0.81
14	0.46	0.01	0.02	0.07	0.47
15	0.73	0.01	0.02	0.14	0.51
16	2.18	0.02	0.01	0.09	0.73
17	1.38	0.02	0.01	0.16	0.36
18	0.13	0.02	0.02	0.02	0.04
19	0.28	0.01	0.01	0.29	0.61
20	0.48	0.01	0.01	0.21	0.78
21	16.03	0.01	0.02	0.17	0.78
22	0.28	0.01	0.02	0.27	0.53
23	0.71	0.01	0.02	0.07	0.51
24	0.87	0.02	0.01	0.18	0.32
25	0.76	0.01	0.01	0.11	0.60
26	1.33	0.01	0.01	0.13	0.94
27	0.29	0.01	0.01	0.08	0.45
28	0.55	0.02	0.01	0.09	0.04
29	0.50	0.02	0.01	0.33	0.79
30	0.23	0.01	0.01	0.50	0.67
31	0.27	0.01	0.02	0.20	0.64
32	0.88	0.01	0.01	0.07	0.79
33	0.65	0.02	0.01	0.34	0.84
34	2.64	0.01	0.02	0.33	0.68
35	0.35	0.01	0.02	0.46	0.58
36	3.87	0.01	0.01	0.13	0.75
37	0.05	0.02	0.01	0.04	0.01
38	5.44	0.02	0.01	0.16	0.64
39	0.05	0.02	0.01	0.07	0.00
40	0.77	0.02	0.01	0.06	0.09
41	0.03	0.02	0.01	0.03	0.00
42	2.04	0.02	0.01	0.28	0.33
43	1.81	0.02	0.01	0.33	0.68
44	2.14	0.02	0.01	0.10	0.22
45	0.68	0.02	0.01	0.02	0.11
46	3.79	0.02	0.01	0.21	0.67
47	2.74	0.02	0.01	0.15	0.57
48	5.06	0.02	0.01	0.21	0.71
49	0.56	0.01	0.03	0.44	0.72
50	0.60	0.01	0.02	0.23	0.19
51	2.42	0.01	0.01	0.14	0.62
52	0.28	0.01	0.02	0.36	0.11

WELL NO.	SO4/HCO3	TANI/TDS	TCAT/TDS	THRD/TDS	SO/SOC
53	0.65	0.02	0.01	0.02	0.09
54	2.55	0.02	0.01	0.24	0.19
55	1.47	0.02	0.02	0.12	0.28
56	0.19	0.02	0.01	0.03	0.03
57	3.26	0.02	0.01	0.20	0.72
58	1.99	0.01	0.02	0.22	0.56
65	0.10	0.01	0.01	0.51	0.72
68	0.54	0.01	0.01	0.03	0.96
69	5.10	0.01	0.01	0.13	0.80
70	0.57	0.01	0.01	0.35	0.86
71	0.61	0.01	0.01	0.39	0.76
72	0.54	0.01	0.01	0.40	0.82
73	4.03	0.01	0.01	0.08	0.77
74	3.53	0.01	0.01	0.09	0.74
75	0.00	0.02	0.01	0.04	0.00
76	0.68	0.01	0.01	0.55	0.95
77	2.90	0.01	0.01	0.62	0.97
78	1.43	0.01	0.01	0.59	0.69
79	0.47	0.01	0.01	0.39	0.92
80	0.65	0.01	0.01	0.36	0.59
81	0.06	0.02	0.02	0.08	0.01
82	1.32	0.01	0.01	0.51	0.61
83	6.74	0.01	0.02	0.66	0.93
84	0.04	0.02	0.02	0.06	0.00
85	1.72	0.01	0.01	0.04	0.92
86	1.78	0.01	0.01	0.05	0.89
87	0.47	0.01	0.01	0.25	0.78

WELL NO.	SO/SOHCC	HC/HC+C	M/M+CA	NK/NKCL	CL+F+NO3
1	0.00	0.99	0.18	0.48	0.46
2	0.77	0.48	0.91	0.70	6.17
3	0.46	0.66	0.63	0.51	1.40
4	0.66	0.56	0.61	0.40	1.29
5	0.49	0.63	0.54	0.76	1.67
6	0.63	0.74	0.51	0.77	0.91
7	0.76	0.78	0.56	0.94	0.74
8	0.70	0.81	0.49	0.92	0.77
9	0.05	0.06	0.85	0.48	92.26
10	0.49	0.79	0.79	0.92	1.22
11	0.48	0.88	0.68	0.93	0.61
12	0.76	0.74	0.59	0.83	0.58
13	0.45	0.77	0.74	0.87	0.89
14	0.24	0.66	0.39	0.86	3.57
15	0.33	0.59	0.57	0.81	3.60
16	0.57	0.56	0.71	0.82	3.84
17	0.49	0.29	0.67	0.58	10.07
18	0.09	0.22	0.67	0.57	39.14
19	0.19	0.85	0.54	0.85	0.88
20	0.24	0.88	0.60	0.92	0.64
21	0.93	0.18	0.73	0.79	7.08
22	0.17	0.80	0.71	0.87	0.97
23	0.33	0.60	0.48	0.81	5.01
24	0.40	0.35	0.59	0.57	7.85
25	0.39	0.66	0.50	0.80	3.75
26	0.43	0.93	0.51	0.97	0.39
27	0.19	0.73	0.55	0.80	3.78
28	0.26	0.07	0.41	0.47	15.78
29	0.25	0.88	0.52	0.85	0.63
30	0.15	0.90	0.54	0.77	0.70
31	0.15	0.87	0.42	0.91	0.66
32	0.38	0.81	0.63	0.90	1.44
33	0.32	0.89	0.78	0.86	0.62
34	0.59	0.45	0.62	0.75	4.33
35	0.17	0.80	0.66	0.81	0.74
36	0.75	0.44	0.65	0.80	6.30
37	0.03	0.11	0.51	0.46	53.14
38	0.70	0.25	0.64	0.70	9.53
39	0.03	0.02	0.52	0.38	130.29
40	0.31	0.12	0.57	0.46	38.16
41	0.02	0.09	0.60	0.45	70.18
42	0.53	0.19	0.52	0.46	16.53
43	0.59	0.54	0.88	0.69	5.08
44	0.61	0.12	0.61	0.35	28.13
45	0.31	0.15	0.55	0.52	33.15
46	0.73	0.35	0.49	0.66	7.59
47	0.68	0.32	0.71	0.69	10.12
48	0.74	0.33	0.66	0.70	5.28
49	0.24	0.82	0.52	0.95	0.81
50	0.25	0.28	0.72	0.77	7.38
51	0.65	0.40	0.71	0.74	8.26
52	0.17	0.32	0.51	0.64	8.30

WELL NO.	C+M/CMS	C+F+B+N3	S.A.R.	B.E.R.1	B.E.R.2
1	0.64	0.51	1.12	0.00	0.09
2	0.34	6.19	5.45	-0.30	-1.39
3	0.68	1.41	0.75	-0.01	-0.04
4	0.46	1.30	0.55	0.07	0.33
5	0.45	1.68	3.43	-0.45	-2.23
6	0.43	0.92	1.60	-0.21	-2.29
7	0.19	0.75	9.18	-0.72	-16.10
8	0.36	0.78	4.36	-0.49	-11.30
9	0.82	92.36	73.24	1.02	0.07
10	0.22	1.23	13.66	-1.14	-9.98
11	0.39	0.62	5.49	-0.74	-11.51
12	0.45	0.58	1.22	-0.18	-3.95
13	0.46	0.90	4.09	-0.69	-5.43
14	0.38	3.57	21.93	-1.81	-5.22
15	0.45	3.62	11.60	-1.27	-3.22
16	0.20	3.85	14.58	-0.88	-3.61
17	0.43	10.09	9.22	-0.40	-0.39
18	0.41	39.19	71.43	-1.05	-0.34
19	0.72	0.89	3.60	-0.67	-4.89
20	0.57	0.65	5.06	-0.92	-9.90
21	0.24	7.10	13.29	-0.73	-2.81
22	0.74	0.98	4.73	-1.09	-5.68
23	0.28	5.02	20.72	-1.27	-3.27
24	0.51	7.89	7.09	-0.32	-0.33
25	0.34	3.77	11.90	-0.89	-3.07
26	0.30	0.42	8.81	-1.04	-30.11
27	0.41	3.81	13.74	-0.81	-2.91
28	0.74	15.83	14.17	0.73	0.10
29	0.65	0.64	2.00	-0.40	-4.46
30	0.84	0.71	0.82	-0.21	-2.41
31	0.68	0.67	5.72	-1.15	-9.67
32	0.22	1.45	13.46	-0.95	-7.79
33	0.60	0.62	2.24	-0.40	-5.28
34	0.50	4.35	5.63	-0.69	-2.07
35	0.80	0.75	1.87	-0.60	-3.28
36	0.22	6.32	14.96	-0.80	-3.02
37	0.89	53.24	38.55	1.05	0.14
38	0.28	9.56	11.86	-0.64	-1.35
39	0.98	130.47	37.47	14.46	0.38
40	0.47	38.22	24.75	0.60	0.14
41	0.90	70.25	52.06	1.78	0.19
42	0.56	16.58	5.58	0.20	0.15
43	0.49	5.68	4.62	-0.38	-1.26
44	0.34	28.17	9.85	1.10	0.47
45	0.19	33.19	51.80	-0.31	-0.09
46	0.33	7.61	7.33	-0.37	-0.97
47	0.30	10.14	12.84	-0.69	-1.23
48	0.31	5.30	6.83	-0.44	-1.31
49	0.80	0.83	7.38	-2.69	-19.70
50	0.77	7.40	13.24	-3.29	-2.31
51	0.29	8.31	13.66	-0.80	-1.83
52	0.88	8.34	7.19	-1.35	-0.82

WELL NO.	SO/SOHCC	HC/HC+C	M/M+CA	NK/NKCL	CL+F+NO3
53	0.27	0.13	0.70	0.50	36.17
54	0.65	0.09	0.48	0.38	25.14
55	0.50	0.21	0.66	0.62	15.12
56	0.09	0.13	0.49	0.50	33.14
57	0.69	0.44	0.64	0.74	5.31
58	0.58	0.39	0.48	0.81	1.45
65	0.09	0.96	0.53	0.57	0.28
68	0.35	0.98	0.29	0.98	0.39
69	0.84	0.44	0.40	0.82	6.14
70	0.36	0.91	0.37	0.88	0.74
71	0.38	0.84	0.38	0.78	1.53
72	0.35	0.89	0.36	0.83	0.93
73	0.80	0.45	0.39	0.82	7.10
74	0.78	0.44	0.40	0.80	7.78
75	0.00	0.25	0.36	0.55	40.07
76	0.40	0.97	0.37	0.86	0.28
77	0.74	0.93	0.51	0.86	0.69
78	0.59	0.61	0.51	0.43	5.74
79	0.32	0.96	0.25	0.92	0.32
80	0.39	0.69	0.32	0.69	5.75
81	0.06	0.18	0.36	0.52	58.42
82	0.57	0.55	0.41	0.55	8.11
83	0.87	0.68	0.54	0.71	6.27
84	0.04	0.08	0.37	0.50	108.90
85	0.63	0.86	0.39	0.94	1.93
86	0.64	0.82	0.38	0.93	2.62
87	0.32	0.89	0.34	0.88	1.13

WELL NO.	C+M/CMS	C+F+B+N3	S.A.R.	B.E.R.1	B.E.R.2
53	0.21	36.21	52.55	0.04	0.01
54	0.60	25.18	7.09	1.11	0.38
55	0.42	15.16	16.46	-0.95	-0.63
56	0.64	33.18	35.63	-0.03	-0.01
57	0.33	5.33	8.11	-0.55	-1.87
58	0.48	1.46	6.22	-1.64	-3.15
65	0.90	0.28	0.19	-0.01	-0.35
68	0.14	0.39	25.38	-0.96	-59.04
69	0.22	6.14	15.28	-0.78	-3.67
70	0.63	0.74	2.76	-0.38	-6.30
71	0.65	1.53	2.39	-0.30	-2.52
72	0.67	0.93	2.04	-0.30	-3.88
73	0.15	7.10	21.80	-0.85	-3.45
74	0.18	7.78	19.98	-0.82	-2.95
75	0.99	40.07	43.95	-0.68	-0.23
76	0.69	0.28	0.58	-0.10	-5.01
77	0.55	0.69	0.97	-0.11	-5.38
78	0.66	5.74	1.01	0.06	0.24
79	0.68	0.32	1.76	-0.31	-10.99
80	0.64	5.75	4.54	-0.33	-1.19
81	0.90	58.42	33.96	-0.42	-0.10
82	0.68	8.11	1.95	-0.06	-0.21
83	0.54	6.27	1.44	-0.09	-1.48
84	0.96	108.90	50.36	-0.14	-0.01
85	0.09	1.93	30.45	-0.93	-16.06
86	0.11	2.62	28.14	-0.92	-11.67
87	0.59	1.13	4.34	-0.53	-6.08

APPENDIX H

CHEMICAL DATA (MOLARITY)

CHEMICAL DATA (MOLARITY)

Explanations of the headings used on pages to are given below.

WELL NO.	number assigned to source of water (usually a piezometer).
MCA	molarity of calcium ion in moles per liter x 10^4.
MMG	molarity of magnesium ion in moles per liter x 10^4.
MMN	molarity of manganese ion in moles per liter x 10^4.
MNA	molarity of sodium ion in moles per liter x 10^4.
MK	molarity of potassium ion in moles per liter x 10^4.
MFE	molarity of iron ion in moles per liter x 10^4.
MSR	molarity of strontium ion in moles per liter x 10^4.
MCU	molarity of copper ion in moles per liter x 10^4.
MLI	molarity of lithium ion in moles per liter x 10^4.
MHCO3	molarity of bicarbonate ion in moles per liter x 10^4.
MCO3	molarity of carbonate ion in moles per liter x 10^4.
MSO4	molarity of sulfate ion in moles per liter x 10^4.
MCL	molarity of chloride ion in moles per liter x 10^4.
MF	molarity of fluoride ion in moles per liter x 10^4.

MPI	molarity of phosphate ion ($H_2PO_4^-$) in moles per liter x 10^4.
MP2	molarity of phosphate ion ($HPO_4^=$) in moles per liter x 10^4.
MP3	molarity of phosphate ion (PO_4^{-3}) in moles per liter x 10^4.
MNO2	molarity of nitrite ion in moles per liter x 10^4.
MNO3	molarity of nitrate ion in moles per liter x 10^4.

WELL NO.	MCA	MMG	MMN	MNA	MK
1	0.462	0.103	0.027	2.653	1.279
2	5.389	52.458	0.005	131.036	14.770
3	12.113	20.366	0.009	13.484	0.575
4	7.759	12.240	0.002	7.830	0.575
5	10.092	11.623	0.004	50.566	1.151
6	12.463	13.166	0.007	25.664	1.343
7	6.674	8.640	0.029	113.637	2.813
8	18.214	17.280	0.002	82.102	1.650
9	1.996	11.417	0.020	848.202	7.609
10	1.559	5.966	0.020	118.531	2.417
11	4.915	10.389	0.004	67.965	2.174
12	16.405	23.452	0.004	24.359	1.944
13	3.992	11.315	0.007	50.566	2.199
14	5.851	3.744	0.009	214.769	3.069
15	6.574	8.743	0.004	143.542	4.246
16	3.530	8.743	0.011	161.485	4.770
17	6.849	14.195	0.007	133.755	5.115
18	1.747	3.538	0.009	519.252	4.284
19	7.759	9.154	0.007	46.760	2.238
20	5.002	7.509	0.004	56.547	2.417
21	10.579	28.801	0.035	263.704	3.453
22	4.167	10.389	0.005	57.091	2.494
23	5.215	4.732	0.002	206.613	2.916
24	7.859	11.417	0.025	98.413	5.384
25	6.911	6.994	0.005	140.280	6.394
26	5.339	5.657	0.004	92.432	4.194
27	4.678	5.657	0.013	139.736	5.102
28	5.477	3.868	0.036	137.017	2.890
29	8.895	9.772	0.005	27.295	2.225
30	9.880	11.623	0.013	12.071	1.931
31	6.300	4.629	0.004	59.809	2.174
32	2.745	4.732	0.005	116.356	2.494
33	4.516	16.458	0.007	32.406	1.547
34	16.342	26.743	0.004	116.900	9.207
35	6.674	13.063	0.009	26.316	2.852
36	9.469	17.280	0.025	244.674	4.923
37	6.712	6.994	0.035	451.287	4.923
38	11.702	21.086	0.047	214.769	6.266
39	21.644	23.863	0.004	799.267	6.586
40	7.423	9.669	0.025	323.513	4.386
41	4.691	6.994	0.016	562.750	5.486
42	24.389	26.332	0.184	125.599	10.678
43	6.262	44.230	0.106	103.850	9.079
44	8.283	12.960	0.027	143.542	5.345
45	2.146	2.654	0.005	358.855	2.839
46	19.523	18.515	0.004	142.998	5.141
47	8.209	20.469	0.031	217.488	6.138
48	9.818	19.235	0.020	116.356	4.118
49	18.463	19.955	0.011	144.629	4.642
50	7.547	19.440	0.009	217.488	7.737
51	7.959	19.338	0.016	225.644	6.777
52	19.399	20.469	0.087	143.542	5.499

WELL NO.	MCA	MMG	MMN	MNA	MK
53	1.335	3.189	0.007	353.417	3.453
54	23.266	21.806	0.011	150.610	5.716
55	7.298	14.297	0.015	241.955	3.210
56	4.329	4.197	0.007	328.950	3.389
57	11.664	21.086	0.007	146.804	2.494
58	4.279	3.991	0.022	56.547	1.675
65	11.876	13.166	0.0	3.045	0.0
68	3.743	1.563	0.009	184.865	1.407
69	19.711	13.166	0.036	277.079	3.581
70	23.453	13.989	0.0	53.502	0.0
71	27.196	16.458	0.200	50.022	1.637
72	25.699	14.400	0.182	40.888	1.765
73	11.976	7.817	0.042	306.657	3.069
74	14.222	9.463	0.0	307.528	0.0
75	7.984	4.526	0.002	491.522	2.813
76	35.928	21.395	0.0	13.919	1.688
77	64.621	67.476	0.455	35.233	2.558
78	45.659	47.727	4.005	30.883	1.381
79	25.699	8.640	0.098	32.623	1.202
80	47.904	22.629	0.382	120.488	2.813
81	22.206	12.755	0.076	635.064	4.604
82	47.405	32.915	0.0	55.242	1.535
83	117.016	139.889	0.0	73.076	3.836
84	29.691	17.692	0.044	1096.138	6.650
85	5.988	3.785	0.0	301.003	2.225
86	7.485	4.526	0.024	308.397	2.506
87	17.964	9.052	0.0	71.336	2.506

WELL NO.	MFE	MSR	MCU	MLI	MHCO3
1	0.030	0.007	0.017	0.115	537.516
2	0.009	0.026	0.008	4.120	56.142
3	0.005	0.021	0.006	0.547	26.516
4	0.004	0.011	0.005	0.461	15.782
5	0.020	0.001	0.009	1.642	27.369
6	0.014	0.025	0.005	0.735	23.960
7	0.014	0.018	0.006	1.786	24.402
8	0.018	0.047	0.009	1.369	29.420
9	0.023	0.050	0.005	3.832	56.851
10	0.047	0.014	0.003	5.604	42.615
11	0.014	0.021	0.009	1.008	40.437
12	0.002	0.070	0.005	0.864	15.498
13	0.014	0.027	0.003	0.908	28.096
14	0.0	0.022	0.003	2.881	69.132
15	0.018	0.038	0.006	2.248	50.854
16	0.018	0.026	0.002	2.132	45.834
17	0.014	0.042	0.008	1.527	40.853
18	0.0	0.032	0.003	4.337	111.399
19	0.002	0.021	0.0	1.181	47.286
20	0.029	0.016	0.005	0.951	38.766
21	0.021	0.067	0.005	3.703	15.785
22	0.013	0.009	0.006	0.836	35.984
23	0.020	0.023	0.008	1.931	73.296
24	0.016	0.019	0.008	1.124	42.679
25	0.013	0.032	0.005	1.570	70.300
26	0.023	0.002	0.005	1.066	38.355
27	0.004	0.023	0.003	2.334	102.371
28	0.002	0.031	0.005	0.792	12.029
29	0.004	0.034	0.005	0.648	40.089
30	0.007	0.033	0.003	0.389	35.956
31	0.014	0.025	0.003	0.648	37.942
32	0.005	0.013	0.005	4.394	58.716
33	0.020	0.015	0.006	0.807	43.342
34	0.007	0.074	0.009	2.478	33.143
35	0.016	0.032	0.030	0.951	27.401
36	0.011	0.066	0.006	2.766	48.203
37	0.007	0.043	0.005	2.910	67.362
38	0.011	0.084	0.014	2.003	30.809
39	0.025	0.252	0.005	4.567	31.694
40	0.013	0.014	0.008	2.622	49.560
41	0.011	0.051	0.003	3.386	71.626
42	0.018	0.115	0.006	1.873	38.795
43	0.018	0.029	0.013	2.089	59.156
44	0.018	0.057	0.006	2.031	37.880
45	0.025	0.0	0.011	2.737	59.377
46	0.025	0.080	0.008	1.815	40.657
47	0.011	0.055	0.014	1.729	47.825
48	0.007	0.078	0.008	1.801	25.284
49	0.0	0.099	0.008	1.297	33.525
50	0.018	0.059	0.006	1.945	26.453
51	0.020	0.018	0.009	1.815	55.083
52	0.005	0.092	0.005	1.772	38.227

WELL NO.	MFE	MSR	MCU	MLI	MHCO3
53	0.0	0.016	0.003	1.599	52.876
54	0.011	0.139	0.003	3.083	23.708
55	0.004	0.049	0.002	1.498	40.310
56	0.009	0.024	0.003	2.089	50.476
57	0.025	0.043	0.009	1.484	41.510
58	0.021	0.019	0.005	0.346	8.902
65	0.0	0.0	0.0	0.0	59.761
68	0.011	0.0	0.0	0.0	124.433
69	0.484	0.0	0.0	0.0	46.499
70	0.174	0.0	0.0	0.0	77.934
71	0.770	0.0	0.0	0.0	75.642
72	0.824	0.0	0.0	0.0	73.677
73	0.152	0.0	0.0	0.0	56.322
74	0.269	0.0	0.0	0.0	61.889
75	0.052	0.0	0.0	0.0	136.713
76	0.005	0.0	0.0	0.0	75.642
77	0.084	0.0	0.0	0.0	74.005
78	0.004	0.0	0.0	0.0	66.146
79	0.041	0.0	0.0	0.0	68.766
80	0.860	0.0	0.0	0.0	123.614
81	1.074	0.0	0.0	0.0	125.088
82	0.005	0.0	0.0	0.0	56.814
83	0.014	0.0	0.0	0.0	65.491
84	0.824	0.0	0.0	0.0	98.892
85	0.0	0.0	0.0	0.0	112.317
86	0.002	0.0	0.0	0.0	111.335
87	0.322	0.0	0.0	0.0	80.881

WELL NO.	MCO3	MSO4	MCL	MF	MBR
1	1.287	0.312	4.307	0.137	0.230
2	6.442	113.996	61.081	0.253	0.185
3	5.014	15.408	13.519	0.211	0.095
4	3.794	23.112	12.518	0.211	0.110
5	13.367	26.131	16.021	0.174	0.120
6	7.647	33.314	8.211	0.216	0.083
7	7.647	63.505	6.809	0.216	0.068
8	12.147	64.025	6.809	0.289	0.095
9	26.608	3.019	921.219	0.442	0.960
10	6.427	26.547	11.015	0.390	0.130
11	5.077	23.528	5.607	0.242	0.068
12	7.714	49.450	5.308	0.179	0.049
13	7.904	17.906	8.211	0.253	0.096
14	16.387	15.824	35.046	0.268	0.095
15	12.147	18.531	35.046	0.353	0.130
16	15.361	49.971	36.048	0.289	0.120
17	8.290	28.109	100.133	0.311	0.220
18	21.594	7.496	390.517	0.353	0.551
19	5.207	6.559	8.312	0.258	0.083
20	10.411	9.370	5.407	0.258	0.084
21	1.283	126.489	70.093	0.216	0.185
22	7.714	5.101	8.913	0.311	0.096
23	16.197	26.026	49.065	0.258	0.165
24	5.977	18.531	78.103	0.279	0.390
25	7.134	26.547	36.048	0.342	0.140
26	14.267	25.506	3.106	0.342	0.270
27	12.147	14.887	37.049	0.532	0.290
28	3.340	3.331	155.205	0.153	0.521
29	10.541	9.994	5.407	0.274	0.095
30	5.847	4.164	4.107	0.147	0.039
31	10.284	5.101	5.808	0.284	0.120
32	12.274	25.818	13.519	0.284	0.120
33	8.290	14.054	5.407	0.268	0.070
34	13.497	43.724	41.054	0.342	0.165
35	9.510	4.789	6.809	0.311	0.083
36	7.134	93.175	62.082	0.353	0.185
37	21.788	1.770	530.702	0.390	0.920
38	19.924	83.805	94.125	0.321	0.310
39	9.510	0.833	1301.723	0.279	0.960
40	17.288	19.051	380.504	0.342	0.650
41	15.487	1.249	700.928	0.289	0.720
42	15.167	39.560	160.212	0.232	0.579
43	6.940	53.615	50.066	0.137	0.280
44	6.940	40.601	280.371	0.253	0.350
45	15.361	20.301	330.437	0.411	0.451
46	7.714	77.038	75.099	0.311	0.210
47	7.004	65.587	100.133	0.232	0.260
48	10.284	64.025	52.069	0.279	0.170
49	13.367	9.370	7.210	0.284	0.185
50	11.054	7.912	68.090	0.289	0.170
51	9.127	66.628	82.109	0.232	0.410
52	6.684	5.309	82.109	0.284	0.360

WELL NO.	MCO3	MSO4	MCL	MF	MBR
53	19.601	17.177	360.477	0.400	0.426
54	4.434	30.191	250.331	0.242	0.360
55	8.934	29.670	150.199	0.268	0.310
56	23.201	4.893	330.437	0.321	0.409
57	9.640	67.669	52.069	0.253	0.170
58	2.057	8.849	14.019	0.179	0.095
65	0.0	2.905	2.257	0.105	0.0
68	0.0	33.314	3.103	0.316	0.0
69	0.0	118.681	60.080	1.211	0.0
70	0.0	22.070	7.334	0.0	0.0
71	0.0	23.112	14.667	0.105	0.0
72	0.0	19.884	8.744	0.105	0.0
73	0.0	113.475	69.670	1.263	0.0
74	0.0	109.311	77.850	0.0	0.0
75	0.0	0.083	400.530	0.105	0.0
76	0.0	25.714	2.595	0.158	0.0
77	0.0	107.229	5.923	0.105	0.0
78	0.0	47.368	42.310	0.105	0.0
79	0.0	16.241	2.821	0.263	0.0
80	0.0	40.081	56.413	0.105	0.0
81	0.0	4.060	583.872	0.158	0.0
82	0.0	37.582	47.105	0.105	0.0
83	0.0	220.704	31.027	0.211	0.0
84	0.0	1.874	1088.765	0.105	0.0
85	0.0	96.610	17.770	0.211	0.0
86	0.0	98.901	24.540	0.211	0.0
87	0.0	18.843	10.436	0.053	0.0

WELL NO.	MP1	MP2	MP3	MNO2	MNO3
1	0.290	0.541	0.0	0.2174	0.176
2	0.025	0.038	0.0	0.0028	0.337
3	0.002	0.042	0.0	0.0020	0.257
4	0.001	0.046	0.0	0.0015	0.192
5	0.002	0.032	0.0	0.0020	0.482
6	0.003	0.045	0.0	0.0061	0.689
7	0.002	0.038	0.0	0.0015	0.386
8	0.004	0.070	0.0	0.0030	0.643
9	0.001	0.116	0.0	0.0022	0.934
10	0.0	0.0	0.0	0.0	0.774
11	0.002	0.020	0.0	0.0015	0.273
12	0.002	0.031	0.0	0.0026	0.272
13	0.001	0.024	0.0	0.0026	0.482
14	0.003	0.046	0.0	0.0013	0.338
15	0.002	0.034	0.0	0.0028	0.627
16	0.006	0.255	0.0	0.0024	2.063
17	0.001	0.030	0.0	0.0022	0.273
18	0.002	0.142	0.0	0.0024	0.498
19	0.002	0.009	0.0	0.0015	0.257
20	0.002	0.029	0.0	0.0017	0.708
21	0.0	0.0	0.0	0.0	0.516
22	0.002	0.070	0.0	0.0028	0.498
23	0.006	0.159	0.0	0.0020	0.757
24	0.015	0.170	0.0	0.0015	0.144
25	0.022	0.692	0.0	0.0020	1.160
26	0.024	0.286	0.0	0.0015	0.467
27	0.086	1.122	0.0	0.0067	0.237
28	0.589	0.634	0.0	0.0017	2.402
29	0.020	0.242	0.0	0.0017	0.612
30	0.145	0.177	0.0	0.0059	2.786
31	0.048	0.220	0.0	0.0026	0.514
32	0.003	0.027	0.0	0.0015	0.596
33	0.002	0.038	0.0	0.0017	0.483
34	0.014	1.007	0.0	0.0028	1.901
35	0.002	0.062	0.0	0.0013	0.289
36	0.002	0.025	0.0	0.0022	0.611
37	0.002	0.179	0.0	0.0017	0.337
38	0.001	0.070	0.0	0.0017	0.870
39	0.001	0.021	0.0	0.7717	0.943
40	0.001	0.056	0.0	0.0196	0.727
41	0.026	0.315	0.0	0.0020	0.579
42	0.318	1.210	0.0	0.0028	4.820
43	0.018	0.209	0.0	5.6516	0.645
44	0.001	0.075	0.0	0.0013	0.709
45	0.002	0.215	0.0	0.0052	0.625
46	0.006	0.089	0.0	0.0022	0.466
47	0.021	0.164	0.0	0.0013	0.789
48	0.001	0.040	0.0	0.0028	0.466
49	0.002	0.079	0.0	0.0015	0.612
50	0.019	0.793	0.0	0.0015	5.434
51	0.013	0.035	0.0	0.0030	0.304
52	0.009	0.135	0.0	0.0017	0.612

WELL NO.	MP1	MP2	MP3	MNO2	MNO3
53	0.001	0.144	0.0	0.0024	0.837
54	0.007	0.124	0.0	0.0020	0.837
55	0.001	0.039	0.0	0.0030	0.772
56	0.006	0.383	0.0	0.0015	0.644
57	0.029	0.242	0.0	0.0017	0.773
58	0.005	0.074	0.0	0.0022	0.321
65	0.0	0.0	0.0	0.0	0.419
68	0.0	0.0	0.0	0.0	0.500
69	0.0	0.0	0.0	0.0	0.097
70	0.0	0.0	0.0	0.0	0.113
71	0.0	0.0	0.0	0.0	0.532
72	0.0	0.0	0.0	0.0	0.419
73	0.0	0.0	0.0	0.0	0.065
74	0.0	0.0	0.0	0.0	0.0
75	0.0	0.0	0.0	0.0	0.113
76	0.0	0.0	0.0	0.0	0.032
77	0.0	0.0	0.0	0.0	0.871
78	0.0	0.0	0.0	0.0	14.999
79	0.0	0.0	0.0	0.0	0.129
80	0.0	0.0	0.0	0.0	0.968
81	0.0	0.0	0.0	0.0	0.145
82	0.0	0.0	0.0	0.0	33.869
83	0.0	0.0	0.0	0.0	31.450
84	0.0	0.0	0.0	0.0	0.145
85	0.0	0.0	0.0	0.0	1.290
86	0.0	0.0	0.0	0.0	1.452
87	0.0	0.0	0.0	0.0	0.855

APPENDIX I

CHEMICAL DATA (ACTIVITY)

CHEMICAL DATA (ACTIVITY)

Explanations of the headings used on pages to are given below. All values are dimensionless.

WELL NO.	number assigned to source of water (usually a piezometer).
ACA	activity of calcium ion x 10^4.
AMG	activity of magnesium ion x 10^4.
AMN	activity of manganese ion x 10^4.
ANA	activity of sodium ion x 10^4.
AK	activity of potassium ion x 10^4.
AFE	activity of iron ion x 10^4.
ASR	activity of strontium ion x 10^4.
ACU	activity of copper ion x 10^4.
ALI	activity of lithium ion x 10^4.
AHCO3	activity of bicarbonate ion x 10^4.
ACO3	activity of carbonate ion x 10^4.
ASO4	activity of sulfate ion x 10^4.
ACL	activity of chloride ion x 10^4.
AF	activity of fluoride ion x 10^4.
API	activity of phosphate ion (H_2PO_4) x 10^4.
AP2	activity of phosphate ion ($HPO_4^{=}$) x 10^4.
AP3	activity of phosphate ion (PO_4^{-3}) x 10^4.
ANO2	activity of nitrite ion x 10^4.
ANO3	activity of nitrate ion x 10^4.

WELL NO.	ACA	AMG	AMN	ANA	AK
1	0.260	0.061	0.015	2.277	1.086
2	2.665	27.663	0.003	108.312	12.004
3	7.884	13.589	0.006	12.049	0.511
4	5.198	8.380	0.001	7.052	0.516
5	6.277	7.451	0.002	44.621	1.008
6	7.817	8.503	0.005	22.699	1.180
7	3.855	5.194	0.017	98.224	2.408
8	10.217	10.130	0.001	70.378	1.399
9	0.818	5.175	0.008	662.793	5.775
10	0.969	3.822	0.012	104.578	2.117
11	3.146	6.829	0.002	60.449	1.922
12	9.729	14.422	0.002	21.211	1.678
13	2.618	7.601	0.005	45.279	1.959
14	3.384	2.254	0.005	185.711	2.628
15	3.928	5.411	0.002	125.251	3.673
16	1.984	5.134	0.006	138.503	4.047
17	3.930	8.485	0.004	115.396	4.369
18	0.827	1.800	0.004	423.712	3.428
19	5.215	6.285	0.005	42.151	2.008
20	3.329	5.110	0.002	50.837	2.162
21	5.173	15.049	0.017	217.263	2.795
22	2.811	7.157	0.004	51.517	2.240
23	2.954	2.797	0.001	177.599	2.480
24	4.738	7.122	0.015	86.092	4.671
25	4.075	4.280	0.003	121.955	5.509
26	3.317	3.623	0.002	81.541	3.674
27	2.768	3.472	0.008	121.603	4.401
28	3.342	2.438	0.022	120.269	2.517
29	5.920	6.650	0.004	24.539	1.990
30	6.835	8.191	0.009	10.967	1.747
31	4.258	3.194	0.002	53.998	1.954
32	1.674	2.982	0.003	102.126	2.172
33	2.957	11.040	0.005	29.005	1.377
34	9.028	15.475	0.002	99.770	7.768
35	4.553	9.090	0.006	23.819	2.570
36	4.817	9.331	0.013	203.934	4.041
37	3.149	3.534	0.016	367.331	3.928
38	5.915	11.325	0.024	178.671	5.131
39	8.473	10.437	0.001	615.874	4.911
40	3.675	5.104	0.013	267.507	3.566
41	2.095	3.396	0.007	451.396	4.300
42	12.777	14.570	0.096	105.578	8.851
43	3.381	25.101	0.057	88.054	7.602
44	4.373	7.217	0.014	120.925	4.442
45	1.078	1.418	0.003	298.026	2.320
46	10.267	10.277	0.002	120.335	4.267
47	4.288	11.298	0.016	182.665	5.083
48	5.416	11.117	0.011	99.268	3.472
49	10.946	12.268	0.006	125.928	4.007
50	4.326	11.610	0.005	187.578	6.606
51	4.152	10.663	0.009	189.445	5.610
52	11.279	12.375	0.051	124.301	4.717

WELL NO.	ACA	AMG	AMN	ANA	AK
53	0.667	1.696	0.004	293.045	2.816
54	12.250	12.116	0.006	126.783	4.746
55	3.936	8.107	0.008	205.092	2.687
56	2.207	2.270	0.004	274.347	2.783
57	6.275	11.931	0.004	124.350	2.086
58	3.027	2.869	0.015	51.686	1.526
65	8.267	9.329	0.0	2.771	0.0
68	2.187	0.949	0.005	160.320	1.209
69	9.709	6.921	0.018	228.772	2.906
70	14.318	8.823	0.0	46.968	0.0
71	16.309	10.219	0.120	43.694	1.418
72	15.755	9.115	0.112	35.936	1.539
73	5.937	4.131	0.021	253.675	2.497
74	7.034	4.991	0.0	254.218	0.0
75	3.853	2.339	0.001	403.399	2.267
76	21.415	13.215	0.0	12.138	1.459
77	31.215	34.906	0.220	28.925	2.062
78	24.189	26.658	2.122	26.044	1.149
79	16.298	5.634	0.062	28.943	1.060
80	25.245	12.583	0.201	101.454	2.337
81	9.835	6.149	0.034	508.083	3.597
82	25.683	18.735	0.0	46.886	1.286
83	47.290	62.721	0.0	56.863	2.896
84	11.463	7.655	0.017	841.014	4.932
85	3.057	2.050	0.0	251.131	1.828
86	3.788	2.433	0.012	256.648	2.053
87	11.124	5.780	0.0	62.872	2.193

WELL NO.	AFE	ASR	ACU	ALI	AHCO3
1	0.017	0.004	0.010	0.100	461.341
2	0.004	0.013	0.004	3.455	46.406
3	0.003	0.013	0.004	0.492	23.693
4	0.002	0.008	0.003	0.417	14.214
5	0.012	0.001	0.006	1.459	24.151
6	0.009	0.015	0.003	0.654	21.192
7	0.008	0.010	0.004	1.557	21.092
8	0.010	0.026	0.005	1.184	25.219
9	0.010	0.019	0.002	3.066	44.424
10	0.029	0.008	0.002	4.976	37.598
11	0.009	0.013	0.006	0.902	35.966
12	0.001	0.040	0.003	0.759	13.496
13	0.009	0.018	0.002	0.817	25.158
14	0.0	0.012	0.002	2.513	59.779
15	0.011	0.022	0.004	1.976	44.374
16	0.010	0.014	0.001	1.846	39.311
17	0.008	0.024	0.005	1.329	35.246
18	0.0	0.014	0.001	3.597	90.902
19	0.001	0.014	0.0	1.070	42.625
20	0.019	0.011	0.003	0.859	34.851
21	0.011	0.032	0.002	3.096	13.005
22	0.008	0.006	0.004	0.757	32.471
23	0.011	0.013	0.004	1.675	63.003
24	0.010	0.011	0.005	0.990	37.335
25	0.007	0.018	0.003	1.376	61.117
26	0.014	0.001	0.003	0.947	33.836
27	0.002	0.013	0.002	2.047	89.086
28	0.001	0.018	0.003	0.700	10.559
29	0.002	0.023	0.003	0.586	36.041
30	0.005	0.023	0.002	0.355	32.668
31	0.010	0.017	0.002	0.588	34.255
32	0.003	0.008	0.003	3.884	51.535
33	0.013	0.010	0.004	0.726	38.793
34	0.004	0.040	0.005	2.136	28.287
35	0.011	0.022	0.020	0.864	24.801
36	0.005	0.033	0.003	2.336	40.177
37	0.003	0.019	0.002	2.409	54.830
38	0.005	0.041	0.007	1.689	25.630
39	0.010	0.092	0.002	3.613	24.422
40	0.006	0.007	0.004	2.199	40.981
41	0.005	0.022	0.001	2.768	57.453
42	0.009	0.059	0.003	1.593	32.611
43	0.010	0.015	0.007	1.791	50.158
44	0.009	0.029	0.003	1.732	31.911
45	0.013	0.0	0.006	2.305	49.312
46	0.013	0.041	0.004	1.546	34.213
47	0.006	0.028	0.007	1.470	40.167
48	0.004	0.042	0.004	1.552	21.571
49	0.0	0.058	0.005	1.138	29.190
50	0.010	0.033	0.004	1.692	22.815
51	0.010	0.009	0.005	1.543	46.246
52	0.003	0.053	0.003	1.547	33.103

WELL NO.	AFE	ASR	ACU	ALI	AHCO3
53	0.0	0.008	0.002	1.345	43.843
54	0.006	0.071	0.002	2.626	19.957
55	0.002	0.026	0.001	1.284	34.168
56	0.005	0.012	0.002	1.765	42.097
57	0.013	0.023	0.005	1.271	35.161
58	0.015	0.014	0.003	0.317	8.137
65	0.0	0.0	0.0	0.0	54.386
68	0.006	0.0	0.0	0.0	107.912
69	0.238	0.0	0.0	0.0	38.392
70	0.106	0.0	0.0	0.0	68.417
71	0.462	0.0	0.0	0.0	66.073
72	0.505	0.0	0.0	0.0	64.755
73	0.075	0.0	0.0	0.0	46.591
74	0.133	0.0	0.0	0.0	51.161
75	0.025	0.0	0.0	0.0	112.202
76	0.003	0.0	0.0	0.0	65.961
77	0.041	0.0	0.0	0.0	60.754
78	0.002	0.0	0.0	0.0	55.781
79	0.026	0.0	0.0	0.0	61.009
80	0.453	0.0	0.0	0.0	104.086
81	0.476	0.0	0.0	0.0	100.077
82	0.003	0.0	0.0	0.0	48.220
83	0.006	0.0	0.0	0.0	50.961
84	0.318	0.0	0.0	0.0	75.875
85	0.0	0.0	0.0	0.0	93.708
86	0.001	0.0	0.0	0.0	92.653
87	0.200	0.0	0.0	0.0	71.285

WELL NO.	ACO3	ASO4	ACL	AF	ABR
1	0.698	0.169	3.657	0.117	0.196
2	3.007	53.215	49.641	0.207	0.151
3	3.196	9.822	12.011	0.187	0.085
4	2.496	15.207	11.219	0.189	0.099
5	8.106	15.845	14.038	0.153	0.105
6	4.680	20.390	7.213	0.190	0.073
7	4.269	35.448	5.829	0.185	0.058
8	6.559	34.568	5.773	0.246	0.081
9	9.920	1.126	699.159	0.339	0.729
10	3.894	16.086	9.649	0.342	0.114
11	3.177	14.724	4.957	0.214	0.060
12	4.435	28.432	4.582	0.155	0.042
13	5.081	11.512	7.312	0.225	0.086
14	9.162	8.847	30.013	0.231	0.081
15	7.042	10.742	30.323	0.306	0.113
16	8.312	27.041	30.585	0.247	0.102
17	4.593	15.572	85.531	0.266	0.188
18	9.574	3.323	312.536	0.284	0.441
19	3.438	4.330	7.457	0.232	0.074
20	6.801	6.121	4.836	0.231	0.075
21	0.591	58.281	56.744	0.176	0.150
22	5.115	3.382	8.005	0.279	0.087
23	8.843	14.208	41.735	0.220	0.141
24	3.500	10.852	67.771	0.243	0.339
25	4.075	15.165	31.060	0.296	0.121
26	8.641	15.447	2.720	0.300	0.237
27	6.967	8.538	31.959	0.460	0.250
28	1.983	1.978	135.187	0.133	0.453
29	6.886	6.529	4.836	0.245	0.085
30	3.984	2.838	3.716	0.134	0.035
31	6.833	3.389	5.219	0.256	0.108
32	7.284	15.322	11.775	0.248	0.105
33	5.321	9.020	4.813	0.239	0.062
34	7.161	23.199	34.636	0.290	0.139
35	6.383	3.214	6.136	0.280	0.074
36	3.443	44.969	50.953	0.291	0.152
37	9.564	0.777	423.452	0.313	0.734
38	9.544	40.142	77.080	0.264	0.254
39	3.353	0.294	970.687	0.210	0.716
40	8.082	8.906	309.370	0.280	0.528
41	6.411	0.517	549.440	0.229	0.564
42	7.573	19.752	132.806	0.193	0.480
43	3.587	27.711	41.921	0.115	0.235
44	3.496	20.450	233.003	0.211	0.291
45	7.307	9.657	270.051	0.337	0.368
46	3.868	38.632	62.332	0.259	0.175
47	3.485	32.636	82.922	0.193	0.216
48	5.448	33.918	43.910	0.236	0.144
49	7.683	5.385	6.223	0.246	0.160
50	6.116	4.378	58.141	0.248	0.145
51	4.535	33.106	67.967	0.193	0.340
52	3.758	2.986	70.433	0.245	0.309

WELL NO.	ACO3	ASO4	ACL	AF	ABR
53	9.265	8.120	294.050	0.328	0.347
54	2.226	15.160	207.856	0.202	0.299
55	4.612	15.317	125.720	0.226	0.260
56	11.225	2.367	271.399	0.265	0.336
57	4.963	34.835	43.548	0.212	0.142
58	1.436	6.176	12.767	0.163	0.087
65	0.0	1.992	2.045	0.096	0.0
68	0.0	18.844	2.666	0.272	0.0
69	0.0	55.154	48.762	0.989	0.0
70	0.0	13.108	6.389	0.0	0.0
71	0.0	13.455	12.706	0.091	0.0
72	0.0	11.865	7.627	0.092	0.0
73	0.0	53.137	56.673	1.034	0.0
74	0.0	51.045	63.275	0.0	0.0
75	0.0	0.038	322.765	0.085	0.0
76	0.0	14.869	2.244	0.137	0.0
77	0.0	48.706	4.775	0.085	0.0
78	0.0	23.957	35.204	0.088	0.0
79	0.0	10.062	2.486	0.233	0.0
80	0.0	20.148	46.855	0.088	0.0
81	0.0	1.663	456.237	0.124	0.0
82	0.0	19.503	39.487	0.089	0.0
83	0.0	80.915	23.424	0.161	0.0
84	0.0	0.649	807.478	0.079	0.0
85	0.0	46.810	14.601	0.174	0.0
86	0.0	47.436	20.104	0.173	0.0
87	0.0	11.370	9.132	0.046	0.0

WELL NO.	AP1	AP2	AP3	ANO2	ANO3
1	0.248	0.290	0.0	0.1839	0.149
2	0.020	0.017	0.0	0.0023	0.274
3	0.002	0.027	0.0	0.0017	0.228
4	0.001	0.030	0.0	0.0014	0.172
5	0.001	0.019	0.0	0.0017	0.423
6	0.003	0.027	0.0	0.0053	0.605
7	0.002	0.021	0.0	0.0013	0.330
8	0.003	0.037	0.0	0.0026	0.545
9	0.001	0.042	0.0	0.0016	0.709
10	0.0	0.0	0.0	0.0	0.678
11	0.002	0.012	0.0	0.0013	0.241
12	0.001	0.017	0.0	0.0022	0.235
13	0.001	0.015	0.0	0.0023	0.429
14	0.003	0.025	0.0	0.0011	0.289
15	0.002	0.019	0.0	0.0024	0.542
16	0.005	0.136	0.0	0.0020	1.750
17	0.001	0.016	0.0	0.0018	0.233
18	0.002	0.061	0.0	0.0019	0.399
19	0.002	0.006	0.0	0.0014	0.230
20	0.002	0.019	0.0	0.0016	0.634
21	0.0	0.0	0.0	0.0	0.418
22	0.002	0.046	0.0	0.0025	0.447
23	0.005	0.086	0.0	0.0017	0.644
24	0.013	0.099	0.0	0.0013	0.125
25	0.019	0.391	0.0	0.0017	0.999
26	0.021	0.172	0.0	0.0013	0.409
27	0.075	0.636	0.0	0.0058	0.204
28	0.516	0.373	0.0	0.0015	2.092
29	0.018	0.157	0.0	0.0016	0.547
30	0.132	0.120	0.0	0.0053	2.521
31	0.044	0.145	0.0	0.0023	0.462
32	0.003	0.016	0.0	0.0013	0.519
33	0.001	0.024	0.0	0.0015	0.430
34	0.012	0.526	0.0	0.0024	1.604
35	0.002	0.041	0.0	0.0012	0.261
36	0.002	0.012	0.0	0.0018	0.502
37	0.001	0.077	0.0	0.0014	0.269
38	0.001	0.033	0.0	0.0014	0.712
39	0.001	0.007	0.0	0.5681	0.704
40	0.001	0.026	0.0	0.0158	0.591
41	0.021	0.127	0.0	0.0015	0.454
42	0.266	0.594	0.0	0.0023	3.996
43	0.015	0.106	0.0	4.7103	0.540
44	0.001	0.037	0.0	0.0011	0.589
45	0.002	0.100	0.0	0.0042	0.511
46	0.005	0.044	0.0	0.0018	0.387
47	0.017	0.080	0.0	0.0011	0.654
48	0.001	0.021	0.0	0.0024	0.393
49	0.002	0.045	0.0	0.0013	0.528
50	0.017	0.433	0.0	0.0013	4.640
51	0.011	0.017	0.0	0.0025	0.252
52	0.008	0.075	0.0	0.0015	0.525

WELL NO.	AP1	AP2	AP3	ANO2	ANO3
53	0.001	0.067	0.0	0.0019	0.683
54	0.006	0.061	0.0	0.0016	0.695
55	0.001	0.020	0.0	0.0025	0.646
56	0.005	0.182	0.0	0.0012	0.529
57	0.025	0.123	0.0	0.0014	0.646
58	0.004	0.052	0.0	0.0020	0.292
65	0.0	0.0	0.0	0.0	0.380
68	0.0	0.0	0.0	0.0	0.430
69	0.0	0.0	0.0	0.0	0.079
70	0.0	0.0	0.0	0.0	0.098
71	0.0	0.0	0.0	0.0	0.461
72	0.0	0.0	0.0	0.0	0.366
73	0.0	0.0	0.0	0.0	0.052
74	0.0	0.0	0.0	0.0	0.0
75	0.0	0.0	0.0	0.0	0.091
76	0.0	0.0	0.0	0.0	0.028
77	0.0	0.0	0.0	0.0	0.702
78	0.0	0.0	0.0	0.0	12.480
79	0.0	0.0	0.0	0.0	0.114
80	0.0	0.0	0.0	0.0	0.804
81	0.0	0.0	0.0	0.0	0.113
82	0.0	0.0	0.0	0.0	28.392
83	0.0	0.0	0.0	0.0	23.743
84	0.0	0.0	0.0	0.0	0.108
85	0.0	0.0	0.0	0.0	1.060
86	0.0	0.0	0.0	0.0	1.189
87	0.0	0.0	0.0	0.0	0.748

APPENDIX J

SATURATION INDICES

SATURATION INDICES

Explanations of the headings used on pages to are given below.

WELL NO.	number assigned to source of water (usually a piezometer).
SI(CACO3)	$CaCO_3$ saturation index of water sample (ion-activity product divided by equilibrium constant K, non-dimensional).
SI(CAMG(CO3)2)	$CaMg(CO_3)_2$ saturation index of water sample (ion-activity divided by equilibrium constant K, non-dimensional).
SI(CASO4)	$CaSO_4$ saturation index of water sample (ion-activity product divided by equilibrium constant K, non-dimensional).
IS	ionic strength of water sample x 10^2.

WELL NO.	SI(CACO3)	SI(CAMG(CO3)2)	SI(CASO4)	IS
1	-1.287	-2.259	-4.729	2.790
2	-1.359	-0.749	-1.221	4.907
3	0.026	1.119	-1.517	1.336
4	-0.438	0.155	-1.510	1.128
5	-0.136	0.627	-1.410	1.713
6	-0.244	0.373	-1.205	1.638
7	-0.379	0.200	-1.271	2.482
8	0.089	0.999	-0.859	2.848
9	0.108	1.872	-3.435	10.065
10	-0.453	0.567	-2.200	1.719
11	-0.542	0.116	-1.731	1.468
12	-0.237	0.548	-0.958	2.185
13	-0.427	0.448	-1.924	1.278
14	-0.099	0.463	-1.928	2.466
15	-0.120	0.774	-1.768	2.107
16	-0.130	1.007	-1.669	2.822
17	-0.024	1.107	-1.622	2.562
18	0.045	1.257	-2.967	5.847
19	-0.544	-0.156	-2.047	1.106
20	-0.398	0.254	-2.088	1.173
21	-0.192	0.936	-0.920	5.134
22	-0.130	1.014	-2.417	1.081
23	0.083	1.021	-1.770	2.723
24	-0.334	0.381	-1.683	2.013
25	0.289	1.471	-1.603	2.248
26	-0.523	-0.090	-1.672	1.723
27	-0.134	0.741	-2.010	2.209
28	-2.035	-3.292	-2.562	1.892
29	-0.242	0.498	-1.791	1.173
30	-1.183	-1.372	-2.095	0.923
31	-0.834	-0.850	-2.216	1.068
32	-0.758	-0.333	-1.969	1.895
33	-0.225	1.074	-1.947	1.290
34	0.585	2.347	-1.054	3.054
35	-0.039	1.146	-2.215	1.009
36	-0.295	0.626	-1.043	4.363
37	0.534	2.018	-2.998	6.045
38	0.376	1.965	-1.003	4.482
39	-0.124	0.772	-2.983	11.857
40	0.243	1.519	-1.875	4.883
41	-0.466	0.155	-3.358	7.305
42	-0.431	0.102	-0.983	3.855
43	-0.389	1.053	-1.399	3.383
44	0.137	1.449	-1.420	3.732
45	0.211	1.418	-2.376	4.593
46	0.073	1.050	-0.788	3.793
47	-0.398	0.514	-1.244	3.904
48	0.040	1.318	-1.116	3.073
49	0.349	1.658	-1.614	2.189
50	-0.042	1.231	-2.113	2.575
51	-0.919	-0.520	-1.246	3.925
52	0.112	1.167	-1.859	2.406

WELL NO.	SI(CACO3)	SI(CAMG(CO3)2)	SI(CASO4)	IS
53	-0.065	1.170	-2.654	4.697
54	-0.027	0.874	-1.109	3.774
55	0.031	1.290	-1.603	3.399
56	0.077	1.079	-2.665	4.325
57	-0.401	0.411	-1.038	3.436
58	-1.068	-1.226	-2.106	0.797
65	0.887	2.656	-2.189	0.887
68	-0.225	0.070	-1.777	2.346
69	-0.174	0.300	-0.687	4.984
70	0.525	1.669	-1.133	1.888
71	-0.180	0.344	-1.044	2.068
72	-0.160	0.276	-1.133	1.848
73	-0.103	0.431	-0.916	4.854
74	-7.789	-14.932	-0.860	4.902
75	-0.062	0.542	-4.229	5.412
76	0.181	0.987	-0.902	2.131
77	0.151	1.282	-0.197	5.391
78	0.204	1.380	-0.615	3.674
79	0.071	0.611	-1.164	1.543
80	0.236	1.028	-0.692	3.759
81	0.281	1.264	-2.171	7.548
82	0.166	1.126	-0.679	3.331
83	0.241	1.559	0.211	10.578
84	0.427	1.585	-2.513	12.456
85	-0.070	0.618	-1.223	4.302
86	-0.224	0.195	-1.150	4.461
87	0.044	0.782	-1.263	1.754

APPENDIX K

FREE ENERGY AND ENTHALPY PARAMETERS

FREE ENERGY AND ENTHALPY PARAMETERS

Explanations of the headings used on pages to are given below.

WELL NO.	number assigned to source of water (usually a piezometer).
F	total Gibb's free energy of twenty ionic constituents of each water sample in calories per liter (ions listed in Table 4).
H	total enthalpy of twenty ionic constituents of each water sample in calories per liter (ions listed in Table 4).
F/MOLE	Gibb's free energy of twenty ionic constituents of each water sample divided by the molarity of the water, in kilocalories per mole.
H/MOLE	enthalpy of twenty ionic constituents of each water sample divided by the molarity of the water, in kilocalories per mole.
MOLE	molarity of the water sample for twenty ionic constituents, in moles per liter.

WELL NO.	F	H	F/MOLE	H/MOLE	MOLES
1	-7719.582	-8983.520	-140.431	-163.424	5.497
2	-4714.434	-5276.840	-105.628	-118.229	4.463
3	-1236.611	-1380.909	-114.298	-127.635	1.082
4	-1021.908	-1166.528	-120.717	-137.801	0.847
5	-1676.223	-1872.412	-105.550	-117.904	1.588
6	-1548.314	-1750.625	-121.347	-137.203	1.276
7	-2529.713	-2799.675	-106.878	-118.283	2.367
8	-2709.724	-3025.495	-115.703	-129.187	2.342
9	-9650.336	-10221.207	-51.242	-54.273	18.833
10	-2082.048	-2253.070	-93.762	-101.463	2.221
11	-1704.395	-1876.045	-105.369	-115.981	1.618
12	-1869.779	-2110.783	-128.411	-144.963	1.456
13	-1362.839	-1505.900	-103.240	-114.078	1.320
14	-3084.469	-3282.091	-83.933	-89.311	3.675
15	-2445.954	-2632.176	-86.386	-92.963	2.831
16	-3066.904	-3366.298	-92.749	-101.804	3.307
17	-2634.781	-2879.685	-77.554	-84.763	3.397
18	-6592.348	-7018.293	-61.856	-65.853	10.658
19	-1400.510	-1536.958	-103.668	-113.768	1.351
20	-1395.756	-1533.997	-101.499	-111.552	1.375
21	-4881.723	-5326.285	-92.997	-101.466	5.249
22	-1280.503	-1390.547	-95.774	-104.005	1.337
23	-3317.881	-3579.749	-85.647	-92.407	3.874
24	-2155.832	-2359.306	-79.681	-87.202	2.706
25	-2798.396	-3048.340	-91.874	-100.080	3.046
26	-1950.417	-2139.593	-101.931	-111.817	1.913
27	-3073.355	-3373.179	-94.195	-103.384	3.263
28	-1801.896	-1921.198	-54.882	-58.515	3.283
29	-1325.143	-1483.525	-114.082	-127.717	1.162
30	-1038.708	-1161.968	-116.285	-130.084	0.893
31	-1316.283	-1434.120	-98.281	-107.080	1.339
32	-2361.290	-2588.331	-97.531	-106.909	2.421
33	-1452.484	-1625.078	-113.709	-127.220	1.277
34	-2909.639	-3175.477	-94.895	-103.565	3.066
35	-1043.572	-1150.533	-105.199	-115.981	0.992
36	-4541.469	-4954.652	-92.496	-100.911	4.910
37	-5993.563	-6440.773	-54.667	-58.747	10.964
38	-4283.691	-4705.215	-88.102	-96.772	4.862
39	-10340.113	-11117.184	-46.938	-50.465	22.029
40	-4749.707	-5146.035	-58.217	-63.074	8.159
41	-7182.625	-7703.129	-52.252	-56.039	13.746
42	-3500.427	-3868.920	-77.772	-85.959	4.501
43	-3353.879	-3717.983	-97.954	-108.588	3.424
44	-3451.725	-3870.479	-63.986	-71.748	5.395
45	-4794.488	-5155.156	-60.198	-64.726	7.965
46	-3702.518	-4099.348	-95.009	-105.192	3.897
47	-4012.497	-4368.902	-84.268	-91.753	4.762
48	-2916.227	-3233.672	-95.910	-106.350	3.041
49	-2246.657	-2338.945	-88.542	-92.179	2.537
50	-2645.162	-2735.746	-70.638	-73.057	3.745
51	-4139.316	-4502.125	-87.045	-94.674	4.755
52	-2415.904	-2543.000	-74.427	-78.342	3.246

WELL NO.	F	H	F/MOLE	H/MOLE	MOLES
53	-4753.051	-5128.027	-58.323	-62.924	8.150
54	-3285.529	-3595.958	-63.811	-69.840	5.149
55	-3493.500	-3733.485	-70.033	-74.844	4.988
56	-4356.074	-4678.715	-57.791	-62.071	7.538
57	-3430.966	-3785.547	-96.382	-106.343	3.560
58	-826.519	-870.873	-81.505	-85.879	1.014
65	-1226.873	-1380.483	-131.170	-147.593	0.935
68	-3601.354	-3929.128	-101.946	-111.224	3.533
69	-5122.785	-5605.711	-94.757	-103.690	5.406
70	-2326.810	-2563.288	-117.179	-129.088	1.986
71	-2399.930	-2648.564	-114.097	-125.918	2.103
72	-2195.385	-2427.919	-117.660	-130.122	1.866
73	-5214.375	-5699.414	-91.399	-99.900	5.705
74	-5305.848	-5757.617	-91.396	-99.179	5.805
75	-6447.004	-6851.852	-61.727	-65.603	10.444
76	-2347.909	-2613.820	-132.593	-147.609	1.771
77	-4826.777	-5388.141	-134.616	-150.272	3.586
78	-3313.094	-3695.753	-110.221	-122.952	3.006
79	-1923.441	-2126.797	-122.886	-135.878	1.565
80	-4305.633	-4727.855	-103.437	-113.580	4.163
81	-8123.750	-8592.547	-58.482	-61.857	13.891
82	-3064.972	-3418.394	-98.055	-109.362	3.126
83	-8636.051	-9670.723	-126.496	-141.651	6.827
84	-12354.660	-12938.328	-52.779	-55.273	23.408
85	-5398.359	-5887.906	-99.748	-108.794	5.412
86	-5519.516	-6021.121	-98.673	-107.640	5.594
87	-2319.710	-2549.696	-109.292	-120.128	2.122

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