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COUNTY GROUND WATER STUDIES 2

GEOLOGY AND GROUND WATER RESOURCES

of Stutsman County, North Dakota

PART III
GROUND WATER AND ITS CHEMICAL QUALITY

By

C. J. HUXEL, JR. and L. R. PETRI

GEOLOGICAL SURVEY

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

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ABSTRACT

Stutsman County comprises an area of about 2,300 square miles in south-central North Dakota. The western part of the county is in the Coteau du Missouri, a part of the Missouri Plateau section of the Great Plains physiographic province; the eastern part is in the Drift Prairie section of the Central Lowlands province. The Missouri Coteau escarpment forms a boundary separating the two physiographic divisions.

Most of the ground water is developed from: (1) the Cretaceous bedrock formations, the Dakota Sandstone and the Pierre Shale, and (2) the overlying Pleistocene glacial drift. Permable deposits of the drift furnish the most readily available and largest supplies of ground water and small quantities of ground water are available from the bedrock formations.

The drift consists of exposed glaciofluvial and glaciolacustrine sediments, buried glacioaqueous sediments, and till.

The Jamestown, Marstonmoor Plain, and the Spiritwood are the major aquifers in the glacial drift. The Jamestown aquifer consists of surficial outwash in the valley of the James River. It is extensively developed in the vicinity of Jamestown. The Marstonmoor Plain aquifer consists of surfical outwash that underlies a pitted plain. The Spiritwood aquifer consists of glacioaqueous sediments in a large buried valley. The Marstonmoor Plain and the Spiritwood aquifers are not extensively developed.

Most wells in the county are used to supply water for domestic or stock-watering needs. Most of the ground water is of relatively poor quality for domestic, municipal, or industrial uses. However, water from surficial sand and gravel deposits can be treated to soften it and to remove iron and manganese from it so that it is acceptable for most uses.

INTRODUCTION

Purpose and Scope of Investigation

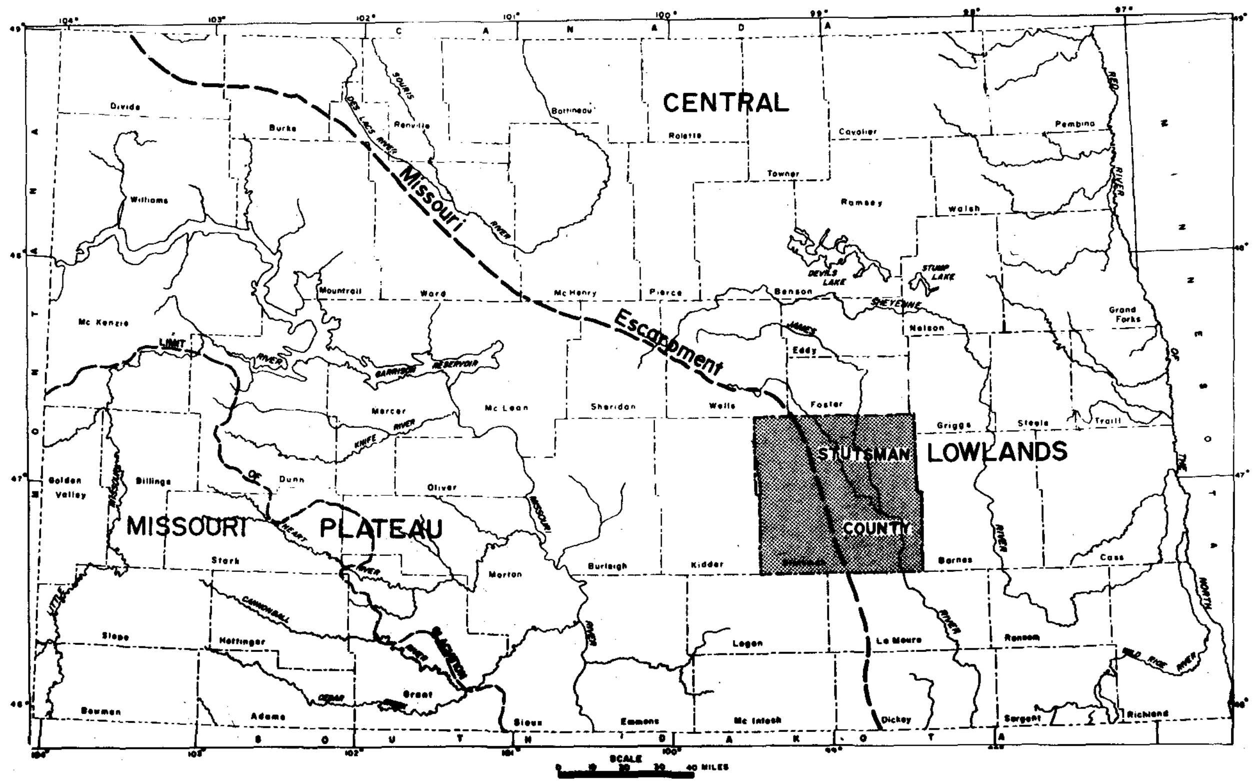
The development of water supplies of suitable quality and quantity for municipal, industrial, and agricultural purposes has long been a major problem in North Dakota. This problem has become acute in the past decade because of urbanization; industrial development, even on a moderate scale; and a growing interest in irrigation with ground water. Recognizing that information on the water resources of Stutsman County was in serious deficit, the Board of County Commissioners of Stutsman County and the city officials of Jamestown requested the U. S. Geological Survey, North Dakota State Water Commission, and the North Dakota Geological Survey to make an investigation of the geology and ground-water resources of the county. Thus the purpose of this report is to define and describe the geohydrologic character of the major water-bearing deposits discovered or better understood as a result of the investigation.

The investigation of the geology and ground-water resources of the county was begun in 1958 and included the following work: (1) assembling and evaluating water data from about 2,000 wells; (2) geologic mapping of the surficial deposits; (3) drilling 200 test holes to determine the extent of the known water-bearing rocks and locating previously unknown water-bearing rocks; (4) determining the hydrologic characteristics of the water-bearing rocks; (5) determining the chemical quality of ground water; and (6) preparing three reports of the results of the investigation.

The results of the investigation are described in a geology report by H. A. Winters (1963), a basic-data report by Huxel and Petri (1963), and this report on the ground-water resources of the county.

Location and Physiography

Stutsman County is in south-central North Dakota and comprises approximately 2,300 square miles. Stutsman County is divided into two major physiographic divisions (fig. 1). The western part of the county is in that part of the Missouri Plateau known as the Coteau du Missouri, an area characterized by lakes and marshes and an absence of integrated drainage. Most of the lakes and marshes are locally called "prairie potholes." The eastern part of the county is within the Drift Prairie of the Central Lowlands province. This area is gently



(Modified from Simpson, 1929 and Lemke, 1958)

FIGURE 1 — Map of North Dakota showing major physiographic divisions and location of Stutsman County.

rolling with many lakes and marshes and a youthful drainage system. The James River and its tributary Pipestem Creek have cut deep, wide valleys. In addition, the Drift Prairie has also been cut by many shallow, irregular, winding coulees. The two major physiographic divisions in the county are divided by the Missouri Coteau escarpment, which trends north-northwest through the central part of the county.

Previous Investigations

The geology and ground-water resources of the Jamestown and Tower quadrangles have been described by Willard (1909). Simpson (1929, p. 230-236) gave a general summary of the ground-water resources of Stutsman County. A report by Abbott and Voedisch (1939, p. 78-81) lists chemical analyses of water from 18 wells in Stutsman County. Well inventory records by the Works Progress Administration and the North Dakota Geological Survey (unpublished records) include data that have been used in defining aquifers described in this report. Wenzel and Sand (1942) described the water-bearing characteristics of the Dakota Sandstone in part of Stutsman County. Adolphson (1961) and Dennis (1948) described the municipal water supplies at Gackle and Wimbledon, respectively. Paulson's report (1962) on ground water in North Dakota is an excellent source of information on the occurrence of ground water in glacial drift.

Well-numbering and Location System

Each well, spring, and test-hole location is described and numbered according to a system based on the public land classification of the U. S. Bureau of Land Management. The system is illustrated in figure 2. The first numeral denotes the township north of the base line, the second numeral the range west of the fifth principal meridian, and the third section in which the well or test hole is located. The letters a, b, c, and d designate respectively the northeast, northwest, southwest, and southeast quarter sections, quarter-quarter sections, and quarter-quarter-quarter sections (10-acre tracts). For example, well 140-62-15daa is in the NE 1/4 NE 1/4 SE 1/4 sec. 15, T. 140 N., R. 62 W. Consecutive terminal numbers are added if more than one well is recorded within a 10-acre tract.

Acknowledgments

Special acknowledgement is due H. A. Winters, who contributed to the author's understanding of glacial processes, deposits, and his-

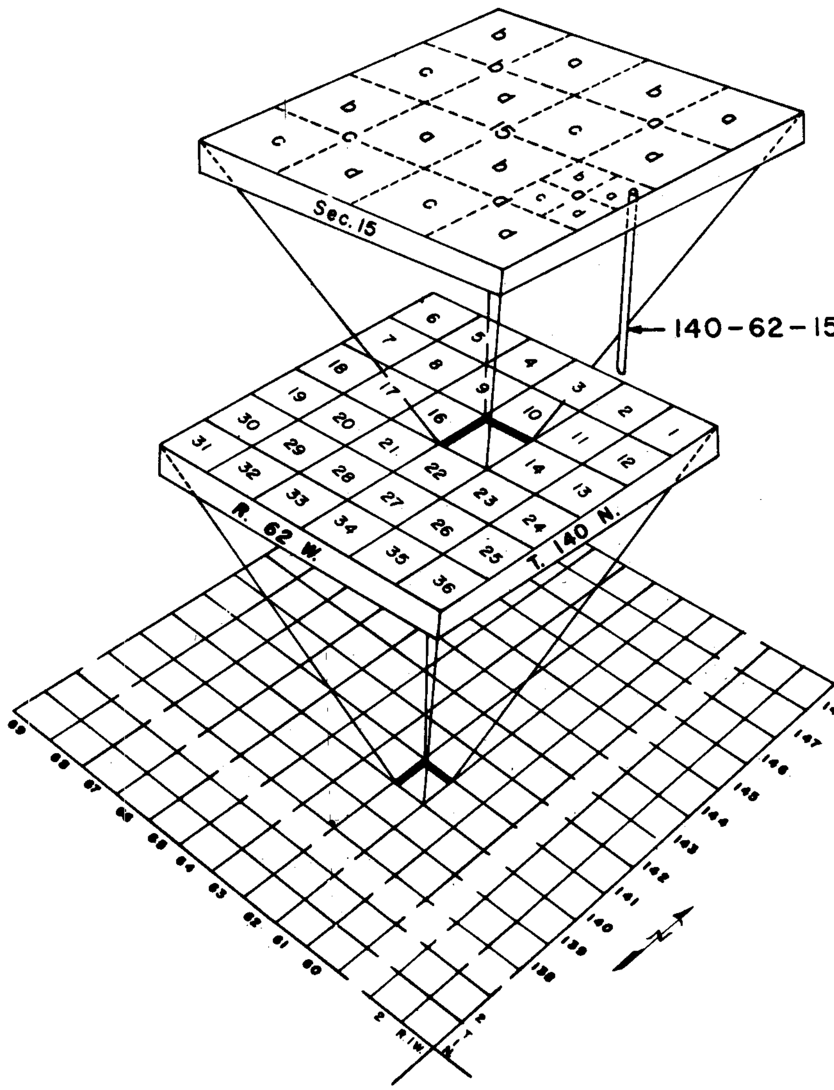


Figure 2 — System of Numbering springs, wells, and test holes.

tory of Stutsman County. He also added valuable criticisms and suggestions in review of this report. Appreciation is also expressed for the information and help from well drillers and from the municipal and county officials.

WATER-BEARING CHARACTERISTICS OF THE GEOLOGIC UNITS

The earth materials of Stutsman County that are significant in the development of ground-water supplies can be divided into two stratigraphic categories: (1) the Cretaceous bedrock formations and (2) the Pleistocene glacial-drift deposits.

The Cretaceous bedrock formations are overlain unconformably by glacial drift in most areas. The bedrock formations that yield ground water in the county are the Dakota Sandstone and the Upper Cretaceous Pierre Shale. However, the permeable deposits of the glacial drift yield more water. The locations of some of the major aquifers in the drift are shown on figure 3. The limited scope of the investigation did not allow the definition of all aquifers in the County. Glacial-drift deposits are generally not uniform and test drilling is desirable to find a suitable production-well location. The aquifers that are shown on figure 3 generally may be expected to yield water supplies, but the illustration is not intended for the selection of specific well sites. In addition to figure 3 the reader is referred to plate 4 of Winter's report (1963) for more detailed information concerning subsurface drift deposits.

Cretaceous Bedrock Formations

DAKOTA SANDSTONE

The Dakota artesian basin in North Dakota was first described in the late 19th century and a complete list of publications through 1939 relating to the basin in North Dakota is given by Wenzel and Sand (1942, p. 11). The Dakota Sandstone has been used as a source of artesian water since the 1880's. Although it continues to supply water to flowing wells in much of South Dakota and eastern North Dakota, it is not widely used in Stutsman County owing to the excessive depth of the formation and poor quality of water. Records of 17 wells that draw or did draw water from the Dakota Sandstone in Stutsman County are available (table 1).

TABLE 1. – Records of artesian wells in the Dakota Sandstone in Stutsman County.

Location	Source	Owner	Depth (feet)	Use or condition (1964)	Date completed	Present water level (feet)	Chemical analysis available (table 5)
137-62-12d	3	Union Central Life Ins. Co.	1,485	Destroyed	Before 1927		
137-63-21b	2	F. Lee	1,300	do	Before 1920		
137-63-21d	3	M. Lee	1,600	do	Before 1937		
138-62-24c	1		1,380	do	Before 1909		
138-63-1c	1,3	E. Steege	1,480 ±20	do	do		
138-63-4c	2	S. F. Corwin	1,358	do	Before 1920		Yes
138-63-9bca	4		1,350	Existing	1900	Flow	Yes
138-66-24dda	4	A. Glinz	1,980	do	1962	-50	
139-63-5a	2	Dakota Meat Company	1,510	Destroyed	Before 1920		
139-63-6	2	Jamestown State Hospital	1,536	do	do		
139-63-6cba	1,2,4	do	1,524	Existing	1890	Flow	Yes
139-63-17a	3	Federal Land Bank	1,460	Destroyed	Before 1937		
140-63-24bcd	4	H. Tahran	1,572	Existing	1961	Flow	Yes
140-63-25	1,2	City of Jamestown	1,570	Destroyed	Before 1909		
140-63-25c	2,3	Western Electric Company	1,490 ±	do	Before 1920		Yes
140-63-25ccc	1,2,4	City of Jamestown	1,476	Existing	1887	Flow	Yes
144-66-2abb	4	R. F. Reimer	1,934	do	1959	-4	Yes

Source:
1. Willard, 1909
2. Simpson, 1929
3. Wenzel and Sand, 1942
4. Huxel and Petri, 1963

In Stutsman County the Dakota Sandstone is overlain by younger Cretaceous formations, which consist mainly of shale. The top of the sandstone was penetrated by oil-test wells at depths ranging from about 1,250 feet in the eastern part of the county to 2,250 feet near the western edge; it dips to the west at about 5 to 10 feet per mile (Winters, 1963, p. 14).

The Dakota Sandstone is described as layers and (or) lenses of friable sandstone interbedded with layers of clay and shale (Simpson, 1929, p. 40-41). Hopkins and Petri (1963, p. 22) estimate that the layers and lenses of sandstone constitute only about one-fourth to one-fifth the total thickness of the formation. On the basis of oil-test well logs, Hansen (1955, p. 17-29) describes the Dakota Sandstone in North Dakota as consisting of a group of formations called the Dakota Group. However, the well-established name Dakota Sandstone is used in this report.

In Stutsman County, as in most of North Dakota, the water of the Dakota Sandstone has been reported to flow from several intervals. These are called artesian flows (Wenzel and Sand, 1942, p. 15). Willard (1909, p. 9) reported three flows and stated that the pressure and chemical quality characteristics of each were different. Hard (1929, p. 49) reported that seven successive flows had been penetrated in drilling a single well. The flows are separated by shale or dense sandstone. Concerning differentiations of flow intervals, Wenzel and Sand (1942, p. 15) have stated: "The chemical character of the water probably provides as good a basis as any for differentiating between the several flow horizons. The water from the upper part of the sandstone is generally soft but somewhat salty and is often assigned to the 'first flow'. The waters from the sandstone at greater depths are usually much harder but lower in chloride and are commonly regarded as 'second flow' waters. However, a water of very high mineral content but apparently of no consistent chemical character is encountered in some places in the deepest sandstone beds; it is designated by some drillers as 'third flow' water."

Artesian pressure in the Dakota Sandstone and yields of wells tapping it began to decline immediately after the first wells were developed in 1886 and have declined ever since. As a result, the area of artesian flow in North Dakota has decreased accordingly. Wenzel and Sand (1942, p. 31-38) present a summary of these changes through 1939.

Since 1959, only three wells have been reported drilled to the Dakota Sandstone in Stutsman County. It is likely, however, that other wells will be drilled to the Dakota, especially in areas where drift aquifers are either absent or furnish inadequate supplies. Because of its great depth and the poor quality of its water, however, it is unlikely that the Dakota Sandstone will be used as a major source of supply, at least in the foreseeable future.

PIERRE SHALE

A thick section of predominantly shale underlies the Pierre Shale and overlies the Dakota Sandstone (Winters, 1963, p. 11). The shale sequence functions mainly as a confining bed on the Dakota Sandstone. The Pierre Shale directly underlies glacial drift everywhere in the county except in a few places where it is exposed (Winters, 1963, p. 12), where it was removed by erosion in pre-glacial valleys (test hole 1874, 143-62-11aba), and in the southwestern part of the county where it is overlain by the Upper Cretaceous Fox Hills Sandstone (Huxel and Petri, 1963, table 2, test holes 1906 and 1907). Outcrops of Pierre Shale are most abundant along parts of the James River and Beaver Creek valleys (Winters, 1963, p. 12).

Subsurface samples from Stutsman County indicate that the Pierre Shale is gray to dark-greenish-gray, dense, usually brittle, noncalcareous shale. No sandy layers were penetrated in any of the test holes drilled into the formation in the county. In this report the various members making up the Pierre Shale are not differentiated and it is considered as a single geologic unit.

The fine texture and the relatively impermeable nature of the Pierre Shale suggest that the formation would not serve as an aquifer; despite this, however, many wells yielding adequate water supplies for domestic and stock uses are finished in the upper part of the shale in Stutsman County.

Pierre Shale is in places extremely fractured and jointed, thus permitting ground water to move along the planes of the fractures and joints and to provide water to wells penetrating the shale. The pressure head of the ground water in the shale differs at different localities — probably for reasons illustrated in figure 4, section B. Well 2 is finished in a fractured zone that is hydraulically connected to permeable zones in the drift (till with sand and gravel layers, silt, sand and gravel). The permeable zones in the drift are hydraulically connected to a source of recharge at the surface (the lake). Well 2 has a high pressure head. Well 1 is finished in a fractured zone of the shale that is buried by relatively impermeable till. Although the

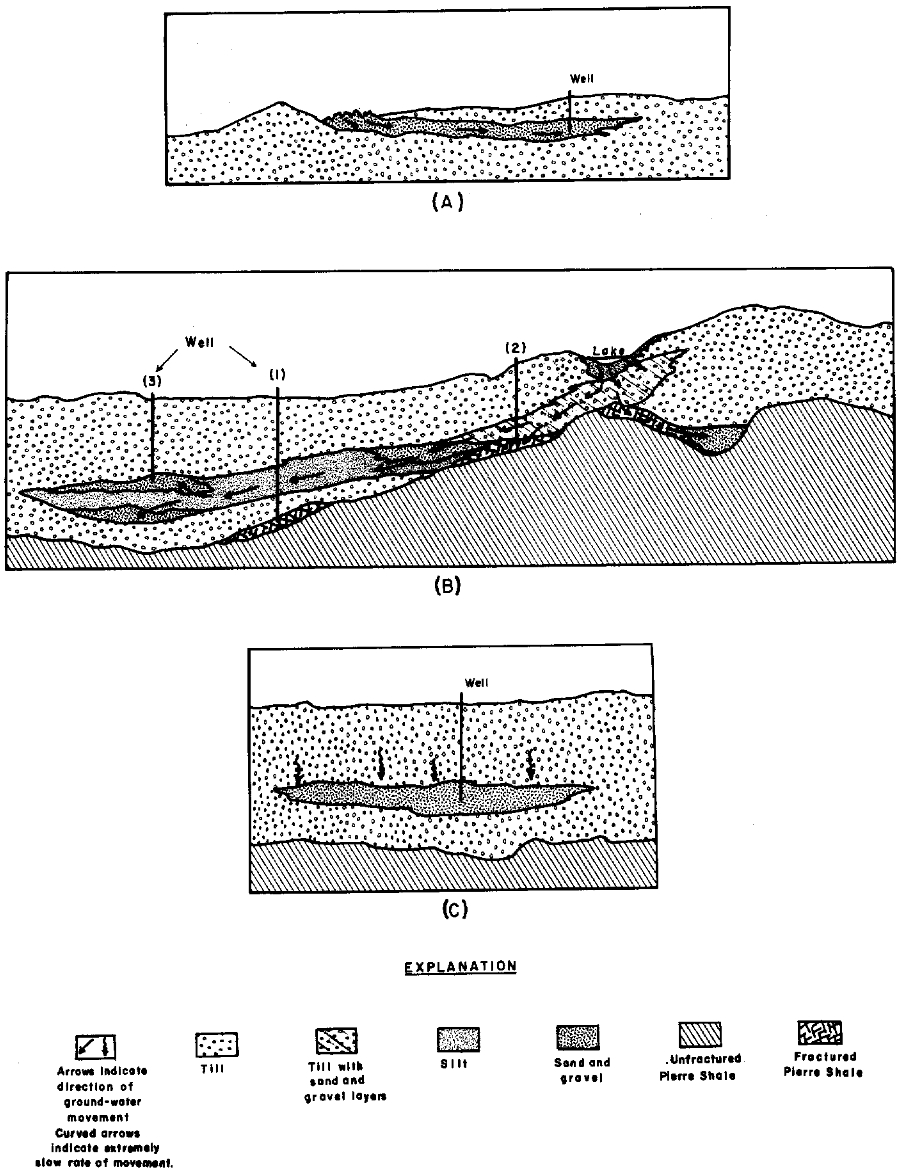


Figure 4 — Idealized sections showing sources of recharge to buried aquifers and possible causes of different pressure head in wells in the upper Cretaceous Pierre Shale.

fractured zone receives small amounts of recharge through the till, it has no effective hydraulic connection with surface sources of recharge or with more permeable zones in the drift. Therefore, the pressure head in well 1 is low.

Glacial Drift

Sediments deposited directly or indirectly as a result of glaciation may be referred to as glacial drift. Drift covers all of Stutsman County except along the bluffs of the James River and other major stream valleys where it has been removed by erosion. Throughout much of the county the drift is more than 100 feet thick and in some places is as much as 500 feet thick. The materials of the drift range from clay-size particles to large boulders.

The drift may be divided into sediment types and geohydrologic units on the basis of: (1) lithology, (2) mode of origin, (3) association with particular landforms, and (or) (4) water-bearing characteristics (table 2). Three major geohydrologic units are recognized in the county; two of these consist of glacioaqueous materials and the third is glacial till. The till was deposited directly by glacial ice with little or no modification by wind or water and consists of approximately equal portions of clay, silt, and sand, with minor amounts of larger particles. Glacioaqueous is a genetic term describing materials that have been deposited from glacial melt water. The three major types of glacioaqueous sediments recognized in the county are: (1) surficial glaciofluvial sediments, (2) surficial glaciolacustrine sediments, and (3) buried glacioaqueous sediments. The term buried glacioaqueous sediments as used in this report refers to deposits of both glaciofluvial and glaciolacustrine origin that are buried by till or are overlain by surficial glaciofluvial or glaciolacustrine sediments.

Ground-water recharge to glacial sediments in Stutsman County is derived from direct infiltration of precipitation, infiltration from streams and lakes, underflow from sediments in adjacent areas, and upward percolation from underlying sediments. A major factor that affects the amount of recharge in any area is the permeability of the underlying materials. Other important factors include the nature of the topography, the type and profusion of vegetation, and climatic conditions. Glaciofluvial sediments readily accept surface recharge because of the high permeability of these materials. Till or glaciolacustrine sediments accept surface recharge at a much lower rate because these sediments are less permeable.

In general, buried glacioaqueous sediments are isolated from the surface by intervening relatively impermeable till and, thus, receive recharge from infiltration of precipitation at extremely low rates. However, where these deposits are contiguous with more permeable deposits that have access to infiltrating precipitation, the rate of recharge resulting from underflow may be large. An example of such recharge is shown by arrows in figure 4 B.

The rate at which ground water moves through a rock unit depends on the permeability of the unit and the hydraulic gradient. Permeabilities of the various deposits of the glacial drift in Stutsman County are classified into the categories of very low, low, moderate, and high. The four categories are arbitrary qualitative estimates based on the texture and modifying texture of the materials making up the deposits and on the observed performance of wells penetrating them. Deposits with very low permeability permit only a negligible amount of ground-water movement through them and function essentially as "permeable confining beds" (Meinzer, 1923, p. 40). Deposits that are too fine-grained to function as aquifers but that are coarse enough to permit appreciable ground-water movement are classified as low in permeability and can function as avenues of recharge to the aquifers with which they are connected. Deposits classified as moderate or high in permeability are sufficiently coarse to function as good aquifers.

Discharge of ground water from saturated glacial sediments takes place by seepage into springs, lakes, marshes, and streams; by evapotranspiration; by flow or withdrawal from wells; and by underflow into adjacent areas.

GLACIOFLUVIAL SEDIMENTS

Glaciofluvial sediments in Stutsman County are classified into four types of deposits — valley outwash, unconfined outwash, ice-contact deposits, and undifferentiated outwash. These deposits are mappable, surficial units and are called geohydrologic units in this report. (See table 2.) Winters (1963, p. 22-23, 75-76) has discussed the lithology and landforms of surficial glaciofluvial sediments in detail.

Valley Outwash Deposits

Valley outwash deposits consist of glaciofluvial sediments that were deposited in valleys. They include the units defined by Winters (1963, pl. 1) as valley outwash, erosional terraces other than those composed of till, pitted valley outwash, and kame terraces. In general, valley outwash deposits are continuous in the drainage system

TABLE 3. – Public supply and industrial wells in the Jamestown aquifer.

Type: B, bored; Dr, drilled; Du, dug.

Use of water: Ind, industrial; PS, public supply; PS (a), auxiliary public supply; U, unused.

	Owner or name	Depth of well (feet)	Diameter or size (inches)	Type	Date completed	Depth to water (feet below land surface)	Length of screen	Use of water	Elevation of land surface	Yield
1.	Midland Continental Railroad	48	36 - 72	B	1912	42	.....	Ind, U	1,420	48,000 gpd.
2.	Northern Pacific Railroad	99	12	Dr	....	13	.....	Ind, U	1,400	600,000 gpd.
3.	Fargo Iron and Metal Co. (No. 1)	24	..	..	1940	..	.....	Ind, U	1,405	8,000 gpd.
4.	Fargo Iron and Metal Co. (No. 2)	24	..	..	1944	..	.....	Ind, U	1,405	16,000 gpd.
5.	Ottertail Power Co.	98	16	Dr	1949	26	.....	Ind	1,410	60,000 - 100,000 gpd.
6.	Bridgeman-Russell Creamery (No. 1)	30	96	Du	1920	24	.....	Ind, U	1,410	60,000 gpd.
7.	Bridgeman-Russell Creamery (No. 2)	90	8	Dr	1932	20	.....	Ind, U	1,410	..Do....
8.	Equity Union Creamery	22	72	Du	1932	18	.....	Ind, U	1,400	10,000 gpd.
9.	City of Jamestown (No. 1)	85	12	Dr	1909	12	.....	PS (a)	1,395	300 gpm.
10.	City of Jamestown (No. 2)	87	10	Dr	1909	12	.....	PS (a)	1,395	..Do....
11.	City of Jamestown (No. 3)	84	10	Dr	1909	12	.....	PS (a)	1,395	..Do....
12.	City of Jamestown (No. 4)	85	10	Dr	1909	12	.....	PS (a)	1,395	..Do....
13.	City of Jamestown (No. 5)	80	16	Dr	1925	13	.....	PS (a)	1,395	500 gpm.
14.	City of Jamestown (No. 6)	80	16	Dr	1928	..	.....	PS (a)	1,395	
15.	City of Jamestown (No. 7)	36	300	Du	1929	..	.....	PS (a)	1,395	1,400 gpm.
16.	City of Jamestown (No. 8)	57	300	Du	1958	14.18	.....	PS (a)	1,395	
17.	City of Jamestown (PS 1)	82.5	16	Dr	1960	10.5	41' 2"	PS	1,390	3 - 5 mgd.
18.	City of Jamestown (PS 2)	87	16	Dr	1960	8.7	41' 2"	PS	1,390	..Do....
19.	City of Jamestown (PS 3)	90	16	Dr	1960	8.6	45' 7"	PS	1,390	..Do....
20.	City of Jamestown (PS 4)	104	16	Dr	1960	12.2	61' 7"	PS	1,390	..Do....
21.	Jamestown State Hospital (No. 1)	40	192	Du	....	20	.....	U	1,385	
22.	Jamestown State Hospital (No. 2)	58	8	Dr	1944	13.62	.....	U	1,385	
23.	Jamestown State Hospital (No. 3)	50	240	Du	1951	31.42	.....	PS	1,385	260,000 gpd.

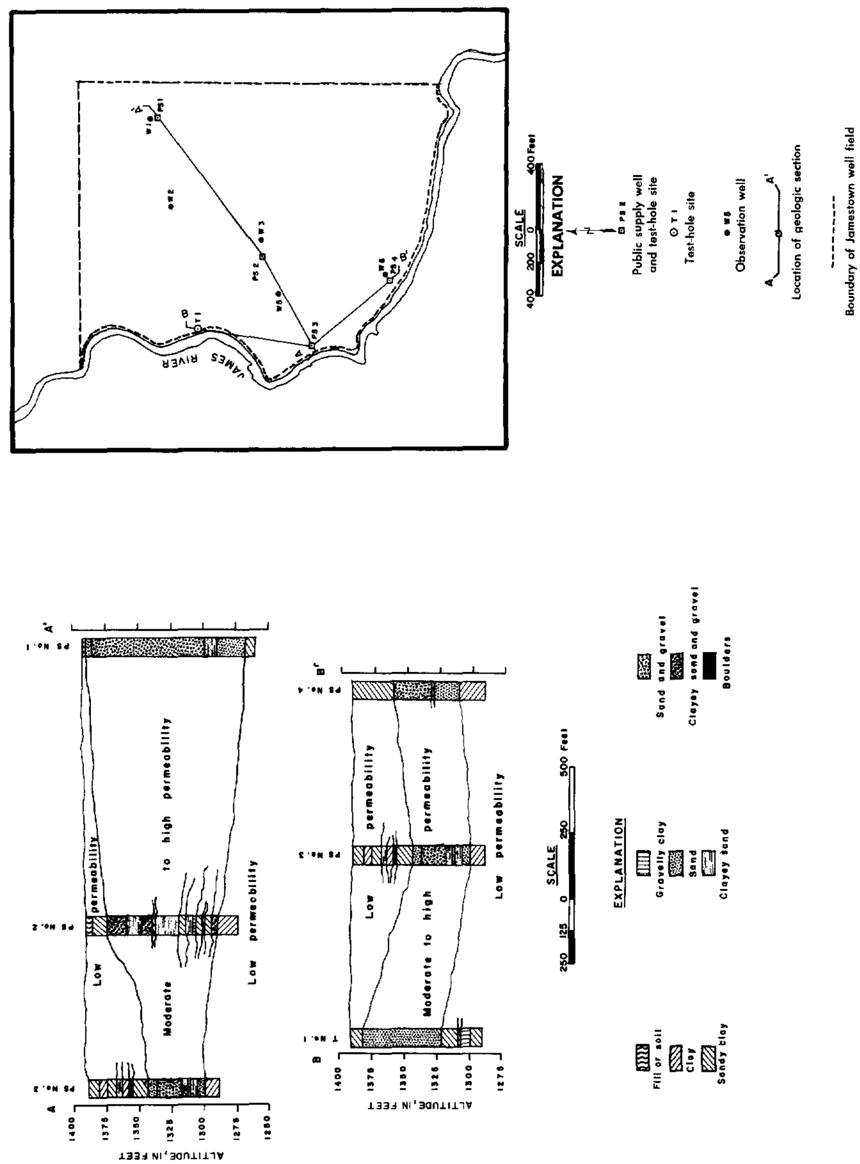


FIGURE 6. Map and geologic sections of the Jamestown well field.

of the Drift Prairie section of Stutsman County. Valley outwash deposits consist of clean to clayey sand and gravel with intercalated beds of silt and clay. The sediments are known to be more than 130 feet thick and to overlie older drift or bedrock. The valley outwash deposits are locally overlain by Recent alluvium or colluvim.

Data from 91 wells in the valley outwash deposits of Stutsman County were collected during this investigation. Most of the wells have small yields, generally less than 10 gpm, and are used for domestic and stock needs. Some have relatively high yields, as much as 1,400 gpm, and are used for industrial and public supply. The valley outwash deposits are not areally extensive, but, in places, they have the potential to yield substantial quantities of water to wells.

Jamestown aquifer. — Valley outwash deposits of the James River valley and Pipestem Creek valley join at Jamestown and form the largest valley outwash aquifer in the county. The configuration of the Jamestown aquifers is shown on figure 3. The largest water users in the county are the city of Jamestown, various industries in

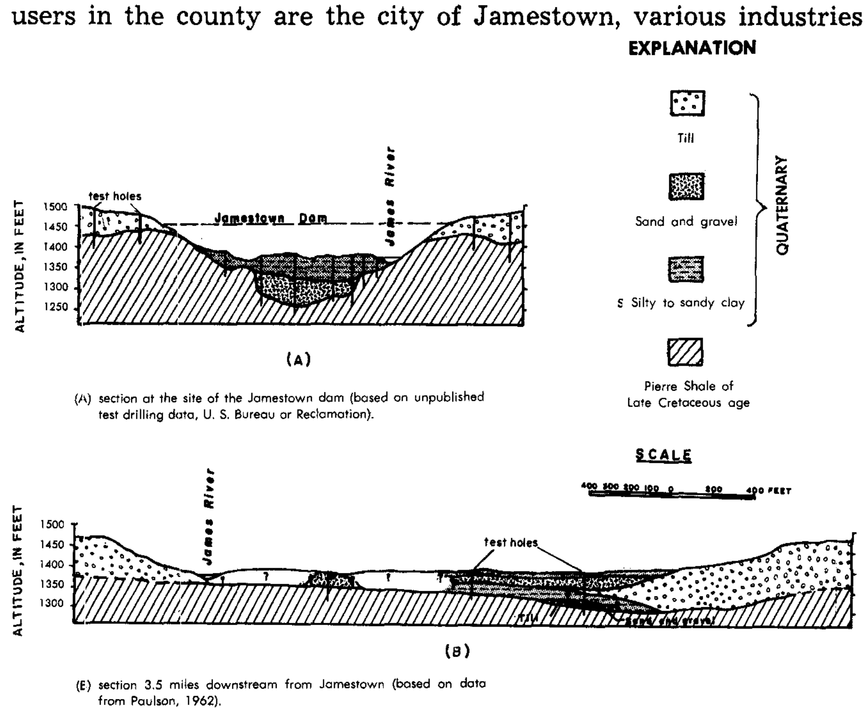


FIGURE 7 — Generalized geologic sections across the James River valley.

Jamestown, and the Jamestown State Hospital (table 3 and figs. 5 and 6); all of these withdraw water from the Jamestown aquifer. In addition, the U.S. Bureau of Sport Fisheries and Wildlife have installed production wells for a national wildlife research laboratory in the James River valley a few miles downstream from Jamestown.

The Jamestown aquifer probably reecives large amounts of recharge by underflow from sand and gravel deposits in the upper James River valley and from the valley outwash deposits in the Pipestem Creek valley. At many places in the James River valley, however, deposits of clay and silt overlie permeable sand and gravel and reduce the effectiveness of recharge from the surface to the coarser sediments (figs. 7 and 8).

This is shown in the generalized geologic sections of the James River valley (fig. 7) and in the geologic sections showing the Jamestown municipal well field (fig. 6).

The Jamestown aquifer contains water under both water-table and artesian conditions. Local artesian conditions in the vicinity of the Jamestown public-supply wells 2, 3, and 4 (unpublished report on the Jamestown aquifer test, Ross Peterson, 1960) are probably caused by overlying and interbedded clay layers as shown in sections

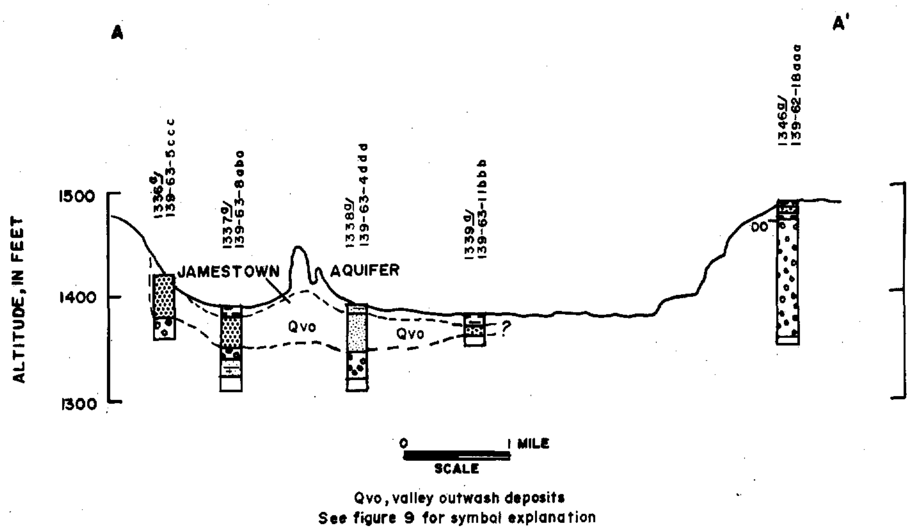


FIGURE 8. Geologic section A-A', Jamestown aquifer.

A-A' and B-B' (fig. 6). Water-level and pumpage records have been kept on the public-supply wells and observation wells in the Jamestown municipal well field since their development in 1960.

More water was withdrawn in 1963 from the Jamestown aquifer from any other aquifer in Stutsman County. Table 4 lists data on public and municipal wells that are now in use or have in the past withdrawn water from the aquifer. Most of the industrial wells in the Jamestown aquifer are no longer in use, but the Otter Tail Power Company well still produces between 0.1 and 0.2 mgd (million gallons per day) during the summer (oral communication from officials of Otter Tail Power Company). The State Hospital has its own water-supply system and pumps about 0.2 to 0.3 mgd from the Jamestown aquifer. Since 1960 an enlarged municipal water-supply system capable of producing 5 mgd has been in operation and has furnished water for most of Jamestown industrial and public facilities. Prior to 1960 the municipal water supply for the city was obtained from 8 wells (table 3, fig. 5) with a combined daily rate of pumping of over 2 mgd. In 1960 the city expanded production from the aquifer in the present municipal well field (fig. 6). Aquifer tests of 18- to 24-hours duration were made on the Jamestown aquifer using each of 4 new wells. Table 4 summarizes the results of these tests.

Plainview aquifer. — Valley outwash deposits in the valley of Pipestem Creek, called the Plainview aquifer on figures 3 and 9, are of sufficient thickness to constitute a source of moderately large quantities of ground water in the vicinity of test hole 1808 (142-65-17dcd). Present (1965) development of ground-water resources in the Pipestem valley outwash deposits, however, is limited to a few low-yielding farm wells.

Seven-mile Coulee aquifer. — Test hole 1366 (140-62-19aaa), figure 9, penetrated 49 feet of permeable valley outwash deposits in the Seven-mile Coulee. Assuming that deposits of similar thickness, permeability, and areal extent are in Seven-mile Coulee and in confluent valleys, they would constitute a good aquifer.

Unconfined Outwash Deposits

Glaciofluvial sediments that are not contained in valleys, and that are not known to have been restricted by an ice sheet characterized by extensive stagnation at the time of deposition, and that are associated with recognizable landforms as described by Winters (1963, p. 22-23) are classified as unconfined outwash. Specific landforms associated with unconfined outwash deposits are referred to

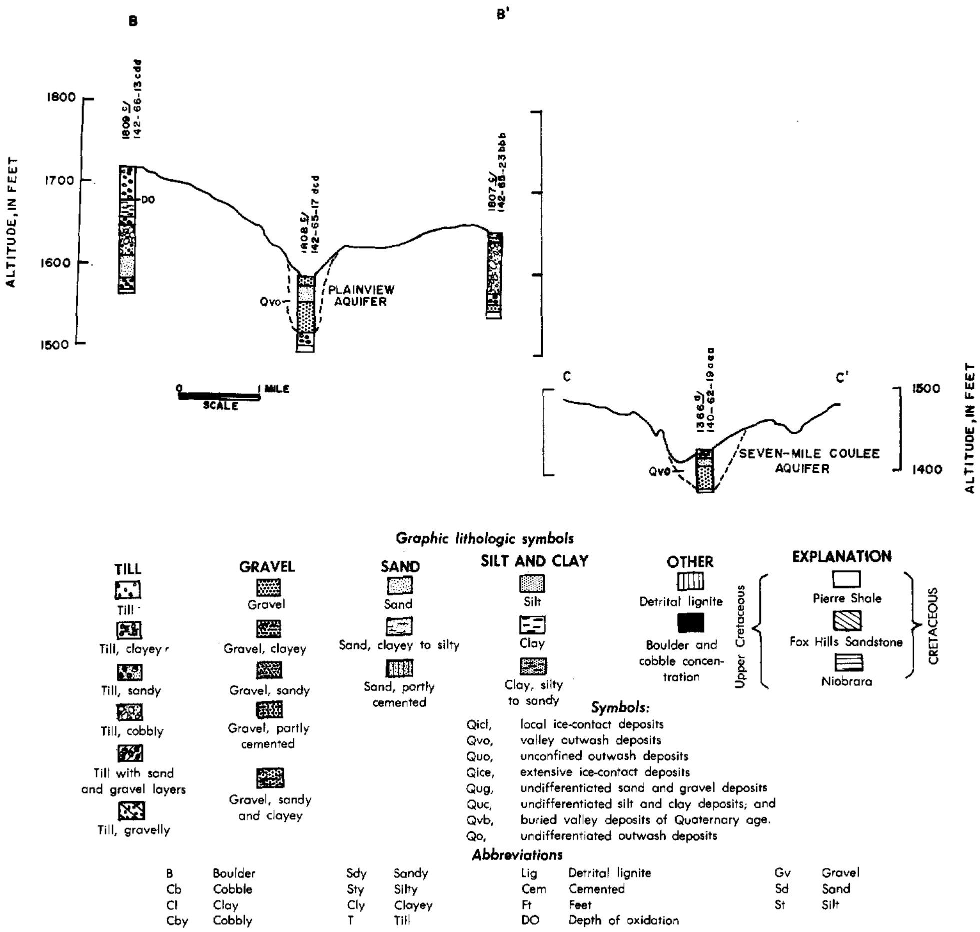


Figure 9. Geologic sections B-B' and C-C', Plainview and Seven-mile Coulee aquifers.

TABLE 4. – Results of aquifer tests performed on aquifers composed of glaciofluvial sediments.

Name or owner of well	Depth (ft.)	Diameter (inches)	Description of aquifer	Ground-water conditions	Thickness (ft.)	Discharge (gpm)	Screen length (feet)	Duration of pumping (hours)	Specific capacity gpm/ft	Specific capacity hours	Coefficient of transmiss-ibility (gpd/ft^2)	Coefficient of storage
Medina City Well 1/	42	10 to 16	Slightly clayey sand and gravel	water table	22	200	23.2	24	21.5	24	74,000	0.209
Jamestown City well No. 8 1/	57	300	Sand and gravel	water table	..		None	24			144,000	0.13
Jamestown public supply No. 1 2/	82.5	16	See fig. 6	water table and artesian	41	630	41.2	18	105	24	Inconclusive (very high)	Inconclusive
Jamestown public supply No. 2 2/	87	16	See fig. 6	water table and artesian	41	744	41.2	21	67 26.5	21 100	151,000	0.0122
Jamestown public supply No. 3 2/	90	16	See fig. 6	water table and artesian	46	640	45.6	18	50 42.5	10 100	161,000	0.012
Jamestown public supply No. 4 2/	104	16	See fig. 6	water table and artesian	62	770	61.6	19	37 32	24 100	149,000	0.012
Bureau of Sport Fisheries and Wildlife 3/	43	8	Sand and fine gravel		10	300	10.0	45	26	45	Inconclusive	Inconclusive

1/ Unpublished records, U. S. Geological Survey.
2/ Unpublished aquifer test analysis by Ross W. Peterson; furnished by North Central Engineers, Jamestown, N. Dak.
3/ Open-file report by Quentin F. Paulson, U. S. Geological Survey.

as outwash plains and pitted outwash plains (Winters, 1963, pl. 1). The unconfined outwash deposits in the Drift Prairie in eastern Stutsman County are irregularly-shaped outwash plains that range from 1 square mile to about 10 square miles in area. The deposits generally consist of fairly well-washed sand and gravel, and some small clay and silt lenses.

The deposits are relatively thin, and most consist of little more than a discontinuous veneer of glaciofluvial sediments overlying relatively impermeable till. Eighteen small-yielding farm wells produce water from the unconfined outwash deposits of the Drift Prairie. In general, unconfined outwash deposits of the Drift Prairie of Stutsman County do not contain large amounts of ground water. However, they yield adequate supplies for domestic and stock use.

One of the largest and most continuous of the unconfined outwash deposits lies southwest of Woodworth and is described by Winters (1963, p. 23, 43) as a pitted outwash plain. This land form is called the Marstonmoor Plain in this report (fig. 3). It includes about 35 square miles in Stutsman County. Thick deposits of sand and gravel underlie the Marstonmoor Plain and extend westward into Kidder County where they are continuous with the thick and extensive body of outwash described by Bradley,Petri, and Adolphson (1963, p. 11) and by Rau, and others (1962, p. 34).

Marstonmoor Plain aquifer. — The Marstonmoor Plain aquifer is penetrated by test holes along section D-D' and E-E' in figure 10 and test hole 1895 (Winters, 1963, pl. 4). It ranges in thickness from 15 to 80 feet and averages 46 feet. The aquifer is composed mostly of clean sand and gravel and is underlain by till or thick sections of silt and clay, except in the area penetrated by test hole 1893 (141-69-1ccc) where the aquifer overlies bedrock. The predominance of fairly well-washed coarse material in the aquifer suggests high permeability.

Ground water in the Marstonmoor Plain aquifer is under water-table conditions. Recharge to the aquifer is largely from rainfall and snowmelt and by lateral underflow from adjoining areas.

Natural discharge from the aquifer is by springs, transpiration from plants, seepage into ponds and lakes, and by evaporation from the soil. Discharge from wells is negligible and at the present time (1965) only about 12 low-yielding farm wells tap this aquifer.

A rough estimate of the amount of water in transient storage in the Marstonmoor Plain aquifer in Stutsman County is 90,000 acre

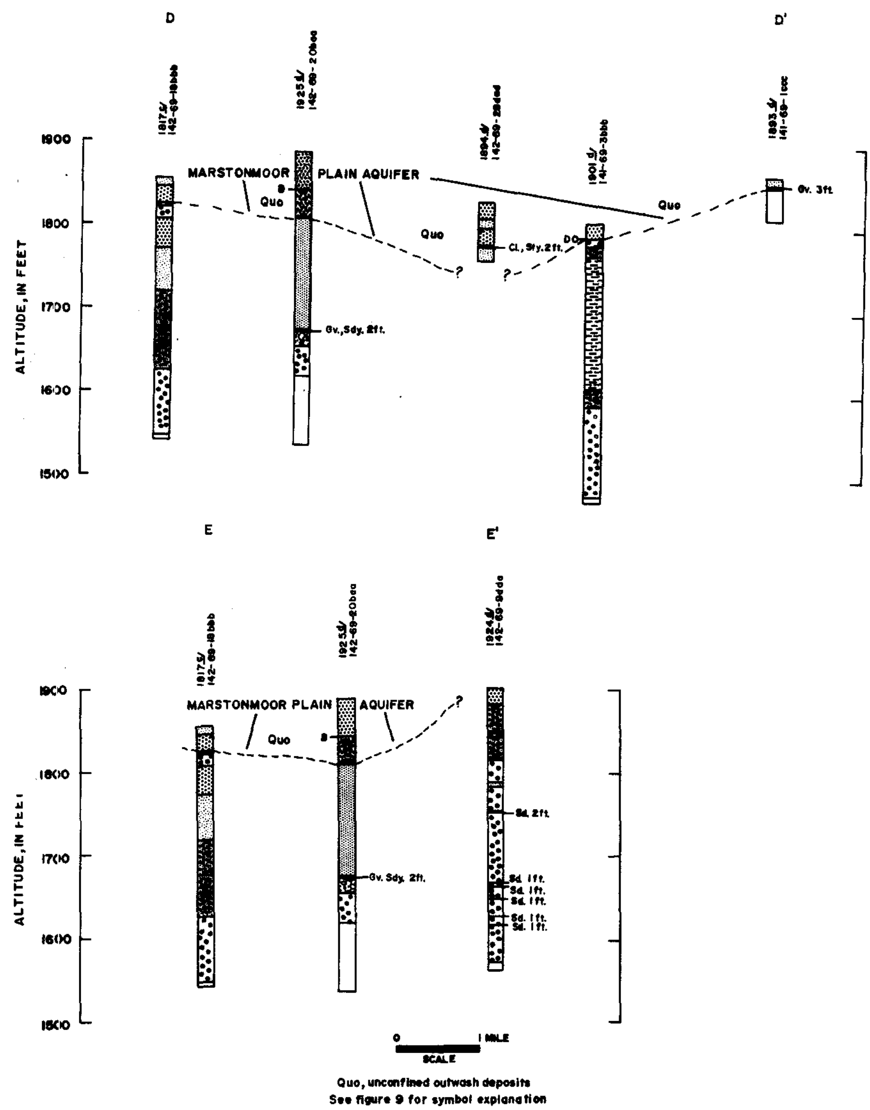


Figure 10 — Geologic sections D-D' and E-E', Marstonmoor Plain aquifer.

feet. The estimate is based on an area of 35 square miles, an average saturated thickness of 28 feet, and an estimated specific yield of 15 percent (from observed texture of test-hole samples).

Ice-contact Deposits

Glaciofluvial sediments that have been deposited in direct contact with glacial ice are termed ice-contact deposits (table 2). The landforms that they comprise ordinarily have ice-contact slopes and may be higher in altitude than the surrounding glacial terrain (Winters, 1963, p. 22-23). For discussion of ground-water conditions ice-contact deposits have been subdivided into two categories, local ice-contact deposits and extensive ice-contact deposits.

Local ice-contact deposits are scattered throughout Stutsman County and are discontinuous, small in areal extent, and generally thin. They comprise the landforms mapped as kames, kame complexes, eskers, and kettle chains (Winters, 1963, pl. 1). The kame complexes are the largest landforms underlain by local ice-contact deposits.

The local ice-contact deposits are generally composed of clayey to silty sand and gravel that is interbedded with till.

Wells in local ice-contact deposits are not common, but some stock wells have been developed in the sand and gravel associated with kettle chains. The large kame complexes that range in size from 1/3 to 4 1/2 square miles have the greatest ground-water storage potential. In general, the small local ice-contact deposits are not good sources of ground water.

Extensive ice-contact deposits in Stutsman County are restricted to the Coteau du Missouri and underlie the landforms described by Winters (1963, p. 43) as ice-restricted outwash plains and ice-walled gravel trains. Winters (1963, p. 23) calls the underlying material stagnation outwash. Two ice-restricted outwash plains are present in the county. One extends from the vicinity of Medina west to Kidder County and the other extends south from T. 138 N., R. 68 W. to the southern boundary of Stutsman County (Winters, 1963, pl. 1). The sediments underlying the two ice-restricted outwash plains range in thickness from less than 1 foot in test hole 1911, 139-67-28cdd (Winters, 1963, pl. 4) to at least 85 feet (test hole 1556, fig. 11). The lithology of the ice-restricted outwash plain sediments is extremely varied and ranges from gravel to clay. In many areas the sediments are intimately associated with till. The sand and gravel deposits may also be interbedded with silt and clay layers. The permeability of the sediments underlying the ice-restricted outwash plains varied greatly because of the wide variation in the deposits of the two ice-restricted outwash plains described above.

Discharge of ground water from the extensive ice-contact deposits underlying the ice-restricted outwash plains and the ice-walled gravel train is largely through evaporation from numerous large and permanent lakes and ponds that are located in them, and from transpiration by plants. In addition, numerous springs and seeps of ground water exist, and five springs are developed for farm use. The lakes and ponds in or adjacent to the extensive ice-contact deposits rarely dry up even in drought years; this indicates that there is effective circulation between the surface- and ground-water reservoirs.

Medina aquifer. — The extensive ice contact deposits in the vicinity of Medina (population 545, 1960 census), mapped as the Medina aquifer (fig. 3, fig 11), furnish the town with its municipal water supply. A 24-hour test of the aquifer indicates that it has a transmissibility of 74,000 gallons per day per foot. The performance of the Medina municipal well indicates that the aquifer can supply moderately large quantities of ground water. (See table 4.)

Goldwin aquifer. — An ice-walled gravel train (Winters, 1963, p. 44-45) extends southwest from a point east of Woodworth and merges with the Marstonmoor Plain aquifer (fig. 3). This deposit has been named the Goldwin aquifer. A test hole in the aquifer penetrated 24 feet of surficial gravel overlying thick clay (test hole 1814, 142-68-12cdd); the gravel constitutes a potentially good aquifer (fig. 14).

Undifferentiated Outwash Deposits

Undifferentiated outwash deposits consist of isolated masses of glaciofluvial sediments that are not characterized by a recognizable landform (table 2). The deposits are scattered throughout the Drift Prairie and Coteau du Missouri of Stutsman County (Winters, 1963, pl. 1), are generally thin and discontinuous, and are usually underlain by till. The areal extent of the sediments ranges from less than a quarter to about 2 square miles. Undifferentiated outwash deposits composed of interbedded layers of clay, silt, sand, and gravel in varying proportions are known to be as much as 32 feet in thickness (test hole 302, 137-69-26bcbl, Paulson, 1952, fig. 8).

The undifferentiated outwash deposits are generally of low to

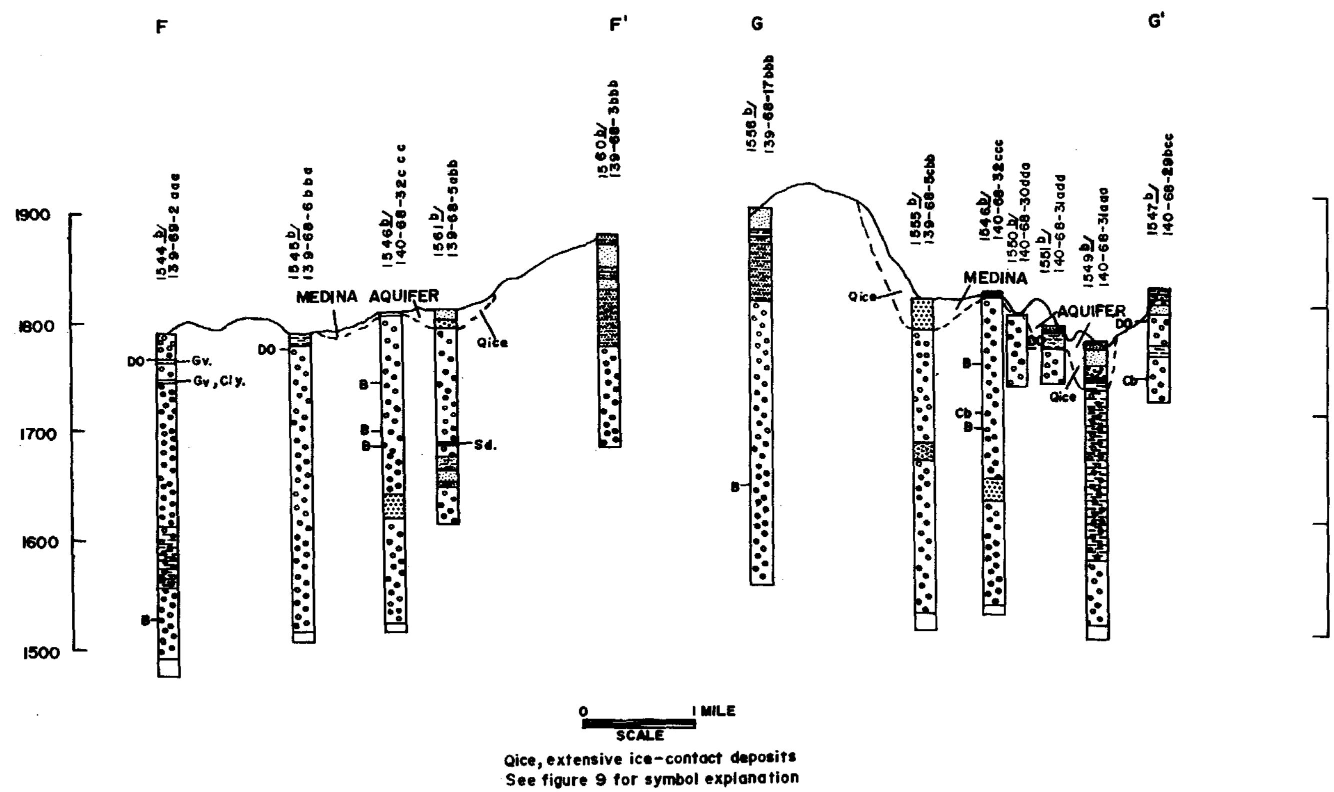


Figure 11 — Geologic sections F-F′ and G-G′, Medina aquifer.

moderate permeability. Data on 10 wells developed in undifferentiated outwash deposits in the county were collected during this investigation. All are small-yielding wells used for domestic or stock-watering purposes. Although the undifferentiated outwash is not a source of large supplies, where it is thick and extensive enough to provide appreciable ground-water storage, it may provide a potential source for small supplies. Undifferentiated outwash deposits may also act as avenues of recharge to buried aquifers with which they are hydraulically connected. For example, it is likely that the undifferentiated outwash mapped in the vicinity of Streeter serves as a source of recharge to the buried aquifer that furnished the town with its water supply.[1]

GLACIOLACUSTRINE SEDIMENTS

Glaciolacustrine sediments are deposited in proglacial lakes. Deposits of glaciolacustrine material in the form of lacustrine plains and perched lacustrine plains are numerous in Stutsman County (Winters, 1963, pl. 1). Winters, (1963, p. 23-24) has discussed the form and origin of these deposits.

Laminated silt and clay in the form of low-lying flat plains have been identified as lacustrine-plain deposits. They are of small areal extent and continuity, generally thin, and are not aquifers.

Perched lacustrine-plain deposits consisting mainly of laminated clay, silt, and fine sand, are numerous throughout western Stutsman County. Some are at a higher altitude than the surrounding terrain. They are discontinuous and limited in areal extent. The thickness of the perched lacustrine-plain deposits ranges from less than a few feet to at least 46 feet (test hole 1559, 139-68-31ddd, fig. 3, and Winters, 1963, pl. 4).

The perched lacustrine-plain deposits are generally not aquifers. They are, however, sufficiently permeable to permit a small amount of ground-water movement. Auger holes in these deposits ordinarily penetrate a distinct water table and the presence of springs and seeps along the margins of the deposits indicates lateral ground-water movement. It is possible that some of the more permanent ponds bordering perched lacustrine-plain deposits in T. 142 N., R. 67 W. (Winters, 1963, pl. 1) are replenished by lateral movement of ground water. Shallow wells in a few such deposits yield small quantities

[1] Paulson (1952, p. 27) has called the deposits that are called undifferentiated outwash deposits in this report, "ice-crevasse fillings."

of water. The perched lacustrine-plain deposit northwest of Medina in T. 140 N., R. 69 W. is composed primarily of fine sand. Three low-yielding farm wells are located in the deposits underlying this plain.

BURIED GLACIOAQUEOUS SEDIMENTS

Buried glacioaqueous sediments are, in general, similar genetically and lithologically to the surficial glaciofluvial and glaciolacustrine sediments.

Buried glacioaqueous sediments are classified in table 2 as: (1) undifferentiated sand and gravel deposits, (2) undifferentiated silt and clay deposits, and (3) buried-valley deposits. The types may grade into one another both laterally and vertically. The first two geohydrologic types are distinguished entirely on the basis of their lithology. The third type is found only in association with bedrock lows which probably represent buried preglacial or proglacial valleys.

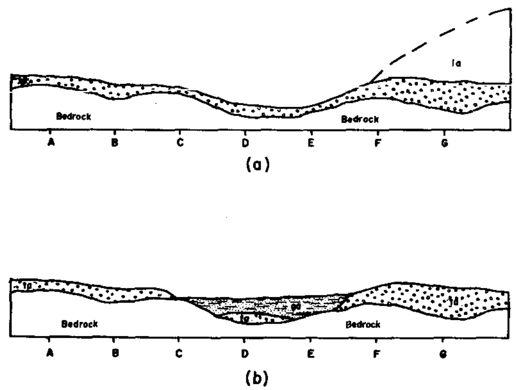
Undifferentiated Sand and Gravel Deposits

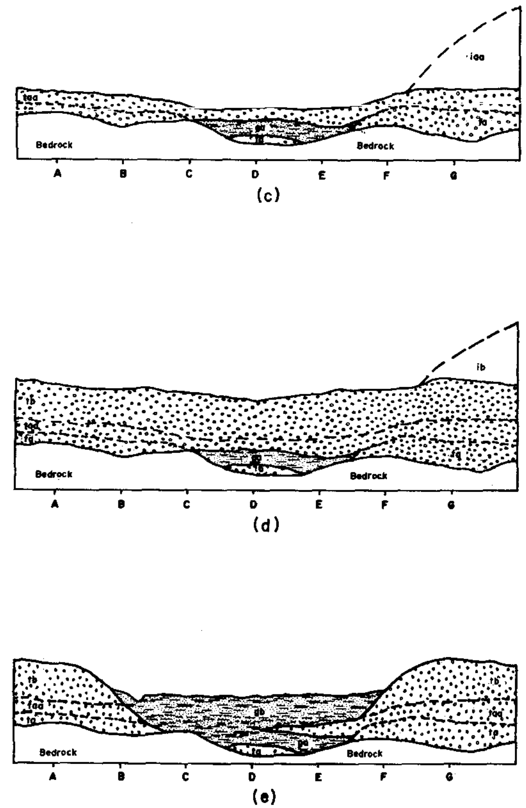
Undifferentiated sand and gravel deposits are distributed randomly throughout the drift of Stutsman County. They have been penetrated by test holes at depths ranging from a few feet (test hole 1805, 142-63-19ddd) to more than 400 feet (test hole 1821, 144-69-24ddd) and range in thickness from less than 2 feet (test hole 1747, 138-64-29cdd) to more than 100 feet (test hole 1923, 142-69-2ddc, Winters, 1963, pl. 4).

Most of the undifferentiated sand and gravel is unconsolidated but zones of partly cemented material ranging from 1 foot to over 40 feet in thickness have been penetrated in some test holes. The cementing material is generally calcium carbonate but consists of iron compounds in some places; it appears in the drill cuttings as angular shards.

The overall range in extent and configuration of the undifferentiated sand and gravel deposits is obscure. Based on evidence from drilling and from well data, the deposits are usually discontinuous and rarely can they be correlated for more than a mile. Detailed subsurface exploration is needed to define the individual deposits more precisely.

Most undifferentiated sand and gravel beds probably were deposited in glaciofluvial environments. Valley outwash deposits, which are protected by their containing walls and their low altitudes, are





EXPLANATION

(a) Ice sheet, ia, deposits till, ta, over bedrock. The margin of ice sheet, ia, is shown retreating in a direction from position A to G.

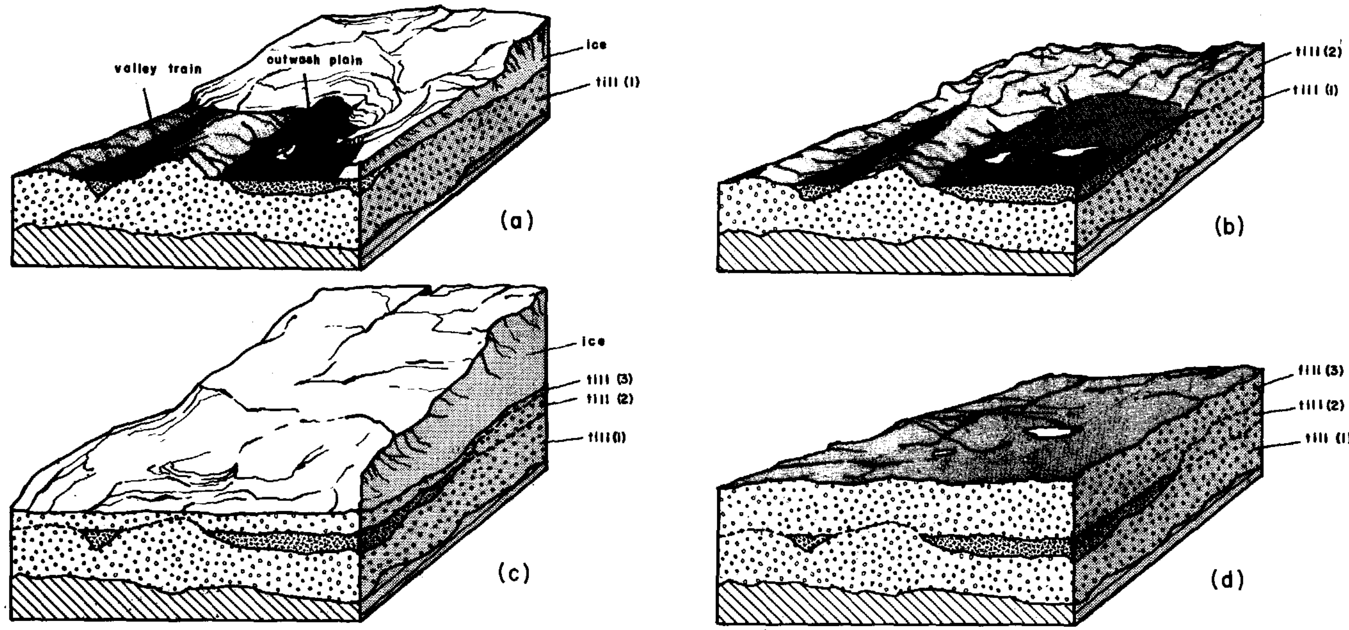
(b) Melt water from the retreating ice sheet, ia, erodes till, ta, exposing the bedrock and then lays down glacioaqueous sediments represented by deposit, ga.

(c) Ice sheet, iaa, representing a readvance of the ice, moves over the area eroding deposit, ga, at position E and burying the entire area under till, taa. The margin of iaa is shown retreating from the area.

(d) Ice sheet, ib, moves over the area and deposits till, tb. The margin of ib is shown retreating from the area.

(e) Melt water from ice, ib, erodes a valley into the older till and then lays down glaciofluvial sediments represented by deposit, gb in the valley. The meltwater valley has been incised into till sheets, ta, taa, and tb and deposit gb directly overlies the deposit ga in the vicinity of positions C and D. From position D to beyond position E the deposit ga is separated from deposit, gb by a tongue of till, taa. The log of a test hole drilled at position E would record glaciofluvial sediments gb as a valley outwash deposit and buried glacioaqueous sediments ga as an undifferentiated sand and gravel or silt and clay deposit. It would be difficult to distinguish between the sediments gb and ga in a test hole drilled at position D where the two deposits are physically and hydraulically connected.

Figure 12 — Idealized sections showing the hypothetical development of a melt-water valley incised into older buried glacioaqueous sediments.



Block (a) shows a glaciated area from which the ice margin is retreating. Valley outwash deposits underlying the valley train and unconfined outwash deposits underlying outwash plain have been laid down by melt water from the retreating ice. Block (b) shows the area free of ice. Till (2) has been deposited by the glacial ice and underlies an end moraine. Block (c) shows the same area covered by ice of a glacial readvance. The ice is depositing till over the entire area burying the valley outwash and unconfined outwash deposits. Block (d) shows the area after the ice margin has retreated. A thick layer of till has completely buried the landscape represented in block (b), preserving the underlying deposits intact.

Figure 13 — Diagrams showing the hypothetical development of deposits of buried glacioaqueous sediment.

more likely to be buried intact than other glaciofluvial deposits. Many of the undifferentiated sand and gravel deposits are probably remnants of proglacial outwash deposited in valleys that were cut into older till and subsequently buried by later ice advances (fig. 12 and 13).

Eric Lake aquifer. — The Eric Lake aquifer is penetrated by 3 test holes and consists of thick deposits of sand and gravel overlying till (fig. 14). Although the deposits are classified as undifferentiated sand and gravel, it is possible that they are associated with a major buried proglacial valley. The areal limits of the aquifer are poorly defined and only 3 wells are known to penetrate it (fig. 3). The small amount of development in the aquifer is probably because the northwestern part of Stutsman County is rather sparsely populated.

Upper Buffalo Creek aquifers. — The Upper Buffalo Creek aquifers occupy an area of about 5 square miles in T. 137 N., R. 66 W., and T. 138 N., R. 66 W. (fig. 3). There are 3 flowing wells in the area that range in depth from 120 to 310 feet. Two other deep wells in the area are reported to have flowed in the past. All of the wells are used to supply farms and the average rate of flow does not exceed about 5 gpm. Test hole 1761 (138-66-35bbb, fig. 14) penetrated three distinct deposits of undifferentiated sand and gravel.

Homer aquifer. — In the central part of T. 139 N., R. 63 W., three test holes penetrated relatively thick deposits of undifferentiated sand and gravel (fig. 3 and 15). These deposits contain water-bearing material called the Homer aquifer, which probably has an east-west dimension of at least 4 miles. The thickness of the undifferentiated sand and gravel ranges from 20 feet in test hole 1340 to 47 feet in test hole 1341. The aquifer consists of coarse sand and fine to medium gravel, which include abundant quantities of detrital shale and some clay. The deposits may be hydrologically and geologically connected with the valley outwash deposits in the James River valley.

The farm wells in the area have small yields, but wells with higher yields could be developed due to the thickness and extent of the deposits. Water levels in wells penetrating the aquifer are approximately 100 feet below land surface.

Klose aquifer. — The Klose aquifer is located in southeastern Stutsman County (fig. 3). Its presence is indicated by data from 10 wells all of which have high water levels and produce from a relatively shallow aquifer; one of the wells flows. No test holes were

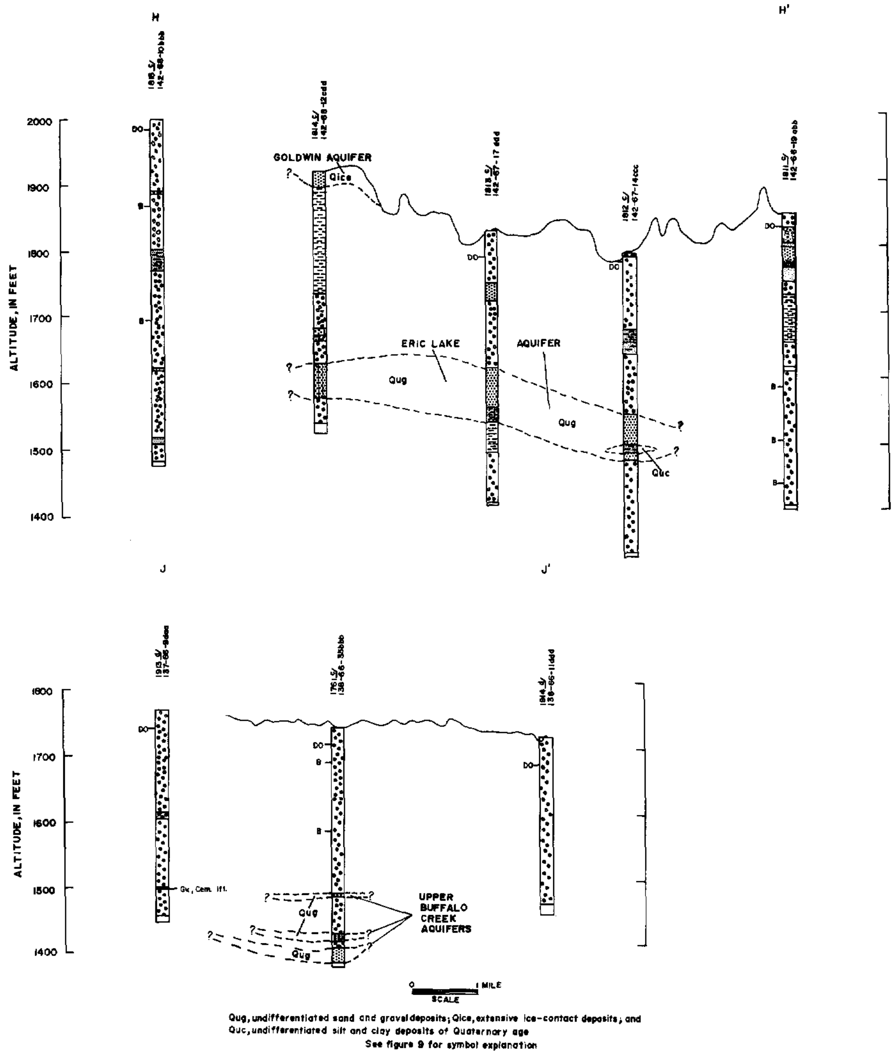
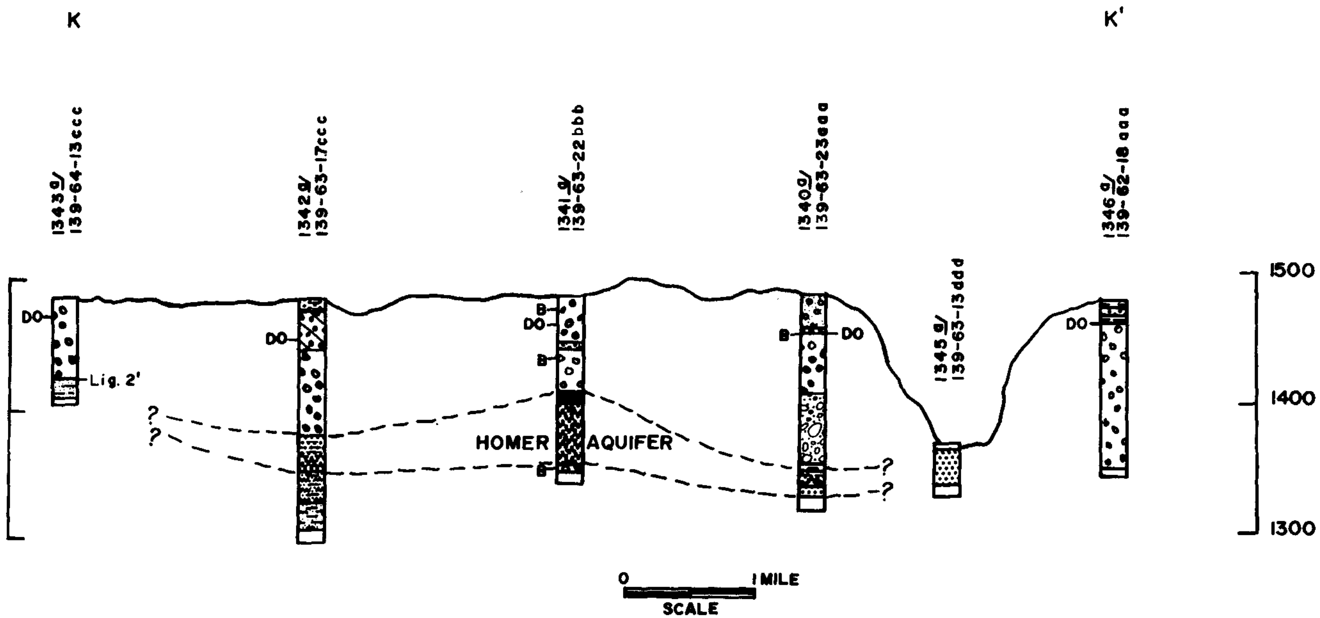


Figure 14 — Geologic sections H-H′ and J-J′, Goldwin aquifer, Eric Lake aquifer, and Upper Buffalo Creek aquifers.



See figure 9 for symbol explanation

Figure 15. — Geologic section K-K', Homer aquifer.

drilled in the vicinity of the aquifer. The aquifer may receive recharge from an esker and a small glacial melt-water channel (Winters, 1963, pl. 1).

Courtenay aquifer. — The Courtenay aquifer is located in northeastern Stutsman County (fig. 3 and 16). The aquifer is 68 feet thick in test hole 1928c and 53 feet thick in test hole 1874. Several holes augered into the aquifer were equipped with casings and used to observe water-level fluctuations.

At least one farm obtains its domestic and stock-water supply from wells penetrating this aquifer. Although it is not areally extensive, the aquifer is thick and is present at a shallow depth; probably, therefore, it can be recharged through the overlying till more readily than aquifers that are deeply buried. Several aquifers of this type exist within the upper part of the drift in Stutsman County, although few are as thick or as potentially prodctive as the Courtenay aquifer.

Deer Lake aquifers. — Deposits of undifferentiated sand and gravel, penetrated by 4 test holes in the Deer Lake Township area, comprise a group of apparently unconnected aquifers (figs. 16 and 17). The various undifferentiated sand and gravel deposits in the Deer Lake Township area are of considerable thickness; nevertheless, they may have low permeability because of clay within the sand and gravel, interbedded layers of clay, and (or) the presence of partly cemented materials.

Streeter aquifer. — Streeter (pop. 485, 1960) obtains its water supply from a shallow undifferentiated sand and gravel deposit overlain by till (fig. 16). The aquifer is probably connected with the undifferentiated outwash deposits west of the town and receives recharge through these deposits (Paulson, 1952, p. 38-42). The configuration of the Streeter aquifer and recharge area is shown on fig. 3. The relation between the aquifer and the recharge area is illustrated in fig. 4a.

Undifferentiated silt and clay deposits

The undifferentiated silt and clay deposits are composed predominantly of silt and clay-sized particles. They range from smooth to sandy and from weakly cohesive to very tight.

Undifferentiated silt and clay deposits that range in thickness from 1 foot to 161 feet were penetrated during test drilling. Their pattern of distribution throughout the drift is equally as complex as

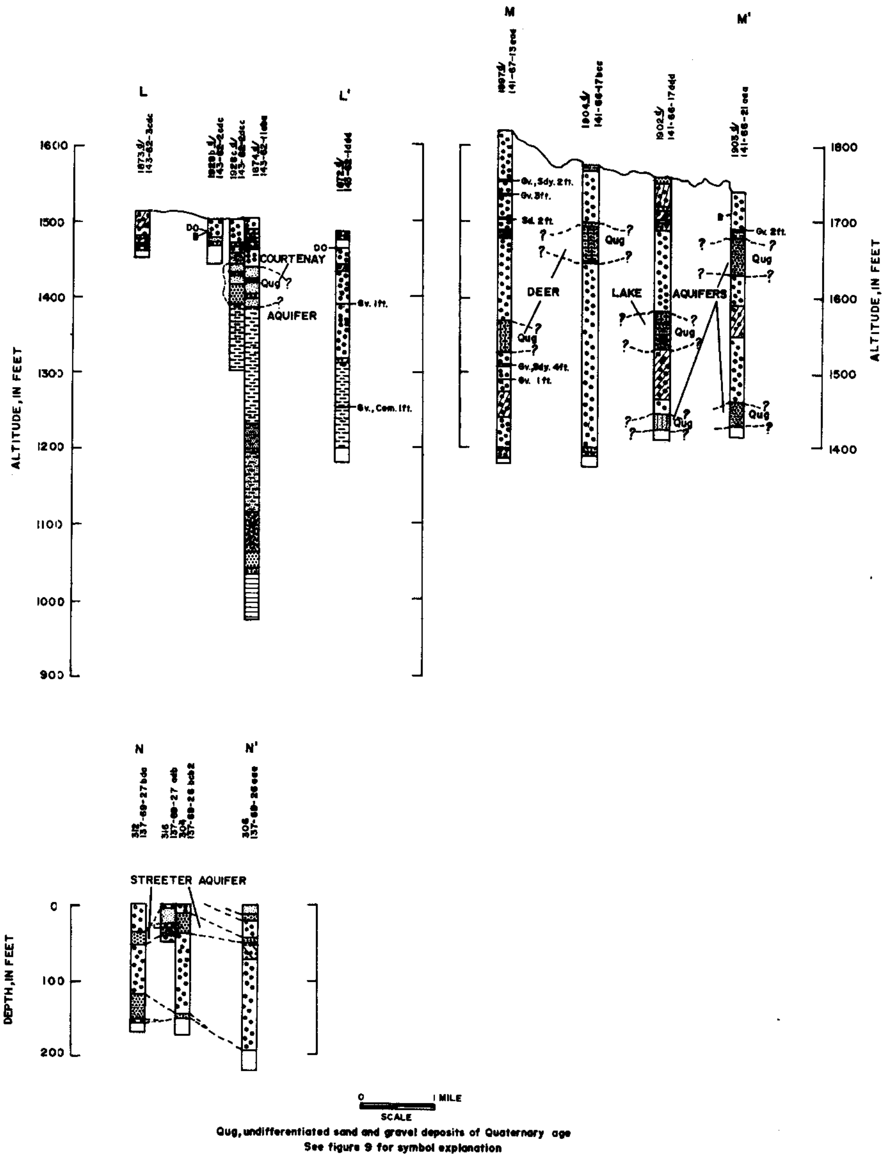


Figure 16 — Geologic sections L-L', M-M', and N-N', Courtenay aquifer, Deer Lake aquifer, and Streeter aquifer.

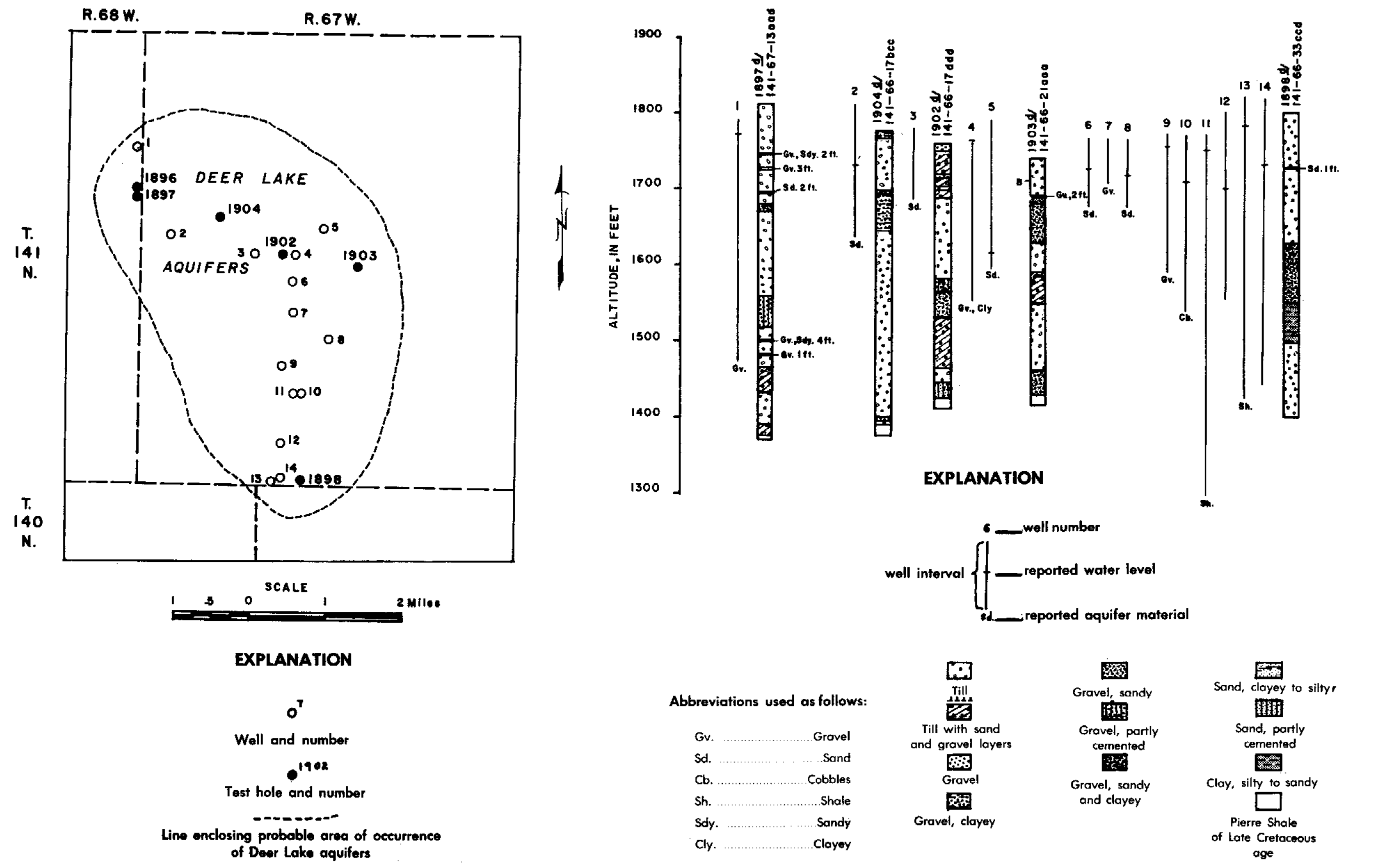


Figure 17 — Map and diagram showing relation between existing wells, test holes, and buried aquifers in the vicinity of Deer Lake township.

that of the undifferentiated sand and gravel deposits, and only test drilling provides definite evidence of their location, extent, and configuration.

The porosity of clay and silt beds is relatively high and they may contain considerable amounts of ground water, but because they are fine-grained, they are relatively impermeable and are not aquifers.

Although the undifferentiated silt and clay beds do not function as aquifers, they have a negative importance with respect to transmission of ground water through the glacial drift. The clay beds act as barriers to ground-water circulation, thus, the movement of ground water in sand and gravel is inhibited by adjacent, relatively impermeable clay beds.

Buried Valley Deposits

Buried valley deposits are glacioaqueous deposits in preglacial or proglacial valleys. The deposits are rather variable in composition. Their distribution reflects, at least in part, the preglacial and proglacial drainage patterns that once existed in Stutsman County. The preglacial drainage pattern is partly represented on a bedrock contour map of the county prepared by Winters (1963, pl. 2).

The buried valley deposits contain sand and gravel having a maximum thickness of 117 feet (test hole 1364, 140-62-23aaa) and silt and clay as much as 300 feet thick (test hole 1594, 140-62-24aaa). The buried valley deposits are the thickest and have the largest known areal extent of any of the buried glacioaqueous deposits.

Spiritwood aquifer. — The Spiritwood aquifer is the most extensive and thickest aquifer known in Stutsman County. It consists of thick deposits of sand and gravel associated with the Spiritwood buried valley complex (Huxel, 1961, p. D-179-181). The aquifer underlies an area of about 45 square miles in the vicinity of Spiritwood in eastern Stutsman County (fig. 3) and extends northeastward into Barnes County where it is even more extensive than in Stutsman County (oral communication, T. E. Kelly, U. S. Geol. Survey). The Spiritwood aquifer ranges in thickness from a featheredge to more than 120 feet (fig. 18). Between 75 and 200 feet of till overlies the aquifer.

About 24 wells tap the Spiritwood aquifer in Stutsman County (fig. 3). The reported water levels in most of these wells range from about 40 feet below ground surface to flowing. Most of the wells are used for domestic and stock-watering purposes (Huxel and Petri, 1963, table 1).

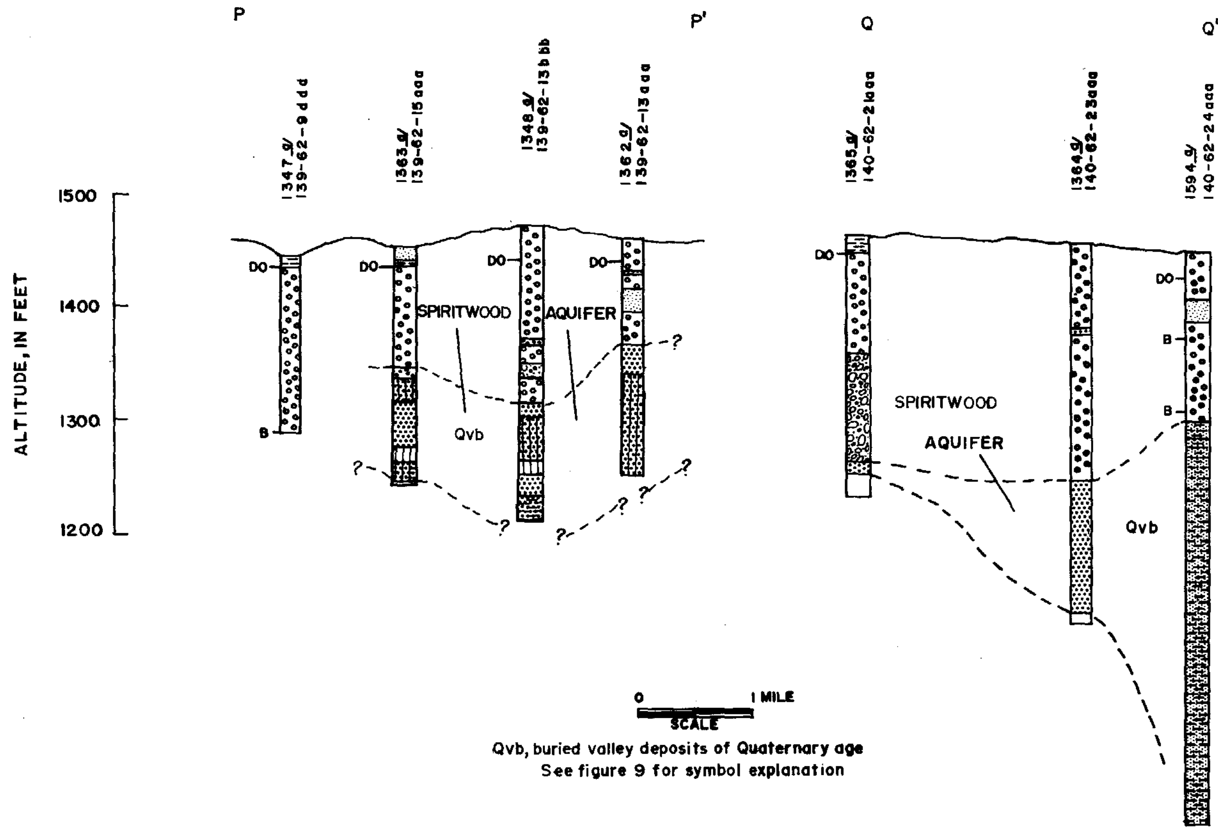


Figure 18 — Geologic sections P-P′ and Q-Q′, Spiritwood aquifer.

Discharge from the Spiritwood aquifer in Stutsman County is by underflow to adjacent areas and withdrawal of water by wells. The total discharge through wells is small. Recharge to the aquifer is by seepage through the overlying drift and by upward leakage from adjacent bedrock. Natural discharge by upward leakage through relatively impermeable deposits may occur at some places. The relatively low total dissolved-solids content of water from the Spiritwood aquifer suggests that there is appreciable ground-water movement through the deposits.

Windsor aquifers. — Test holes in the vicinity of Windsor penetrated the deposits of a buried valley in which there is one or more aquifers, which in this report are called the Windsor aquifers (fig. 3). The Windsor aquifers are under artesian conditions, and six wells in the aquifer flow. There are 10 wells penetrating the aquifer in the area and these wells range in depth from 113 to 400 feet. In test hole 1582, (fig. 19) 41 feet of sand and gravel are penetrated, and in test hole 1584, 68 feet of partially cemented gravel were found overlying the Pierre Shale. Because the Windsor artesian aquifers lie in a buried valley system, it is possible that they may extend beyond the area shown in figure 3.

Midway aquifer. — Thick buried valley deposits contained in a bedrock low in Midway Township (T. 140 N., R. 64 W.) were penetrated by test holes (fig. 3). The sand and gravel of these deposits is extensively interbedded with silt and clay. The sand and gravel contains clay in some places and is partially cemented in others (fig. 19). Consequently, although the deposits are thick, the permeability is low at some sites.

Mount Moriah aquifer. — The Mount Moriah aquifer (fig. 3) consists of sand and gravel. Test hole 1922 (fig. 19) penetrated 245 feet of the deposits, which underlie 160 feet of till. The sand and gravel is extensively interbedded with silt and clay and in many places contains clay or is partly cemented. The deposits may be associated with the ancestral Cannonball Valley (Winters, 1963, p. 33-36 and pl. 2). No wells are known to tap the aquifer, but this may simply be due to the fact that it has not been explored rather than to any limitation in the permeability or areal extent of the aquifer.

Sydney aquifer. — Near Sydney, a buried valley is cut into the bedrock. The aquifer consists of sand and gravel. The thickness of the aquifer ranges from 13 feet in test hole 1756 to 47 feet in test hole 1752 (fig. 19). No wells are known to tap this aquifer.

TILL

The most extensive landforms of Stutsman County are end moraine, ground moraine, and hummocky stagnation moraine (Winters, 1963, pl. 1) and all are composed largely of till. Till is also the most abundant drift material in the subsurface and it influences much of the ground-water movement. Test holes have penetrated till that ranged in thickness from less than 10 to 400 feet.

The typical till of Stutsman County consists of an unstratified and unsorted mass of silty to sandy clay that binds together larger fragments of igneous, metamorphic and sedimentary rock. The nature of the till in the subsurface has been determined from test drilling (Huxel and Petri, 1963, p. 6-9). Lithology of the surficial till was described in detail by Winters (1963, p. 24-34).

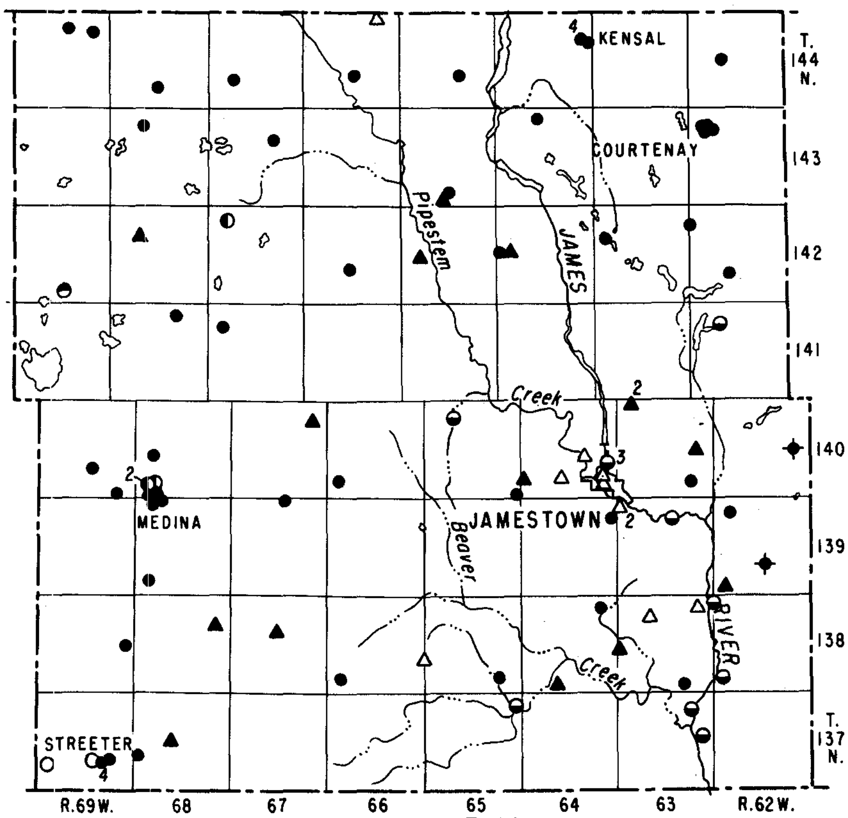
Geohydrologic variations in till lithology are shown by the division of the till into units in each test-hole log (Huxel and Petri, 1963, table 2). These till units do not necessarily have stratigraphic significance; rather the observed variation in gross till lithology is described.

The permeability of till is generally very low and it is not considered an aquifer. In most cases it restricts the movement of ground water into or out of more permeable deposits that it completely or partially encloses. The till is not, however, an absolute barrier to ground-water movement. Wells have been dug as much as 80 feet into the till and have been reported dry at the time of their completion. Over a period of months these "dry" wells gradually accumulate ground water until their water levels finally stabilize.

The differing till lithologies and their patterns of distribution in the subsurface can be important in ground-water studies. Differentiation of tills of differing permeabilities permits evaluation of recharge possibilities to buried aquifers adjacent to the tills. For example, a buried aquifer that is contiguous with a till that is interbedded with sand and gravel or a sandy till has a greater recharge potential than an aquifer that is continguous with a silty or clayey till.

CHEMICAL QUALITY OF THE WATER

The chemical quality of ground water generally is attributable to inorganic solids dissolved from the earth materials with which the water has had contact. These dissolved solids may cause hardness of the water, stain laundry, discolor food products, form scale in pipes, and produce other undesired effects. Significant amounts of these dissolved solids may limit the economic use of the water.



EXPLANATION

Valley outwash deposits

Unconfined outwash deposits

Ice-contact deposits

Undifferentiated outwash deposits

Buried valley deposits

Undifferentiated sand and gravel deposits

Pierre Shale

Dakota Sandstone

Numeral beside symbol indicates number of wells if more than one

Figure 20 — Map showing chemical — quality sampling sites.

TABLE 5. – Chemical composition and physical characteristics of the ground water, Stutsman county.

[Figures in parentheses indicate number of wells or springs for which water was analyzed. Results in parts per million except as indicated]

	Temperature (° F)	Silica (SiO_2)	Alumina (Al_2O_3)	Iron (Fe)	Manganese (Mn)	Zinc (Zn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$
Dakota Sandstone																		
		(8)	(1)	(8)	(7)	(1)	(10)	(10)	(7)	(6)	(10)	(10)	(10)	(7)	(7)	(6)	(10)	(10)
Maximum		27	5.0	6.0	0.23	0.0	293	102	2,360	24	561	1,430	3,500	3.9	16	5.6	6,150	1,150
Minimum		9.1	5.0	.1	.00	.0	4	9.7	375	9.6	202	.3	213	1.2	.4	.94	2,220	105
Average		14	....	1.6	.12	....	78	32	1,150	15	355	922	899	2.4	3.3	3.1	3,170	327
Median		11	....	1.0	.16	....	53	23	705	13	335	1,090	260	2.4	.6	3.2	2,340	213
Pierre Shale																		
	(10)	(12)	(1)	(15)	(11)	(1)	(16)	(16)	(16)	(14)	(16)	(16)	(16)	(16)	(16)	(14)	(16)	(16)
Maximum	48	29	6.1	9.8	0.77	1.4	119	43	2,520	39	835	950	3,860	1.6	14	4.4	6,970	474
Minimum	41	13	6.1	.0	.00	1.4	8.3	3.5	307	4.1	585	.8	11	.0	.3	.77	867	35
Average	45	26	....	.2	.19	....	52	19	997	14	699	248	1,070	.4	3.7	2.8	2,810	207
Median	45	27	....	.6	.13	....	45	13	700	11	695	202	372	.3	1.9	3.2	2,190	164
Undifferentiated sand and gravel deposits																		
	(30)	(46)	(13)	(53)	(44)	(13)	(53)	(53)	(52)	(35)	(53)	(53)	(53)	(52)	(52)	(34)	(53)	(53)
Maximum	51	32	17	11	2.8	4.4	518	444	796	19	833	2,720	368	0.8	390	0.86	5,360	3,120
Minimum	42	12	4.9	.0	.0	.0	45	12	5.7	4.7	244	23	.4	.0	.0	.02	352	183
Average	45	26	10	1.0	.64	1.4	185	103	147	10	475	636	80	.3	43	.36	1,570	880
Median	44	27.5	12	.4	.50	1.0	163	60	80	10	439	437	46	.3	3.2	.24	1,220	704
Buried valley deposits																		
	(1)			(2)	(1)		(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
Maximum	42	......	....	1.8	0.00	....	74	22	164	9.8	494	181	40	0.4	5.3	0.30	766	274
Minimum	42	......	....	.9	.00	....	24	14	133	5.5	432	53	37	.1	.0	.30	512	118
Average	.....	......	....	1.3	......	....	49	18	148	7.6	463	117	38	.2	2.6	.30	639	196
Undifferentiated outwash deposits																		
				(2)			(2)	(2)	(2)		(2)	(2)	(2)	(2)	(2)		(2)	(2)
Maximum	.....	......	....	1.2	......	....	83	85	21	......	250	359	40	0.0	....	.....	755	561
Minimum	.....	......	....	.4	......	....	39	17	17	......	170	....	5.6	.0	.0	.....	332	176
Average	.....	......	....	.8	......	....	61	51	19	......	210	....	23	.0	....	.....	543	368
Ice-contact deposits																		
	(3)	(4)		(4)	(4)		(4)	(4)	(3)	(3)	(4)	(4)	(4)	(4)	(4)	(3)	(4)	(4)
Maximum	40	28	....	8.4	0.81	....	112	44	29	6.0	459	126	24	0.2	53	0.15	596	438
Minimum	44	27	....	.2	.13	....	73	28	11	3.8	249	57	7.3	.0	.3	.05	394	296
Average	45	21	....	2.4	.46	....	95	34	16	4.8	344	93	12	.1	18	.09	482	380
Median	46	26	....	.5	.45	....	98	34	11	4.7	333	95	14	.2	8.0	.07	468	394
Unconfined outwash deposits (one sample only)																		
	44	23	....	0.04	0.29	....	79	27	4.8	2.5	267	81	13	0.1	2.9	0.01	417	310
Valley outwash deposits																		
	(8)	(11)	(1)	(11)	(10)	(1)	(11)	(11)	(11)	(9)	(11)	(11)	(11)	(10)	(11)	(10)	(11)	(11)
Maximum	49	32	8.4	4.6	1.5	1.5	193	64	174	9.8	574	406	73	0.4	92	0.53	1,190	672
Minimum	42	16	8.4	.0	.0	1.5	40	22	23	2.7	208	62	2.9	.0	.1	.07	377	196
Average	46	27	....	1.8	.6	....	112	41	75	6.1	418	207	28	.2	21	.28	743	448
Median	46	27	....	1.0	.5	....	109	40	61	6.5	435	212	24	.2	2.6	.32	787	435

The chemical analysis of water from more than a hundred wells and springs in Stutsman County were studied to determine the suitability of the water for use.

The chemical quality of the ground water is influenced by the chemical and physical characteristics of the sediments through which the water moves. Therefore, water quality may range significantly from one geologic unit to another. The areal distribution of the sampling sites is shown in figure 20 for each of the geohydrologic units. The sampling sites for water from the Pierre Shale and from undifferentiated sand and gravel deposits are fairly numerous and are well distributed throughout the county and are chiefly from domestic and stock wells. Samples were obtained from all the wells that were known to produce water from the Dakota Sandstone. The Dakota Sandstone underlies the whole county at relatively great depths. Distribution of sampling sites for water from valley outwash deposits, outwash plain deposits, ice-contact deposits, and buried valley deposits was limited by the relatively small areal extent of these units.

The chemical composition and physical characteristics of the ground water are summarized in table 5 from chemical analyses given in tables 3 and 4 of Huxel and Petri (1963).

Most of the samples were analyzed 1950-62, but some were analyzed as early as 1909. Methods of laboratory analysis and of reporting analytical results differed somewhat from one agency to another. To provide uniformity, some of the laboratory results originally reported were converted to present standard reporting units of the U. S. Geological Survey.

Variations of ground water 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).

Water from both the Cretaceous bedrock and the Pleistocene drift is nearly colorless when it is discharged from the well. Generally, iron and manganese precipitate soon after the water is exposed to the air and the water appears to be colored. These precipitates will settle to the bottom of a container if the water is allowed to stand.

Most of the water in Stutsman County is very hard. The hardest water is from undifferentiated sand and gravel deposits, and the softest water is from Pierre Shale.

Water from Cretaceous Bedrock

The dissolved-solids content of the samples of water from Cretaceous bedrock generally ranged from 1,000 to 3,000 ppm. One sample of water from the Pierre Shale had a dissolved solids content of 6,970 ppm. The percentages of the major constituents in the water are shown on figure 21. Most of the water from the Dakota contains sodium as the chief cation and sulfate as the chief anion and thus is of the sodium sulfate type. Some of the water, however, is of the sodium chloride type. Most of the water from the Pierre is of the sodium chloride type, but some is of the sodium bicarbonate type.

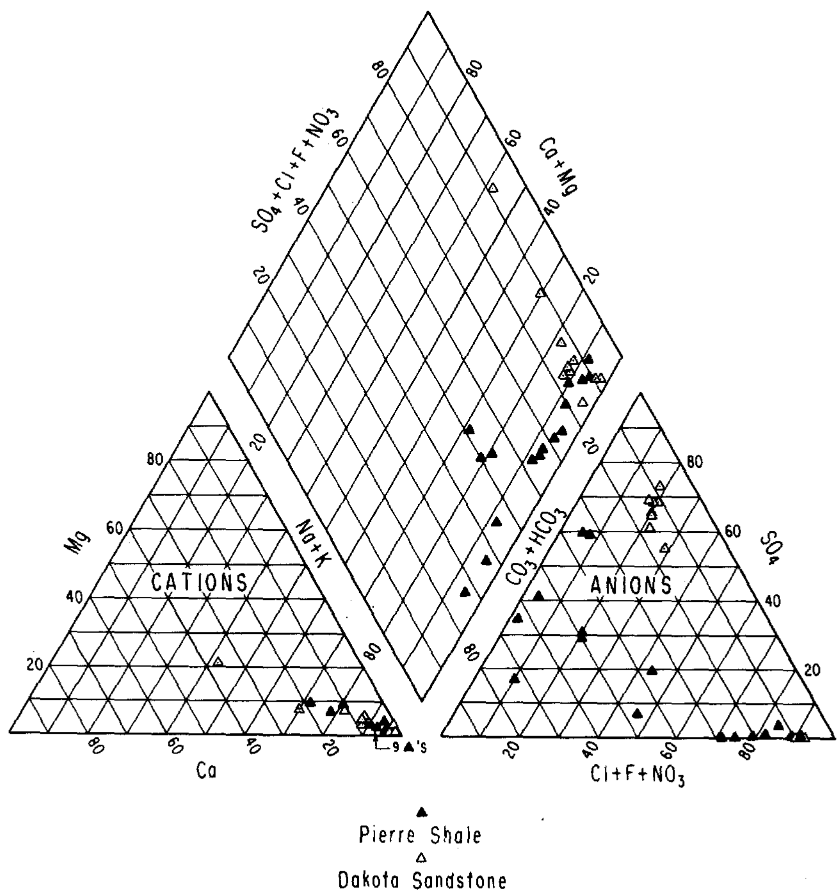


Figure 21 — The percentages of the major constituents in water from Cretaceous bedrock.

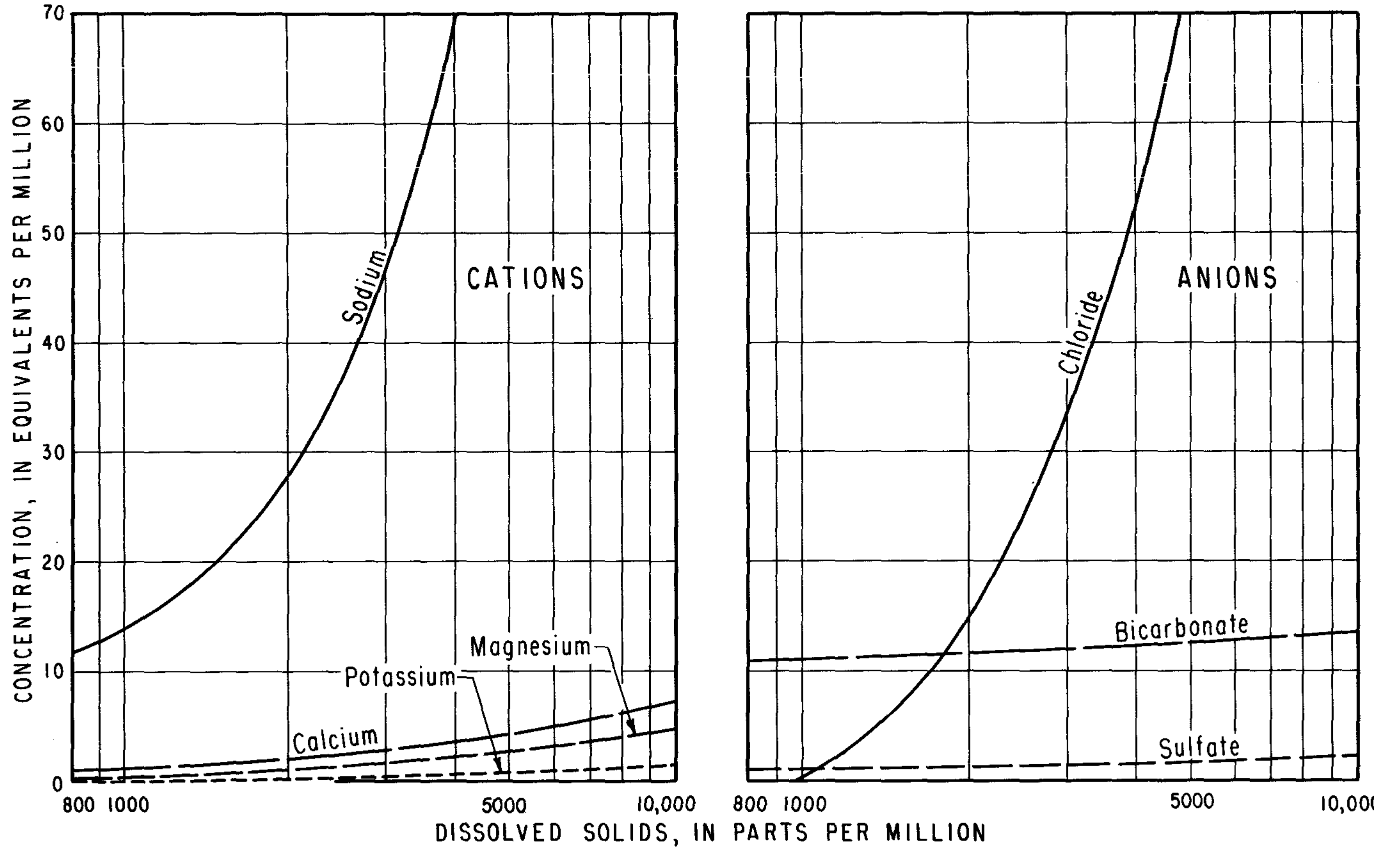


Figure 22 — Relation of major ions to dissolved solids in water from Pierre Shale.

and gravel deposits overlain by till and recharged mostly by water that has percolated through the till are likely to contain water relatively high in dissolved solids.

The percentages of the major constituents in water from Pleistocene drift is shown in figure 23. The wide scatter of points representing water from undifferentiated sand and gravel deposits illus-

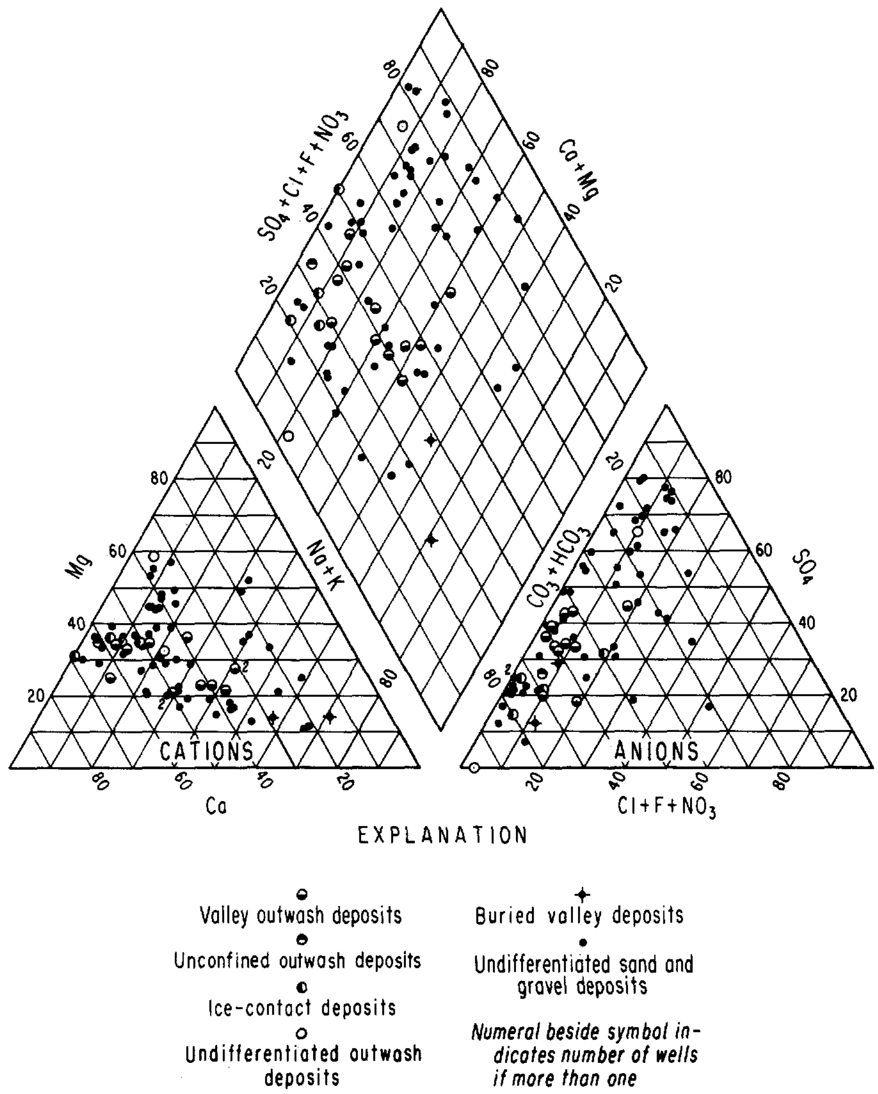


Figure 23 — The percentages of the major constituents in water from Pleistocene drift.

The chemical character of the water from the Pierre Shale varies with dissolved-solids content (fig. 22). Sodium is the principal cation of all dissolved solids concentrations. Bicarbonate is the principal anion in the water having less than about 2,000 ppm. Bicarbonate concentration is consistently higher in water from the Pierre than in water from any of the other geohydrologic units.

Examination of table 5 discloses several noteworthy facts relating to some constituents in the water in Stutsman County. The first is that the boron content of the water from the bedrock is higher than that of water from the glacial drift. Generally, the boron content of the water from the bedrock is from 1 to 5 ppm, whereas that of water from the drift is less than 0.5 ppm. Therefore, differences in boron content may help to distinguish the geohydrologic source of water.

The average of 2.4 ppm of fluoride from the Dakota Sandstone (table 5) contrasts sharply with the averages of 0.4 ppm or less for the water from Pierre Shale and Pleistocene drift. Only one sample (from Pierre Shale) had a fluoride content that exceeded the minimum fluoride content of water from the Dakota. The fluoride content is helpful in differentiating between water from the Dakota and water from other units.

Two additional facts are the relatively low silica content of water from the Dakota and the low nitrate content of water from both the Dakota and the Pierre. The silica content of water from the Dakota averages about half that of the water from the Pierre and glacial drift. Most high concentrations of nitrate in ground water are associated with drainage of nitrogen-laden water from barnyards, fertilized fields, and outhouses; the thickness of relatively impervious till overlying bedrock prevent seepage of such water into the bedrock aquifers.

Water from Pleistocene Drift

Aquifers in the Pleistocene drift located at or near the land surface generally have water with low dissolved solids consisting mostly of calcium and bicarbonate. Aquifers in which many shale fragments or much till is incorporated generally have water with dissolved solids that differ according to the amount and composition of the shale fragments or till present. Water from such aquifers generally has, in addition to calcium and bicarbonate, significant concentrations of sodium, sulfate, and, in some places, chloride. Sand trates the variableness in chemical composition of the water from this unit. The scatter of points representing water from other units of Pleistocene drift is relatively slight.

Water from the undifferentiated sand and gravel deposits ranges widely in chemical character and the dissolved solids concentration ranged from 352 ppm to 5,360 ppm. The chemical character and concentration seem to be independent both of location within the county and of well depth.

Percentage of samples in which dissolved solids exceeded given concentrations

Percent	Ppm	Percent	Ppm	Percent	Ppm
84	500	16	2,500	4	4,500
66	1,000	12	3,000	2	5,000
38	1,500	10	3,500	0	5,500
25	2,000	8	4,000		

Water from the various surficial sand and gravel deposits, in contrast to that from the undifferentiated sand gravel deposits, is fairly uniform in chemical composition (table 5); the dissolved solids ranged from 332 to 1,190 ppm. Two wells in the Spiritwood aquifer produced water that was similar in chemical composition to water from the surficial sand and gravel deposits. These samples may not be representative of water from other buried valley deposits.

There are some general relationships between the dissolved solids and the concentrations of the major constituents in water from the Pleistocene drift (fig. 24). Water containing up to about 3,000 ppm of dissolved solids contains calcium, magnesium, and sodium in that order of abundance. Above 3,000 ppm, both magnesium and sodium tend to exceed calcium. Up to about 1,300 ppm of dissolved solids, bicarbonate is the most abundant anion. Above 1,300 ppm, bicarbonate remains fairly constant, and sulfate increases rapidly and is clearly the chief single constituent causing high dissolved solids in the water. A small fraction of the water from undifferentiated sand and gravel deposits is of the sodium chloride type; however, most of the water is of the calcium sulfate type or calcium bicarbonate type. Most of the water from the valley outwash deposits, outwash plain deposits, and ice contact deposits is of the calcium bicarbonate type. The samples of water from buried valley deposits were of the sodium sulfate type.

Nitrate concentrations in about 25 percent of the samples of the

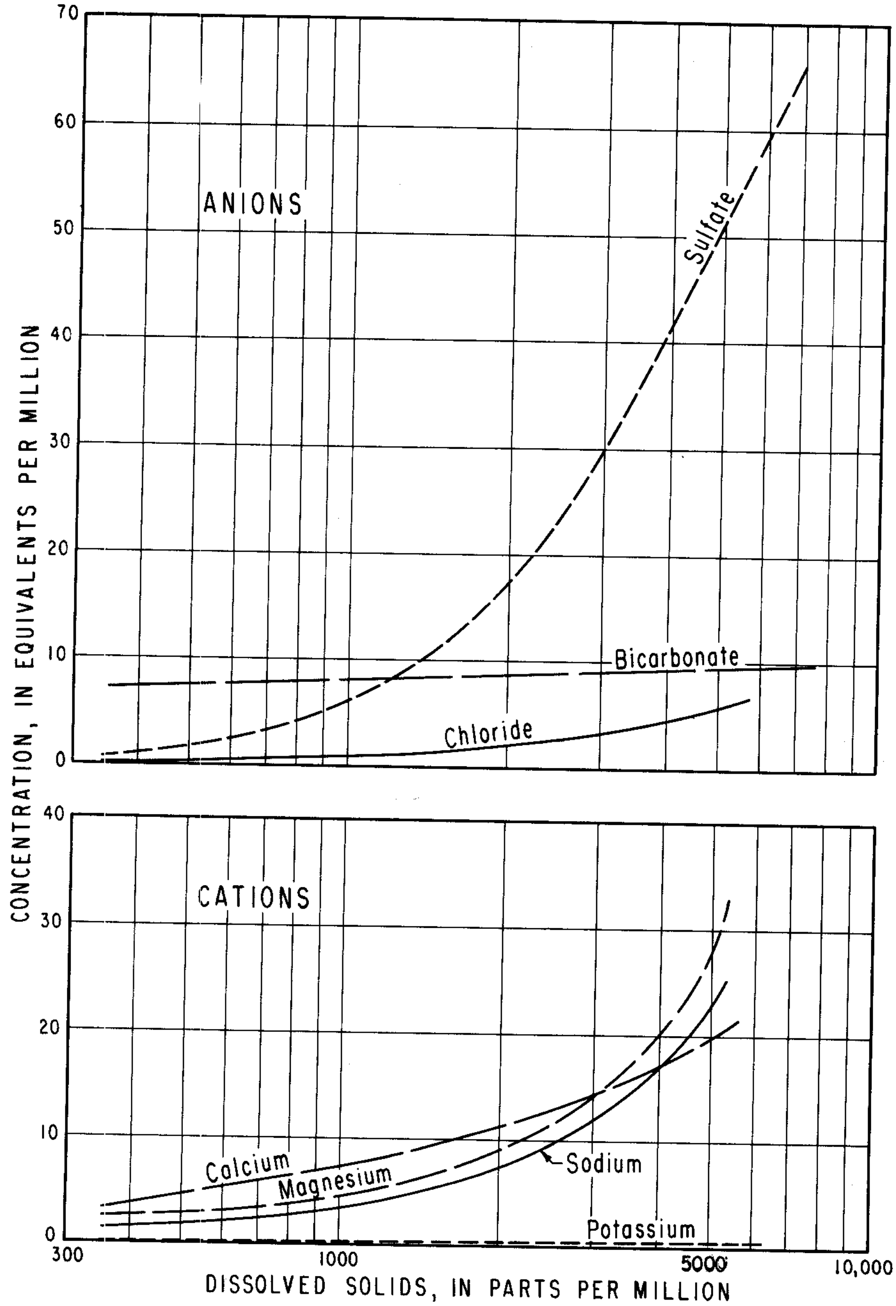


Figure 24 — Relations of major constituents to dissolved solids in water from Pleistocene drift.

water from shallow undifferentiated sand and gravel deposits exceeded 45 ppm. The samples were from wells less than 40 feet deep. Many of the wells are in or near barnyards.

Suitability of the Water for Use

The ground water in Stutsman County is used principally for municipal, domestic, and stock supplies. Most of the water used industrially is from the few municipal supplies of which the largest is the supply for Jamestown. At the present, ground water is used for irrigation in areas of valley outwash. Perhaps, irrigation may prove feasibile in some areas of buried valley deposits. The suitability of ground water for irrigation is also of interest to many residents who irrigate flowers, lawns, and small gardens.

MUNICIPAL, DOMESTIC, AND STOCK SUPPLY

Ideally, drinking water should be cool, clear, colorless, odorless, free of offensive taste, and free of pathogenic or noxious organisms. Also, it should be free of high concentrations of any chemical constituents that may be physiologically harmful, esthetically objectionable, or economically damaging. Nature seldom provides such an "ideal" water; few supplies can be found that could not be improved by some form of water treatment.

For drinking water, most people prefer a temperture of 50°F or lower. According to the California Institute of Technology (1957), p. 392), temperatures of 60° F or higher are usually objectionable to many people and temperatures of 65° F or higher are objectionable to most people. The average temperature of about 45° F contributes significantly to the palatability of the water from Pierre Shale and Pleistocene drift. The average temperature of 62° F, however, undoubtedly detracts from the palatability of the water from the Dakota Sandstone. The low average temperature of most of the ground water is undoubtedly an advantage to farmers in cooling and preserving dairy products destined for market.

Most of the ground water when pumped is clear, nearly colorless, and odorless. However, water from some of the old flowing wells tapping the Dakota Sandstone contains fine sand and rust particles which settle rapidly from the water. The water becomes cloudy upon exposure to the air because of the formation of iron, manganese, and possibly aluminum oxides. None of the water sampled had objectionable odor, but some had objectionable taste. Taste, however,

Table 6.–Relation of the quality of water in Stutsman County to drinking-water standards of the U. S. Public Health Service.

WATER-BEARING UNIT	Dissolved solids			Iron (Fe)			Manganese (Mn)			Sulfate (SO_4)			Chloride (Cl)			Fluoride (F)			Nitrate (NO_3)		
	Percentages of samples having concentrations greater than the standards or multiples thereof																				
	500 ppm a	1,000 ppm	2,000 ppm	0.3 ppm a	0.6 ppm	1.2 ppm	0.05 ppm a	0.10 ppm	0.20 ppm	250 ppm a	500 ppm	1,000 ppm	250 ppm a	500 ppm	1,000 ppm	1.7 ppm a	3.4 ppm	6.8 ppm	45 ppm a	90 ppm	180 ppm
Dakota Sandstone	100	100	100	63	63	25	57	57	0	80	80	80	60	20	20	72	14	0	0	0	0
Pierre Shale	100	94	56	60	47	27	55	55	18	37	12	0	56	44	44	0	0	0	0	0	0
Undifferentiated sand and gravel deposits; Buried valley deposits	84	62	24	44	31	7	78	71	51	65	40	20	7	0	0	0	0	0	22	15	7
Undifferentiated outwash deposits; Ice-contact deposits; Valley outwash deposits	65	6	0	66	50	31	87	87	46	35	0	0	0	0	0	0	0	0	18	6	0

a Drinking water standards.

cannot be evaluated objectively, for what to one person may taste objectionable may to another taste good. No attempt was made in this investigation to determine the presence or absence in the water of harmful micro-organisms.

The suitability of water for drinking commonly is evaluated in relation to the standards of the U. S. Public Health Service (U. S. Department of Health, Education, and Welfare, 1962), which are given, in part, in table 6. The dissolved-solids content of most of the water from the Dakota Sandstone, Pierre Shale, and undifferentiated sand and gravel deposits exceeds the recommended limit by several fold. The dissolved-solids content of most of the water from the other aquifers exceeds the standard concentration by only a few hundred parts per million. Drinking of water having 2,000 to 4,000 ppm of dissolved solids probably does not cause physiological effect of a permanent nature in people. However, such water is likely to be unpalatable, a poor thirst quencher, and a laxative to some people. Water having a very high dissolved-solids content is likely to contain one or more individual constituents in high concentration, is likely to be very hard, and is likely to be esthetically objectionable as well.

Iron and manganese, which chemically are closely related, were found in ground water from all the aquifers. The samples did not contain amounts known to cause harmful physiological effects. They do, however, affect adversely the taste of the water and may discolor food products during cooking. Also, they stain porcelain, enamelware, and fabrics. Concentrations of both iron and manganese in most of the water are sufficiently high to be objectionable. Much of the iron probably can be removed by chemical softening processes. Manganese, however, is more difficult to remove than iron and frequently is not removed at all by ordinary softening methods. Both iron and manganese can be precipitated merely by allowing the water to stand in contact with the atmosphere for a sufficient time.

Large amounts of sulfate in water, especially in combination with magnesium, act as a laxative to new users. Most people who regularly drink water containing much sulfate develop a tolerance for it, but the upper limit that the body can tolerate is not known. The sulfate content of most of the water from Dakota Sandstone and from undifferentiated sand and gravel deposits is much in excess of the recommended limit.

The high chloride content in much of the water from the Dakota Sandstone and Pierre Shale causes a salty taste.

Many cities add fluoride to the drinking water to reduce dental decay among children. On the other hand, too much fluoride can cause mottled teeth, fluorosis, and skeletal damage (California Institute of Technology, 1957, p. 257). The amount added during fluoridation, therefore, must be carefully controlled to keep it near the optimum. The optimum concentration according to the Standards varies with the average amount of water people consume; therefore, it depends on climatic conditions and varies from one part of the country to another. The optimum concentration of fluoride in drinking water in North Dakota is 1.2 ppm and 2.4 ppm constitutes grounds for rejection of the supply (U. S. Department of Health, Education and Welfare, 1962, p. 8).

Nitrate is the end product in the decomposition of organic wastes; therefore, high concentrations of nitrate may indicate pollution of the water. High concentrations of nitrate in water used for preparing feeding formulas may cause methemoglobinemia, a blue-baby disease (Silverman, 1949).

Hard water causes curd to form when soap is added and causes scale in water pipes, heaters, and boilers. Hardness of water commonly is evaluated according to the following graduations:

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

Most of the ground water in Stutsman County is very hard.

The raw water from the municipal supply in Jamestown contains excessive amounts of iron and manganese and is very hard. The water is softened by the lime process and is fluoridated and chlorinated. During the softening process the dissolved solids are also reduced and iron and manganese are removed. Data in the table below, provided by the Jamestown Water Department, show the quality of the raw and finished water.

Constitutuent or property	Raw water, wells 1, 2, 3, 4 (January 1962)	Finished water, storage tank (June 1962)
	ppm	ppm
Dissolved solids	918	586
Hardness as $CaCO_3$	312	95
Irone (Fe)	2.9	0.0
Manganese (Mn)	.3	0.0
Sulfate (SO_4)	208	230
Chloride (Cl)	32	25
Fluoride (F)	.5	.5
Nitrate (NO_3)	28	0.0

INDUSTRY

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

Water used in heat exchangers, such as heaters, boilers, and air conditioners, should not be corrosive, scale forming, nor conducive to slime formation. Corrosion is a very complex process; among the characteristics of water that may contribute to corrosion are low pH, low alkalinity (reported as bicarbonate), low hardness, high content of free carbon dioxide, and high concentrations of iron sulfate or magnesium chloride. Corrosion is impeded by the presence of a thin coating of scale on metal surfaces. Scale formation generally is caused by calcium and magnesium, which precipitate as carbonates or sometimes with sulfate; it can also be caused by silicates, oxides of iron, and other substances. The relative corrosiveness or scale-forming tendencies of ground water from Stutsman County was estimated with the "Langlier calcium carbonate saturation index" (Powell, 1954, p. 278).

The calcium carbonate saturation index for 80° F was positive for water from all but two wells in Stutsman County and averaged between +0.2 and +0.6 for all aquifers. Consequntly, near room temperature the water from all aquifers has at least a slight tendency to form scale. The tendency to form scale increases with temperature and is pronounced in the water at 160° F, a temperature commonly used in home water heaters. Water from the Pierre Shale and from the undifferentiated sand and gravel deposits have much stronger tendencies for scale formation than water from other aquifers as can be seen from the following table by their greater indexes.

Water-bearing unit	Average calcium saturation index (All values are positive) at 80° F	at 160° F
Dakota Sandstone	0.3	1.0
Pierre Shale	.6	1.4
Undifferentiated sand gravel deposits	.6	1.4
Buried valley deposits	.3	1.1
Undifferentiated outwash deposits	.2	.9
Ice-contact deposits	.3	1.1
Confined outwash deposits	.2	.9
Valley outwash deposits	.3	1.1

The higher concentrations of iron in the water are conducive to the growth of iron bacteria that may form slime which in turn may interfere with efficient use of water in coolers and air conditioners. Disinfectants or growth inhibitors may be required to control the growth of the bacteria unless the iron is removed from the water.

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

Water used for processing comes into contact with, or is actually incorporated into, a product. The quality-of-water requirements depend on the product manufactured and are very exacting for some products (California Institute of Technology, 1957). Some of the ground water in Stutsman County would be suitable for many industrial uses if it is softened and if the iron and manganese are removed. However, the dissolved solids, sulfate, and chloride contents, which would remain in much of the water even after softening, would detract greatly from the suitability of the water for some industrial uses.

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

Constituent or Property	Food processing (general)	Carbonated beverages	Laundering	Plastics clear, uncolored	Tanning
Color	....	10	....	2	10-100
Dissolved solids	850	850-855	....	200	....
Hardness	10-250	200-250	50	....	50-135
Alkalinity ($CaCO_3$)	30-250	50-128	....	....	135
Iron and manganese	0.2-0.3	0.1-1.5	.2	.2	.2
Sulfate	....	250	....	....	....
Chloride	....	250	....	....	....
Fluoride	1.0	0.2-1.0	....	....	....
pH	....	....	....	....	8.0

IRRIGATION

Water for irrigation should be of such quality that continued use of it will not adversely affect the productivity of the land. High concentrations of dissolved solids in the water may cause undesirable accumulations of salts in the root zone of the soil, and disproportionately high concentrations of sodium in the water may cause the soil to become impermeable. Concentrations of bicarbonate too much in excess of the concentrations of calcium and magnesium may cause the pH of the soil to become high and may cause a soil condition as "black alkali". Also, high concentrations of boron in the water may be toxic to some plants.

According to a system of classifying water proposed by the U. S. Salinity Laboratory Staff (1954), the tendency of water to cause accumulations of salt in the root zone of the soil is called the "salinity hazard" of the water and is indicated by the letter "C" and numbers 1 to 4; the higher the salinity hazard, the higher the subscript. The tendency of water to cause the soil to become impermeable because of too much sodium is called the "sodium hazard" of the water and is indicated by the letter "S" and numbers 1 to 4; the higher the sodium "hazard", the higher the number.

Nearly all the water from bedrock and much of the water from undifferentiated sand and gravel deposits is either of the C4-S4 or the C4-S3 class; because of the very high salinity hazard and the high or very high sodium hazard, the water from these aquifers is of poor quality for irrigation. Some of the water from the undifferentiated sand and gravel deposits and most of the water from the other Pleistocene drift aquifers are of either the C2-S1 or the C3-S1 class, have no excess of bicarbonate, and have low concentrations of boron. These waters, therefore, are of fair to good quality for irrigation. Water from some of the buried valley deposits, however, according to the two samples from the Spiritwood aquifer, may have excessive concentrations of bicarbonate.

SUMMARY

Sources of ground water in Stutsman County are the Cretaceous bedrock formations and the Pleistocene glacial drift. The drift furnishes the most readily available and the largest ground-water supplies.

The bedrock formations that function as aquifers are the Dakota Sandstone and the Upper Cretaceous Pierre Shale. The shale is an aquifer only in its upper part where it is fractured or jointed. The water from the Dakota Sandstone has limited use because of its depth and high mineral content. The Pierre Shale furnishes some ground-water to many farms in Stutsman County, especially in areas where adequate supplies from the glacial drift are not available.

Glacial drift is the most important water-bearing material in Stutsman County. It is a complex of materials that have a very low to high permeability and range in size from clay to boulders. The drift is classified as: (1) glaciofluvial, (2) glaciolacustrine, (3) buried glacioaqueous, and (4) till. With the exception of till, the sediment types are classified into two or more geohydrologic units on one or more of the following bases: lithology, associated landforms, position in the drift, and water-bearing characteristics (table 2).

The three major aquifers in Stutsman County are: (1) the Jamestown aquifer which consists of valley outwash deposits; (2) the Marstonmoor Plain aquifer which consists of unconfined outwash deposits; and (3) the Spiritwood aquifer which consists of buried valley deposits. The Jamestown aquifer furnishes water to the city of Jamestown and several industries and institutions in Jamestown. The Marstonmoor Plain aquifer is virtually undeveloped as a source of ground-water supply, but its size and its assumed permeability indicate that its water-yielding potential is equal to that of the Jamestown aquifer. The Spiritwood aquifer is buried under a thick cover of till and is areally the largest aquifer in Stutsman County. It is tapped only by farm wells yielding supplies for domestic and stock uses. Its capacity for furnishing large ground-water supplies is unknown, however, its size and the coarseness of its sediments indicate that it is an excellent aquifer.

Till greatly influences the occurrence and movement of ground water in the drift. It is generally a tight, silty, clay with minor admixtures of sand, gravel, cobbles, and boulders.

The dissolved-solids content of water from the Dakota Sandstone and of more than half the water from the Pierre Shale exceeded 2,000 ppm. Most of the water from these Cretaceous deposits was very hard but some from the Pierre was soft. Most of the water from the Dakota was of the sodium sulfate type and most of the water from the Pierre was of the sodium chloride type.

Dissolved solids concentration in samples of water from undifferentiated sand and gravel deposits of Pleistocene age ranged from 352 to 5,360 ppm, whereas that from surficial sand and gravel deposits ranged from 332 to 1,190 ppm. Most of the water from deposits of Pleistocene age is of the calcium bicarbonate type if the dissolved solids concentration is less than 1,300 ppm. If the dissolved solids concentration exceeds 1,300 ppm, most of the water is of calcium sulfate type.

The boron content of 1 to 5 ppm for water from the Dakota and the Pierre and the average fluoride content of 2.4 ppm for water from the Dakota are significantly higher than the content of these constituents in water from other aquifers. Fluoride and boron content of the water are helpful in distinguishing between waters from bedrock units and geohydrologic units of the drift.

Because of the high dissolved solids, iron, manganese, sulfate or chloride contents of the water and because of the hardness, most of the ground water is of relatively poor quality for domestic, municipal, or industrial uses. However, softening and iron and manganese removal from water of surficial sand and gravel deposits, such as the valley outwash deposits used for municipal supply by Jamestown, results in water that is acceptable for most uses.

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