STATE OF SOUTH DAKOTA
Archie Gubbrud, Governor

STATE GEOLOGICAL SURVEY
Allen F. Agnew, State Geologist

SPECIAL REPORT 21

WATER SUPPLY FOR THE CITY OF VERMILLION

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Vermillion, South Dakota
June, 1963

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INTRODUCTION

Present Investigation

This report is the result of a special investigation by the South Dakota State Geological Survey during the summer and fall of 1961 and the summer of 1962 in and around the city of Vermillion, Clay County, South Dakota (fig. 1). In the fall of 1959 the Vermillion City Council requested that a complete survey be made of the ground water conditions in the Vermillion area.

Presently the city is supplied by three wells which produce from a depth of 110 feet. The source of these wells is a glacial outwash deposit beneath the alluvium in the Missouri River Valley. An adequate quantity of water is supplied by these wells, but the concentration of minerals in the water makes treatment costly.

On August 16, 1961, an investigation of the ground water conditions in an area of approximately 36 square miles around the city was initiated. This study was carried out through August 31, 1961, full time and during September and October on a part-time basis. The program was continued full time between August 14 and August 31, 1962, when the field work was completed.

During this investigation, 14 test holes were drilled with the State Geological Survey's power auger drills to an average depth of 86 feet. Thirty-one water samples were pumped from various depths in these test holes. Six attempts at pumping these test holes failed owing to the variability of the aquifer. These samples, and 13 samples from domestic wells, were analyzed by the State Geological Survey's water analysis equipment and by the State Chemical Laboratory. The area was mapped geologically and water wells were inventoried.

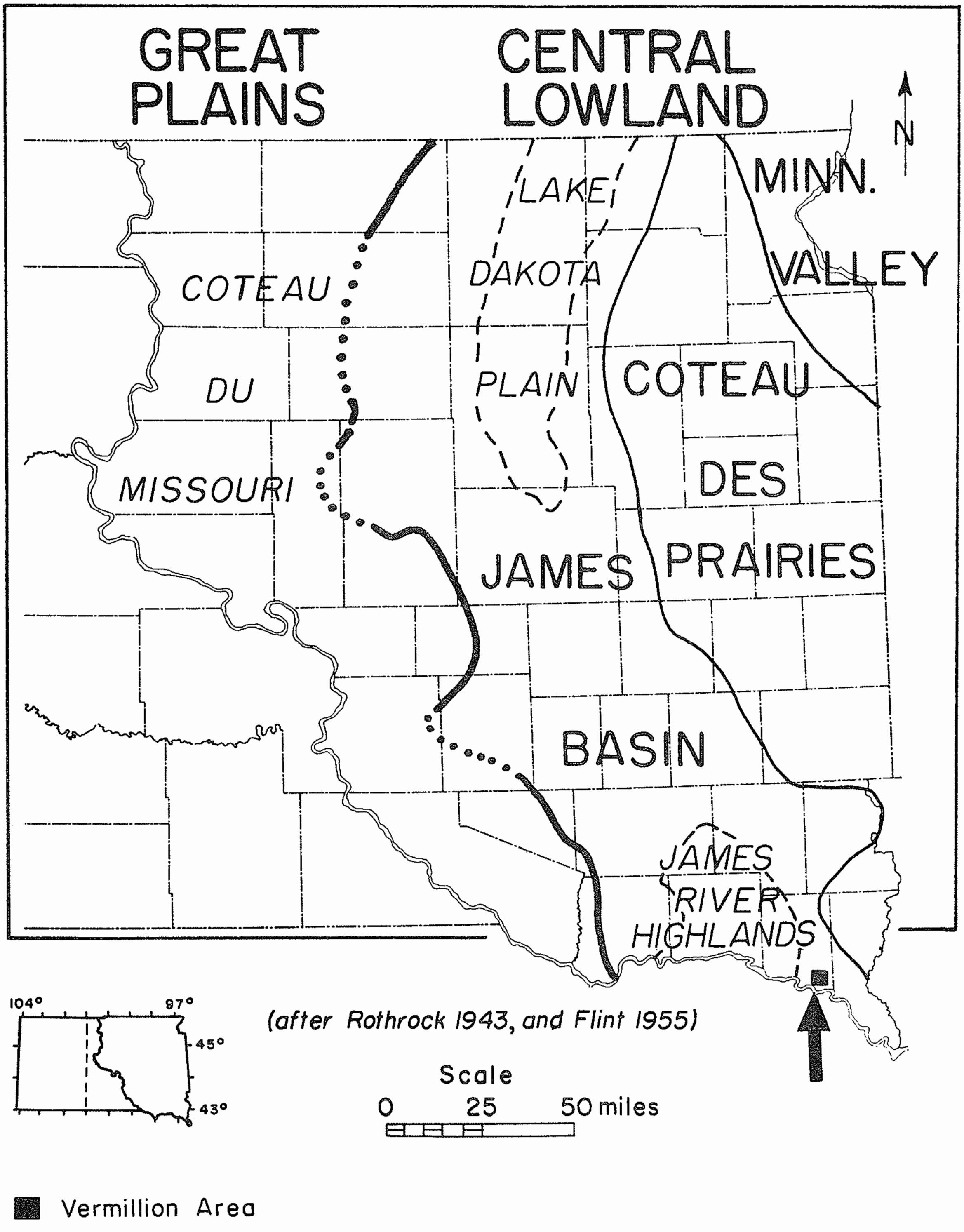
In addition to these field investigations all library material, including records of previously drilled wells, was studied and interpreted.

The investigation showed that four aquifers are available as future water supplies in the Vermillion area. A surface valley train outwash is located in the Vermillion River Valley north of town (fig. 2). This outwash should contain great quantities of water but may be too far removed from the city for consideration.

The present city water supply originates in a buried outwash gravel in the Missouri River Valley. The drilling of additional city wells in this outwash would not produce water of sufficiently better quality to warrant the expense.

It is recommended that the city of Vermillion test further the surface alluvium in the Missouri River Valley lying on the outwash gravel. This testing should be carried out in the vicinity of State Geological Survey Test Holes 8 and 9, a mile south of the city wells (fig. 3); these holes produced water of considerably better quality than the present city supply.

Another favorable area for testing is in Sections 13 and 14, T. 92 N., R. 52 W., where domestic wells show water of better quality than the city supply. This area is underlain by a buried pre-glacial valley that has been filled with sands and gravels which are an excellent water source.



(after Rothrock 1943, and Flint 1955)

Figure I. Major Physiographic Divisions of Eastern South Dakota and the location of the Vermillion Area

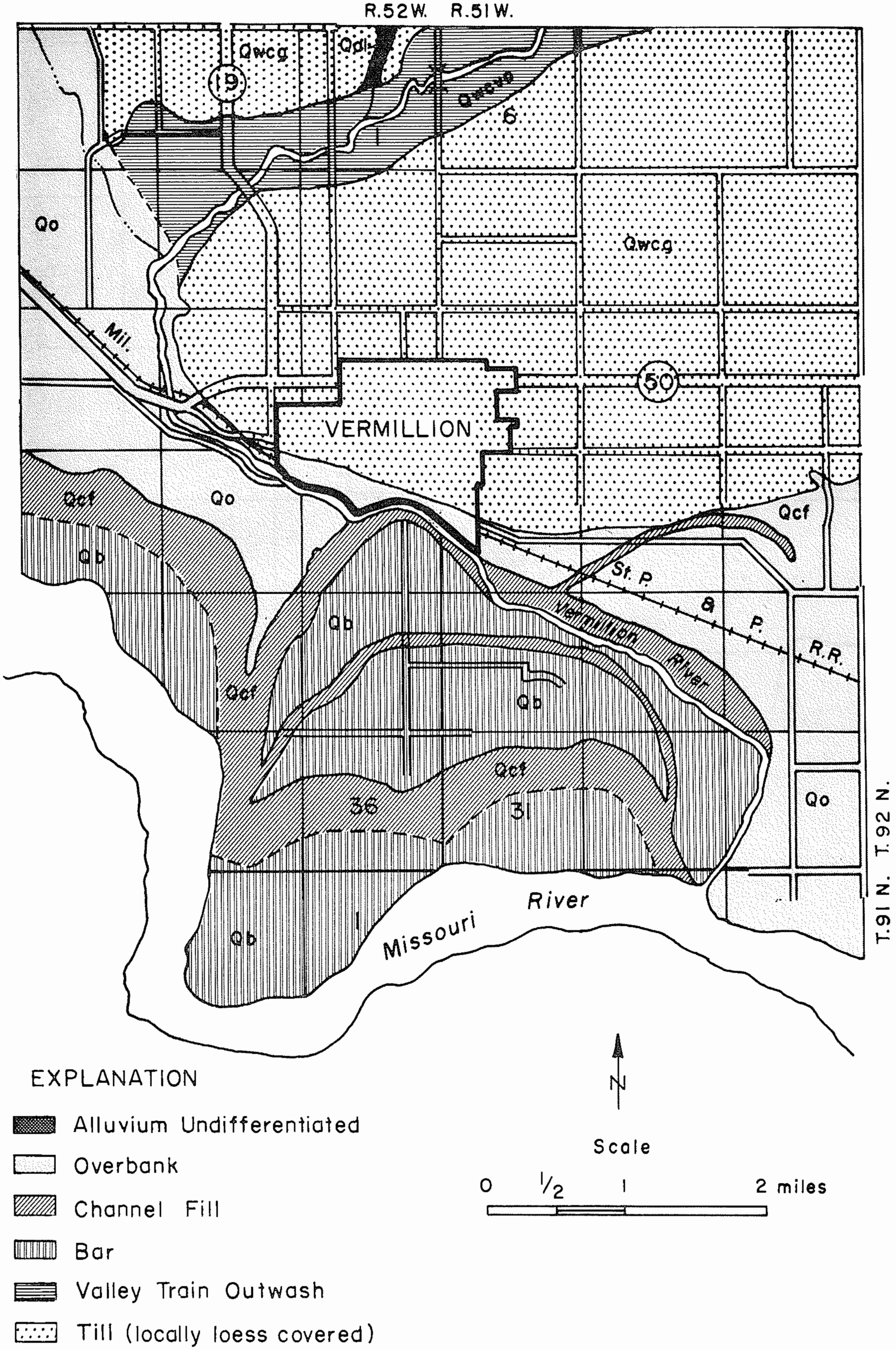
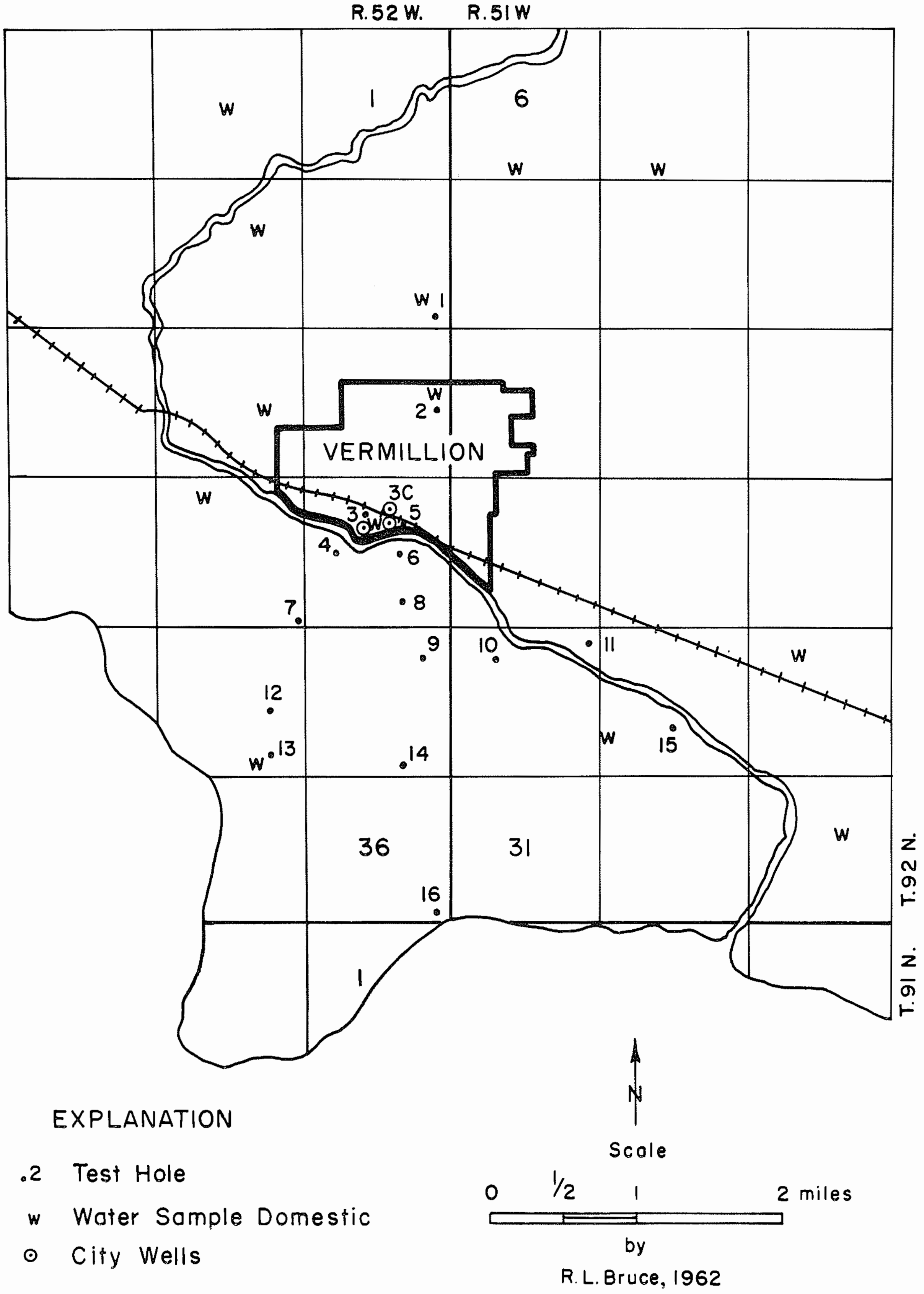


Figure 2. Geologic Map of Vermillion Area.

(Adapted from Jorgensen 1960, and Christensen, in preparation)

Figure 3. Data Map of Vermillion Area



The field work and preparation of this report were performed under the supervision of Merlin J. Tipton, Assistant State Geologist. Geologic assistance was given by Robert Schoon, geologist-driller for the State Geological Survey and Richard Brown, Cleo Christensen, Mike Clancy, Nat Lufkin, Keith Munneke, Steve Pottratz, and Loren Rukstad. The writer wishes to thank the residents of the Vermillion area for their cooperation, especially R. F. Patterson, Mayor when the project was originated, and Ralph Leer who was Mayor during the remainder of the project.

Special thanks are due to the South Dakota State Chemical Laboratory in Vermillion for reconditioning the field analysis kit and for providing a portable pH meter, and to the U. S. Geological Survey for providing the specific conductance meter. These instruments made it possible to obtain quick chemical analyses of water.

Location and Extent of Area

The city of Vermillion is in Clay County in southeastern South Dakota, and has a population of 6,102 (1960 census). The area is in the James Basin division of the Central Lowland physiographic province (fig. 1).

Climate

The climate is continental temperate, with large daily fluctuations in temperature. The mean annual temperature is 50 degrees F., and the average annual precipitation is 24.08 inches, at the U. S. Bureau Station in Vermillion.

Topography and Drainage

Two types of topography are present in the Vermillion area. The northern part is youthful glacial moraine--rolling hills and valleys with knobs and kettles, while the southern part is the broad relatively flat surface of the Missouri River flood plain.

The drainage in the area is controlled by the Missouri River, which flows in a southeasterly direction, and by its tributary, the Vermillion River.

GENERAL GEOLOGY

Surficial Deposits

The surficial deposits of the Vermillion area can be divided into two types: those resulting from glaciation during the Pleistocene Epoch and those resulting from deposition of streams during Recent time.

The glacial deposits are collectively called drift and can be divided into till and outwash sediments. Till consists of clay- and silt-size particles mixed randomly with sand, pebbles, and boulders, and was deposited by the glacial ice itself. Outwash sediments consist chiefly of sand and pebbles with minor amounts of silt and clay, and were deposited by meltwater streams.

The area north of the Missouri River Valley is covered with loess and till (fig. 2), with the exception of the valley outwash in the Vermillion River Valley. The Vermillion Valley is partially filled with an outwash deposit composed of sand and gravel with local lenses of clay. The outwash extends to the north and is 30 to 126 feet thick, with an average thickness of 55 feet (Christensen, in preparation). This outwash is covered with a thin veneer of recent alluvium. Small tributary stream valleys which drain the till bluffs also contain minor amounts of alluvium.

The Recent deposits of the Missouri flood plain in the Vermillion area are collectively called alluvium, and have been divided into channel fill, bar, and overbank deposits. Channel fill deposits are composed chiefly of clay and silt-size particles and are deposited in abandoned stream channels. Bar deposits are chiefly sand and are the result of deposition by the stream. Overbank deposits are caused by river deposition while in flood stage and are composed of silts and clays (Jorgensen, 1960). These alluvial deposits range from 40 feet to more than 100 feet in thickness.

Directly beneath the Recent alluvium in the Missouri Valley is a glacial outwash, which is more than 100 feet thick in some areas (Jorgensen, 1960, p. 9). The present city wells are producing from this outwash. This outwash consists of sand and gravel with occasional large boulders. Much of the gravel contains fragments of lignitic coal.

A buried pre-glacial valley extends through the Vermillion area from the north and joins the Missouri River Valley in the vicinity of Vermillion (Flint, 1955, pl. 7). This buried valley was cut into bedrock and filled with as much as 138 feet of glacial outwash and stream deposits which are covered by as much as 127 feet of till. This buried valley is known to underlie the northern part of the city and the area to the north for at least one mile. It represents the course of an ancient river which flowed through South Dakota before the coming of the glaciers. Figure 4 shows an electric and gamma-ray log of the State Geological Survey's Test Hole 2 (located on the campus of the State University). This log shows 130 feet of outwash in this old valley.

The relationships of these deposits are shown on the cross section (fig. 5). The data presented do not indicate if the outwash in the Missouri River Valley and that in the pre-glacial valley are continuous.

Subsurface Bedrock

Stratified sedimentary rocks of Cretaceous age lie beneath the surficial deposits in the Vermillion area (fig. 5). These sediments in descending order are the Niobrara, Carlile, Greenhorn, and Graneros Formations, and the Dakota Group. These sediments may be absent locally in the area.

The Niobrara Formation, in the subsurface, consists of bluish-gray clay-marl with a high percentage of organic calcium carbonate, and is locally highly fractured. This formation crops out locally north of the city of Vermillion along the Vermillion River, where it is a white- to yellowish-brown argillaceous marl (called "chalk rock" by many local residents).

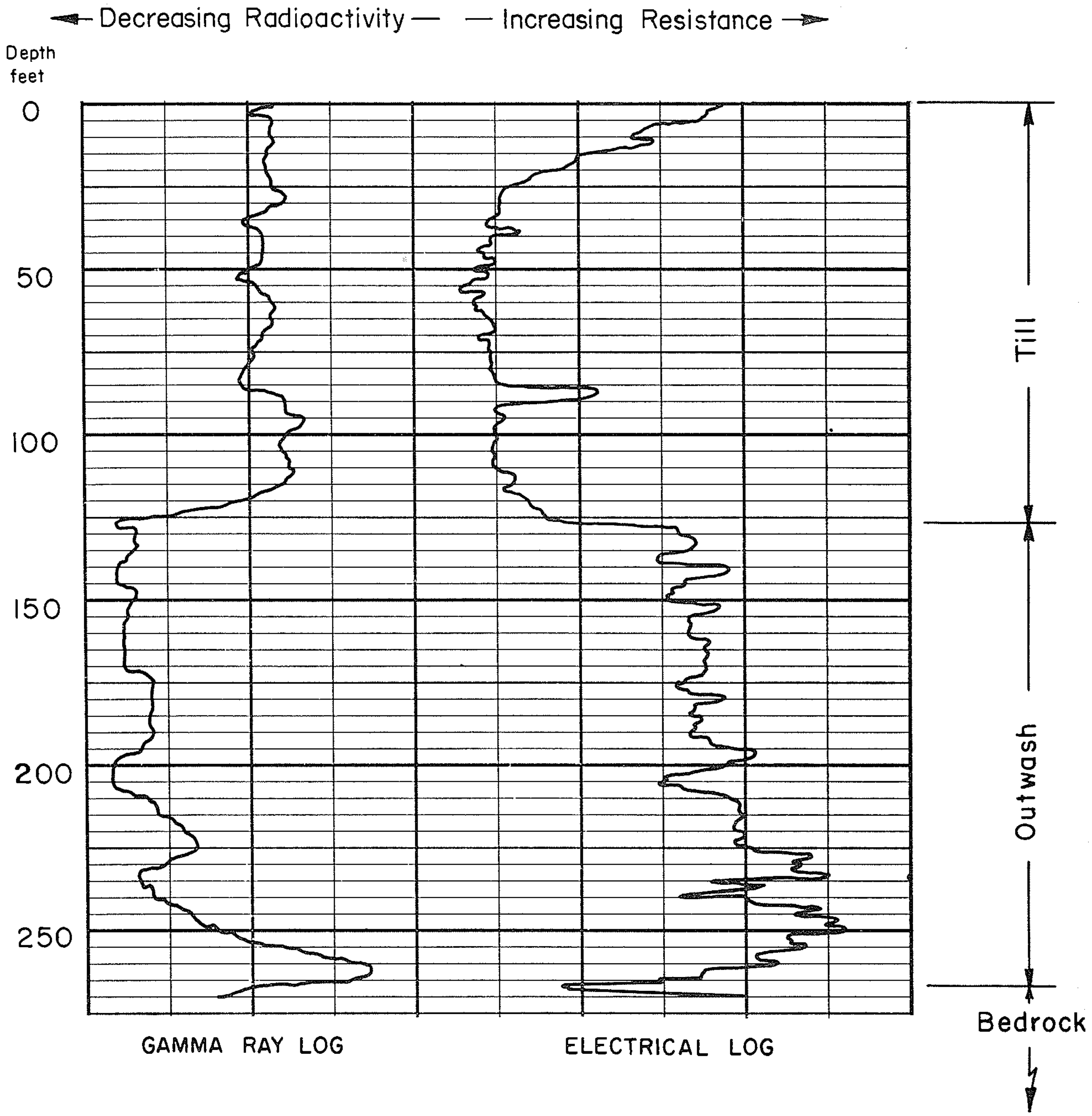


Figure 4. Gamma-Ray and Electric Log of State Geological Survey Test Hole 2

(for location see fig 3)

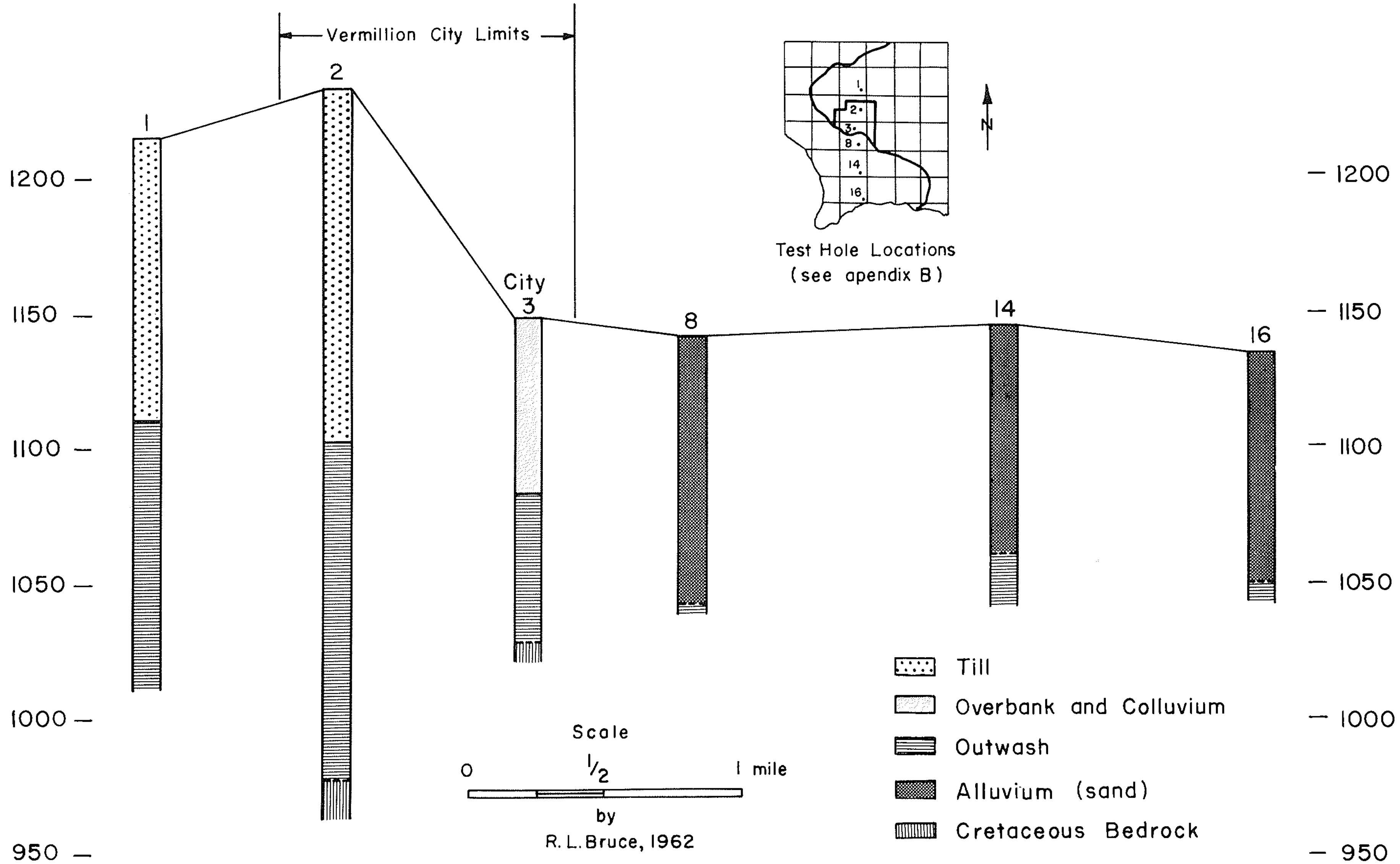


Figure 5. Geologic Cross Section of the Vermillion Area

The Carlile consists of medium- to dark-gray bentonitic shale. The Codell Sandstone Member of this formation is composed of brown siltstone and fine sand interbedded with thin silty shale and is present near the top of the formation. The Greenhorn Limestone and Graneros Shale are white limestone and dark siliceous shale, respectively.

The Dakota Group consists chiefly of fine to coarse, light-colored sandstones interbedded with gray shales.

The Cretaceous sediments may be underlain either by the limestones, dolomites, shales and sandstones of Paleozoic age or by the crystalline rocks of Precambrian age.

OCCURRENCE OF GROUND WATER

Principles of Occurrence

Ground water may be defined as water contained in voids of openings of rock or sediments below the water table. Therefore, the water table marks the upper surface of the saturated zone of the water-bearing formation. The common belief that water occurs in "veins" which criss-cross the area in a disconnected maze is not true, as water occurs nearly everywhere below the surface of the ground. The existence of a water supply is controlled by the water table; this is not a static level, but fluctuates, and in a general way reflects the surface topography. The water table ranges from a few feet to many tens of feet below the surface; in the Vermillion area it ranges from 6 to 40 feet below the surface.

The amount of water which is contained in the reservoir rock or aquifer is controlled by the porosity and permeability of the rock. Porosity is a measure of the percentage of voids in a rock and is expressed in the ratio of pore space to the total volume of rock.

Porosity is dependent on (1) the shape and arrangement of individual particles, (2) the degree of sorting of the particles, (3) the degree of cementation and compaction of the particles, and (4) the amount of material which has been removed by percolating ground water. Sands and gravels usually have porosities that range from 20 to 40 percent depending on the above conditions, whereas sandstones have porosities of 15-25 percent. Sandstones have lower porosities owing to their higher degree of compaction and cementation.

Permeability is a measure of the rate at which a fluid will pass through a material. A material that has a high percentage of interconnected pores likewise has a high permeability, whereas a material that has high porosity but in which the pores are not connected will have low permeability. Therefore, it can be seen that porosity and permeability are not synonymous but are nevertheless related.

Nearly all ground water is derived from precipitation. Rain or melting snow either percolates directly downward to the water table and becomes ground water, or drains off as surface water. Surface water either evaporates, escapes to the ocean by streams, or percolates downward to the 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, and is accomplished in three ways: (1) by downward percolation of precipitation from the ground surface, (2) by downward percolation from surface bodies of water, and (3) by lateral underflow of water in transient storage.

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

Ground Water in Glacial Deposits

Till does not yield water readily because of its highly unsorted nature and low porosity and permeability. On the other hand, outwash material is a favorable source for ground water.

One surface outwash deposit exists in the Vermillion area; and is confined to the valley of the Vermillion River north of town. This outwash consists of 30-126 feet of sand and gravel. The saturated part of the deposit is a very good aquifer. No geologic investigation of this aquifer was made because of its distance from town, but the city may decide to test it further.

The outwash material in the pre-glacial buried valley is a potential aquifer for the city of Vermillion. Test Holes 1 and 2 penetrated this aquifer, and numerous farm wells north of Vermillion derive their water from this source.

Test Hole 2 was drilled on the University of South Dakota campus. Electric and gamma-ray logs (fig. 4) were run on this hole with the State Geological Survey's Widco logger, to determine the character and thickness of this aquifer. An electric log shows graphically the resistance of the sediments to the passage of electrical current. Because deposits of different lithologies have different electrical resistances, it is possible to differentiate one lithologic type from another. In general the resistance of a lithologic type is influenced by its moisture content and therefore is related to its porosity. Sands, gravels, and sandstones contain more moisture than clays, silts, and shales, and because chemically pure water is a poor conductor of electricity, the resistance of these coarser sediments is higher than the finer, less saturated sediments.

The gamma-ray curve shows the concentration of gamma-ray emitting elements in a deposit. Almost all deposits contain small, but measurable amounts of radioactive elements. Generally sands, gravels, and sandstones are low in radioactivity, while clays, silts, and shales are relatively high in radioactivity (Haun and LeRoy, 1958, p. 331). Thus, the electric log and gamma-ray log when used in conjunction are a very good indication of the lithologies of the deposits encountered in a test hole.

Figure 4 shows that at a depth of 127-265 feet, a lithologic type was penetrated which has a much higher resistivity and lower radioactivity than the beds above or below. This is interpreted to be the buried valley outwash deposit. The rough or jagged edge of the electric log indicates areas of thin clay or silt lenses in the sands and gravels. Some of the larger lenses are also shown on the gamma-ray log. These lenses are minor features, however, and do not seriously detract from the aquifers potential.

The outwash which is found beneath the alluvium in the Missouri River Valley is also a good aquifer. The three Vermillion city wells produce from this aquifer at a depth of 110 feet.

Sulfates: Sulfate concentration in excess of 500 ppm gives a bitter taste to water, and may have a laxative effect on persons unaccustomed to it.

Chlorides, Sodium: A maximum concentration not to exceed 250 ppm is recommended for chlorides, for in combination with sodium it yields table salt (NaCl) and may give a salty taste to water and be harmful to persons on low-salt diets.

Magnesium, Calcium: These are the major elements causing hardness in water when they are in combination with bicarbonates and sulfates. Magnesium should not exceed 50 ppm.

Total Hardness: Total hardness is defined as the soap-consuming capacity of water. Water with less than 100 ppm is considered soft water, and below 250 ppm in South Dakota is considered fairly soft.

Fluoride: The recommended fluoride concentration is 0.9 to 1.5 ppm. Concentrations in this range have been found to reduce tooth decay; however, concentrations in excess of 3.0 ppm may cause mottling or pitting of tooth enamel.

Nitrates: Nitrates in excess of 10 ppm concentration may be harmful to infants and greatly in excess of this amount may be harmful to all persons and to animals.

pH: This is a mathematical expression indicating the concentration of hydrogen ions in water. A pH of 7.0 is neutral, less than 7.0 is acid, and greater than 7.0 is alkaline. Most waters in South Dakota are in the alkaline pH range of 7.2 to 8.0.

Iron, Manganese: The Drinking Water Standards recommend that iron and manganese should not exceed 0.3 and 0.05 ppm, respectively. Iron and manganese are nuisance chemicals as they cause deposits in water distribution mains and service lines, and leave stains on plumbing fixtures and on light-colored clothes. Iron leaves red or reddish-brown deposits and stains; manganese stains and deposits are black or gray.

Table 1 shows quality of water samples taken from the aquifers in the Missouri River Valley. These samples were pumped from the various depths by use of the State Geological Survey's portable suction pump. The test holes were drilled to depths ranging from 75 to 104 feet (the depth depended on what deposits were encountered) with a jeep-mounted, three-inch, power flite-auger drill. The drill augers were then removed and a $1\frac{1}{4}$ inch galvanized pipe with a six-foot sand point was forced into the hole.

The pipe and sand point were then left in the hole until the water in the pipe reached a height of less than 20 feet. The hole was pumped for a minimum of 3 hours to make certain a completely uncontaminated sample was obtained. Samples were collected in one-quart inert plastic bottles, and tested as soon as possible after collection by the State Geological Survey or the State Chemical Laboratory.

The depths in Table 1 at which "no sample" is indicated (holes 9,10,14 and 15) mean that no water sample was recovered although pumping continued for many hours.

Table 2 shows the quality of the water samples collected from various sources in the Vermillion area, as compared with the U. S. Department of Health drinking water standards, and with water from the untreated and treated city wells.

Table 1--Chemical Analyses of State Geological Survey test hole Water Samples*

Test Hole No.**	Depth of Sample in feet	Total Solids	Sulfates	Chlorides	Calcium	Magnesium	Total Hardness $CaCO_3$	Iron	Manganese	Fluoride	Sodium	Nitrate	pH
Public Health Standards (1961)		1000***	500***	250		50		0.3	0.05	0.9- 1.7****		10	
City Well Untreated	110	1093	340	11	168	61	676	2.1	1.4	0.6	88	0.0	7.4
City Well Treated	110	609	332	7	24	21	146	0.0	0.0	1.2	133	0.0	8.8
4	50	527	146	8	134		180	1.3					7.4
	75	942	274	4	226	63	824	9.4	Trace	0.2	91	1.0	7.2
	115	976	320	5	159	55	625	5.1	Trace	0.4	82	1.0	7.2
6	20		243	22	183		520	.2(?)					
	50		377	48	282	13.7	760	.15(?)					
	75	1390	675	43	230	54	796	.35	.13	None	68	.3	
	109	1250	681	42	180	54	672	.56	None	None	86	.2	
7	50	1131	243	16	268		460	1.5					7.8
	75	768	305	13	94	52	488	3.51	None	None	60	.7	
	100	866	317	8	119	36	448	3.06	None	None	57	1.0	
8	50		33.9	8	197		395	0.3(?)					
	80	438	43	None	72	20	262	0.14	None	None	27	.4	
	100	724	243	7	43	43	384	5.6	None	None	60	.6	

* All concentrations in parts per million

** see figure 3 for location

*** modified for South Dakota by the State Department of Health (written communications, February 5, 1962)

**** Optimum

Table 1--Chemical Analyses of State Geological Survey test hole Water Samples*--Continued

Test Hole No. **	Depth of Sample in feet	Total Solids	Sulfates	Chlorides	Calcium	Magnesium	Total Hardness $CaCO_3$	Iron	Manganese	Fluoride	Sodium	Nitrate	pH
9	50		Trace	8	183		260	.1(?)					
	75	470	42	3	78	16	260	Trace	None	None	26	.2	
	100	No Sample											
10	50	875	214	12	286		430	.05					7.8
	75&100	No Sample											
11	50	1462	554	44	352		810	.15					7.8
	75	1338	704	42	193	51	695	25.52	None	None	65	.4	
	100	1382	736	47	215	49	742	3.2	None	None	57	.1	
12	50	838	385	12	73	58	420	3.1	Trace	0.2	89	1.5	8.2
	75	921	292	20	169		450	0.2(?)					
	100	936	309	7	90	52	440	5.82	None	None	80	1.7	
13	25	1800	462	16	240	37	750	8.2					7.2
	50	1787	486	20	247	53	830	7.5					7.1
	75	902	307	10	226	6	590	7.8	Trace	0.2	68	1.3	7.2
	92	814	330	10	182	9	492	9.4	Trace	0.2	67	0.2	7.1
14	54	1230	Trace	8	84	36	350	4.6					7.2
	75	No Sample											
	100	No Sample											
15	53	1425	534	16	233	34	720	8.2					7.0
	78	1330	690	25	328	8	850	14.2	1.8	0.2	46	None	6.9
	100	No Sample											
16	48	1155	146	16	205		500	2.0					7.2
	66	654	227	8	111	35	423	6.5	Trace	None	61	1.7	7.2

Table 2--Chemical Analyses of Domestic Water Well Samples*

	Name and Location**	Total Solids	Sulfates	Chlorides	Calcium	Magnesium	Total Hardness $CaCO_3$	Iron	Manganese	Fluoride	Sodium	Nitrate	pH
1	U.S. Dept. of Public Health Drinking Water Standards(1961)	1000***	500***	250		50		0.3	0.05	0.9-1.7****		10	
2	City Well Untreated	1093	340	11	168	61	676	2.1	1.4	0.6	88	0.0	7.4
3	City Well Treated	609	332	7	24	21	146	0.0	0.0	1.2	133	0.0	8.8
4	Leo Albers Sec. 2, T. 92 N., R. 52 W.	1592	656	44	303	4	800	.45					7.4
5	Stanley Munger Sec. 11, T. 92 N., R. 52 W.	1325	486	20	198		530	.15					7.1
6	Golf Course Sec. 12, T. 92 N., R. 52 W.	1370	704	40	276	36	836	0.3	0.9	1.6	60	0.25	
7	University Well Sec. 13, T. 92 N., R. 52 W.	1525	534	48	310	4	760	0.2(?)					7.1
8	Prairie Bowling Lanes Sec. 14, T. 92 N., R. 52 W.	834	305	5	90	51	435	.35	None	None	80	.3	
3	Howard Morse Sec. 23, T. 92 N., R. 52 W.	1379	185	8	268		600	4.0					7.9

* All concentrations in parts per million

** see figure 3 for location

*** modified for South Dakota by the State Department of Health (written communications, February 5, 1962)

**** Optimum

Table 2--Chemical Analyses of Domestic Water Well Samples*--Continued

	Name and Location	Total Solids	Sulfates	Chlorides	Calcium	Magnesium	Total Hardness $CaCO_3$	Iron	Manganese	Fluoride	Sodium	Nitrate	pH
14	Wester Farm Sec. 26, T. 92 N., R. 52 W.	1925	535	60	282	34	840	8					7.0
15	Fred Schofstall (2 wells)	1348	292	16	226	10	580	0.2					7.2
	Sec. 30, T. 92 N., R. 52 W.	1183	170	8	232	9	460	5.9					7.3
9	G. O. Johnson Sec. 5, T. 92 N., R. 51 W.	1016	439	6	29	128	602	2.04	Trace	None	35	.4	
10	H. C. Johnson Sec. 6, T. 92 N., R. 51 W.	1048	489	17	133	61	582	6.62	None	None	39	0.1	
11	A. A. Cotton Sec. 28, T. 92 N., R. 51 W.	1571	608	48	282	31	830	0.4					7.1
12	C. Fuller Sec. 33, T. 92 N., R. 51 W.	1625	510	52	296	15	800	3.5					7.1

State Geological Survey test holes penetrated this aquifer. The sands and gravels of this outwash produce great quantities of water, but the presence of some unfavorable chemical ions makes its quality generally poor.

Ground Water in Alluvium

The alluvium below the water table in the Vermillion and Missouri Rivers, as well as in the minor tributary streams, holds a large quantity of water; however, some types of alluvium yield water very slowly owing to their low permeability.

Two types of alluvium mapped in the Vermillion area are believed to have sufficient porosity and permeability to supply adequate water supplies for the city. These are the areas mapped as bar and channel fill (fig. 2).

In this area, 14 Geological Survey test holes were drilled in order to determine the lithology, depth, and water content of these sands, and the quality of the water contained in them.

Great supplies of water are contained in this area, although local variations in the deposition of these deposits have created clay lenses at some depths.

Ground Water in Bedrock

The Niobrara Marl and the Codell Sandstone Member of the Carlile Shale are water producers in some areas in South Dakota. These formations, however, are not suitable aquifers in the Vermillion area.

Some communities derive their water supply from the artesian sandstones of the Dakota Group. The quality of this water is so poor, however, that it needs no further consideration here.

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 soil and underlying deposits as the water percolates downward to the water table, and (3) from 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 and 2 show the chemical properties of water samples taken in the Vermillion area as compared with the present city supply and with the standards for drinking water established by the U. S. Department of Public Health. In Table 1 the first column shows the well number (See fig. 3) and the second column shows the depth from which the sample was pumped.

An explanation of the chemical analysis data and the recommended maximum concentrations of ions of elements follows:

Total Solids: Total solids is a measure of the total amount of chemicals and minerals in a water. The concentration is recommended not to exceed 1000 parts per million (ppm). In general, the higher the total solids, the poorer the quality.

Samples 4,5,6,7,8,9, and 10 were collected from wells which produce from the buried outwash in the pre-glacial valley north of town. Sample 8 was taken from the new well at the Prairie Bowling Lanes, and is of better quality than the city wells in all elements. Except for iron, wells 4,5,6, and 7 have a poorer quality than the city wells and wells 9 and 10 are poorer in all elements.

On the basis of well 8, it is possible that test holes pumped from this aquifer north of town would produce water of better quality than the city's present supply.

Water samples 11 and 12 are probably produced from the outwash beneath the alluvium in the Missouri River Valley but due to the variability of this deposit these samples may originate in the alluvium. These samples are generally of poorer quality than the present city supply.

Samples 13,14,15 and 16 are from shallow wells (less than 50 feet deep) in the alluvium of the Missouri River Valley. Since these tests are shallow, and show in general, a high iron content; they have not been considered as a potential supply.

The data from Table 1 have been used to draw maps which show areas of favorable quality water for future exploration.

Quality Maps

The quality maps (figs. 6 and 7) were developed to show the most favorable area in the Missouri River Valley for future well location. The maps show overall quality of the water at the 75- and 100-foot levels. The contour lines and patterns show areas where the quality is better than the Public Health standards, areas where it is worse than the standards but still better than the present city supply, and areas where it is worse than both.

These maps were developed by selecting the five most important quality elements in this area. These are total solids, total hardness, sulfates, iron and manganese. The remaining elements are not considered to be "trouble" elements, for their concentrations are in general, very low and all are below the standards.

A problem arose in constructing these maps. A method has to be devised which would show these elements in their proper perspective in relation to the other elements. Obviously a concentration of iron of 9 ppm compared to total solids of 500 ppm seems low. But a concentration of 9 ppm iron is 30 times larger than the recommended limits and 500 ppm total solids is but one-half the recommended limit.

Therefore, a mathematical relationship was developed which gave each of the elements equal rank. This was accomplished by letting the recommended maximum for each element equal an arbitrary 100. For example:

Total solids should not exceed 1000 ppm. Therefore, 1000 ppm total solids=100. Similarly,

250 ppm sulfates = 100
0.3 ppm iron = 100
0.05 ppm manganese = 100
250 ppm total hardness = 100
Total = 500

The limits for total hardness of 250 were selected by the author as an arbitrary figure after studying the results in Table 1.

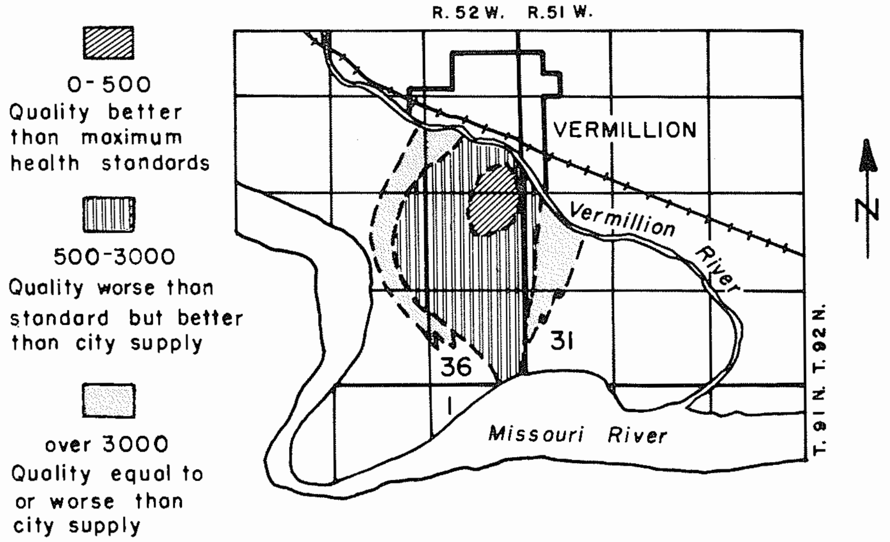


Figure 6. Quality of 75-foot Water Samples

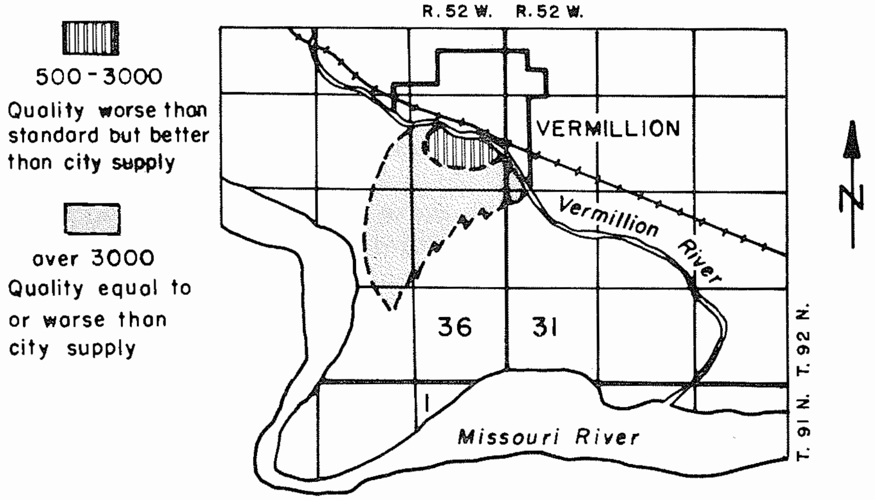


Figure 7. Quality of 100-foot Water Samples

A ratio, therefore, can be established to determine how the concentrations of the elements in each sample ranks in comparison to the 100 maximum for the Public Health standards.

If we let:

s = concentration of element in sample in ppm

(PH) = maximum concentration in ppm recommended by Public Health

100 = arbitrary number assigned to each (PH)

x = quality of element in each sample

Then:

$$\frac{s}{X} = \frac{(PH)}{100}$$

Solving for X we get

$$X = \frac{100s}{(PH)} \qquad \text{(formula 1)}$$

By applying this formula to each element and adding the results we get a maximum recommended by Public Health of 500. The totals for each sample figured with this formula are found in Table 3.

Table 3.--Concentration of Chemical Elements in each Water Sample

Public Health Standards	500
City Well Untreated	3948

Well No. (for locations see fig. 3)	75-foot level	100-foot level
4	3133	1700
6	969	717
7	1496	3016
8	214	2141
9	159	---
11	9059	1796
12	---	2271
13	2600	3133
14	1163	---
15	8984	---
16	2446	---

Hole No. 8 will serve as an example for the calculation of these totals. Hole 8 at the 75-foot depth by chemical analysis contains:

Total solids	438 ppm
Sulfates	43 ppm
Total hardness	262 ppm
Iron	0.14 ppm
Manganese	0.00 ppm

By applying formula 1 to total solids we get:

$$X = \frac{100\ (0.14)}{1000}$$

$$X = 43.8$$

Similarly for iron:

$$X = \frac{100\ (0.14)}{0.3}$$

$$X = 46.7$$

Similarly when:

X = = 8.6
sulfates

X = = 104.8
Total Hardness

X = = 0
Manganese

Total = 214.1

This total is the figure given in Table 3. All qualities were figured in the same way.

A general rule can be now formulated--the lower the figure, the better the water quality.

Figure 6 shows the quality figures from Table 3 of areas in the Missouri River Valley at the 75-foot level. It shows that most of the area studied at this depth contains water of better quality than that now being utilized by the city. One area in the center of the map has exceedingly good quality water, which is much better than the city's present supply. This area would be the most suitable spot for further exploratory drilling by the city.

The water at this depth was pumped from the surface alluvium deposits. These deposits are fine to medium sand, and would necessitate special well construction before new city wells could be completed.

Figure 7 shows the quality figures from Table 3 plotted for the same area but at a depth of 100 feet. The samples from this depth are coming either from the bottom of the alluvium or from the top of the gravel outwash below. The quality at this depth is poorer than that at the 75-foot depth. It can be seen that only a small area has better quality water than the present city supply.

The poorer quality water in the 100 foot samples is due to the higher content of iron (See fig. 9).

Iron Concentration Maps

Figures 8 and 9 show the concentration of iron at the 75- and 100-foot depths. They are included to show the distribution of iron in relation to the better quality areas shown on Figures 6 and 7.

It can be seen that the greatest concentration of iron is in the same areas where the most unfavorable quality water is found. It is obvious that Figures 6 and 7 and Figures 8 and 9 show almost identical patterns. Therefore, it is safe to conclude that iron is directly related to the overall quality of the water samples in the Missouri River Valley near Vermillion.

The high concentration of iron at the 100-foot depth may be explained by a higher content of iron-bearing sediments at this depth. Probably the quality of this water is influenced by the outwash gravel directly below. This outwash has a higher content of iron than the alluvium overlying it.

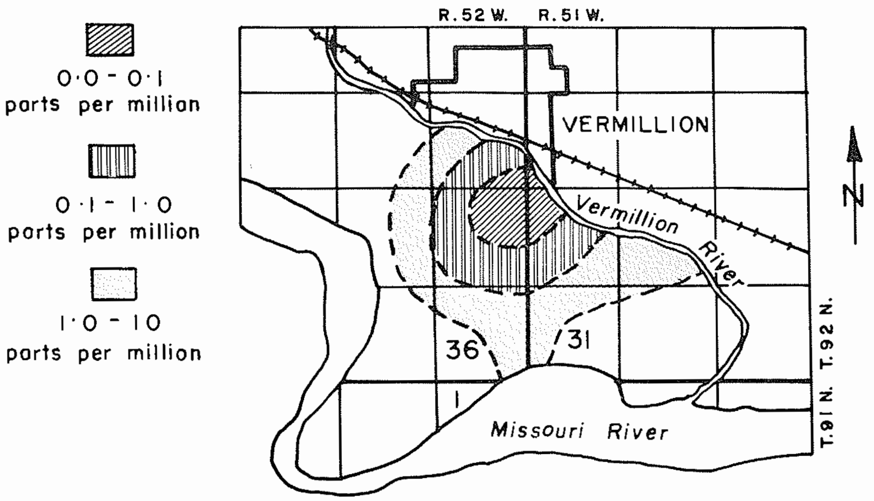


Figure 8. Iron Content of 75-foot Water Samples

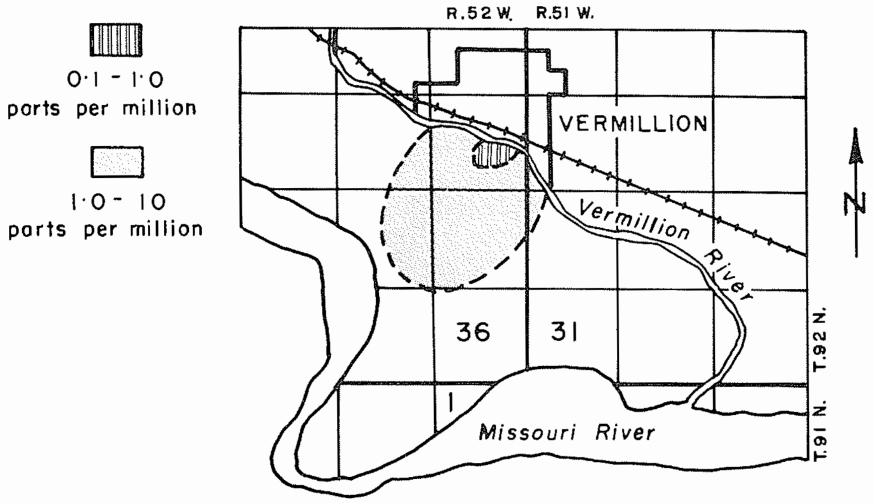


Figure 9. Iron Content of 100-foot Water Samples

CONCLUSIONS AND RECOMMENDATIONS

Four Pleistocene glacial aquifers occur in the Vermillion area. These are: (1) the surface outwash valley train contained in the Vermillion River Valley north of the city of Vermillion; (2) the buried outwash contained in the wide pre-glacial valley; (3) the buried outwash gravels in the Missouri River Valley under the Recent alluvium; and (4) the Recent alluvium in the Missouri River Valley.

The outwash in the Vermillion River Valley has great potential as a ground water aquifer, and the city may want to drill test holes to determine if the quantity and quality of water desired can be obtained in this aquifer. It is, however, a great distance from the city, and aquifers which will produce water of adequate quality and quantity are found closer to Vermillion.

The outwash in the pre-glacial valley is a potential aquifer for the city of Vermillion. Water samples taken from seven wells in this aquifer show that the overall quality of the aquifer in this area is the same or worse than the city's present supply. One very good sample was taken from the well at the Prairie Bowling Lanes. This well tested very low in all elements. The city may want to test this aquifer further to determine if this quality can be found closer to the city.

It is recommended, therefore, if the city decides to test this aquifer further, that a series of test holes be drilled in Sections 13 and 14, T. 92 N., R. 52 W., and that water samples be pumped from these holes from at least three depths. If these samples show a quality sufficiently better than the city's present supply, then the city can develop wells at the best depth and location.

The city is pumping its present supply from the buried gravel outwash in the Missouri River Valley. It is felt that this aquifer cannot produce water of sufficiently better quality than the city is now receiving to warrant relocating the city wells in this aquifer. The fact cannot be overlooked, however, that areas of better quality may exist in this aquifer.

The sands in the surface alluvium in the Missouri River Valley are a possible source for future well locations. This aquifer is highly variable in its quality as is shown on Figures 3 and 6, but the maps show the best quality in the area of Test Holes 8 and 9 (See fig. 3). The quality of the water in this area is much better than that in the present city wells.

It is recommended, therefore, that the city drill a test hole in the vicinity of Geological Survey Test Holes 8 and 9 and pump three water samples--one from the alluvial sand, one from the contact of the sand and the outwash gravel, and one from the outwash gravel itself. This will show the exact depth in which to develop the wells, and will also show the relationship in quality between these two aquifers.

Regardless of the location selected for further development, the city should, on the basis of <u>test holes</u>, pick a location for a <u>test well</u>. This test well should be test-pumped by licensed engineers for a minimum of 72 hours. These tests are extremely important to determine if the aquifer is continuous and also to determine what capacity and type of permanent well should be constructed.

It is suggested that the city contact a commercial well-drilling company licensed by the State of South Dakota, to test-drill the areas 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 South Dakota should be hired to design the well and the water system.

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APPENDIX A

Logs of Test Holes in Vermillion Area*

(for locations see figure 3)

Test Hole No. 1 (Test hole at Vermillion Golf Course by Commercial Driller, logged by S. D. Geological Survey)
Surface Elevation: 1215 feet
Depth to Water: Not Measured

0-105	till
105-205	outwash sands and gravels

* * * * * *

Test Hole No. 2 (Drilled by S.D.G.S. for University)
Surface Elevation: 1237 feet
Depth to Water: Not Measured

0-13	till, buff, sandy, pebbly
13-95	till, gray, sandy, pebbly; some 6" gravel and sand lenses
95-116	till, gray, very sandy and pebbly
116-117	gravel, pea-size
117-119	till, gray, sandy
119-120	gravel, pea-size
120-130	till, gray, sandy
130-257	sand, medium- to coarse-grained
257-261	shale? medium-gray, plastic
261-270	bedrock

* * * * * *

Test Hole No. 3
Surface Elevation: 1145 feet
Depth to Water: Not Measured

0-4	silt, sandy, clayey
4-9	clay, brown, sandy
9-14	clay, blue-gray, silty; some sand
14-19	clay, dark blue, silty
19-34	clay, dark blue, very dense

* * * * * *

Test Hole No. 3C (City Well #3 drilled by Commercial Driller, logged by S.D.G.S.)
Surface Elevation: 1145 feet
Depth to Water: Not Measured

0-65	overbank and colluvium
65-120	outwash sand and gravel
120-127	bedrock

* * * * * *

*Surface elevation accurate to (+) 5 feet

Test Hole No. 4
Surface Elevation: 1140 feet
Depth to Water: 19 feet

0-4	top soil
4-34	sand, brown, fine, clayey
34-54	sand, blue-brown, fine, clayey
54-94	sand, medium; some clay
94-104	gravel, pea-size; sand coarse

* * * * * *

Test Hole No. 5
Surface Elevation: 1150 feet
Depth to Water: None

0-4	silt, sandy, clayey
4-9	clay, brown, sandy
9-14	clay, blue-gray, silty
14-19	clay, dark blue, silty
19-34	clay, dark blue

* * * * * *

Test Hole No. 6
Surface Elevation: 1140 feet
Depth to Water: 10 feet

0-4	No sample
4-14	silt, brown, sandy
14-19	sand, fine, silty
19-84	sand, fine
84-104	sand, medium, and gravel

* * * * * *

Test Hole No. 7
Surface Elevation: 1140 feet
Depth to Water: 6 feet

0-4	top soil
4-32	clay, blue, sandy
32-49	sand, brown, medium
49-54	sand, brown, coarser

* * * * * *

Test Hole No. 8
Surface Elevation: 1143 feet
Depth to Water: 9 feet

0-9	sand, brown, silty
9-100	sand, fine, clean
100-104	sand, gravelly; coal

* * * * * *

Test Hole No. 9
Surface Elevation: 1138 feet
Depth to Water: Hole Caved--No Data

0-9	sand, brown, fine, silty
9-64	sand, gray, fine; some gravel, clean
64-69	sand as above, clayey
69-97	sand, gray, fine; some gravel
97-104	sand and gravel

* * * * * *

Test Hole No. 10
Surface Elevation: 1140 feet
Depth to Water: 13 feet

0-14	sand, dark brown; silt, blue-gray
14-54	sand, gray; coal
54-79	sand, gray-brown; fine gravel

* * * * * *

Test Hole No. 11
Surface Elevation: 1135 feet
Depth to Water: 15 feet

0-2½	top soil
2½-4	clay, brown
4-10	clay, sandy, moist
10-59	sand, medium, clean
59-91	sand, gray, fine
91-104	sand, coarse; gravel, pea-size

* * * * * *

Test Hole No. 12
Surface Elevation: 1138 feet
Depth to Water: Not Measured

0-5	clay, brown, sandy, silty
5-9	sand, fine, clayey
9-79	sand, brown, medium

* * * * * *

Test Hole No. 13
Surface Elevation: 1142 feet
Depth to Water: Not Measured

0-12	silt, brown, sandy
12-74	sand, clean
74-104	sand and pea-size gravel

* * * * * *

Test Hole No. 14
Surface Elevation: 1145 feet
Depth to Water: Not Measured

0-6	clay, dark brown, silty
6-22	sand, light brown, clean, medium
22-40	sand, clean, medium
40-104	sand, coarser

* * * * * *

Test Hole No. 15
Surface Elevation: 1133 feet
Depth to Water: 12 feet

0-9	clay, brown to gray, some sand
9-24	sand, clayey
24-89	sand, medium, clayey
89-104	sand and pea-size gravel

* * * * * *

Test Hole No. 16
Surface Elevation: 1133 feet
Depth to Water: 11 feet

0-19	sand, brown, fine, silty
19-59	sand, medium, silty
59-89	sand as above, coarse
89-92	gravel

* * * * * *

APPENDIX B

Table 4--Records of Wells

Well Locations: letters stand for quarter section, first number for section, second for township north, third for range west.

Water-Bearing Material: letter W stands for water sample taken and analysed (see table 2)

Well Location	Owner or Tenant	Depth of Well below land Surface (feet)	Water-Bearing Material	Depth to Water
SW-4-92-51	Waldred Papin	150	sand	20
SE-5-92-51	Phil Anderson	200-250 ?	sand	?
SW-5-92-51	G. O. Johnson	135	sand-W	?
SW-6-92-51	H. C. and J. A. Johnson	142	sand-W	70
		120	sand	50
SE-6-92-51	E. V. and Vern Heikes	135	sand	35
NE-7-92-51	E. V. and Vern Heikes	130	sand	30-40
SW-8-92-51	W. A. Buryanek	135	sand	?
SE-8-92-51	Phil Anderson	160	sand	?
SW-16-92-51	E. A. Ouellette	120	sand	?
NE-20-92-51	D. R. McLeod	155	?	?
NE-20-92-51	Fred Ufford	300	?	?
SW-21-92-51	Axel Jensen	80	?	?
NW-21-92-51	Robert Fuchs	250 ?	sand	?
NW-28-92-51	Cotton	120	gravel-W	9
NE-33-92-51	C. Fuller	95	gravel-W	12
SE-2-92-52	Leo Albers	85	sand-W	?
		65	sand	?
NW-2-92-52	Josephine Weeks	185	sand	?
NE-3-92-52	Lewis Peterson	110	sand	?

Appendix B--Table 4--Records of Wells--continued

Well Location	Owner or Tenant	Depth of Well below land Surface (feet)	Water-Bearing Material	Depth to Water
SE-5-92-52	Leonard Bottolfson	?	?	flows
SW-10-92-52	Alfred Anderson	?	?	flows
SE-11-92-52	Gordon Collar	143	sand	?
NE-11-92-52	Stanley Munger	140-150	sand	?
		100	sand-W	?
SE-12-92-52	Ben Seiler	160	sand	?
SE-13-92-52	University of South Dakota	---	sand-W	?
SE-14-92-52	Prairie Bowling Lanes	---	sand-W	?
SE-23-92-52	Howard Morse	50	alluvium-W	?
SE-25-92-52	Wester	35	alluvium-W	?
SE-30-92-52	Fred Scholfstall	35	alluvium-W	?
		35	alluvium-W	?