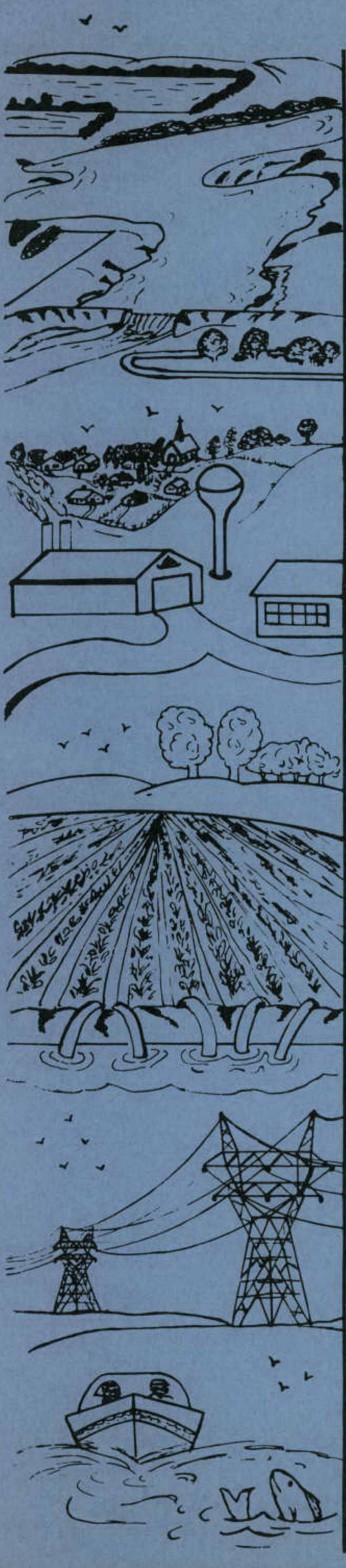

GROUND-WATER SURVEY OF THE ROCK LAKE AREA

TOWNER COUNTY, NORTH DAKOTA

N.D.S.W.C. PROJECT NO.1364

by

Alain A. Kahil, Geologist

NORTH DAKOTA GROUND WATER STUDIES

NO. 63

PUBLISHED BY
NORTH DAKOTA STATE WATER CONSERVATION COMMISSION
1301 STATE CAPITOL, BISMARCK, NORTH DAKOTA

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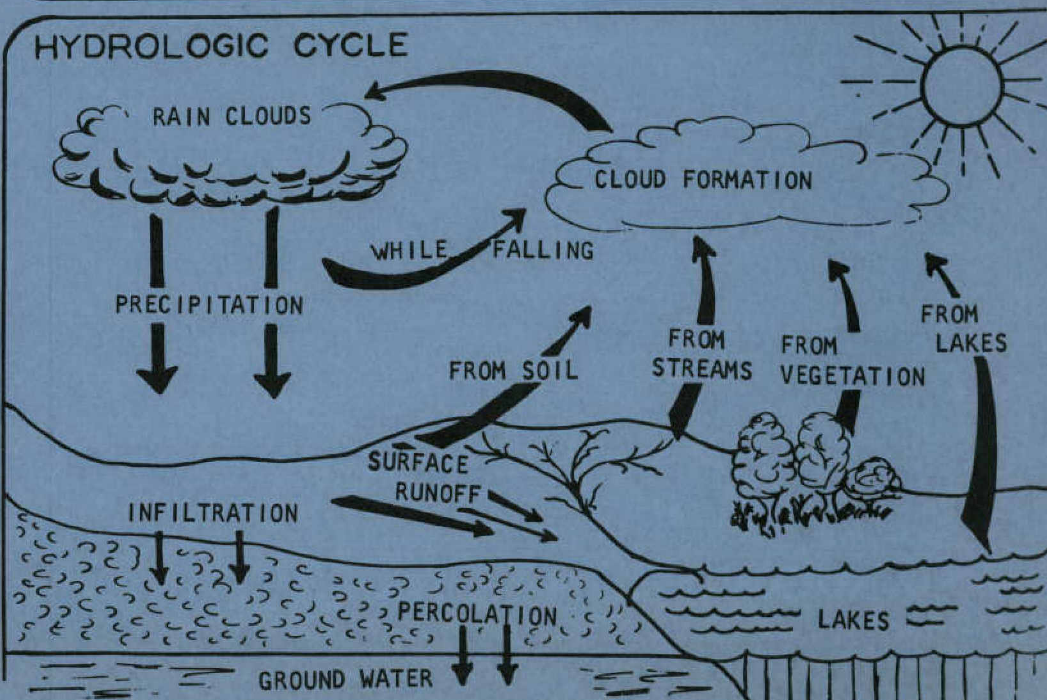

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GROUND-WATER SURVEY OF THE ROCK LAKE AREA

TOWNER COUNTY, NORTH DAKOTA

INTRODUCTION

Purpose and Location

On September 21, 1964, the North Dakota State Water Commission began a ground-water survey for the village of Rock Lake. The survey was undertaken at the request of the Village Council, to locate an aquifer suitable for a municipal water supply.

The village of Rock Lake is located in the north-central part of Towner County (Fig. 1), one mile east of the junction of State Highway 5 and U. S. Highway 281. Portions of the village are included in sections 5, 6, 7, and 8 of Township 161 North, Range 66 West.

The village has a population of 350 (1960 census) and is served by the Great Northern Railway. There are no industries in town that would require a greater amount of water than the collective average household need.

There is no municipal water supply in the village of Rock Lake. The water used by the villagers is derived from private wells. These are usually located within the village limits and are almost invariably completed in the Pierre Shale which underlies the entire study area.

In the past sewage and other wastes have been released into Rock Lake. However, a modern sewage system has now been installed which disposes the wastes into a lagoon east of town. There are persons living outside the village limits who still use Rock Lake for the disposal of sewage. For several years the Village Council has encouraged these people to use the city sewage facilities, but these attempts have not been entirely successful.

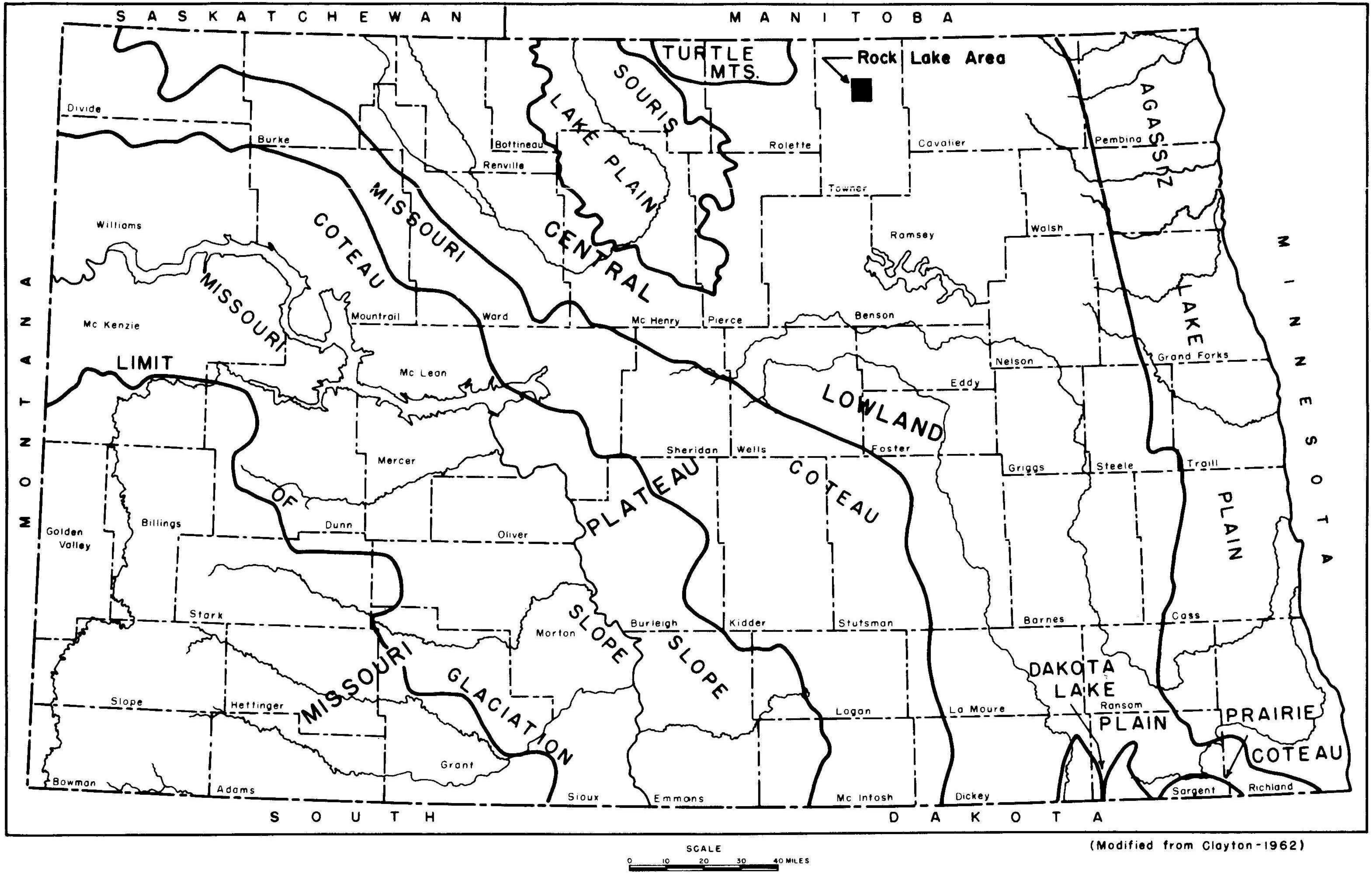

FIGURE I--MAP OF NORTH DAKOTA SHOWING PHYSIOGRAPHIC UNITS AND LOCATION OF THE ROCK LAKE AREA

Scope of Study

The study undertaken involves an area of about thirty square miles situated around the village of Rock Lake. It includes an inventory of selected wells, a topographic study using aerial photographs, the drilling of fifteen test holes, and the installation of observation wells in test holes 1 (NW$\frac{1}{4}$,NE$\frac{1}{4}$,SW$\frac{1}{4}$, Sec. 7, Twp. 161 N., R.66 W.), 4 (SW$\frac{1}{4}$,SE$\frac{1}{4}$,NW$\frac{1}{4}$,Sec. 6, Twp. 161 N., R.66 W.), 6 (SW$\frac{1}{4}$,SE$\frac{1}{4}$,SW$\frac{1}{4}$, Sec. 18, Twp. 161 N., R.66 W.), and 10 (NE$\frac{1}{4}$,NE$\frac{1}{4}$,NE$\frac{1}{4}$, Sec. 14, Twp. 161 N., R.67 W.). Detailed chemical analyses of water samples collected from these observation wells and Rock Lake were made by the State Laboratories Department. Bacteriological analyses of water from observation wells 1, 6, and 10 were made by the North Dakota State Department of Health in Bismarck. Due to the lack of topographic coverage, an altimeter survey was made by the author in order to determine the elevation of the test hole sites. These elevations have not been published due to their low order of accuracy.

Well-numbering System

The well numbering system used in this report, illustrated in Figure 2, is based on the location of the well in the Federal system of rectangular survey of public lands. The first numeral denotes the township north of the base line; the second denotes the range west of the fifth principle meridian; and the third numeral denotes the section in which the well 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). Thus well 161-66-15daa would be located in the NE$\frac{1}{4}$, NE$\frac{1}{4}$, SE$\frac{1}{4}$, Section 15, Township 161 North, Range 66 West.

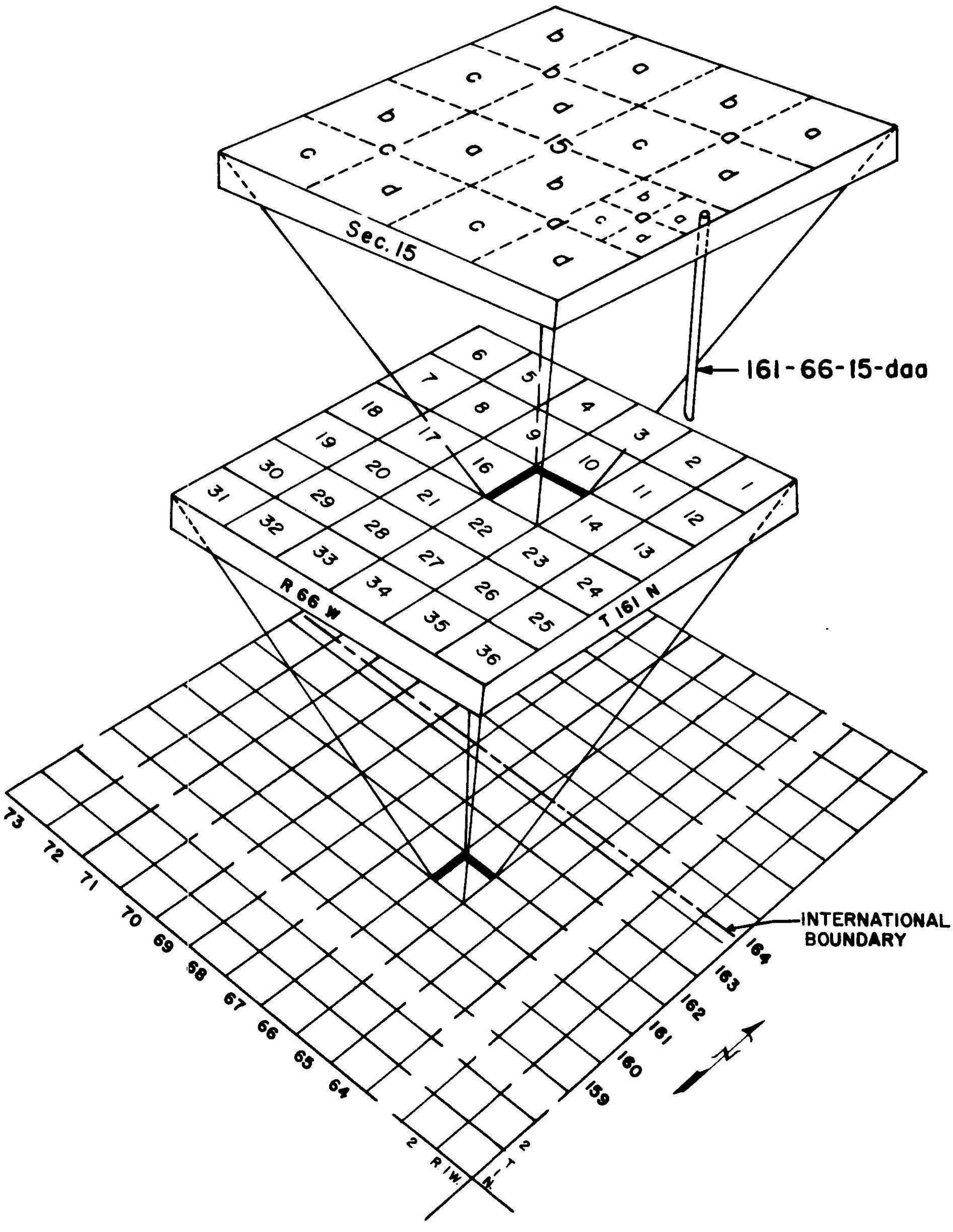

FIGURE 2--SYSTEM OF NUMBERING WELLS AND TEST HOLES.

Local Climatic and Drainage Conditions

The United States Weather Bureau does not maintain a recording station at Rock Lake. The closest stations are at Rolla, Bisbee, Munich, and Hansboro. These stations surround the Rock Lake area, and thus give an approximation of the climatic conditions at Rock Lake. They record a long term average annual temperature of 37.2, 38.0, 36.3*, and 37.1°F respectively, and a long term average annual precipitation of 17.56, 16.85, 16.89*, and 17.50 inches respectively. (U. S. Weather Bureau Annual Summary, 1948-1964.)

The drainage in the area is poorly integrated. According to Simpson (1929, p. 237) a fraction of one percent of the precipitation is removed by runoff; the rest either is absorbed directly by the soil, or accumulates in catchment areas to form lakes and swamps from which it evaporates or percolates into the ground.

The majority of the Rock Lake area is in the Pembina drainage system (Figure 3); the remainder is in the Mauvais Coulee drainage system which is included in the larger Devils Lake drainage basin. The drainage divide passes through Rock Lake forming two natural outlets for the lake water. The southern outlet has been artificially closed off because water repeatedly overflowed the banks of the shallow drainage channels south of Rock Lake causing considerable flooding of farmland in that area.

Previous Investigation

No detailed hydrologic or geologic investigations have been made in the Rock Lake area or the adjoining areas prior to this study.

Howard Simpson, in a report published in 1929 (p. 236), describes the general geology and hydrology of Towner County. Included in his report is a list of typical wells of the county and two chemical analyses of water from wells within the county.

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* Figures given for Munich are not true long term averages, but are averaged over a 17 year period.

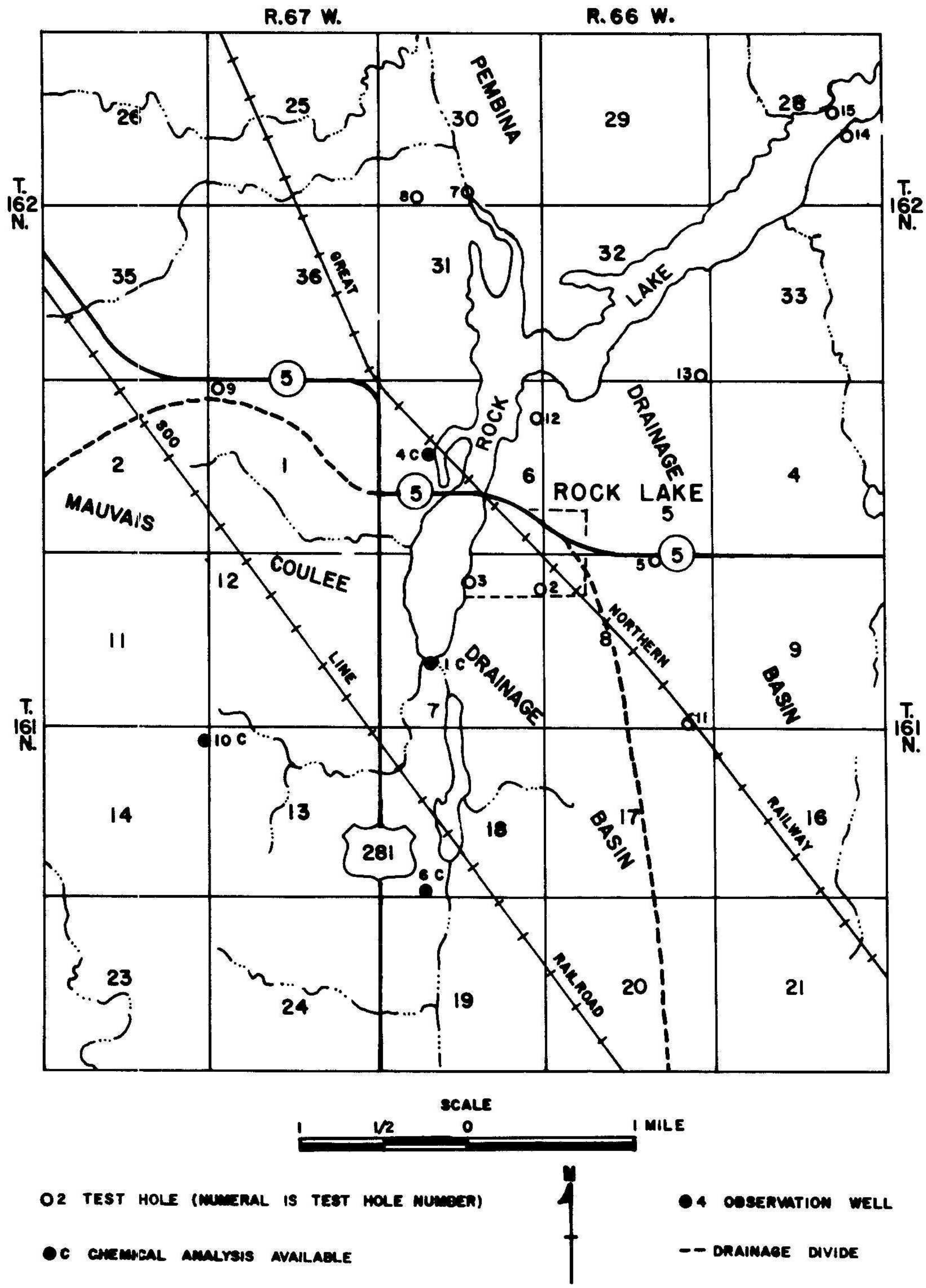

FIGURE 3--MAP SHOWING TEST HOLE LOCATION AND DRAINAGE DIVIDE
(FROM UNPUBLISHED MAPS OF THE STATE WATER COMMISSION)

Chemical analyses of water collected from within Towner County are published in a report by Abbott and Voedisch (1938). Two of these analyses are of waters obtained from within the Rock Lake area and are included in Table 2.

GEOLOGY

Pierre Shale

The only bedrock encountered in the Rock Lake area is the Pierre Shale of the Montana Group, deposited as marine sediments during the Late Cretaceous Period. The Pierre Shale, in the study area, consists primarily of an indurated, dark greenish-gray to olive-gray, unfractured shale, usually interbedded with a lighter-colored, soft, bentonitic (?) clay. The shale layers are hard and almost totally impervious to water.

The Pierre Shale, although encountered in all of the 15 test holes drilled during this study, was never completely penetrated; thus, its thickness in the Rock Lake area is not known. The deepest penetration into the formation was $51\frac{1}{2}$ feet in test hole 3 (161-66-7abc).

Test hole drilling indicates that the surface of the Pierre Shale is somewhat irregular in the area. A difference in elevation of about 160 feet was found on the bedrock surface within the village limits (161-66-7abc and 161-66-7aad), and a maximum difference of about 379 feet throughout the study area (161-66-7abc and 161-67-14aaa).

Glacial

The Rock Lake area is in the Young Drift Section of the Central Lowland Province, West of the Mississippi (Fenneman, 1938) (Figure 1). The entire province was glaciated during the Pleistocene Epoch. The material deposited as a result of glaciation, glacial drift, masks the preglacial topography in the province, giving it its characteristic undulating surface of low relief.

The material incorporated in a glacier is deposited in two principle ways. The bulk of this material is deposited directly by the ice and consists of an unstratified, heterogeneous mixture of clay, sand, gravel, and boulders, called till. The remainder is deposited by glacial meltwaters in the form of stratified drift, composed of variably-sorted silt, sand, and gravel. When found below the water table, or when underlain by impervious material, these deposits may form good aquifers, depending on the nature of the detritus forming them and the presence of a source of recharge.

In the Rock Lake area, the thickness of the glacial drift ranges from zero (161-66-7abc and 161-66-6aad) to 409½ feet (161-67-14aaa). Within the glacial drift, there are sand and gravel deposits that range in thickness from 2 feet (161-66-8ddc) to 18 feet (161-66-8ddc). The most significant sand and gravel deposits, however, are those that were deposited directly on bedrock (161-66-7cab, 161-66-6bdc, 161-66-18cdc, and 161-67-14aaa).

The present topography of the Rock Lake area was formed primarily by the Post-Cary maximum drift advance number 3 (Lemke and Colton, 1959, p. 53) which is believed to be the last glacial advance over this area. It is represented in the study area by ground moraine, the topographic expression of which where unaltered, is a rolling till plain with several shallow depressions.

Portions of the ground moraine in the Rock Lake area were modified by meltwater from the receding glacier. The meltwater deposited sand and gravel outwash along a sluiceway which starts in Canada, passes through the center of the Rock Lake area, and ends in Glacial Lake Cando, located in the southeast corner of Towner County (Colton, and others, 1963). These outwash deposits were partly eroded at a later date and are now represented by disconnected bodies of sand and gravel. The sluiceway entered the Rock Lake area from the north in two separate channels. One occupied the present Mauvais Coulee channel, while the other followed a course corresponding to the present Rock Lake. These two channels joined about one mile north of the village to form a single channel (Fig. 4) (Colton, and others, 1963).

The topography of the eastern half of the study area has less relief than that of the ground moraine in the west. This area consists of a ground moraine reworked by meltwaters which flooded the area, on one or several occasions, and readjusted the previously deposited drift.

The Rock Lake area can therefore be divided into three parts with respect to the surface topography, the ground moraine, the outwash channel, and the modified ground moraine as indicated in Figure 4.

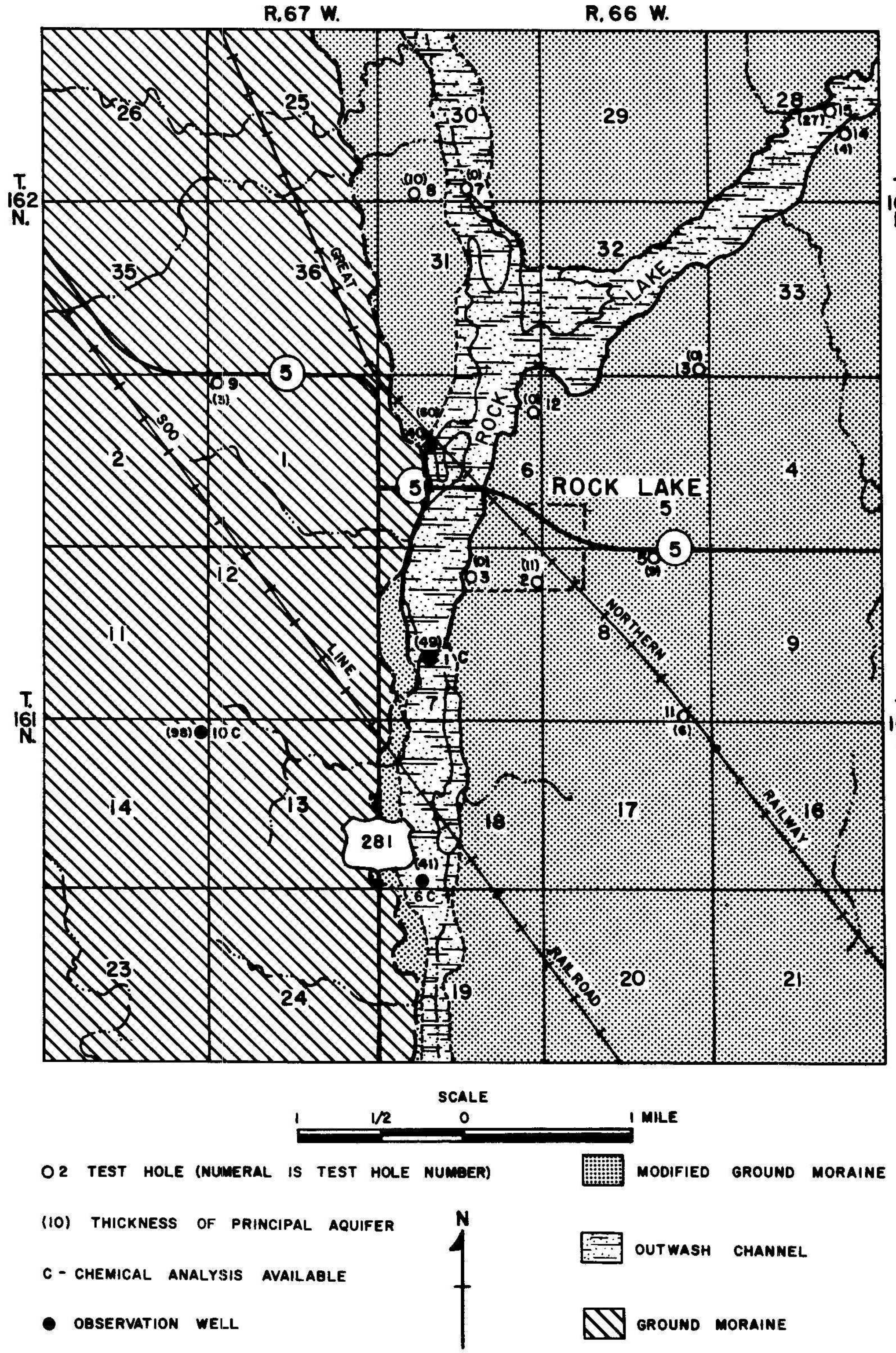

FIGURE 4--MAP SHOWING THE TOPOGRAPHIC DIVISIONS OF THE ROCK LAKE AREA

HYDROLOGY

The Pierre Shale is generally considered a poor aquifer due to the highly impervious nature of the shale. Some water is obtained from sand occasionally found interbedded with the shale; however, the sand receives very little recharge from the shale and, consequently, the quantity of water available from such aquifers is limited. A larger source of water is available from the Pierre Shale wherever the upper portion is weathered and jointed (Abbott and Voedisch, 1938, p. 35). These two conditions, however, are of a local extent in North Dakota and were not encountered in the Rock Lake area.

Glacial drift aquifers in the Rock Lake area constitute a more dependable source of water. In the four observation wells, sand and gravel bodies were encountered that ranged from forty-nine (161-66-7cab) to ninety-eight (161-67-14aaa) feet in thickness.

The sand and gravel in observation wells 6 (161-66-18cdc) and 10 (161-67-14aaa) were deposited before the last glaciers advanced over the area and are thus found, at the present, buried beneath younger glacial drift deposits. The aquifer in observation wells 1 (161-66-7cab) and 4 (161-66-6bdc) was deposited as glacial outwash from the last glacier that retreated from the Rock Lake area and thus crops out at the surface wherever it is not covered by recent alluvium.

Stiff diagrams are used for comparing the chemical composition of various water samples. They consist of a graphical representation of the ionic concentration of the different constituents dissolved in water, in equivalents per million. An ion is a charged atom or group of atoms. In Figure 5 cations (positive ions) are plotted on the left of a vertical zero line while anions (negative ions) are plotted on the right. Equivalents per million is a unit expressing the combining power of the different ions in a solution. Thus a certain number of equivalents per million cations will combine with the same number of equivalents per million anions. This method of addition and subtraction of cations and anions cannot be made when their concentrations are expressed in parts per million. Stiff diagrams of waters collected from the Rock Lake area (Figure 5), indicate that the water from the observation wells fall into two distinct groups. The first includes water from observation well 1 and 4 while the other includes water from observation wells 6 and 10.

The time difference in the deposition of the aquifers and the quality of the water in the aquifers indicates a possible hydrologic separation between the two groups, and a possible hydrologic connection between the observation wells within each group. A hydrological connection means that water can flow relatively unimpeded from one location to another while a hydrological separation means that the flow of water between two locations is absent, or highly restricted.

The aquifer encountered in observation well 1 is believed to be hydrologically connected to the lake because of the nature of outwash deposits. Outwash deposits, form continuous deposits of permeable material along meltwater channels. It is improbable that all of the outwash deposits between observation well 1 and the lake were removed by erosion subsequent to their deposition, due to the presence of 49 feet of sand and gravel at a distance of about 35 yards from the lake. Thus, in addition to direct recharge from precipitation, this aquifer is usually recharged by Rock Lake. Seasonal fluctuation in the lake level, however, may cause the aquifer to discharge into the lake.

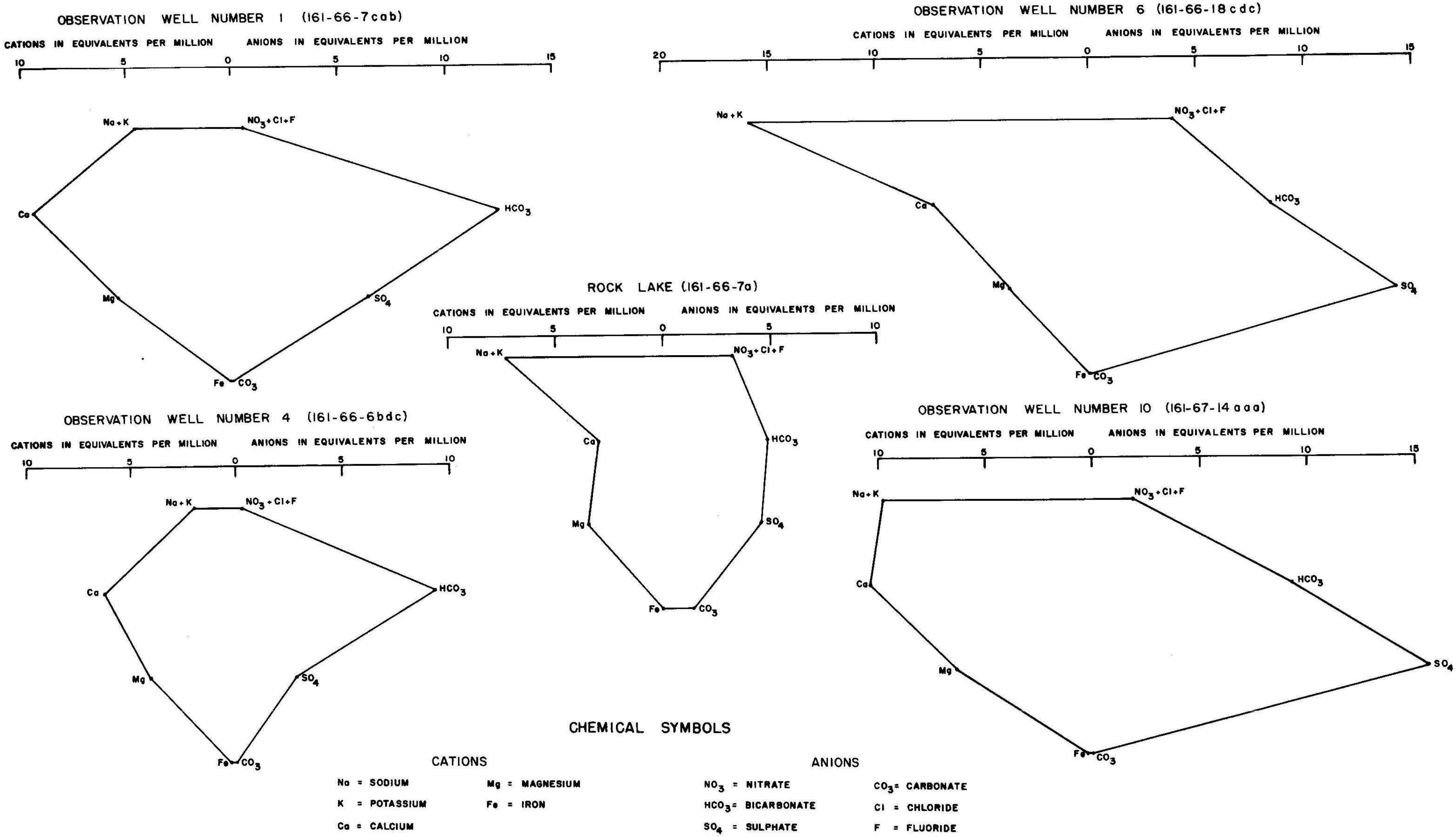

FIGURE 5 --STIFF DIAGRAMS OF CHEMICAL ANALYSIS OF WATER FROM OBSERVATION WELLS AND ROCK LAKE

The hydrologic connection of observation well 4 to observation well 1 may be absent due to possible post-glacial erosion of the detritus between the two observation wells. As observation well 1 is hydrologically connected to the lake, a hydrological connection between the two observation wells will be represented by a similarity in the elevation of the water levels in observation well 4 and the lake. Any significant dissimilarity in the elevations of the water levels would indicate that observation well 4 is not hydrologically connected to Rock Lake or observation well 1. Several water level measurements should be made before the hydrological connection or separation of the observation well to the lake can be established.

The quantity of the recharge entering the aquifer encountered in observation well 4 will depend on whether it is hydrologically connected to the lake. If this connection exists, then the same situation is present as in the case of observation well 1. If, on the other hand, this connection is absent, the aquifer will be recharged only by direct infiltration of precipitation.

WATER QUALITY

Chemical analyses of water samples collected in this study, along with chemical analyses of water from the Rock Lake area obtained from the North Dakota State Department of Health and from Abbott and Voedisch (1938) are given in Table 2. Table 3 gives the significance of various constituents in water for domestic or municipal supplies in North Dakota (Schmid, 1965).

Glacial drift water is superior in quality to the Pierre Shale water in the Rock Lake area. Excessive concentrations of sodium, total dissolved solids, and either sulfates or chlorides are found in the Pierre Shale water. The removal of such material is not economically feasible; thus, the water from the Pierre Shale is undesirable for domestic use. The glacial drift water has a very high hardness content as well as excessive iron concentration. Sulfates are present in objectionable concentrations in observation wells 6 (161-66-18cdc) and 10 (161-67-14aaa). The presence of hardness and high iron concentration in drinking water is not physiologically harmful to humans; however, they are objectionable in water for household use because of the color iron imparts to laundered goods and because of the increased soap consumption caused by hardness. Hardness and iron can be readily reduced making the water from observation wells 1 and 4 more desirable for a municipal supply than Pierre Shale water.

Due to the hydrologic connection of observation well 1 to the lake, the quality of the water in the well may change upon pumping the well. This change will be caused by a greater quantity of lake water entering the aquifer. The rate of pumping will determine the extent to which the water from the well will approximate the quality of the lake water. The same situation will be present for the aquifer encountered in observation well 4 if it is hydrologically connected to Rock Lake. The quality of water from the lake is generally better than that of the observation wells. The only two significant disadvantages of lake water is its higher sodium content and its probable bacterial content. The iron content of the lake water is higher than that present in observation well 1, however, in either case the iron is in excessive concentrations and should be removed before the water is used for a municipal supply. The concentration of total dissolved solids is higher in the lake water than that in the water from observation well 4; however, both concentrations are within the average range. Thus, the increase of total dissolved solids caused by the lake water mixing with the water in the observation well would be of no practical significance.

Bacteriological analyses of water from observation wells 1, 6, and 10 indicates that observation well 1 may be contaminated with intestinal bacteria. Bacterial contamination can be removed by a chlorination process.

RECOMMENDATIONS

From available data the aquifer encountered in observation well I (161-66-7cab) appears to be the most reliable source of water for the village of Rock Lake. The quality of the water obtained from a well in this aquifer will vary with the variation in the quality of the lake water, and the rate at which the well is pumped. Treatment of the water for the reduction or removal of possible bacterial contamination, iron, and possibly hardness will, however, probably have to be undertaken throughout the year.

If the aquifer encountered in observation well 4 is not hydrologically connected to the lake and if the quality of the water derived from it is preferable to the village, the amount of water capable of being derived from the aquifer will have to be determined before the aquifer can be used for a municipal water supply. Such a determination would require additional test drilling, observation well installation, and a pumping test.

Test hole II (161-66-8ddc) encountered an aquifer consisting of 18 feet of gravel, which may be a potential source of water for a municipal supply. This gravel lacks the red stain which was present in most of the other gravel encountered in this study. This may indicate the presence of a water with low iron concentration. However, additional investigation would be necessary to determine the extent and nature of the aquifer and whether a source of recharge is present. Such investigations need not be undertaken unless the other sources of water are undesirable to the village.

TABLE I

SUMMARY OF TEST HOLE LOGS

The following logs are summarized from those compiled by the author during the drilling operations. Information used in the logs was obtained from direct analysis of the cuttings, the driller's log and electric logs. All figures for depth and thickness are to the nearest half foot.

The Wentworth scale, as represented in Pettijohn (1957, p. 18), is used for grain size nomenclature.

The color names and designations were obtained from the Rock-Color Chart by Goddard, and others (1951). All color descriptions are of wet samples.

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	161-66-6aad Test Hole 1364-12			
	Topsoil..............................	1	0	1
Pierre Shale:				
	Shale, olive gray (5Y4/1) to dark greenish gray (5 GY4/1); interbedded with bentonitic (?) clay layers, slightly sandy at places............	22	1	23
	Shale, olive black (5Y8/1); interbedded with bentonitic (?) clay layers.....	8½	23	31½
	161-66-6bdc Test Hole 1364-4			
Glacial Drift:				
	Topsoil..............................	1	0	1
	Sand, fairly well-to well-sorted, predominately angular, predominate size ¼ mm..........................	39	1	40
	Gravel, fairly well-sorted, subrounded to well-rounded, between 5 and 30 mm in size; interbedded with sand layers, poorly-sorted, average size 1 mm....	21	40	61
Pierre Shale:				
	Shale, olive black (5Y2/1); interbedded with clayey bentonitic (?) layers...	12½	61	73½

TABLE I.--Summary of Test Hole Logs-continued

Formation	Material	Thickness (feet)	Depth (feet) From	To
	161-66-7aad **Test Hole 1364-2**			
Glacial Drift:				
	Topsoil	1	0	1
	Clay, very pale orange (10 YR8/2), sandy, noncohesive, very soft, oxidized	½	1	1½
	Till, light olive gray (5 Y6/1), sandy; very fine; cohesive, highly calcareous	8½	1½	10
	Sand, fairly well-sorted, angular to well-rounded, average size about 1 mm, oxidized	4	10	14
	Clay, (till?), silty matrix with shale fragments, cohesive, soft, noncalcareous, top slightly oxidized; interbedded with clay, dark greenish gray (5 GY4/1), highly calcareous	19	14	33
	Gravel, sandy, poorly-sorted, angular to well-rounded, average size 2 mm, oxidized	8	33	41
	Till, dusky yellow green (5 GY5/2), silty, cohesive, hard	10	41	51
	Gravel, sandy, poorly-sorted, subangular to well-rounded, average size 2 mm	11	51	62
	Till, olive gray (5 Y4/1), gravelly and bouldery, cohesive	22	62	84
	Boulder, granite	1	84	85
	Silt, greenish gray (5 GY5/1), gravelly, cohesive, soft, brittle, silt grades downward to a fine sand	37	85	122
	Sand, grading into till	43	122	165
Pierre Shale:				
	Shale, olive black (5 Y2/1), cohesive, very hard	13½	165	178½
	161-66-7abc **Test Hole 1364-3**			
	Topsoil	1	0	1
Pierre Shale:				
	Shale, olive black (5 Y2.5/1), cohesive, very hard; interbedded with bentonitic (?) clay layers, cohesive, soft	51½	1	52½

TABLE I.--Summary of Test Hole Logs-continued

Formation	Material	Thickness (feet)	Depth (feet) From	To
	161-66-7cab Test Hole 1364-1			
Glacial Drift:				
	Topsoil	1	0	1
	Sand, pale yellowish orange (10 YR8/6), clayey, fairly poorly-sorted, mostly angular, predominate size ½ mm, oxidized	2	1	3
	Sand, fairly well-sorted, subangular to subrounded, predominate size 3/4 mm	27	3	30
	Gravel, slightly sandy, fairly well-sorted, between 5 and 25 mm in size.	20	30	50
Pierre Shale (?):				
	Shale (?), greenish gray (5 GY5/1), cohesive, soft, noncalcareous, unoxidized	13	50	63
	161-66-8aba Test Hole 1364-5			
Glacial Drift:				
	Topsoil	1	0	1
	Boulder, dolomite	½	1	1½
	Till, predominately grayish orange (10 YR7/4) to dark yellowish orange (10 YR6/6), cohesive, fairly soft, highly calcareous, oxidized	9½	1½	11
	Till, olive gray (5 Y3.5/1) to dark greenish gray (5 GY3.5/1), silty, cohesive, fairly hard, unoxidized, dolomite boulders	14	11	25
	Pierre Shale (?), dark greenish gray (5 GY3/1), cohesive, soft, non-to very slightly calcareous, bentonitic (?) clay matrix with shale fragments	2	25	27
	Till, dark greenish gray (5 GY4/1) to olive gray (5 Y4/1), cohesive, hard, highly calcareous	27	27	54
	Till, as above; interbedded with gravel, mostly rounded to subrounded	23	54	77
	Sand, poorly-sorted, mostly angular, average size 1½ mm; interbedded with gravel	9	77	86
	Till, olive gray (5 Y4/1), gravelly, highly calcareous	56	86	142
Pierre Shale:				
	Shale, olive black (5 Y3/1), interbedded with clayey bentonitic (?) layers; lenses of sand, white, very fine, non-to very slightly calcareous	15½	142	157½

TABLE I.--Summary of Test Hole Logs-continued

Formation	Material	Thickness (feet)	Depth (feet) From	To
	161-66-8ddc Test Hole 1364-11			
Glacial Drift:				
	Topsoil	1	0	1
	Till, light brownish gray (5 YR6/1) to light olive gray (5 Y6/1), soft, extremely calcareous, oxidized, laminated	1	1	2
	Till, very pale orange (10 YR8/2) to pale yellowish orange (10 YR8/6), soft, highly calcareous, oxidized	2	2	4
	Till, very pale orange (10 YR8/2) to light olive gray (5 Y4/1), soft, extremely calcareous, oxidized, laminated	2	4	6
	Gravel, poorly-sorted, oxidized	2	6	8
	Till, dark yellowish orange (10 YR6/6) to greenish gray (5 GY6/1), soft, calcareous, oxidized	6	8	14
	Silt, olive gray (5 Y4/1), sandy, slightly calcareous	49	14	63
	Till, olive gray (5 Y3/1), cohesive, hard, calcareous, unoxidized	64	63	127
	Clay, olive gray (5 Y4/1), highly calcareous, contains sulfides; interbedded with silt, cohesive, soft, highly calcareous, contains sulfides.	8	127	135
	Sand, gravelly, poorly-sorted	6	135	141
	Clay, olive gray (5 Y4/1), sandy, highly calcareous, contains sulfides.	8	141	149
	Pierre Shale, olive black (5 Y2/1), interbedded with bentonitic (?) clay layers	7	149	156
	Gravel, fairly poorly-sorted, angular to subrounded, average size 4 mm	18	156	174
	Till (?), olive green (5 Y4/1) and dark greenish gray (5 GY4/1), non-calcareous, interbedded with gravel	12	174	186
Pierre Shale:				
	Shale, olive black (5 Y2/1) and olive gray (5 Y3/2), interbedded with bentonitic (?) clay layers	24	186	210

TABLE I.--Summary of Test Hole Logs-continued

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	161-66-18cdc Test Hole 1364-6			
Glacial Drift:				
	Topsoil	½	0	½
	Till, dark yellowish orange (10 YR6/6), cohesive, hard, highly calcareous, oxidized	16½	½	17
	Till, olive gray (5 Y4/1) to dark greenish gray (5 GY4/1), cohesive, highly calcareous	23	17	40
	Till, olive gray (5 Y4/1), cohesive, highlycalcareous	76	40	116
	Gravel, clayey, very poorly-sorted	9	116	125
	Till, dark olive green (5 GY4/1), sandy, cohesive, brittle, slightly calcareous	3	125	128
	Pierre Shale (?), olive gray (5 Y4/1) to dark greenish gray (5 GY4/1), cohesive, soft, contains sulfides; sand laminations, fine, white	17	128	145
	Sand, poorly-sorted, angular to rounded	21	145	166
	Sand, fairly well-sorted, angular to well rounded, between ¼ to ½ mm in size	10	166	176
	Gravel, poorly-sorted, maximum size 20 mm	11	176	187
Pierre Shale:				
	Shale, interbedded with clayey bentonitic (?) layers	12½	187	199½
	161-67-1bbb Test Hole 1364-9			
Glacial Drift:				
	Topsoil	1	0	1
	Till, very pale orange (10 YR8/2) to light olive green (5 Y6/1), silty, cohesive, soft, highly calcareous, oxidized	4	1	5
	Till, olive gray (5 Y4/1), cohesive, fairly hard, calcareous	12	5	17
	Till, dark greenish gray (5 GY4/1), cohesive, fairly hard, highly calcareous, sandy in parts	3	17	20
	Sand, fairly well-sorted, mostly angular, average grain size 3/4 mm	3	20	23
	Till, dark greenish gray (5 GY4/1) to olive gray (5 Y4/1), cohesive, fairly hard, slightly calcareous	109(?)	23	132(?)

TABLE I.--Summary of Test Hole Logs-continued

Formation	Material	Thickness (feet)	Depth (feet) From	Depth (feet) To
	161-67-1bbb Test Hole 1364-9 (continued)			
Glacial Drift:				
	Silt, dark greenish gray (5 GY4/1) to olive gray (5 Y4/1), cohesive, soft, highly calcareous, laminated.........	42(?)	132(?)	174
	Silt, olive gray (5 Y4/1) to dark greenish gray (5 GY4/1), sandy.......	12	174	186
	Till, olive gray (5 Y4/1) to dark greenish gray (5 GY4/1), cohesive, soft, highly calcareous..............	11	186	197
	Silt, olive gray (5 Y4/1), interbedded with sandy silt, cohesive, hard, calcareous, contains sulfides; sand lenses, fine, white.................	43	197	240
	Shale (?), dark greenish gray (5 G4/1), silty, cohesive, highly calcareous, weathered (?)......................	13	240	253
	Till, dark greenish gray (5 G4/1) to dark greenish gray (5 GY4/1), bouldery, cohesive, very hard, highly calcareous	15	253	268
	Shale (?), dark greenish gray (5 G4/1) to dark greenish gray (5 GY4/1), cohesive, highly calcareous..........	15	268	283
	Clay, dark greenish gray (5 GY3/1), silty, cohesive, hard, extremely compact, slightly to noncalcareous...	2	283	285
Pierre Shale:				
	Shale, olive black (5 Y2/1), interbedded with clayey bentonitic (?) layers....	30	285	315
	161-67-14aaa Test Hole 1364-10			
Glacial Drift:				
	Topsoil................................	1	0	1
	Till, yellowish gray (5 Y8/1) and light olive gray (5 Y6/1), cohesive, soft, highly calcareous, oxidized..........	2	1	3
	Till, grayish orange (10 YR7/4) to light olive gray (5 Y6/1), silty, cohesive, soft, highly calcareous, oxidized..........................	1	3	4
	Till, dark yellowish brown (10 YR4/2) to moderate yellowish brown (10 YR5/4), silty, sandy (very fine), cohesive, soft, noncalcareous, oxidized........	7	4	11

TABLE 1.--Summary of Test Hole Logs-continued

Formation	Material	Thickness (feet)	Depth (feet) From	To
	161-67-14aaa Test Hole 1364-10 (continued)			
Glacial Drift:				
	Till, dark yellowish orange (10 YR6/6) to olive gray (5 Y4/1), cohesive, highly calcareous, oxidized.........	3	11	14
	Sand, fairly well-sorted, mostly angular, ½ mm predominant size...............	4	14	18
	Till, olive gray (5 Y4/1) to dark greenish gray (5 GY4/1), bouldery, cohesive, very hard, highly calcareous	37	18	55
	Till, same as above; contains gravel, subrounded to subangular, average size 5 mm.........................	5	55	60
	Till, dark greenish gray (5 GY4/1), cohesive, calcareous................	37	60	97
	Till, olive gray (5 Y3.5/1), silty, cohesive, fairly hard, calcareous...	50	97	147
	Gravel, very poorly-sorted, angular to rounded, size ranges from 2 to 20 mm............................	7	147	154
	Till, olive gray (5 Y3.5/1), gravelly, cohesive, fairly hard, calcareous...	22	154	176
	Silt, olive gray (5 Y5/1), cohesive, hard, highly calcareous, contains sulfides.........................	17	176	193
	Gravel, fairly well-sorted, mostly subangular to subrounded...........	4	193	197
	Silt, olive gray (5 Y5/1), bouldery, cohesive, hard, highly calcareous, contains sulfides.................	6	197	203
	Gravel, clayey.........................	5	203	208
	Silt, olive gray (5 Y5/1), bouldery, cohesive, hard, highly calcareous, contains sulfides; interbedded with shale, olive black (5 Y2/1), cohesive, hard............................	3	208	211
	Silt, olive gray (5 Y5/1), bouldery, cohesive, hard, calcareous, interbedded with lignite...............	4	211	215
	Clay, olive gray (5 Y4/1) to dark greenish gray (5 GY4/1), sandy, slightly calcareous, interbedded with lignite..........................	66	215	281
	Sand, poorly-sorted, mostly angular to subangular; grades into gravel......	37	281	318
	Gravel, sandy, very poorly-sorted, angular to rounded, between 1 and 5 mm in size.........................	61	318	379
Pierre Shale:				
	Shale, dark greenish gray (5 GY4/1) to dark greenish gray (5 G4/1), cohesive, very hard, noncalcareous, interbedded with bentonitic (?) clay layers.....	30½	379	409½

TABLE I.--Summary of Test Hole Logs-continued

Formation	Material	Thickness (feet)	Depth (feet) From	To
	162-66-8daa Test Hole 1364-14			
Glacial Drift:				
	Topsoil	½	0	½
	Sand, well-sorted, mostly angular, predominant size ½ mm, oxidized	3½	½	4
	Till, grayish orange (10 YR7/4) to pale yellowish orange (10 YR8/6), silty, highly calcareous, oxidized	7	4	11
	Silt, light olive gray (5 Y5.5/1), clayey, sandy, calcareous, oxidized.	23	11	34
	Till, dark greenish gray (5 GY3.5/1), calcareous	5	34	39
	Silt, dark greenish gray (5 GY4/1), interbedded with a sandy silt	2	39	41
	Sand, well-sorted, average size ¼ mm	4	41	45
	Till, dark greenish gray (5 GY4/1), silty, cohesive, calcareous	6	45	51
	Gravel, poorly-sorted	11	51	62
	Till, dark greenish gray (5 GY3.5/1), cohesive, crumbly	4	62	66
Pierre Shale:				
	Shale, interbedded with bentonitic (?) clay layers	28½	66	94½
	162-66-28acd Test Hole 1364-15			
	Dam filling	8	0	8
Glacial Drift:				
	Sand, fairly well-sorted, mostly angular, predominant size ½ mm, oxidized	1	8	9
	Till, yellowish gray (5 Y8/1), clayey, fairly cohesive, soft, highly calcareous, oxidized	2	9	11
	Clay, dark greenish gray (5 Y3/1), sandy, fairly cohesive, soft, calcareous	3	11	14
	Sand, fairly well-sorted, angular to rounded, predominant size ½ mm	17	14	31
	Gravel, poorly-sorted, gradational contact with above sand	10	31	41
Pierre Shale:				
	Shale, olive black (5 Y2/1), cohesive, hard, interbedded with bentonitic (?) clay	22	41	63

TABLE I.--Summary of Test Hole Logs-continued

Formation	Material	Thickness (feet)	Depth (feet) From	To
	162-66-30dcc Test Hole 1364-7			
Glacial Drift:				
	Topsoil............................	1	0	1
	Till, predominantly olive gray (5 Y4/1), cohesive, calcareous, oxidized.....	2	1	3
	Sand, poorly-sorted, rounded to sub-rounded, oxidized.................	5	3	8
	Silt, moderately yellowish brown (10 YR5/4) to dark yellowish brown (10 YR4/2), highly calcareous......	2	8	10
Pierre Shale:				
	Shale.............................	21½	10	31½
	162-66-30ccc Test Hole 1364-8			
Glacial Drift:				
	Topsoil............................	1	0	1
	Till, dusky yellow (5 Y6/4) to light olive gray (5 Y6/1), cohesive, non-calcareous, oxidized..............	6	1	7
Pierre Shale:				
	Shale, olive gray (5 Y3/1), cohesive, hard, massive, oxidized...........	3	7	10
	Shale, dusky blue (5 PB3/2) and dark gray (N3), cohesive, hard, massive, interbedded with bentonitic (?) clay layers; sand laminae, white, noncalcareous...................	11	10	21
	162-66-32ddd Test Hole 1364-13			
Glacial Drift:				
	Topsoil............................	1	0	1
	Till, pinkish gray (5 YR8/1), silty, noncohesive, soft, highly calcareous, oxidized..........................	2	1	3
	Till, grayish orange (10 YR7/4) to dark greenish gray (5 GY4/1), cohesive, soft, calcareous, oxidized.........	9	3	12
	Till, mostly dark greenish gray (5 GY4/1), cohesive, hard, calcareous, contains small lenses of white sand........	93	12	105
Pierre Shale:				
	Shale, dark greenish gray (5 G4/1) to medium bluish gray (5 B5/1), cohesive, soft, noncalcareous..............	21	105	126

TABLE I.--Summary of Test Hole Logs-continued

Formation	Material	Thickness (feet)	Depth (feet) From	To
	162-66-30dcc **Test Hole 1364-7**			
Glacial Drift:				
	Topsoil..............................	1	0	1
	Till, predominantly olive gray (5 Y4/1), cohesive, calcareous, oxidized.....	2	1	3
	Sand, poorly-sorted, rounded to subrounded, oxidized.................	5	3	8
	Silt, moderately yellowish brown (10 YR5/4) to dark yellowish brown (10 YR4/2), highly calcareous......	2	8	10
Pierre Shale:				
	Shale.................................	21½	10	31½
	162-66-30ccc **Test Hole 1364-8**			
Glacial Drift:				
	Topsoil..............................	1	0	1
	Till, dusky yellow (5 Y6/4) to light olive gray (5 Y6/1), cohesive, noncalcareous, oxidized..............	6	1	7
Pierre Shale:				
	Shale, olive gray (5 Y3/1), cohesive, hard, massive, oxidized...........	3	7	10
	Shale, dusky blue (5 PB3/2) and dark gray (N3), cohesive, hard, massive, interbedded with bentonitic (?) clay layers; sand laminae, white, noncalcareous...................	11	10	21
	162-66-32ddd **Test Hole 1364-13**			
Glacial Drift:				
	Topsoil..............................	1	0	1
	Till, pinkish gray (5 YR8/1), silty, noncohesive, soft, highly calcareous, oxidized..........................	2	1	3
	Till, grayish orange (10 YR7/4) to dark greenish gray (5 GY4/1), cohesive, soft, calcareous, oxidized.........	9	3	12
	Till, mostly dark greenish gray (5 GY4/1), cohesive, hard, calcareous, contains small lenses of white sand.........	93	12	105
Pierre Shale:				
	Shale, dark greenish gray (5 G4/1) to medium bluish gray (5 B5/1), cohesive, soft, noncalcareous...............	21	105	126

TABLE 2

Chemical analyses of Water from Selected Wells, Test Holes and Rock Lake

(Analytical results in parts per million except as indicated)

Location	Well Depth (feet)	Aquifer	Date of collection	Silica (SiO_2)	Total Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids		Hardness as $CaCO_3$		Percent sodium	Sodium adsorption-ratio	Specific conductance (micromhos at 25° C)	pH
																	Sum	Residue on evaporation at 180° C	Calcium magnesium	Noncarbonate				
161-65-6d** John Bradley	210	Pierre Shale (?)	8-25-64	-	-	-	-	779	-	378	6	-	-	-	22	-	3,334 /2		390	-	-	-	4,170	7.8
161-66-6bdc* Observation well #1	50	Sand & Gravel	9-25-64	25	7.2	124	50	40	11	566	0	134	9.8	0.3	3.0	0	678	673	515	51	14	0.8	1,040	7.5
161-66-7 /1 N. W. Hawkins	160	Pierre Shale	-	24	0	62	21	677	-	527	-	1,072	114	0.4	6.7	-	-	2,282	242	-	-	-	-	-
161-66-7 /1 School District #28	204	Pierre Shale	-	27	0	36	17	989	-	730	-	78	1,155	0.4	1.7	-	-	2,661	159	-	-	-	-	-
161-66-7** Myron Dammen	171	Pierre Shale (?)	3-16-62	-	0.65	24	8	1,093	-	671	0	130	1,265	-	Trace	-	3,191	-	95	-	-	-	4,783	7.55
161-66-7a* Rock Lake	-	Surface Water	9-25-64	-	3.4	59	43	168	-	244	64	214	113	0.5	2.0	-	-	985	325	17	53	4.0	1,310	9.0
161-66-7cab* Observation well #1	50	Sand & Gravel	9-24-64	-	2.2	188	66	105	-	624	0	305	19	0.5	0	-	-	1,230	740	116	24	1.7	1,720	7.8
161-66-18cdc* Observation well #6	190	Sand & Gravel	9-30-64	23	0.7	144	45	348	27	514	0	689	137	0.4	3.0	0.7	1,670	1,660	545	124	57	6.5	2,370	7.9
161-67-14aaa* Observation well #10	376	Sand & Gravel	10-7-64	21	0.82	208	78	215	18	568	0	747	63	0.6	3.0	0.12	1,630	1,640	840	375	35	3.2	2,210	7.8
162-67-25** Edwin Kaliva	-	-	1-?-61	-	2.2	66.0	20.7	1,322.0	-	652.7	0	30.0	1,817.5	-	11.1	-	3,922.2	-	250.0	-	-	-	4,170	-

* Analysis by State Laboratories Department
** Analysis obtained from North Dakota State Health Department

/1 Abbott and Voedisch, 1938, p. 81
/2 Calculated from specific conductance

TABLE 3

WATER QUALITY EXPLANATION

The following explanation gives the significance of the various constituents of a complete analysis for a domestic or municipal water supply in North Dakota.

Bicarbonate (HCO_3) has no significance in natural water, however, there are certain standards to be maintained in water treatment plants. A water high in bicarbonate content will tend to have a flat taste.

Boron (B) has no physiological or esthetic significance.

Calcium (Ca) is one of the primary causes of hardness.

Carbonate (CO_3) has no significance in natural water, however, there are certain standards to be maintained in water treatment plants.

Chloride (Cl) over 250 ppm may have a salty taste to persons unaccustomed to high chloride concentrations. Persons may become accustomed to higher concentrations.

Fluoride (F) is believed to prevent decay in children's teeth within the limits of 0.9 to 1.5 ppm in North Dakota. Higher concentrations cause mottled teeth.

Hardness is classified by the North Dakota State Department of Health as follows:

0 - 200 ppm	Low
200 - 300 ppm	Average
300 - 450 ppm	High
Over 450 ppm	Very high

Calcium and magnesium are the primary causes of hardness. Hardness, which increases soap consumption, can be removed by water softening systems.

Iron (Fe) over 0.3 ppm may cause staining of laundry and fixtures. Over 0.5 ppm iron may be tasted by persons unaccustomed to water with a high iron content. A water with a high iron content will adversely affect the taste of coffee and tea made from such water. Iron removal systems are available.

Magnesium (Mg) is one of the primary causes of hardness. Over 125 ppm magnesium may have a laxative effect on persons unaccustomed to this type of water.

Nitrate (NO_3) over 45 ppm can be toxic to infants, much larger concentrations can be tolerated by adults. Nitrate in excess of 200 ppm may have a deleterious affect on livestock health.

Potassium (K) in small amounts is essential to animal nutrition.

pH should be between 7.0 and 9.0 for domestic use.

Silica (SiO_2) has no physiological or esthetic significance.

Sodium (Na) has no physiological or esthetic significance except for persons on salt free diets.

Sodium percent (% Na) indicates the sodium hazard of irrigation water.

Sodium Adsorbtion Ratio (S.A.R.) indicates the sodium hazard of irrigation water.

Specific Conductance is a general indication of total dissolved solids and a measure of salinity. Used primarily for irrigationanalyses.

Sulfates (SO_4) are classed as follows:

0 - 300 ppm	Low
300 - 700 ppm	High
Over 700 ppm	Very high

250 ppm is the limit set by the U. S. Public Health Service, however, a North Dakota State Department of Health Survey indicates no laxative effect is noticed until sulfates reach 600 ppm, over 750 ppm there is generally a laxative effect.

Total Dissolved Solids are classed as follows by a North Dakota State Department of Health Survey:

0 - 500 ppm	Low
500 -1400 ppm	Average
1400 -2500 ppm	High
Over 2500 ppm	Very high

Calcium and magnesium are the primary causes of hardness. Hardness which increases soap consumption, can be removed by water softening systems.

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