STATE OF SOUTH DAKOTA
Archie Gubbrud, Governor

STATE GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

SPECIAL REPORT 27

GROUND WATER SUPPLY FOR THE CITY OF MARION

by
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Science Center
University of South Dakota
Vermillion, South Dakota
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INTRODUCTION

Present Investigation

This report is the result of a special investigation by the South Dakota State Geological Survey conducted during the summer of 1963, from July 16 to August 18, in and around the city of Marion, Turner County, South Dakota (fig. 1), for the purpose of helping the city to locate future water supplies. The city now obtains its water from three wells, which take their water from the Niobrara Chalk. These wells are at a depth of about 300 feet and are located within the city limits (fig. 2). At the present time, the city water supply would seem to be sufficient, but there have been summers when water restriction has been necessary. In planning for both present and future uses, the city first requested the help of the State Geological Survey in November, 1960, but because of prior commitments the Survey was unable to begin the Marion project until July, 1963.

A survey of the ground water possibilities was made of a 64 square-mile area around the city, and consisted of geologic mapping, a well inventory, the drilling of 28 rotary test holes to an average depth of 161 feet and 19 auger test holes to an average depth of 82 feet, and the taking of 15 water samples for analysis.

As a result of this survey it was determined that the city should drill several more test holes in the lower buried outwash at a depth of about 165-195 feet, in the vicinity of Rotary Test Hole R-14 which is located in the northeast part of the city (fig. 2). The water in this outwash is of fairly good quality, and the extent of the outwash is believed to be large enough to furnish a sufficient water supply for the city of Marion.

The field work and preparation of this report were performed under the supervision of Cleo M. Christensen, ground water geologist. The services of Robert A. Schoon, geologist-driller, and his assistants, Lloyd R. Helseth and John A. Moore, as well as the services of Lynn Huenemann and Harry Haywood, operators of the jeep auger drill, are gratefully acknowledged. The writer also wishes to thank Nat Lufkin of the Geological Survey and the members of the State Chemical Laboratory for analyzing the water samples collected and Rene Fournier whose field assistance was extremely helpful. Special thanks go to Mayor Otto Arbeiter and the other residents in and around Marion, who cooperated throughout the project.

Location and Extent of Area

The city of Marion is located in Turner County in east-central South Dakota, and has a population of 843 (1960, census). The area is in the James Basin of the Central Lowlands physiographic province (fig. 1).

Climate

The climate is continental temperate, with large daily and seasonal fluctuations.

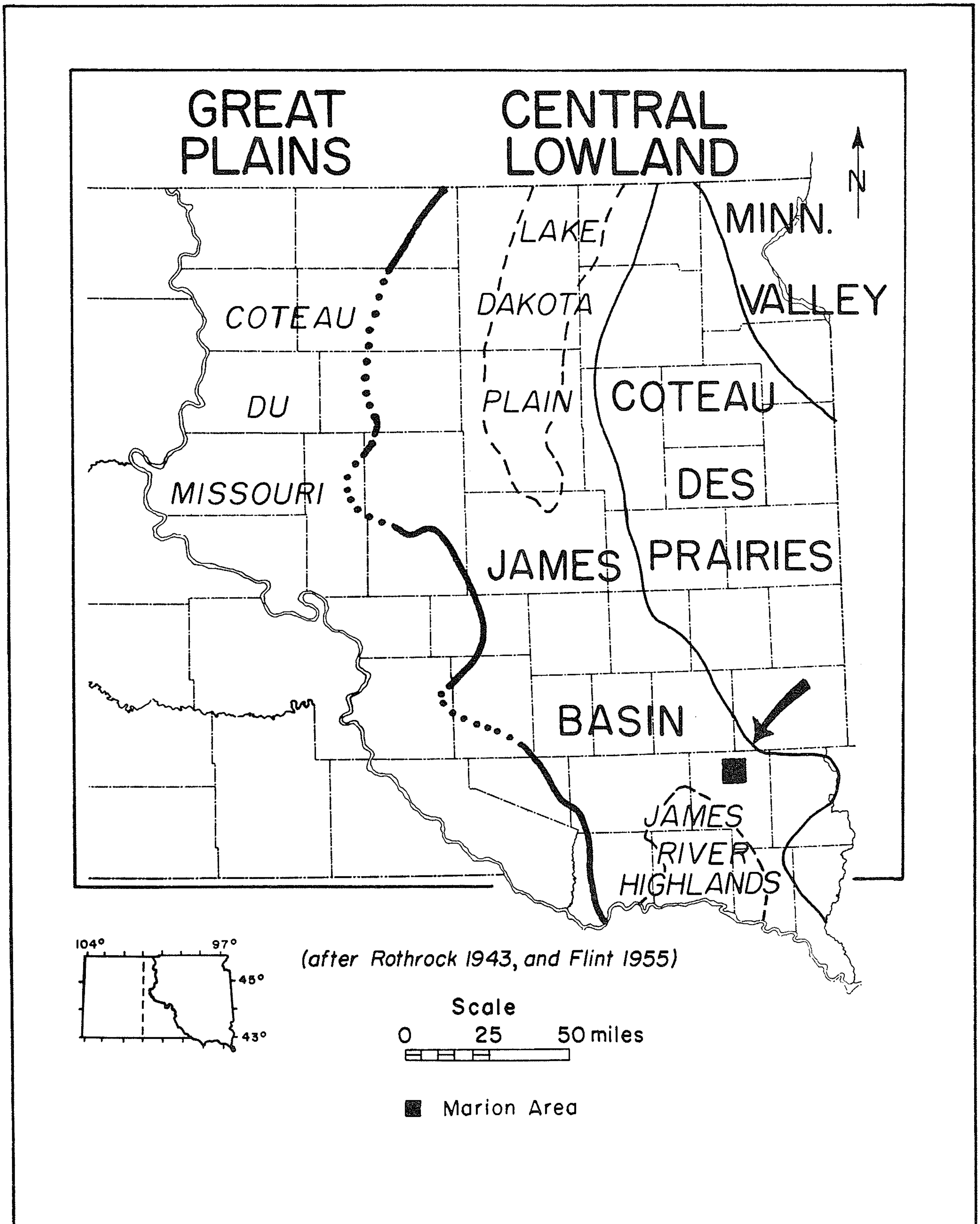
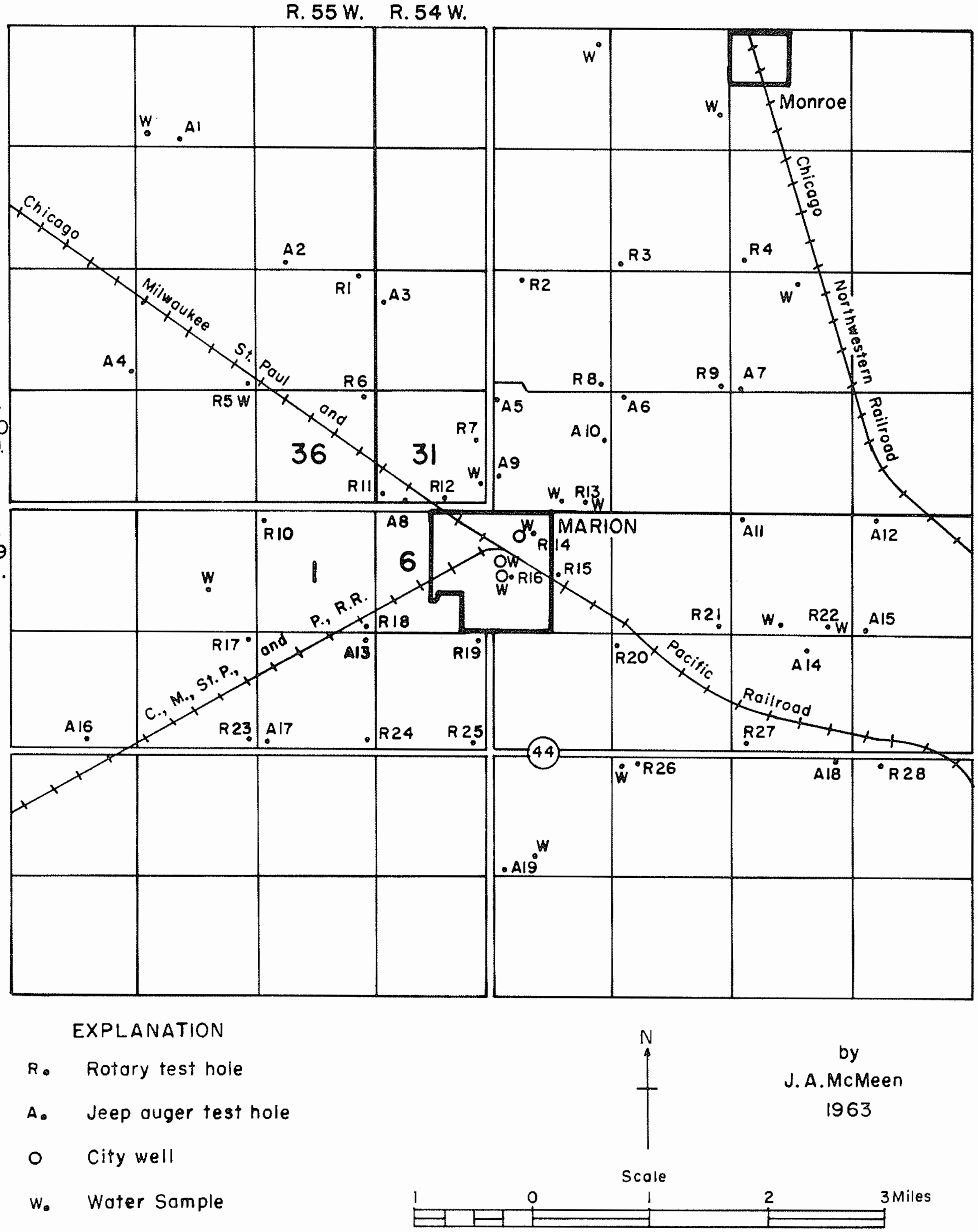


Figure I. Major Physiographic Divisions of Eastern South Dakota and the Location of the Marion Area.

Figure 2. Data Map of the Marion Area.



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Drafted by Bruno Petsch

The average daily temperature is 47.5° F. and the average annual precipitation is 23.6 inches at the U. S. Weather Bureau Station in Marion.

Topography and Drainage

The topography of the area is typically youthful glacial moraine--rolling hills and valleys with numerous knobs and kettles. The area is drained to the southeast by the West Fork of the Vermillion River and its tributaries.

GENERAL GEOLOGY

Surficial Deposits

The surficial deposits of the Marion area are mostly the result of glaciation late in the Pleistocene Epoch. The glacial deposits are collectively termed drift, and can be divided into till and outwash deposits. Till consists of clay and silt randomly mixed with boulders, pebbles and sand; all were carried and deposited by the ice itself. The outwash material was deposited by meltwater streams from the ice and is better sorted, consisting mostly of pebbles and sand with minor amounts of silt and a few boulders.

Alluvial material has been deposited along the West Fork of the Vermillion River since the retreat of glaciers from this area (fig. 3). This alluvium consists of silt, clay, and small amounts of sand and gravel.

Subsurface Bedrock

Stratified rocks of Cretaceous age lie beneath the surface deposits in the Marion area. The Niobrara Chalk is located immediately beneath the glacial drift and is underlain by either the Carlile Shale or, depending on the locality, the Dakota Group. In some instances both the Carlile and Dakota are absent and the Niobrara is believed to rest directly on the Precambrian Sioux Quartzite.

The Niobrara Chalk consists of white to cream massive calcareous chalk containing numerous fossil shells.

The Carlile Shale is a medium- to dark-gray bentonitic shale with pyrite concretions, and layers of fine brown siltstone.

The Dakota Group consists of a series of alternating sandstones and shales.

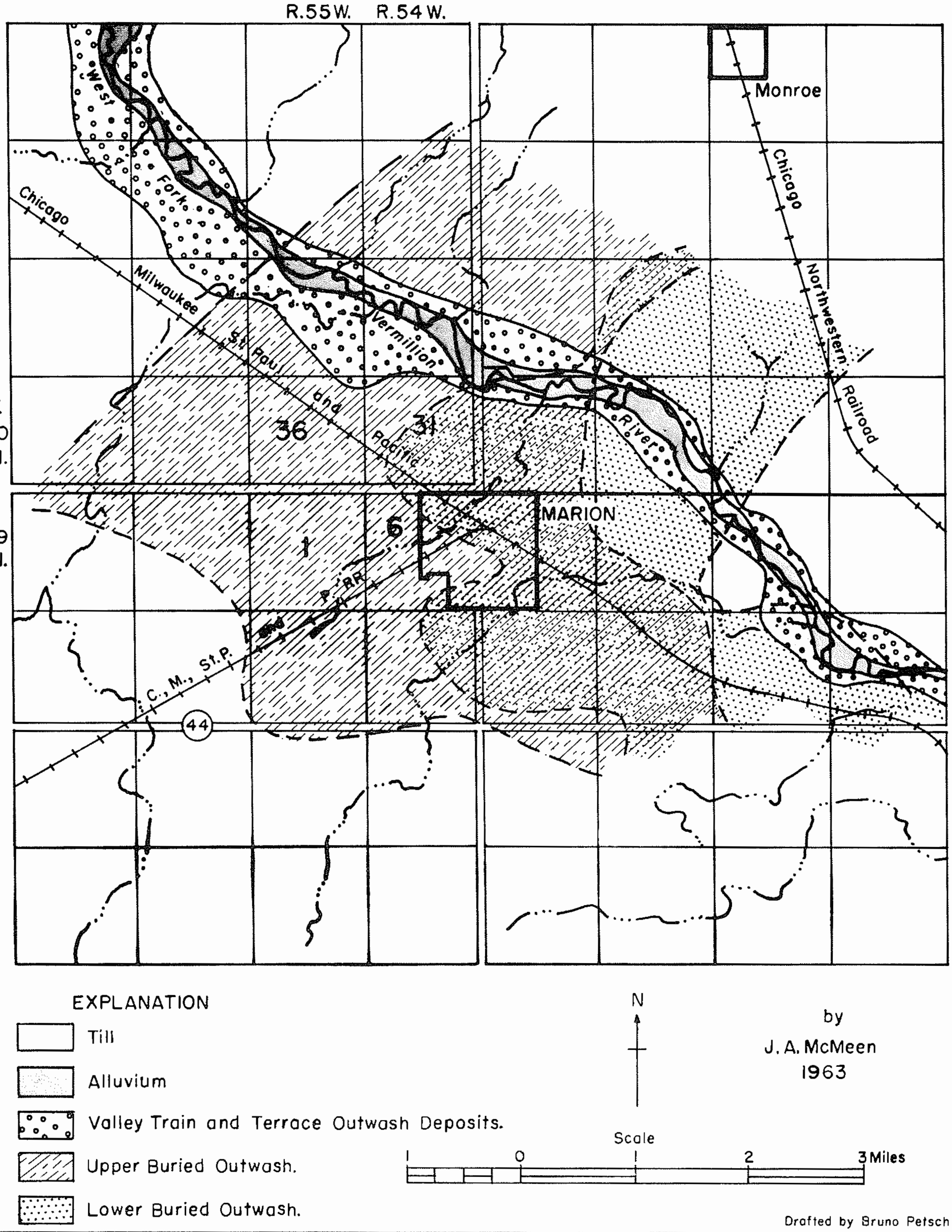
The Sioux Quartzite is a pink to purple, very hard, quartzitic sandstone, locally called "granite", "Sioux Falls Granite", or "quartzite".

OCCURRENCE OF GROUND WATER

Principles of Occurrence

Ground water occurs almost everywhere in the ground, at a depth which varies from a few feet to several tens, or even hundreds of feet. The top

Figure 3. Geologic Map of Marion and Vicinity.



of this zone of saturation is known as the water table, and in the Marion area it is at a depth of 5-44 feet.

The type of material containing the water governs the amount of water that can be withdrawn and, in part, the rate of natural recharge. For instance, a sand and gravel (such as that found in the outwash channel along the West Fork of the Vermillion River) will yield more water to a well than till, shale, or quartzite because of the size of the particles which make up the deposit, and the lack of cementation of these particles.

Nearly all ground water is derived from precipitation. Rain or melting snow either percolates directly downward to the water table, becoming ground water, or drains off as surface water. Surface water either evaporates, escapes to the ocean by streams, or percolates downward to the ground water table. In general, ground water moves laterally down the hydraulic gradient, and is said to be in transient storage.

Recharge is the addition of water to an aquifer (water-bearing material), and is accomplished in three ways: (1) direct precipitation of rain or snow on the ground surface, (2) downward percolation from surface bodies of water, and (3) lateral underflow of water in transient storage.

Discharge, or the removal of ground water, is accomplished in four main ways: (1) evaporation and transpiration of plants, (2) seepage upward or laterally into surface bodies of water such as springs, (3) lateral underflow of water in transient storage, and (4) by pumping.

The volume of water capable of being stored in a saturated material is equal to the volume of voids or pore spaces in the material. A measurement of the capability of a material to store water is called porosity. Therefore porosity is the ratio of the volume of voids in the material to the rock volume. The shape and arrangement of grains in a material affect the porosity greatly, but size of the grains has little effect. Sands and gravels usually have porosities of 20-40 percent, whereas sandstones normally have porosities of 15-25 percent; this lower porosity of sandstone is due to closer packing and the cementation of the particles.

Permeability is the rate at which a fluid will pass through a substance. If the pore spaces of a material are connected, the permeability of that material will be high. If the pore spaces are not connected, the permeability will be low. Thus, a material may have high porosity and still not yield water readily because of low permeability. Sands and gravels, however, tend to have both high porosity and high permeability. Thus the geologist is not concerned with finding a "vein" when looking for a good water supply; but because water occurs almost everywhere in the ground, he is searching instead for a sand or gravel deposit that lies beneath the water table.

Ground Water in Glacial Deposits

Outwash deposits occur as a valley train and as terraces along the West Fork of the Vermillion River. These deposits are closely related, both geologically and hydrologically and were thus mapped as a single unit (fig. 3). The terrace outwash deposits occur from 70 to 90 feet above the valley train deposits, and consequently contain only small amounts of water, because any water which enters these terraces percolates downward into and recharges the valley train deposits. Thus, the valley train deposits form a much better ground water aquifer than do the terrace deposits.

The thickness of the valley train deposits in the area mapped for this study averages over 60 feet. (See Appendix B.) Because of mechanical limitations and the type of material being penetrated, most of the auger test holes could not be drilled deep enough to determine the true thicknesses of the valley train deposits, thus only an estimate of true thickness can be given. The valley train deposits appear to be saturated throughout.

Most of the auger test holes in the valley train deposits contained very fine sand with silt and interbedded clays and only a small amount of gravel. Test Hole A-3, however, contained much coarser material, but it appears that this is a local condition. In general the valley train deposits are too fine-grained to be considered as a possible supply for the city.

Two buried outwashes were discovered in the Marion area (fig. 3). Both of these outwashes were test drilled extensively (see Appendix A) to determine their thickness and extent. Water samples were taken from each outwash for comparison purposes. The water from the upper buried outwash at a depth of 90 feet was found to be of a poor quality (table 1, samples 4, 5, 6, 7), thus it was felt that this upper outwash did not warrant additional study.

The lower buried outwash was found to have a better quality of water on the average (table 1, samples 8, 9, 10, 11, 12) and was studied in more detail. The thickest part of the lower buried outwash is thought to be within the Marion city limits (fig. 4) and the surface of the outwash appears to slope from east to west (fig. 5). The surface of the lower buried outwash is at a depth of 115-165 feet and the outwash has a maximum thickness of 35 feet (Rotary Test Hole R-14).

Ground Water in Alluvium

Alluvium is present above the valley train deposits in the West Fork of the Vermillion River Valley (fig. 3). The alluvial materials were deposited by the Recent streams and consist of clay and silt with minor amounts of sand and gravel. The alluvium holds large quantities of water where it is below the water table, but will not yield water readily because of low permeability.

Ground Water in Bedrock

The Niobrara Chalk furnishes water for the city of Marion and many farms in the area. The water in this formation is contained in joints and solution cavities along bedding planes, and is of fair quality; however, the yield is rather low.

Sandstones of the Dakota Group constitute an aquifer in the Marion area at a depth of 240-500 feet. The water obtained from these sandstones appears to be of good quality, as evidenced by water analysis 15 in table 1.

Table 1.--Chemical Analyses of Water Samples from the Marion Area

Sample	Source	Parts Per Million											
		Calcium	Sodium	Magne-sium	Chloride	Sulfate	Iron	Manga-nese	Nitrate	Fluoride	pH	Hardness $CaCO_3$	Total Solids
A		--	--	50	250	500*	0.3	0.05	10.0*	0.9-1.7**	--	--	1000*
B	Niobrara	139	150	44	15	503	0.8	0.1	1.0	0.6	7.6	530	1121
C		114	170	38	17	439	4.5	0.2	0.5	0.6	7.3	450	1053
D		69	258	25	21	358	0.9	0.0	2.0	1.0	7.6	276	1051
1	***	525	68	201	0	1987	0.0	0.0	1.5	1.2	7.4	2136	3352
2	****	129	29	68	0	453	0.8	0.0	Trace	0.2		602	980
3	Sand Lens	594			12	729	1.0				7.5	680	2210
4	Upper Buried Outwash	452			16	510	6.0				7.4	1050	2885
5		565			24	292	0.35				7.9	260	1322
6		508			12	632	1.65				7.5	600	1948
7		325			20	875	2.5				7.4	700	2050
8	Lower Buried Outwash	650			12	486	4.5				7.6	960	2885
9		452			24	437	0.05				7.8	240	1430
10		167	350	54	17	1093	4.9	0.9	0.0	0.2	7.8	639	2058
11		126	120	58	14	670	8.2	0.8	0.3	0.8	7.9	554	1284
12		109	120	40	11	518	22.8	0.6	0.2	0.6	7.9	438	1036
13	Niobrara	451			16	486	0.9				7.5	480	1840
14		310			26	584	0.9				7.9	240	1485
15	Dak.	61		0	12	73	1.25				7.4	150	700

* Modified for South Dakota by State Department of Health (written communication, February 5, 1962).
** Optimum
*** Terrace Gravel
**** Vermillion River Outwash

Locations of Water Samples

A. U. S. Department of Public Health Drinking Water Standards (1961)
B. Marion city well
C. Marion city well
D. Marion city well
1. Rotary Test Hole R-5 SE$\frac{1}{4}$ sec. 26, T. 100 N., R. 55 W.
2. Rotary Test Hole R-22 SE$\frac{1}{4}$ sec. 3, T. 99 N., R. 54 W.
3. A. Kippes (farm) NE$\frac{1}{4}$ sec. 27, T. 100 N., R. 54 W.
4. J. Mehlbrech (farm) SE$\frac{1}{4}$ sec. 16, T. 100 N., R. 54 W.
5. H. Gossen (farm) SW$\frac{1}{4}$ sec. 17, T. 99 N., R. 54 W.
6. L. Schmidt (farm) SE$\frac{1}{4}$ sec. 3, T. 99 N., R. 54 W.
7. Rotary Test Hole R-18 SE$\frac{1}{4}$ sec. 1, T. 99 N., R. 55 W.
8. F. Lingbeek (farm) NE$\frac{1}{4}$ sec. 17, T. 100 N., R. 54 W.
9. E. DeHoogh (farm) SE$\frac{1}{4}$ sec. 32, T. 100 N., R. 54 W.
10. S. Kramer (farm) SE$\frac{1}{4}$ sec. 31, T. 100 N., R. 54 W.
11. Rotary Test Hole R-13, after 250 gallons, SE$\frac{1}{4}$ sec. 32, T. 100 N., R. 54 W.
12. Rotary Test Hole R-13, after 750 gallons, SE$\frac{1}{4}$ sec. 32, T. 100 N., R. 54 W.
13. H. Wentzel (farm) NW$\frac{1}{4}$ sec. 16, T. 99 N., R. 54 W.
14. H. Ortmann (farm) SW$\frac{1}{4}$ sec. 14, T. 100 N., R. 55 W.
15. B. Tieszen (farm) SE$\frac{1}{4}$ sec. 2, T. 99 N., R. 55 W.

Figure 4. Map showing thickness of Lower Buried Outwash Sediments in the Marion Area.

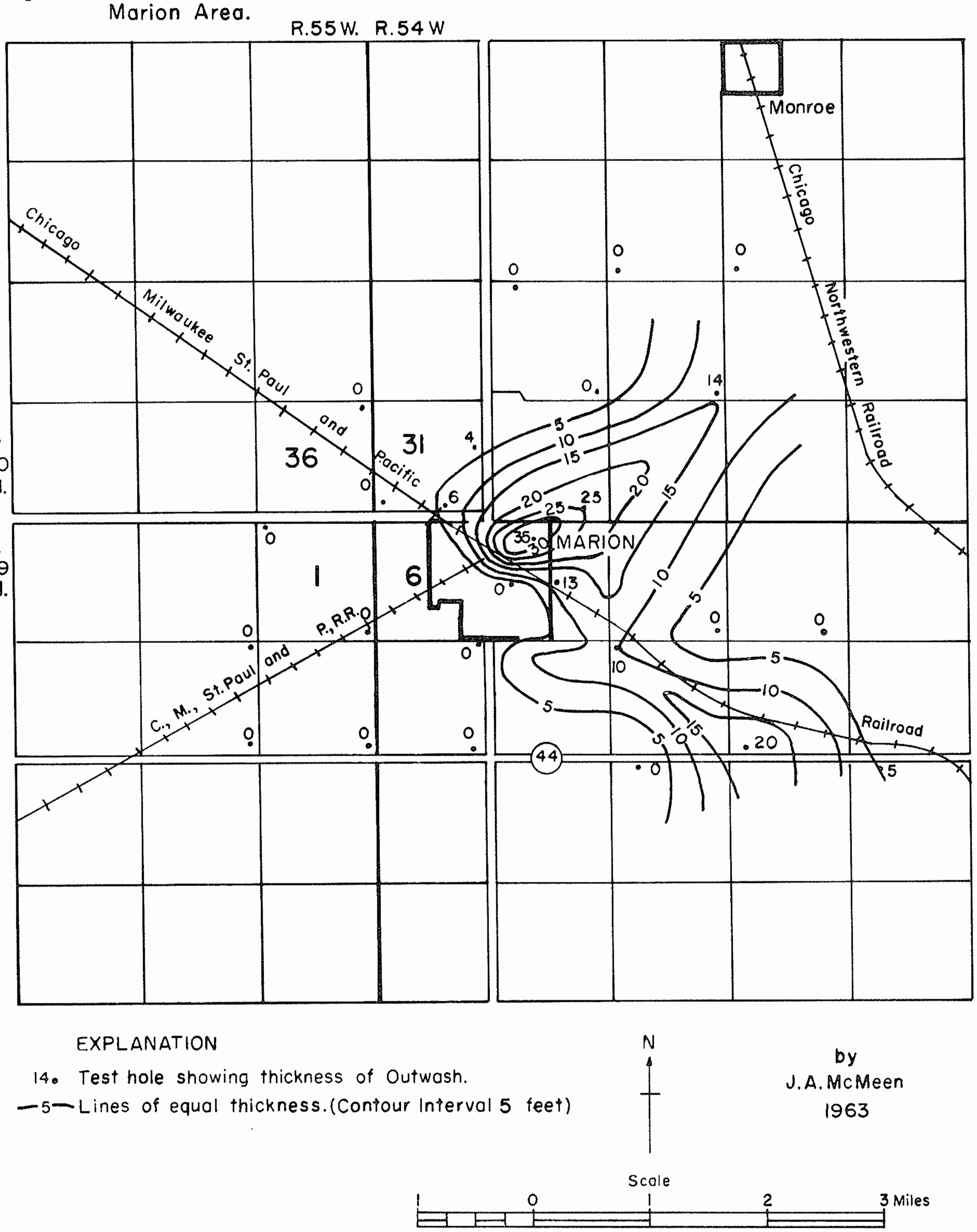


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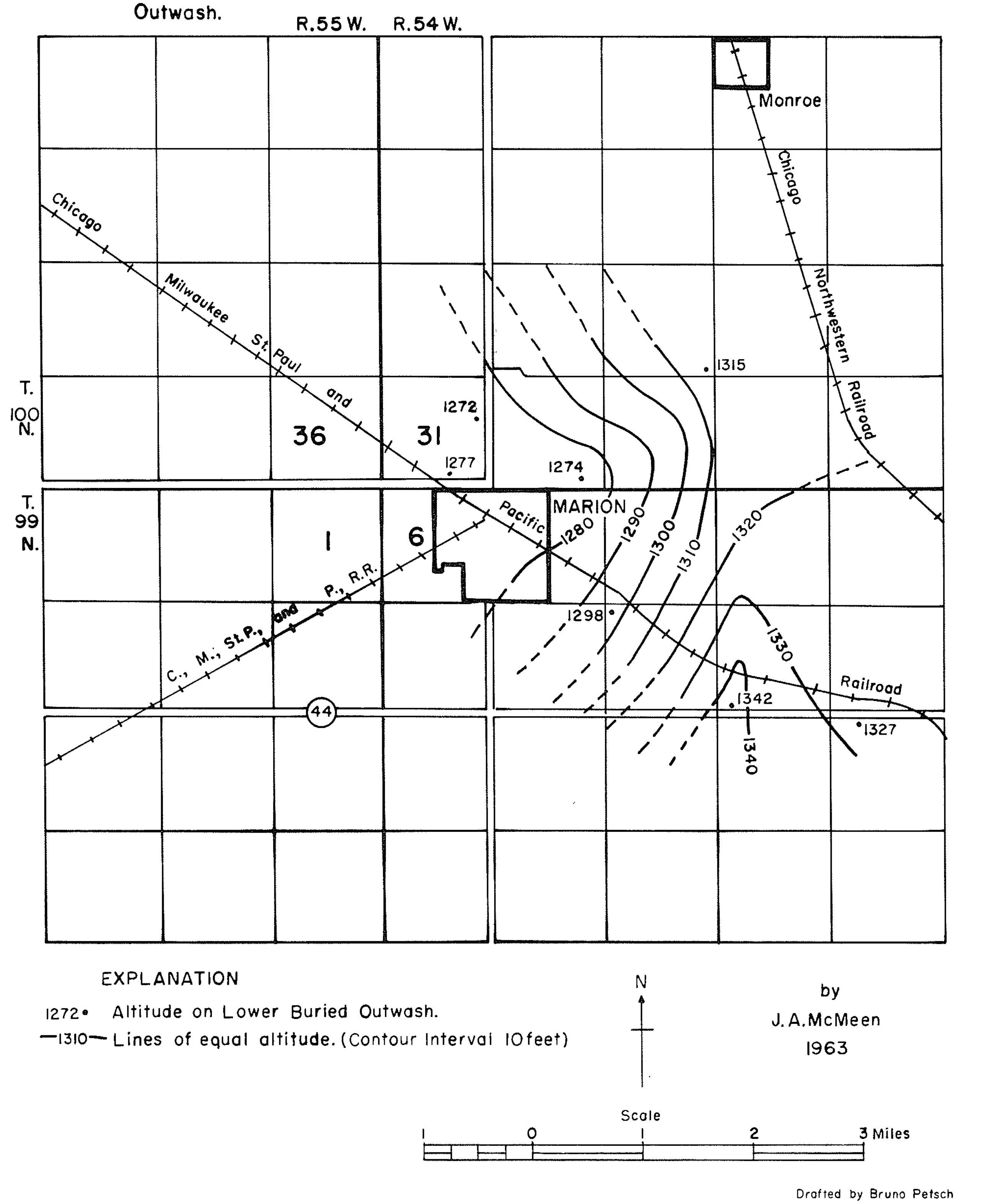
Figure 5. Map showing Configuration of the Surface of the Lower Buried Outwash.



The Sioux Quartzite also is a possible source of water in the area. Because of the good quality of the water obtained from the sandstones overlying the Sioux Quartzite, it would be expected that any water obtained from the quartzite would also be of a good quality, as the water contained in the cracks or fissures in the quartzite would recharge the overlying sandstones.

Quality of Ground Water

Precipitated water is nearly pure before it reaches the ground. However, all ground water contains minerals which are obtained: (1) from the atmosphere, (2) from the soil and underlying deposits as the water percolates downward to the water table, and (3) from the deposits below the water table, in which the water is circulating. In general, the more minerals a water contains, the poorer its quality.

Table 1 shows the chemical properties of various waters in the Marion area, as compared with the present city water and with the standards for drinking water established by the U. S. Department of Public Health. The three city wells (samples B, C, D) are of fair quality, however, they tested higher in iron and total solids than the standards suggested by the U. S. Department of Public Health. In addition, samples B and C tested higher than the standard set for manganese, and sample B was also high in sulfate. High iron and manganese content results in the formation of undesirable deposits in the pipes and pumps of the city water system. Total solids is a measure of the total amount of minerals dissolved in the water. Samples 4 through 12 come from the buried outwash channels in the area. As can be seen the quality of this water is slightly poorer than the quality of the city water. The water from the lower buried outwash (samples 8 through 12) is generally of a better quality than that from the upper buried outwash (samples 4 through 7) although it too is of a quality slightly poorer than that which the city is now using. Sample 12 which is the best water taken from the lower buried outwash is comparable to the city's present water supply with the exception of the unusually high iron content. This high iron concentration is objectionable and the water would have to be treated for the removal of iron before it could be used as a source of supply for the city.

CONCLUSIONS AND RECOMMENDATIONS

The city of Marion has three possible choices in obtaining water. The Niobrara Chalk, from which the present city wells are producing, might be further developed; however, the yield from the chalk is not very great (about 50 gal./min.). Because of this limited yield and because this yield may be cut even further in future years by installation of new wells, it is recommended that the city consider the possibility of establishing a well in the lower buried outwash at a depth of 165-190 feet. The most likely location for this well would be in the immediate vicinity of Rotary Test Hole R-14 (fig. 2), as this hole contained the greatest thickness of outwash encountered (35 feet).

Another possibility for a well in the Marion vicinity would be in the sandstones of the Dakota Group. Only one sample from this aquifer is represented on table 1 (sample 15). As can be seen the water from this source is significantly lower in sulfates than the other samples, but has a rather high iron content. However, everything considered, the quality of this water is better than any of the aquifers tested. It must be remembered that one sample from this aquifer is not sufficient and more samples would need to be taken from this same source before arriving at any conclusions about the quality of water in this aquifer. Also, the Dakota Group is much deeper than the lower buried outwash, and is probably not present within the city limits; whereas, the depth to the lower buried outwash is much less and the outwash exists within the city limits. It is recommended that the city drill several more test holes between Rotary Test Hole R-13 and R-14 in order to determine the best site for establishing a well in the lower buried outwash.

After a well site is chosen, a test well should be installed and test pumped. This test-pumping should be conducted by licensed engineers and should be run for a minimum of 72 hours. In this way the yield, drawdown, and recovery of the aquifer can be determined.

It is suggested that the city contract with a commercial drilling company licensed by the State of South Dakota to test-drill the area recommended. The city officials should consult the State Water Resources Commission with regard to obtaining a water right and a permit to drill a city well, and the State Department of Health with regard to the biological and chemical suitability of the water. A consulting engineering firm licensed in the State of South Dakota should be hired to design the well and adjoining water system.

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Rothrock, E. P., 1943, A Geology of South Dakota, Pt. 1: The Surface: S. Dak. Geol. Survey Bull. 13, pl. 2.

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APPENDIX A

Logs of Rotary Test Holes in the Marion Area

(for location see figure 3)

Test Hole R-1
Location: NE¼ sec. 25, T. 100 N., R. 55 W.
Surface Elevation: 1401.8 feet

0-15	clay, buff, sandy
15-35	clay, gray, sandy
35-37	gravel, pea-size
37-50	clay, gray, sandy
50-52	gravel, pea-size
52-75	clay, gray, sandy
75-90	sand, coarse, slightly clayey
90-120	clay, gray, pebbly and sandy
120-122	sand, coarse
122-150	Niobrara Chalk

* * * * *

Test Hole R-2
Location: NW¼ sec. 28, T. 100 N., R. 54 W.
Surface Elevation: 1438.2 feet

0-35	clay, buff, sandy
35-65	clay, gray, sandy and pebbly
65-120	clay, gray, very sandy
120-180	clay, gray, very sandy, and a few thin gravels
180-190	Niobrara Chalk

* * * * *

Test Hole R-3
Location: SW¼ sec. 19, T. 100 N., R. 54 W.
Surface Elevation: 1450.8 feet

0-21	clay, buff, sandy and pebbly
21-145	clay, gray, very sandy
145-175	clay, gray, sandy, and with gravel stringers
175-185	clay, gray, sandy
185-	hit quartzite boulder and abandoned hole

* * * * *

Test Hole R-4
Location: $SW\frac{1}{4}$ sec. 20, T. 100 N., R. 54 W.
Surface Elevation: 1458.7 feet

0-23	clay, buff, sandy
23-65	clay, gray, sandy
65-190	clay, gray, very sandy
190-220	clay, gray, sandy, pebbly, interbedded with gravel
220-235	clay, gray, pebbly
235-	hit a rock and abandoned hole

* * * * *

Test Hole R-5
Location: $SE\frac{1}{4}$ sec. 25, T. 100 N., R. 55 W.
Surface Elevation: 1443 feet

0-27	gravel, oxidized to 19 feet
27-29	clay, gray, sandy
29-34	sand, coarse
34-75	clay, gray, sandy
75-90	gravel, pea to nut-size
90-95	clay (?), abandoned hole due to caving in of overlying gravel

* * * * *

Test Hole R-6
Location: $NE\frac{1}{4}$ sec. 36, T. 100 N., R. 55 W.
Surface Elevation: 1422.8 feet

0-27	gravel, water level at 11 feet
27-30	clay, gray, sandy
30-60	sand, coarse, and pea gravel
60-65	clay, gray, sandy, abandoned hole

* * * * *

Test Hole R-7
Location: $NE\frac{1}{4}$ sec. 31, T. 100 N., R. 54 W.
Surface Elevation: 1429.3 feet

0-5	clay, buff, sandy
5-17	gravel, pea-size and oxidized
17-54	clay, gray, sandy
54-59	gravel, pea-size
59-133	clay, gray, sandy
133-135	gravel, pea-size
135-139	clay, gray, sandy
139-140	gravel, pea-size

(continued on next page)

Test Hole R-7--continued

140-157	clay, gray, sandy
157-161	sand, coarse, and gravel
161-185	Niobrara Chalk

* * * * *

Test Hole R-8
Location: SE$\frac{1}{4}$ sec. 29, T. 100 N., R. 54 W.
Surface Elevation: 1396 feet

0-9	gravel, oxidized
9-11	clay, buff
11-17	sand, coarse, water bearing
17-37	clay, gray, sandy
37-49	gravel, pea-size, and sand
49-95	clay, gray, sandy to very sandy
95-110	Niobrara Chalk

* * * * *

Test Hole R-9
Location: SE$\frac{1}{4}$ sec. 28, T. 100 N., R. 54 W.
Surface Elevation: 1465.7 feet

0-45	sand, buff, slightly clayey
45-122	sand, fine to coarse and gray, unoxidized clay
122-151	clay, gray, very sandy
151-165	sand, coarse and granular
165-176	clay, gray, pebbly, abandoned hole

* * * * *

Test Hole R-10
Location: NW$\frac{1}{4}$ sec. 1, T. 99 N., R. 55 W.
Surface Elevation: 1443 feet

0-15	clay, buff, sandy
15-85	clay, gray, sandy and pebbly, a few sandy stringers present
85-92	gravel, pea-size
92-182	clay, gray, sandy, a few sandy stringers present
182-185	sand, coarse
185-200	Niobrara Chalk

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Test Hole R-11
Location: SW$\frac{1}{4}$ sec. 31, T. 100 N., R. 54 W.
Surface Elevation: 1444 feet

0-15	clay, buff, sandy
15-92	clay, gray, very sandy
92-107	gravel, pea to nut-size
107-148	clay, gray, sandy
148-170	Niobrara Chalk

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Test Hole R-12
Location: SE$\frac{1}{4}$ sec. 31, T. 100 N., R. 54 W.
Surface Elevation: 1436.3 feet

0-20	clay, buff, sandy
20-35	clay, gray, sandy
35-37	sand, coarse
37-60	clay, gray, sandy
60-62	sand
62-125	clay, gray, sandy with thin sand stringers
125-135	clay and interbedded pea gravel
135-159	clay, gray, sandy
159-165	gravel, pea-size
165-185	Niobrara Chalk

* * * * *

Test Hole R-13
Location: SE$\frac{1}{4}$ sec. 32, T. 100 N., R. 54 W.
Surface Elevation: 1439 feet

0-25	clay, buff, sandy
25-51	clay, gray, sandy
51-55	sand and pea gravel
55-145	clay, gray, sandy with a few 4-inch gravel stringers
145-150	gravel, pea-size
150-165	clay, gray, pebbly
165-190	gravel, pea-size, with a few thin clays, could not penetrate

* * * * *

Test Hole R-14
Location: NW$\frac{1}{4}$ sec. 5, T. 99 N., R. 54 W.
Surface Elevation: not measured

0-135	no circulation, all clay
135-165	clay, gray, sandy
165-195	gravel, pea-size
195-200	sand, fine (?)

* * * * *

Test Hole R-15
Location: $SE\frac{1}{4}$ sec. 5, T. 99 N., R. 54 W.
Surface Elevation: not measured

0-17	clay, buff, sandy
17-65	clay, gray, soft, sandy
65-70	gravel, pea-size
70-135	clay, gray, sandy
135-140	gravel, pea-size
140-145	clay, gray, sandy
145-151	gravel, nut-size (3/4 - 1 inch in diameter)
151-159	clay, gray, sandy
159-172	gravel, pea to nut-size
172-200	Niobrara Chalk

* * * * *

Test Hole R-16
Location: $SW\frac{1}{4}$ sec. 5, T. 99 N., R. 54 W.
Surface Elevation: 1448.2 feet

0-16	clay, buff, sandy
16-76	clay, gray, very sandy with thin gravels
76-78	sand, coarse, and pea gravel
78-95	clay, gray, sandy
95-105	gravel, pea-size and coarse sand
105-145	clay, gray, sandy
145-185	Niobrara Chalk

* * * * *

Test Hole R-17
Location: $NE\frac{1}{4}$ sec. 11, T. 99 N., R. 55 W.
Surface Elevation: 1451.6 feet

0-17	clay, buff, sandy
17-90	clay, gray, very sandy
90-140	clay, gray, very sandy with occasional thin streaks of gravel, abandoned hole

* * * * *

Test Hole R-18
Location: $SE\frac{1}{4}$ sec. 1, T. 99 N., R. 55 W.
Surface Elevation: 1451.9 feet

0-27	clay, buff, sandy
27-35	clay, gray, sandy
35-90	clay, gray, very sandy

(continued on next page)

Test Hole R-18--continued

90-105	gravel, pea-size, and sand
105-125	clay, gray, sandy

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Test Hole R-19
Location: NE$\frac{1}{4}$ sec. 7, T. 99 N., R. 54 W.
Surface Elevation: 1449.8 feet

0-10	clay, buff, sandy
10-50	clay, gray, sandy
50-55	gravel, pea-size
55-70	sand, fine
70-130	clay, gray, very sandy
130-135	gravel, pea-size
135-175	clay, gray, sandy
175-185	Niobrara Chalk

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Test Hole R-20
Location: NW$\frac{1}{4}$ sec. 9, T. 99 N., R. 54 W.
Surface Elevation: 1453.2 feet

0-15	clay, buff, sandy
15-85	clay, gray, sandy
85-90	sand, coarse
90-145	clay, gray, sandy, pebbly
145-150	gravel, pea-size
150-155	clay, gray, sandy
155-165	gravel, pea to nut-size
165-170	bedrock (?)

* * * * *

Test Hole R-21
Location: SE$\frac{1}{4}$ sec. 4, T. 99 N., R. 54 W.
Surface Elevation: 1415.8 feet

0-30	gravels (terrace deposits)
30-118	clay, gray, sandy
118-155	Niobrara Chalk

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Test Hole R-22
Location: SE$\frac{1}{4}$ sec. 3, T. 99 N., R. 54 W.
Surface Elevation: 1355.5 feet

0-35	sand, fine to coarse, and pea gravel
35-	hole caving and thus abandoned

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Test Hole R-23
Location: SE$\frac{1}{4}$ sec. 11, T. 99 N., R. 55 W.
Surface Elevation: 1459 feet

0-24	clay, buff, sandy
24-65	clay, gray, sandy
65-90	clay, gray, very sandy
90-140	clay, gray, sandy and pebbly, abandoned hole

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Test Hole R-24
Location: SE$\frac{1}{4}$ sec. 12, T. 99 N., R. 55 W.
Surface Elevation: 1455.5 feet

0-23	clay, buff, sandy
23-98	clay, gray, very sandy
98-101	gravel, pea-size
101-145	clay, gray, sandy, abandoned hole

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Test Hole R-25
Location: SE$\frac{1}{4}$ sec. 12, T. 99 N., R. 55 W.
Surface Elevation: 1457 feet

0-19	clay, buff, sandy
19-175	clay, gray, sandy to very sandy
175-185	Niobrara Chalk

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Test Hole R-26
Location: NW$\frac{1}{4}$ sec. 16, T. 99 N., R. 54 W.
Surface Elevation: 1465.1 feet

0-21	clay, buff, sandy
21-90	clay, gray, sandy
90-95	gravel, pea to nut-size

(continued on next page)

Test Hole R-26--continued

95-185	clay, gray, sandy, with a few thin gravel streaks
185-215	Niobrara Chalk

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Test Hole R-27
Location: SW$\frac{1}{4}$ sec. 10, T. 99 N., R. 54 W.
Surface Elevation: 1471.7 feet

0-21	clay, buff, sandy
21-130	clay, gray, sandy
130-150	gravel, pea to nut-size
150-180	clay, gray, sandy
180-215	Niobrara Chalk

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Test Hole R-28
Location: NW$\frac{1}{4}$ sec. 14, T. 99 N., R. 54 W.
Surface Elevation: 1441.9 feet

0-15	clay, buff, sandy
15-25	gravel, pea-size, iron stained
25-55	clay, buff, sandy
55-115	clay, gray, sandy
115-120	gravel, pea-size
120-150	clay, gray, sandy
150-155	Niobrara Chalk (weathered)
155-185	Niobrara Chalk (unweathered)

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APPENDIX B

Logs of Auger Test Holes in the Marion Area

(for location see figure 3)

Test Hole A-1
Location: SW$\frac{1}{4}$ sec. 14, T. 100 N., R. 55 W.

0-4	topsoil, black
4-9	alluvium, black, pebbly, very sandy
9-14	sand, fine, brown, silty, saturated, to clay, black, pebbly
14-19	silt, black, sandy, saturated
19-24	sand, medium, brown, pebbly
24-29	sand, fine, dark gray, silty, saturated
29-34	sand, fine, gray, silty, saturated
34-84	sand, very fine, gray, silty, saturated

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Test Hole A-2
Location: SW$\frac{1}{4}$ sec. 24, T. 100 N., R. 55 W.

0-4	silt, black, clayey
4-9	silt, dark brown, moist
9-14	clay, black, sandy to pebbly, saturated
14-24	gravel, pea-size, brown, silty, saturated
24-34	sand, brown, fine to medium, clay, saturated
34-49	sand, fine to medium, gray, clayey, saturated
49-64	clay, gray, sandy to pebbly, saturated
64-74	sand, fine to medium, gray, some clay, saturated
74-99	sand, fine to medium, gray, saturated

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Test Hole A-3
Location: NW$\frac{1}{4}$ sec. 30, T. 100 N., R. 54 W.

0-7	silt, black, clayey
7-9	sand, fine, brown, silty, saturated
9-16	clay, black, silty; and sand, brown, saturated
16-39	sand and gravel, pea-size, brown, saturated
39-69	no cuttings; probably same as from 16-39

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Test Hole A-4
Location: SE$\frac{1}{4}$ sec. 27, T. 100 N., R. 55 W.

0-4	topsoil and clay, buff, with a few pebbles

(continued on next page)

Test Hole A-4--continued

4-19	clay, buff, a few pebbles
19-24	clay, buff, sandy, saturated
24-34	clay, buff, sandy, pebbly, and sand, fine, saturated
34-39	clay, brown and gray, very sandy, pebbly, and sand, brown, clayey, saturated
39-79	clay, gray, sandy, pebbly, saturated

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Test Hole A-5
Location: $NW\frac{1}{4}$ sec. 32, T. 100 N., R. 54 W.

0-4	topsoil, black, silty
4-14	clay, black, silty
14-19	clay, dark brown, silty
19-24	silt, black, sandy, pebbly, saturated
24-34	silt, black, sandy, pebbly, clayey, saturated
34-44	sand, gray, clayey, very fine, saturated
44-49	silt, gray, pebbly, clayey, saturated
49-64	silt, gray, pebbly, clayey, sandy, saturated
64-79	silt, gray, pebbly, clayey, saturated, sandy
79-84	clay, gray, silty, sandy, pebbly

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Test Hole A-6
Location: $NW\frac{1}{4}$ sec. 33, T. 100 N., R. 54 W.

0-4	topsoil, black
4-9	sand, fine to medium, dark brown, clayey, moist
9-14	gravel (5-15 mm.), some clay, saturated
14-24	gravel, finer, some clay, saturated
24-29	gravel (2-10 mm.), brown, sandy
29-34	gravel, finer, brown, sandy
34-44	sand, clayey, saturated, brown, very coarse
44-49	sand, fine to medium, gray, clayey, saturated
49-54	clay, gray, sandy, saturated
54-84	clay, gray, very pebbly

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Test Hole A-7
Location: $SW\frac{1}{4}$ sec. 27, T. 100 N., R. 54 W.

0-2	topsoil
2-9	clay, buff, a few pebbles present
9-19	clay, buff, a few pebbles present, clay is darkening
19-29	clay, brown

(continued on next page)

Test Hole A-7--continued

29-44	clay, dark brown, moist
44-54	clay, brown, saturated
54-59	sand, very fine, brown, clayey, saturated
59-69	sand, very fine, gray, much clay, saturated
69-74	clay, gray, sandy, saturated
74-79	sand, very fine, gray, saturated
79-84	sand, fine to medium, gray, silty, saturated

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Test Hole A-8
Location: SW$\frac{1}{4}$ sec. 31, T. 100 N., R. 54 W.

0-4	clay, yellow
4-14	clay, brown, pebbly
14-24	clay, dark brown, pebbly, moist
24-29	clay, yellow, silty, saturated
29-34	clay, yellow, silty to sandy, saturated
34-39	sand, very fine, buff, clayey, saturated
39-49	sand, fine to medium, buff, clayey, saturated
49-59	sand, fine, gray, clayey, saturated
59-69	clay, gray, sandy

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Test Hole A-9
Location: SW$\frac{1}{4}$ sec. 32, T. 100 N., R. 54 W.

0-19	clay, dark buff, pebbly
19-24	clay, dark buff, very sandy, moist
24-29	silt, buff, sandy, clayey, saturated
29-34	sand, buff, silty, saturated
34-44	clay, buff, sandy, saturated
44-54	silt, buff, sandy, clayey, saturated
54-59	clay, gray, sandy, saturated
59-74	clay, gray, pebbly, saturated
74-79	clay, gray, pebbly to sandy, saturated

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Test Hole A-10
Location: SW$\frac{1}{4}$ sec. 32, T. 100 N., R. 54 W.

0-9	clay, yellow
9-14	clay, gray, silty
14-19	clay, brown, pebbly
19-34	clay, gray, sandy, saturated
34-44	clay, gray, sandy to pebbly, saturated

(continued on next page)

Test Hole A-10--continued

44-54	clay, gray, silty, saturated
54-74	clay, gray, silty, pebbly, saturated
74-94	clay, gray, silty to pebbly, saturated

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Test Hole A-11
Location: NW$\frac{1}{4}$ sec. 3, T. 99 N., R. 54 W.

0-4	topsoil
4-9	clay, black, very pebbly, saturated
9-14	clay, black, very pebbly, saturated, changing to clay, gray, pebbly
14-29	clay, gray, pebbly, saturated
29-59	clay, gray, sandy, saturated
59-69	clay, gray, sandy, saturated, pebbly
69-84	clay, gray, sandy, saturated

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Test Hole A-12
Location: NW$\frac{1}{4}$ sec. 2, T. 99 N., R. 54 W.

0-1	topsoil, black
1-14	clay, yellow, saturated at 8 feet
14-24	clay, yellow, silty, saturated
24-29	clay, dark brown, pebbly
29-34	clay, buff, pebbly, saturated
34-39	clay, gray, pebbly, saturated
39-49	clay, buff, sandy, saturated
49-74	clay, gray, sandy, saturated
74-79	clay, buff, sandy, silty

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Test Hole A-13
Location: NW$\frac{1}{4}$ sec. 12, T. 99 N., R. 55 W.

0-4	clay, dark brown
4-9	silt, yellow, clayey, saturated
9-14	silt, buff, saturated
14-19	sand, fine, brown, clayey, saturated
19-29	clay, brown, very sandy to pebbly
29-34	clay, gray, sandy
34-39	clay, dark brown and incorporated gray, sandy clay
39-89	clay, gray, pebbly
89-94	sand, brown, saturated; sand at 89-94 may have come from above at 14-19

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Test Hole A-14
Location: $NE\frac{1}{4}$ sec. 10, T. 99 N., R. 54 W.

0-1	topsoil, black
1-9	gravel, coarse, brown
9-14	gravel, coarse; grading to a gray, pebbly clay
14-34	clay, gray, slightly pebbly
34-39	clay, gray, sandy, saturated
39-79	clay, gray, very sandy and saturated

* * * * *

Test Hole A-15
Location: $SW\frac{1}{4}$ sec. 2, T. 99 N., R. 54 W.

0-4	topsoil, black, silty
4-9	silt, black, moist, at 8' water
9-14	silt, black, saturated
14-19	clay, gray, sandy, saturated
19-24	clay, gray, sandy to pebbly, saturated
24-39	gravel, pea-size, gray, and gravel, finer, saturated, clayey
39-49	silt, gray, saturated
49-64	silt, gray, saturated, pebbly
64-81	clay, gray, pebbly

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Test Hole A-16
Location: $SE\frac{1}{4}$ sec. 10, T. 99 N., R. 55 W.

0-3	topsoil, black
3-4	clay, brown, pebbly
4-9	clay, yellow, silty, pebbly
9-17	clay, brown, pebbly
17-19	clay, brown, pebbly, saturated
19-24	clay, gray, silty
24-29	clay, gray, silty to sandy
29-54	clay, gray, silty to sandy, nearly saturated
54-69	clay, gray, silty, saturated

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Test Hole A-17
Location: $SW\frac{1}{4}$ sec. 12, T. 99 N., R. 55 W.

0-4	clay, black, silty, and buff, slightly silty clay
4-14	clay, buff, slightly silty
14-19	clay, buff, slightly silty, becoming darker
19-29	clay, gray, silty, moist
29-34	clay, gray, silty, moist, a few pebbles

(continued on next page)

Test Hole A-17--continued

34-84	clay, gray, silty
84-89	clay, gray, silty, nearly saturated
89-103	clay, gray, silty, moist

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Test Hole A-18
Location: NE$\frac{1}{4}$ sec. 15, T. 99 N., R. 54 W.

0-19	clay, buff, small pebbles present
19-24	clay, brown, pebbly
24-44	clay, buff
44-49	sand, very fine, buff, saturated
49-69	sand, very fine, buff, clayey, saturated

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Test Hole A-19
Location: SW$\frac{1}{4}$ sec. 17, T. 99 N., R. 54 W.

0-4	topsoil, black
4-9	clay, buff, very silty
9-14	clay, buff, silty
14-19	clay, dark brown, silty
19-24	clay, yellow, sandy, saturated
24-79	clay, gray, silty
79-103	clay, gray, sandy, possibly gravel from 85-103

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APPENDIX C

Table 2.--Record of Wells

Well location: letters stand for quarter section, first number for section, second for township north, third for range west
Type of well: Du, dug; D, drilled; B, bored
Water-bearing material: o, outwash; ss, sandstone; sl, sand lens; ch, chalk; q, quartzite
Use of water: S, stock; D, domestic

Well Location	Owner or Tenant	Type of Well	Depth of Well (ft)	Geologic Source	Water-Bearing Material	Use of Water
SW-2-99-54	George Goffer	D	150	Glacial	(?)	S,D
SW-3-99-54	Lloyd Schmidt	D	100	Glacial	o	S,D
NW-3-99-54	J. J. Fitzjerald	D	100	Niobrara	ch	S,D
SE-3-99-54	Al Splonskowski	D	190	(?)	(?)	S,D
NE-4-99-54	Ralph Handwerk	D	200	Niobrara	ch	S,D
SE-4-99-54	H. H. Pfaff	D	190	Niobrara(?)	ch	S,D
NW-4-99-54	Walter Buse	D	200	Niobrara	ch	S,D
NE-5-99-54	Sam Buse	D	295	Dakota(?)	ss	S,D
NW-6-99-54	Harry Herlyn	D	210	Niobrara	ch	S,D
NW-7-99-54	Walter Bousfield	D	412	Dakota	ss	S,D
NE-7-99-54	Joe Freimuth	D	200	Niobrara	ch	S,D
NE-8-99-54	A. Sturzenbecker	D	268	Niobrara	ch	S,D
NW-8-99-54	Herb Preheim	D	190	Glacial	o	S
SW-8-99-54	Lawrence Kramer	D	365	Niobrara	ch	S,D
SE-9-99-54	Herb Janssen	D	300	Niobrara	ch	S
SW-9-99-54	Bruce Handwerk	D	240	Glacial	sl	S,D
SE-11-99-54	Melvin Schmidt	D	400	Niobrara	ch	S

Appendix C-Record of Wells--continued

Well Location	Owner or Tenant	Type of Well	Depth of Well (ft)	Geologic Source	Water-Bearing Material	Use of Water
NE-11-99-54	Andrew P. Andersen	D	170	Sioux(?)	q	S
SW-14-99-54	Rudy Sturzenbecker	D	185	Niobrara(?)	ch	S,D
NE-14-99-54	John Cink	D	50	Glacial	o	S
NW-14-99-54	Arnold Schmidt	D	225	Niobrara(?)	ch	S
NE-15-99-54	Sam Begeman	D	150±	Niobrara	ch	S,D
NW-16-99-54	Henry Wentzel	D	300	Niobrara(?)	ch	S,D
NE-16-99-54	Clarence Cink	D	180	Niobrara	ch	S,D
SW-17-99-54	Harry Gossen	D	90	(?)	(?)	S,D
SW-18-99-54	Dick DeHoogh	D	240	(?)	(?)	S
SE-18-99-54	Walt Albrecht	D	255(?)	Niobrara	ch	S
NW-18-99-54	Earl Wieman	D	170±	(?)	(?)	S
NE-19-99-54	Elmer Schmidt	D	503	Dakota	ss	S,D
SW-19-99-54	A. Schmidt	D	235	Niobrara	ch	S,D
SE-21-99-54	Harry Woltzen	D	230	Niobrara(?)	ch	S,D
SE-22-99-54	John Solheim	D	150	Niobrara	ch	S
NE-23-99-54	Harley Schrag	D	300	Dakota	ss	S
NE-1-99-54	Clarence Schmidt	D	218	Niobrara	ch	S,D
NW-1-99-55	H. F. Tieszen	D	445	Dakota	ss	S,D
SE-2-99-55	Benjamin Tieszen	D	442	Dakota	ss	S,D
SW-2-99-55	Abe Tieszen	D	213	Niobrara	ch	S,D
NW-3-99-55	Henry Wiens	D	160	Glacial	o	S,D
NE-11-99-55	Don Waltner	D	500	Dakota	ss	S,D

Appendix C-Record of Wells--continued

Well Location	Owner or Tenant	Type of Well	Depth of Well (ft)	Geologic Source	Water-Bearing Material	Use of Water
SE-11-99-55	Hubert Luke	D	400	Dakota	ss	S,D
NW-12-99-55	Henry Ensz	D	200	Niobrara	ch	S,D
SW-12-99-55	Harold Becker	D	424	Sioux(?)	q	S,D
NE-13-99-55	David Kaufman	D	500	Dakota	ss	S,D
SE-14-99-55	Leland J. Kleinsasser	D	238	Niobrara	ch	S,D
SW-14-99-55	Anna Becker	D	250	Niobrara	ch	S,D
NW-14-99-55	A. P. Wiens	D	240	Niobrara	ch	S,D
SW-14-99-55	Wallace Deckert	D	266	Niobrara	ch	S
NE-15-99-55	Leslie Tieszen	D	90	(?)	(?)	S,D
SE-15-99-55	Elias Kaufman	D	250	Niobrara	ch	S,D
NW-22-99-55	Paul Schrag	D	290	Niobrara	ch	S
NE-23-99-55	Sollie Kaufman	D	232	Niobrara	ch	S,D
SW-24-99-55	Lloyd Schrag	D	570	Dakota	ss	S,D
NE-24-99-55	Harry Graber	D	260	(?)	(?)	S
NW-14-100-54	George Griebel	D	40	(?)	(?)	S
SE-15-100-54	Roland Gross	D	220	(?)	(?)	S,D
NE-15-100-54	Berdell B. Langerock	D	126	Glacial	o	S
SE-16-100-54	John Mehlbrech	D	84	Glacial	o	S
NW-16-100-54	Lawrence Guischer	D	70	Glacial	sl	S
NW-17-100-54	Lawrence Loof	D	180	Glacial	o	S,D
NE-17-100-54	Francis Lingbeek	D	170	Glacial	o	S
NE-18-100-54	Luverne Herlyn	D	217	Sioux	q	S,D

Appendix C-Record of Wells--continued

Well Location	Owner or Tenant	Type of Well	Depth of Well (ft)	Geologic Source	Water-Bearing Material	Use of Water
SE-19-100-54	Ed. F. Tieszen	D	191	Glacial(?)	sl	S,D
SE-20-100-54	Francis Langerock	D	220	Niobrara	ch	S,D
SW-20-100-54	Ruben Haar	D	209	Niobrara	ch	S
NW-21-100-54	Luverne Langerock	D	190(?)	Niobrara(?)	ch	S
SE-21-100-54	Glen Langerock	D	223	Glacial	sl	S,D
SW-22-100-54	Omer Merrigan	D	90	Glacial	o	S
NE-23-100-54	E. R. Malzer	D	240	Dakota(?)	ss	S
NE-26-100-54	Sam Lenderts	D	170	(?)	(?)	S
SW-26-100-54	W. P. Fansin	D	198+	(?)	(?)	D
NE-27-100-54	Anthony Kippes	D	200	Glacial	sl	S,D
SE-27-100-54	Vincent Kippes	D	200	Niobrara	ch	S,D
NW-28-100-54	E. F. Tieszen	D	333	Sioux	q	S
SE-28-100-54	John Kippes	D	185	Glacial	o	S
SE-29-100-54	Frank Gossen	D	200	Niobrara	ch	S,D
SE-29-100-54	Harold Pankratz	D	160	Niobrara	ch	S,D
NE-30-100-54	John Engbrecht	D	168	Glacial	o	S,D
SE-31-100-54	Sam Kramer	D	130	Glacial	o	S,D
SW-31-100-54	Edward Iwerks	Du	25+	Glacial	o	S
SE-32-100-54	Earl DeHoogh	D	180	Glacial	sl	S,D
NW-34-100-54	George Dykstra	D	184	Glacial	sl(?)	S,D
Sw-35-100-54	Harry Bemelman	D	38	Glacial	sl	S
NE-35-100-54	W. B. Kasten	D	200	Sioux(?)	q	S

Appendix C-Record of Wells--continued

Well Location	Owner or Tenant	Type of Well	Depth of Well (ft)	Geologic Source	Water-Bearing Material	Use of Water
SW-12-100-55	Arnold T. Iahrt	D	250	Niobrara	ch	S,D
SE-13-100-55	Edwin Jantzen	D	175	Glacial	o	S,D
NE-13-100-55	Konda Brothers	D	180	Glacial	o	S,D
SW-13-100-55	Lloyd Ratzlaff	D	240	Niobrara	ch	S,D
SW-14-100-55	Harold Ortmann	D	205	Niobrara	ch	S,D
NE-14-100-55	Carmi Olfert	D	200	Niobrara	ch	S,D
SE-22-100-55	Marvin Ortmann	B	100	Glacial	o	S
SE-23-100-55	Willard Epp	D	175	Glacial	o	S,D
SE-24-100-55	Bud Arbeiter	D	170(?)	(?)	(?)	S,D
NE-24-100-55	John Deckert	D	168	Glacial	o	S,D
SW-25-100-55	John Ensz	D	400	Dakota	ss	S
NE-25-100-55	Ellsworth Heckel	D	200	Glacial	sl	S,D
NE-26-100-55	Clarence Engbrecht	D	180	Glacial	o	S,D
SW-27-100-55	Willie Koehn	D	170	Niobrara	ch	S,D
SE-27-100-55	Willie Koehn	D	60	Glacial	o	S
SW-34-100-55	Herbert Becker	D	400	Dakota	ss	S,D
SE-34-100-55	Harvey Ortmann	D	165	Glacial	o	S,D
NE-34-100-55	Martin Tieszen	D	398	Dakota	ss	S,D
NE-34-100-55	Martin Tieszen	D	435	Dakota	ss	S
NE-35-100-55	Jacob Becker	D	442	Dakota	ss	S,D
SE-35-100-55	Art Tieszen	D	160(?)	Glacial	o	S,D
NE-36-100-55	Lester Ensz	D	180	Niobrara	ch	S,D
SE-36-100-55	William Jurgens	D	180	Niobrara	ch	S,D