STATE OF SOUTH DAKOTA
Archie Gubbrud, Governor

STATE GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

SPECIAL REPORT 28

WATER SUPPLY FOR THE CITY OF WATERTOWN, SOUTH DAKOTA

by
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Science Center
University of South Dakota
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INTRODUCTION

Present Investigation

This report contains the results of a special investigation by the South Dakota Geological Survey from June 16 to August 1, 1963, in and around the city of Watertown, Codington County, South Dakota (fig. 1), for the purpose of assisting the city in locating a future water supply.

Watertown now receives its water from Lake Kampeska. A filtration plant at the lake has a capacity of about 1,000 gallons per minute. A supplementary water supply is obtained from eight shallow wells which average 27 feet in depth and have a combined capacity of about 2,500 gallons per minute.

A survey of the ground water possibilities was made in an area of about 104 square miles around the city. This survey consisted of the drilling of 60 test holes with the Survey's hydraulic auger drill, the drilling of six test holes with the Survey's jeep-mounted auger drill, the collection of 15 water samples for quality analysis, and a review of the geology as mapped by Steece (1957) and Tipton (1957).

As a result of this investigation, five areas were located which would probably supplement the city's present supply.

The field work and preparation of this report were performed under the supervision of Lynn S. Hedges, staff ground-water geologist. The assistance and advice from Allan Wood, graduate assistant, was also very helpful. The aid of Keith Munneke and John Cassens, who drilled 60 test holes with the Survey's hydraulic auger drill rig, and of Lynn Huenemann and Harry Haywood, who drilled six holes with a Geological Survey jeep-mounted auger drill rig, is gratefully acknowledged.

The cooperation of the residents in and around Watertown, especially John Babcock, City Engineer, is gratefully appreciated.

Location and Extent of Area

The city of Watertown is located in Codington County in northeastern South Dakota, and has a population of 14,077 (1960 census). The area is in the Coteau des Prairies division of the Central Lowlands physiographic province (fig. 1).

Climate

The climate is continental temperate with large daily fluctuations in temperature. The average daily temperature is 42.0° F., and the average annual precipitation is 27.96 inches at the U. S. Weather Bureau Station in Watertown.

Topography and Drainage

The drainage in this area is controlled primarily by the Big Sioux River, which flows in a southeasterly direction. The tributary streams are dendritic in pattern and the most prominent stream is Gravel Creek (fig. 2).

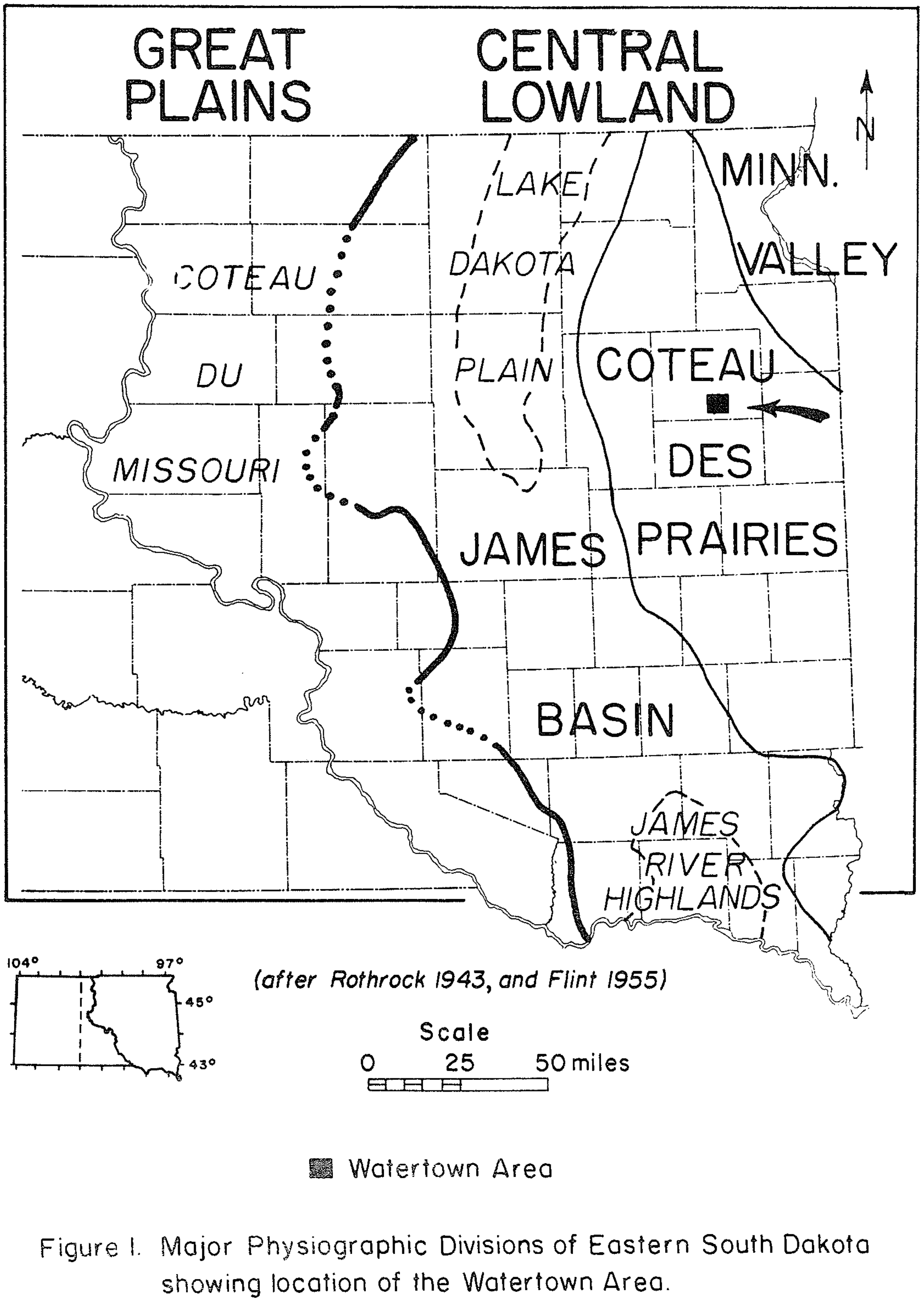
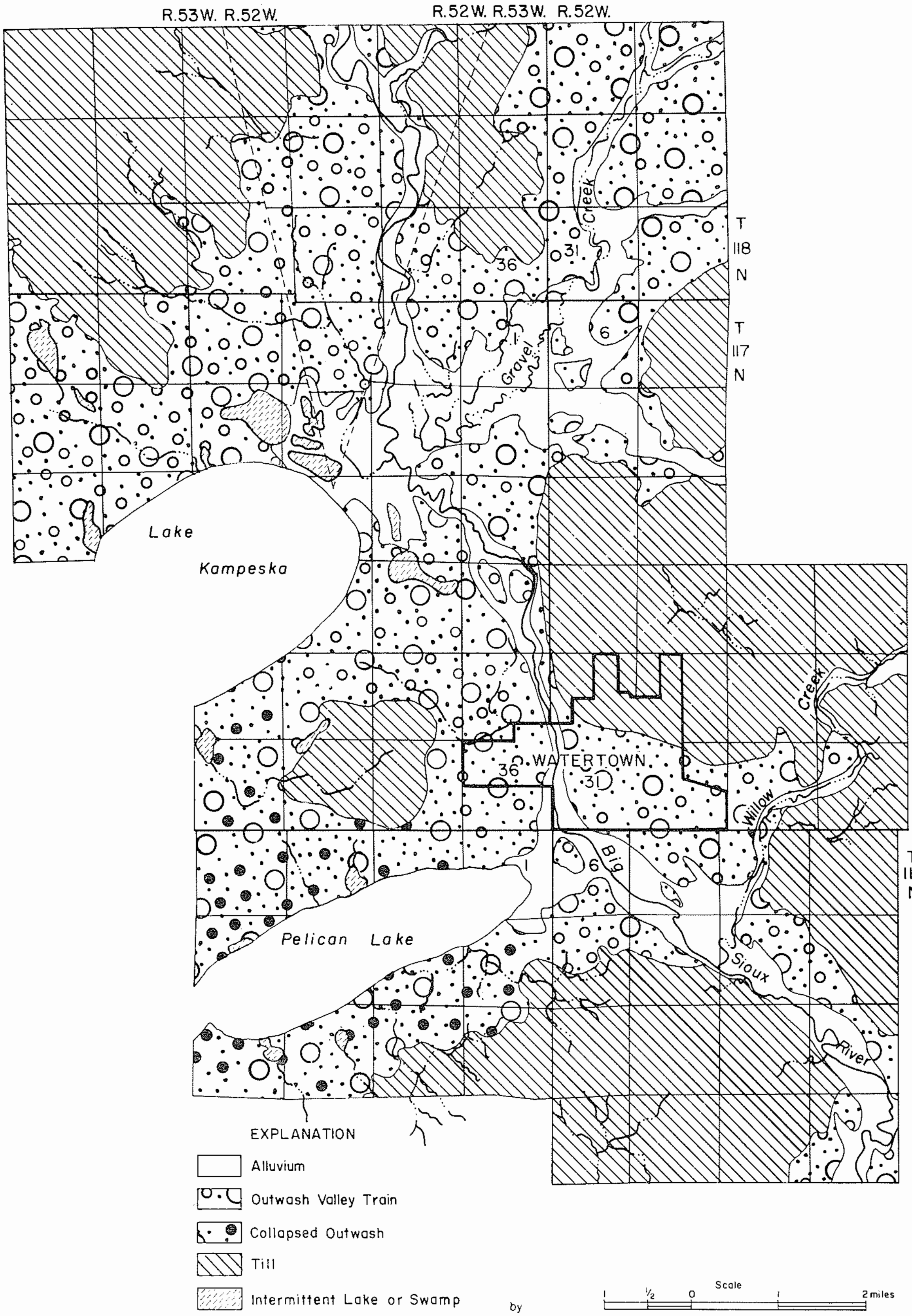


Figure I. Major Physiographic Divisions of Eastern South Dakota showing location of the Watertown Area.

Figure 2. Geologic Map of Watertown Area.



by
Loren Rukstad 1963
after Fred V. Steece 1957

Drafted by Bruno Petsch

Three distinct types of deposits are present in the Watertown area: glacial till, collapsed outwash, and outwash valley train (fig. 2). The glacial till topography is typical youthful glacial moraine--rolling hills and valleys with knobs and kettles. The collapsed outwash has an uneven, pitted topography. The outwash valley train topography is generally flat to slightly undulating.

GENERAL GEOLOGY

Surficial Deposits

The surficial deposits of the Watertown area are chiefly the result of glaciation late in the Pleistocene Epoch. The glacial deposits are collectively termed 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 ice itself. This is the major surficial deposit to the east of the Watertown area (fig. 2).

Outwash sediments consist chiefly of sand and pebbles with minor amounts of silt and clay, and were deposited by meltwater streams from the wasting glacier. In the Watertown area there are two types of outwash: collapsed outwash and outwash valley train.

Collapsed outwash is sediment that was deposited on or against the ice. As the ice wasted away the sediments literally collapsed, leaving an uneven topography.

Outwash valley train deposits consist of sediments that were deposited by meltwater after it left the margin of the ice. As a general rule, outwash valley train sediments contain less interstitial silt and clay than collapsed outwash sediments, and therefore are generally a more favorable aquifer.

Alluvium consists of silt- and clay-sized particles with minor amounts of sand and gravel, deposited by recent streams since the retreat of the glaciers. Alluvium is present along the Big Sioux River, Gravel Creek, and in minor amounts along Willow Creek (fig. 2).

Subsurface Bedrock

No bedrock is exposed in the Watertown area. However, data obtained from well logs in the vicinity reveal that beneath the surficial deposits are stratified sedimentary rocks of Cretaceous age. These deposits in descending order are the Pierre, Niobrara, Carlile, Greenhorn and Graneros Formations, and the Dakota Group.

The Pierre Formation consists of light- to dark-gray fissile shale with many thin bentonite beds and concretionary layers of iron-manganese. The thickness of the Pierre Formation in South Dakota is variable; in the Watertown area the average thickness is about 240 feet.

The Niobrara Formation is mainly light- to dark-gray chalk and marl which contains numerous microscopic white specks. The formation contains thin impure bentonite beds and microfauna. The Niobrara ranges from 30 to 250 feet in thickness and averages 90 feet in this area.

The Carlile Formation consists chiefly of gray fissile shale; it has thin interbedded sands and impure limestone. The Codell Member is a sandstone near the top of the formation. The Carlile averages 200 feet in thickness.

The Greenhorn Formation is light- to dark-gray fragmental limestone and light- to dark-gray marl and marly shale. The limestone is dense and usually is easily recognized both in well cuttings and in exposures. The thickness of the Greenhorn in this area averages 30 feet.

The Graneros Formation is chiefly siliceous shale, but locally is sandy. The thickness of the Graneros Formation averages 150 feet.

The Dakota Group consists of fine to coarse sandstone interbedded with shale. In the Watertown area the Dakota Group is about 80 feet thick.

In this area the Dakota Group is underlain by Precambrian rocks of three types: the Sioux Quartzite, serpentinite, and granite comparable with the Ortonville granite of the Milbank area.

OCCURRENCE OF GROUND WATER

Principles of Occurrence

Ground water may be defined as water contained in the voids or 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. The existence of a water supply is controlled by the water table, which 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 Watertown area it ranges from 3 to 33 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 number 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 to 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 is high in 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 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 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, 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, (3) by lateral underflow of water in transient storage, and (4) by pumping from wells.

Ground Water in Alluvium

Alluvium is present along Gravel Creek, the Big Sioux River, and Willow Creek in the Watertown area (fig. 2). This alluvium contains large amounts of water where it is below the water table, but because of low permeability does not yield water readily.

Ground Water in Glacial Deposits

As was stated earlier, glacial deposits can be divided into till and outwash. Till, because of its unsorted nature and the larger amounts of clay, usually does not yield water readily. Outwash generally is a good source of water, due to its high porosity and permeability.

The outwash deposits in the Watertown area include the valley train outwash along the Big Sioux River and Willow and Gravel Creeks; and the collapsed outwash west and southwest of Watertown (fig. 2).

The valley train outwash consists of stratified deposits of poor- to well-sorted sand and gravel, and is characterized by a nearly level topography. The collapsed outwash is a semistratified, poorly sorted, fine sand to coarse gravel with till inclusions, and is characterized by uneven topography. The collapsed outwash in this area is too variable in character and thickness to be a potential aquifer for the city of Watertown.

Figure 3 shows five possible areas the city of Watertown may consider in locating future water supplies. Although all areas are probably hydraulically connected, each will be assigned a number and discussed as a separate aquifer.

Aquifer 1.--This aquifer is located 4 to 7 miles north of Watertown and covers an area of about 3 square miles. The aquifer in this area ranges from 30 to 80 feet in thickness, and averages about 45 feet. State Geological Survey Test Holes 5, 6, 10, 11, 12, 18, and 19 (fig. 4, Appendix A) penetrated the aquifer and showed that it consisted of poor- to well-sorted sand and gravel with minor amounts of silt and clay. A typical cross-section in this area is illustrated in Figure 5 (Cross-section C-C').

Figure 3. Map showing areas of best potential for ground water development.

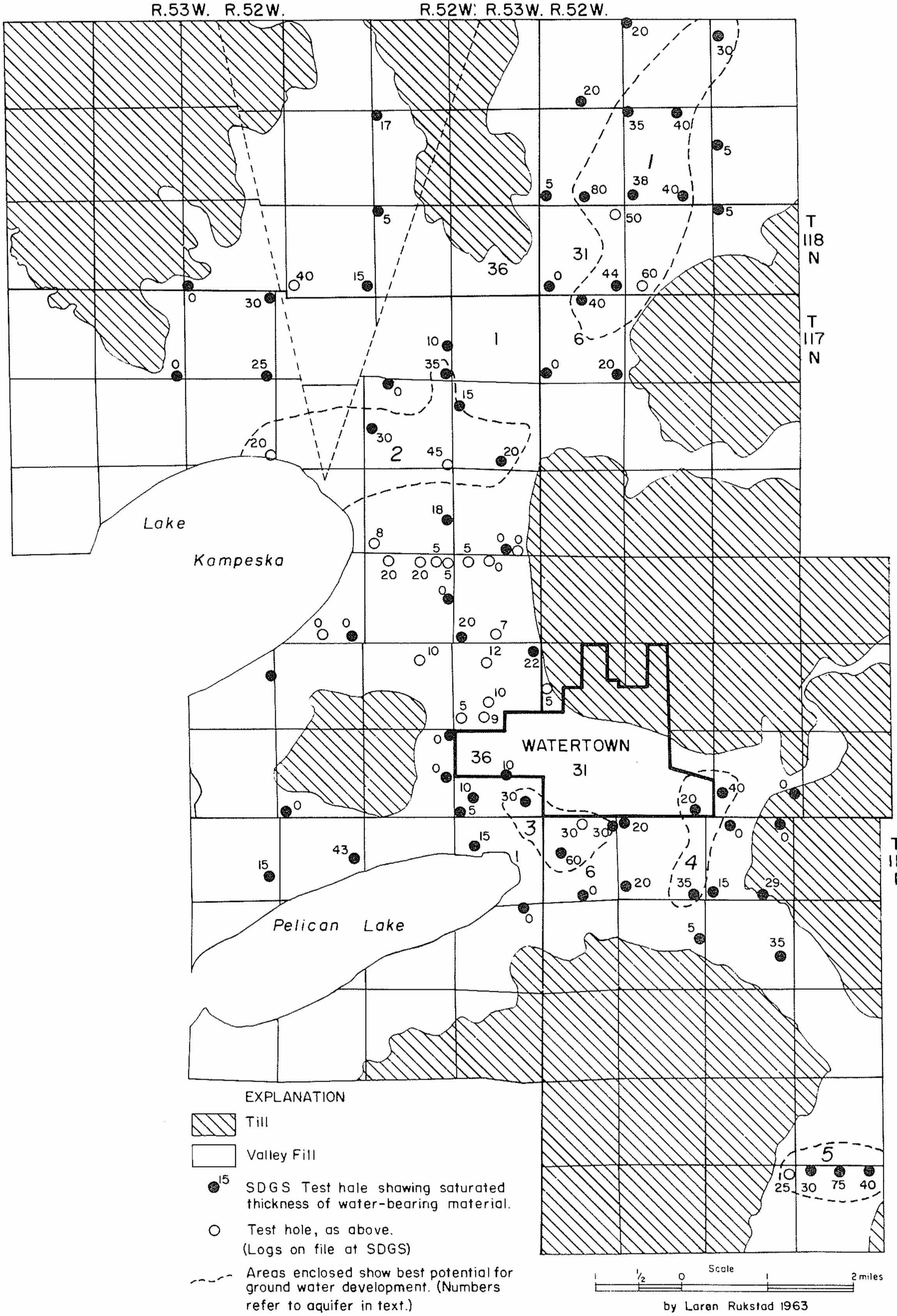


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Figure 4. Data Map of Watertown Area.

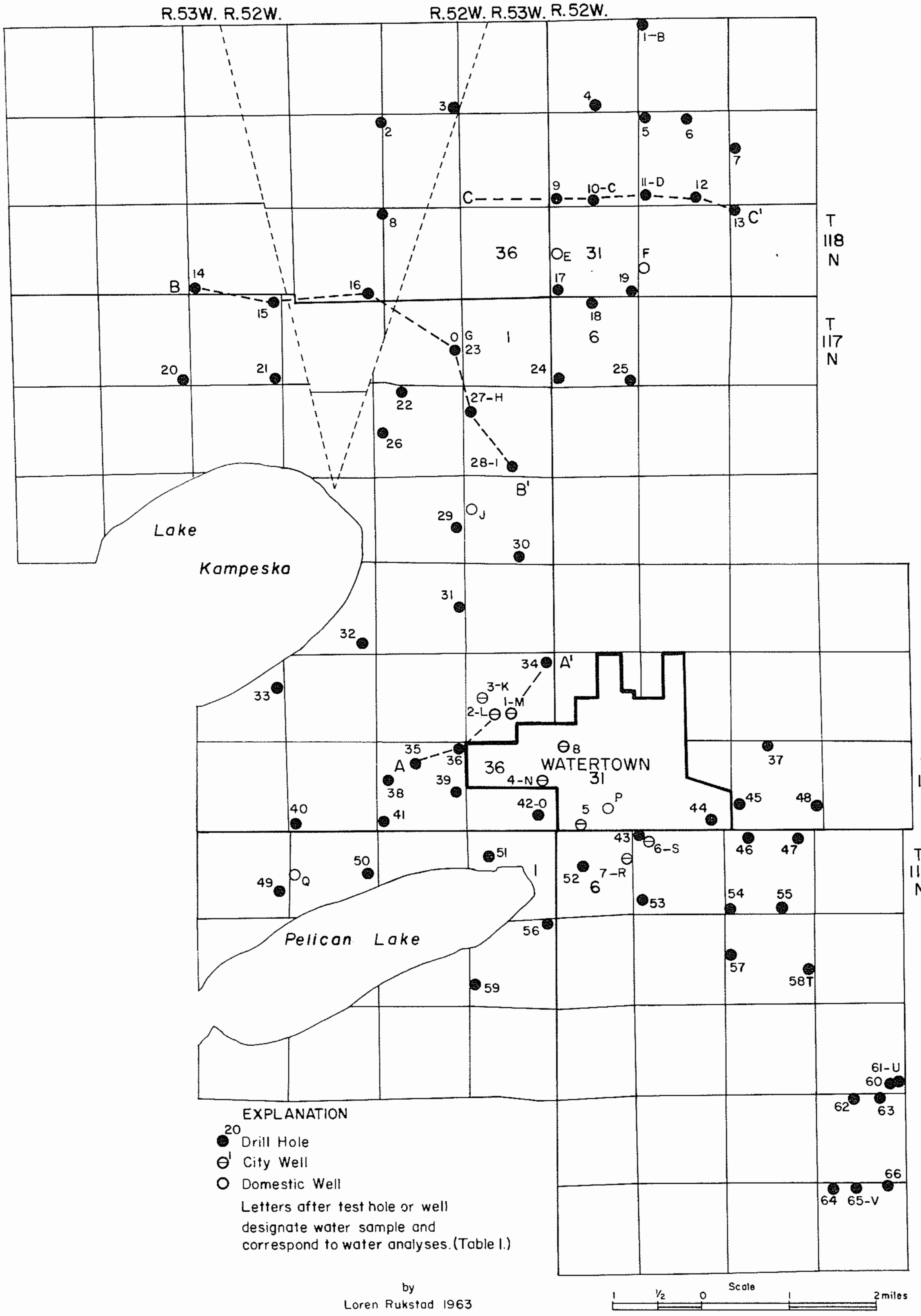

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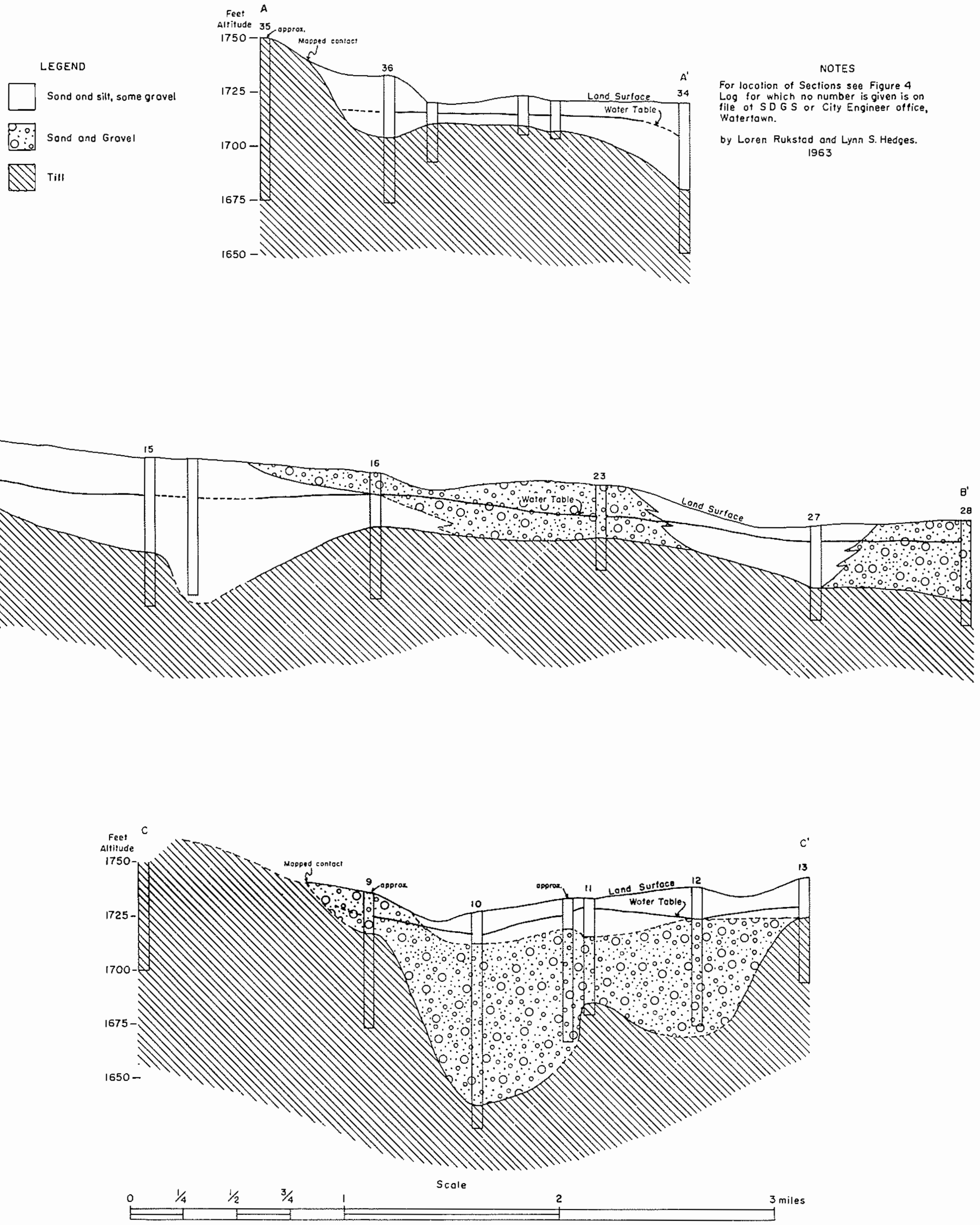
Figure 5. Geologic Cross-Sections in the Watertown Area.



NOTES

For location of Sections see Figure 4
Log for which no number is given is on file at S D G S or City Engineer office, Watertown.

by Loren Rukstad and Lynn S. Hedges.
1963

Drafted by Bruno Petsch

Although this aquifer is located in a tributary to the Big Sioux aquifer, hydraulic continuity with the Big Sioux is maintained with Aquifer 1, so ample recharge should be available to maintain a well field of several high capacity wells.

Aquifer 2.--This aquifer is located about 3 miles northwest of Watertown on the northeast shore of Lake Kampeska. The aquifer trends eastward about 3 miles with an average width of about 1 mile, thus having an area of about 3 square miles. The aquifer ranges from 15 to 45 feet in thickness, and averages about 30 feet. State Geological Survey Test Holes 26, 27, and 28 (fig. 4, Appendix A) penetrated the aquifer and showed that it consisted of sand and gravel with minor amounts of clay. Other test holes within the area showed the aquifer contains more sand and silt than Aquifer 1 and thus is less likely to sustain high-yield wells.

Aquifer 2 is in an ideal location for recharge from underflow from the Big Sioux valley to the north, the gravel channel extending northwest from Lake Kampeska, and from the direct infiltration of water from Lake Kampeska.

Aquifer 3.--Aquifer 3 is located southwest of town between the city limits and the east end of Lake Pelican. Present City Well 5 lies on the north boundary of the aquifer and City Well 7 is near the southeast edge of the boundary. This aquifer is about 1.25 miles long and averages about 0.6 miles wide, thus encompassing an area of about 0.75 square miles. The aquifer ranges from 30 to 60 feet in thickness. State Geological Survey Test Holes 42 and 52 (fig. 4, Appendix A) penetrated 30 and 60 feet of aquifer, respectively. Two other test holes in the area penetrated 30 feet of aquifer. The test holes in this area show a slightly higher sand and clay content than is desirable; however, due to the thickness, a properly constructed well in this area would probably yield sufficient quantity for a city well.

Aquifer 3 is in a good location for natural recharge by underflow from the Big Sioux valley and from direct infiltration from Lake Pelican.

Aquifer 4.--Aquifer 4 is located on the southeast corner of town. This aquifer is about 1.5 miles long and averages about 0.4 miles in width, thus having an area of about 0.6 square miles. State Geological Survey Test Holes 44 and 45 (fig. 4, Appendix A) show 30 and 40 feet, respectively, of saturated sand and gravel. The logs of these test holes indicate a clean, fairly well sorted sand and gravel.

Aquifer 4 is situated such that natural recharge from underflow and infiltration from surface water is probably less than in any of the three previous aquifers.

Aquifer 5.--Aquifer 5 is located about 4 miles southeast of Watertown in the Big Sioux valley. This aquifer is about 1.25 miles in length and averages about 0.5 miles in width, thus having an area of about 0.6 square miles. The aquifer ranges from 25 to 75 feet in thickness. Test Holes 64, 65, and 66 (fig. 4, Appendix A) showed the material to consist principally of sand with varying amounts of gravel. Test Hole 65 flowed water from a depth of approximately 50 feet. The flow was estimated at about 15 gallons per minute.

Although the valley is little more than a mile wide at this spot, recharge should be ample to sustain several high capacity wells.

Electric logs from the Watertown Substation well, United States Bureau of Reclamation and Coteau Test Well #2, sec. 6, T. 116 N., R. 55 W., by the South Dakota State Geological Survey, indicate that the glacial deposits are approximately 500 feet thick in the Watertown area. Sand and gravel deposits buried under glacial till often occur and may provide large quantities of water.

The time and expense of drilling deep holes to test the glacial deposits is beyond the scope of the present investigation; however, the city may wish to explore this possibility. Any competent well driller familiar with the area could test the deeper glacial deposits.

Recharge at Watertown Well Field

The Watertown well field is located in a narrow sector of the valley outwash train (figs. 2 and 4). The minimum width of the valley is about 1.5 miles, bounded on the east by a continuous till barrier, and on the west by a till mound in the outwash valley train. Test holes (on file in the State Geological Survey files and the City Engineer's office, Watertown), and City Wells 1, 2, 3, 4, and 8 indicate that the average thickness of saturated sand and gravel across this restriction is 10 to 15 feet. If the hydraulic gradient, the permeability of the material, and the saturated thickness of the aquifer are known, then recharge from underflow through this restriction can be estimated, assuming natural conditions exist.

Rothrock (1933, p. 4) states:

> "A natural dam crosses the valley near Watertown approximately one and three quarters miles in length. It is overlain with sand and gravel to an average depth of fourteen feet. When the lake is full, a gradient of more than one foot per mile is established in the underflow. Under this head water will move about two feet per day through medium sized gravel or coarse sand. Using these figures, the loss of water from the lake when it is full amounts of 1,900,000 gallons per day."

During May, 1964, (Hedges) constructed a paper analog model for the Watertown area. Estimated values were used for pumpage and drawdown. From the results of this theoretical model a water-level contour map was drawn which indicated that any withdrawal exceeding about 2,000,000 gallons per day may seriously influence the water levels in the area about the present well field near Watertown.

The two examples discussed above indicate that approximately 2,000,000 gallons per day of water passes through the narrow section of the outwash channel near Watertown where the present well field is located. The estimated pumpage of seven of the city wells is about 2,500,000 gallons per day if the eight wells are all pumping at capacity rates. Fortunately, Watertown requires this amount of water only at peak consumption periods during the later part of summer, and hence prolonged periods of maximum pumpage do not occur.

In both of the above examples it should be stressed that only estimated values have been used. It should further be pointed out that these estimated figures apply only to the aquifer in the natural state. Large withdrawals of water from pumping (an unnatural state) will steepen the hydraulic gradient which can induce more rapid recharge. This unknown factor, the induced recharge from pumping, should be accurately determined by pumping tests before long-range development and management is planned.

Figure 5 shows cross-sections in three selected sites across the Big Sioux valley. Section A-A' is through the present well field (City Wells 1, 2, and 3). This section shows a maximum saturated aquifer thickness of about 10 to 15 feet. If a well is constructed with a 10-foot screen, the maximum safe drawdown is about 5 feet. Oral communication with John Babcock, City Engineer, revealed that the city wells have 5 to 10 feet of drawdown when pumping.

Section B-B' (fig. 5) is at a site midway between Watertown and the northern edge of the study area, and crosses the east end of Aquifer 2. This section shows an average thickness of 20 to 25 feet of saturated sand and gravel. Wells constructed in this area would have 10 to 15 feet of safe drawdown.

Section C-C' (fig. 5) is at a site along the northern edge of the study area, and crosses Aquifer 1. The average saturated thickness of sand and gravel is approximately 50 feet, thus wells completed at a depth of 60 feet could have 20 feet of screen and still have about 30 feet of saturated sand and gravel above the screen.

Ground Water in Bedrock

Some subsurface strata yield sufficient water for domestic purposes, but in most cases it is of poorer quality than surficial water, or does not produce a sufficient quantity for larger wells. Water is available from the Dakota Group, the Codell Member of the Carlile Shale, the Niobrara Formation, and the Sioux Quartzite.

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, it can be said that the more minerals a water contains the poorer its quality.

Geologic mapping, subsurface investigation from drill-hole information, and study of water analyses have shown that in general the waters of Lake Kampeska, the Big Sioux River and the sands and gravels in the Big Sioux valley train deposits are hydraulically connected with one another. This intimate relationship makes quantitative evaluation difficult with limited data. Factors that must be considered in evaluating the quality of water from any one point in the Watertown area are: (1) the geological setting at that point; (2) the season of the year; (3) amounts, intensity, and date of precipitation; (4) location in respect to bodies of surface water (rivers, lakes, streams); (5) location in respect to ground water withdrawals; (6) location with respect to hydraulic gradients; and (7) the aquifers are not isolated but interconnected.

Table 1 is a comparison of water analyses from the Watertown area with the State modified Public Health Standards for drinking water. Upon examination, the table shows that with about four exceptions the water quality is fairly consistent.

Except for iron and manganese, nearly all the water analyzed meets the drinking water standards. Iron and manganese occur somewhat erratically in concentrations from 0 to 1.9, and these will generally be the elements whose concentrations will be most important in the Watertown area.

Water analyses C, D, and F were obtained from wells or test holes in Aquifer 1. These three analyses illustrate a range in quality to be expected in the Watertown area. Even Sample F, the poorest of the three, would be adequate for a city supply.

Water analyses H and I are from Aquifer 2, and Sample G is from a location about $\frac{1}{4}$-mile north of Aquifer 2. These three samples have nearly identical good quality water, except Sample H shows a high iron concentration.

Sample O is from Aquifer 3 and is high in iron content and slightly over the limits in total solids. Samples P and R are from City Wells 5 and 7, respectively. Although these wells are marginal to Aquifer 3, the water is very similar to Sample O from Aquifer 3.

There are no analyses from Aquifer 4; however, there is no reason to suspect that the water in this area should differ appreciably from Aquifers 1, 2, or 3.

Sample V is from Aquifer 5 and is high in sulfates and total solids. In addition, the hardness content is excessively high. This poorer quality is possibly a reflection of poorer quality water from a glacial artesian source which was penetrated in the test hole (#65) from which the sample was collected.

A glacial artesian source often contains poorer quality water because the water generally has had more time to dissolve minerals from the deposits through which the water is moving. Also, poorer quality water may be recharging the aquifer from the surrounding deposits.

Generally speaking, the water quality becomes slightly poorer from north to south in the area studied. There are probably several factors responsible for the poorer quality water. (1) The valley is wider to the north, and as a result contaminated runoff from the uplands has more chance for dilution after entering the aquifer. (2) The aquifers to the north are nearer to the lake. The lake has a good quality water, and acts as a recharge reservoir for at least part of the year. (3) The area around Watertown and southward is the recipient of any possible contamination or pollution resulting from urbanization. (4) The southern reach of the area studied is in a more restricted valley which allows concentration of contaminated runoff from the uplands and concentration of poorer quality water recharged from the confining walls of the valley.

CONCLUSIONS AND RECOMMENDATIONS

A potential supply of water is available in the area studied, to supply a city several times the present size of Watertown. As far as

Table 1.--Chemical Analyses of Water Samples
from the Watertown Area
(See fig. 2 and next page for sample locations)

Sample	Source	Parts Per Million											
		Calcium	Sodium	Magnesium	Chlorides	Sulfate	Iron	Manganese	Nitrate	Fluoride	pH	Hardness CaCO3	Total Solids
A		---	---	50	250	500*	0.3	0.05	10.0*	0.9-1.7**	---	---	1000*
B	All samples from shallow glacial outwash	110		9	4	97	0.05				7.4	310	614
C		51	4	28	---	105	0.2	---	Trace	---		242	352
D		133		11	4	97	---				7.6	290	638
E		124		-7	20	48	---				7.5	280	682
F		169		27	116	97	---				7.4	530	1184
G		118		1	8	39	---				7.7	300	642
H		127		---	4	82	0.75				7.3	320	672
I		197		43	4	81	---				7.3	320	666
J		135		20	56	53	Trace				7.3	420	1147
K		69	6	21	9	45	---	0.3	---	0.2	7.5	261	333
L		102	10	29	10	84	0.3	0.7	---	0.1	7.3	377	450
M		90	9	36	8	110	1.8	1.5	---	0.2	7.7	380	487
N		113	48	38	76	147	---	0.2	1.5	0.2	7.3	440	681
O		535		-210	40	69	1.0				7.5	500	1040
P		101	51	60	109	225	0.1	---	7.3	---		500	852
Q		675		-322	56	48	0.1				7.9	400	907
R		145	18	51	11	288	1.9	0.9	---	0.2	7.4	575	900
S		122	25	47	28	255	0.5	0.5	---	0.2	7.6	498	776
T		107		-2	---	58	0.05				7.3	260	600
U		353		-53	4	341	Trace				7.2	670	2335
V		578		-82	4	682	0.05				7.1	1120	1365

* Modified for South Dakota by State Department of Health (written communication, February 5, 1962)

** Optimum

	Location of Water Sample	Depth (feet)
A.	U.S. Department of Public Health Drinking Water Standards (1961)	
B.	Test Hole #1, NWNW sec. 20, T. 118 N., R. 52 W.	30
C.	Test Hole #10, SWSE sec. 30, T. 118 N., R. 52 W.	54
D.	Test Hole #11, SWSW sec. 29, T. 118 N., R. 52 W.	24
E.	H.D. Heinricks, NWSW sec. 31, T. 118 N., R. 52 W.	12
F.	M. Easburg, NWSW sec. 32, T. 118 N., R. 52 W.	12
G.	Big Sioux Conifer Farm, SENE sec. 2, T. 117 N., R. 53 W.	48
H.	Test Hole #27, SWNW sec. 12, T. 117 N., R. 53 W.	24
I.	Test Hole #28, SWSE sec. 12, T. 117 N., R. 53 W.	35
J.	Art Tesch, SWNW sec. 13, T. 117 N., R. 53 W.	16
K.	City Well #3	27
L.	City Well #2	27
M.	City Well #1	27
N.	City Well #4	27
O.	Test Hole #42, SESE sec. 36, T. 117 N., R. 53 W.	24
P.	City Well #5, SWSW sec. 31, T. 117 N., R. 53 W.	30
Q.	R.E. Kahnke, SWNW sec. 3, T. 116 N., R. 53 W.	
R.	City Well #7	22
S.	City Well #6	26
T.	Test Hole #58, NESE sec. 9, T. 116 N., R. 52 W.	20
U.	Test Hole #61, SESE sec. 15, T. 116 N., R. 52 W.	30
V.	Test Hole #65, NENW sec. 27, T. 116 N., R. 52 W.	Flowed

Water analyses K, L, M, N, R, and S were obtained from Public Water Supply data (1961).
Samples C and P were analyzed by the State Chemical Laboratory, Vermillion
Samples B, D, E, F, G, H, I, J, O, Q, T, U, and V were analyzed by the State Geological Survey field kit, Vermillion

quantity of water is concerned, engineering, management, and economics will be the major factor in development of a sound water supply program for the present and future. Almost without exception, the quality of the water north of Watertown in the area studied is of good quality, except for a possible high iron and/or manganese content. The high iron and manganese seems to be a characteristic of glacial aquifers and the Watertown area is no exception.

There are five areas the city may develop for future water supplies. Aquifer 1, 5 miles north of town, has about the best quality water in the area. It also has the best potential from a quantity standpoint. This area should easily sustain a well field the size of the present city well field. In addition, higher capacity wells could probably be constructed in this area than in the present well field.

Aquifer 2 is less homogeneous than Aquifer 1, and therefore is less desirable for developmental purposes. More detailed drilling and testing would show to what extent this aquifer could be developed. There is some doubt at the present time whether a well field of high capacity yields could be sustained in this area.

Aquifers 3 and 4 are small areas the city could test for an additional well or two. Factors to consider with these areas are proximity to potential contamination and pollution, probable limited yield, and apparent poorer quality water than those areas to the north. One factor in favor of Aquifers 3 and 4 is the nearness to existing water mains.

Aquifer 5 has poor quality water, is 5 miles from town, and is situated such to be easily contaminated or polluted from industrial or sewage effluent from Watertown. The city may wish to consider it for an industry using large quantities of water and whose effluent might endanger contamination of the city's present water supply.

It is recommended that before any future development is done in the immediate area of the present well field that tests be made to accurately determine the amount of water available in recharge through the restriction in the valley near Watertown. This is a mandatory requirement for any safe management and development plans. This should be done before further development of present well field or installation of additional wells in Aquifers 3 or 4.

If and when the city decides to install additional wells in any of the recommended areas, several more test holes should be drilled to determine the extent and thickness of the aquifer. On the basis of these test holes, a location should be picked and a test well installed and test pumped. The test pumping should be conducted by licensed engineers and should be run for a minimum of 72 hours.

It is suggested that the city contact a commercial drilling company licensed by the State of South Dakota to drill the well. The city officials should also 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 water system.

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APPENDIX A

Logs of Test Holes in the Watertown Area

(for location see figure 2)

Test Hole No. 1
Surface elevation: 1,762 feet
Depth to water: 14 feet

0-14	clay, brown, sandy and gravelly
14-29	sand and gravel, little clay
29-34	clay stringer
34-39	sand, coarse, gravel, fine
39-49	clay, blue

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Test Hole No. 2
Surface elevation: not taken
Depth to water: 4 feet

0-12	alluvium
12-19	gravel, fine, silty
19-36	gravel, fine
36-59	clay, green

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Test Hole No. 3
Surface elevation: not taken
Depth to water: 14 feet

0-19	till, brown
19-69	till, brown, sandy and gravelly
69-74	till, blue

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Test Hole No. 4
Surface elevation: 1,747 feet
Depth to water: 9 feet

0-17	clay, some unsorted sand and gravel
17-37	sand, some clay
37-64	no cuttings

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Test Hole No. 5
Surface elevation: 1,747 feet
Depth to water: 5 feet

0-5	clay, sand, gravel, poorly sorted
5-29	clay, sand, gravel, poorly sorted
29-64	sand and gravel, some clay
64-74	till, blue

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Test Hole No. 6
Surface elevation: 1,756 feet
Depth to water: 8 feet

0-4	clay, some pebbles
4-14	gravel, fine
14-49	gravel, fine
49-54	gravel, more clay
59-64	till, blue

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Test Hole No. 7
Surface elevation: not taken
Depth to water: 14 feet

0-10	sand, brown, clayey
10-17	clay, some sand
17-39	clay, brown, some sand
39-44	clay, blue

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Test Hole No. 8
Surface elevation: not taken
Depth to water: 14 feet

0-14	sand, red, some clay
14-34	sand, brown, some clay
34-49	clay, some sand
49-74	clay, blue

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Test Hole No. 9
Surface elevation: not taken
Depth to water: 12 feet

0-19	clay, brown, some sand and gravel

(continued on next page)

Test Hole No. 9--continued

19-29	till, brown
29-64	clay, blue

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Test Hole No. 10
Surface elevation: 1,727 feet
Depth to water: 10 feet

0-9	gravel, red
9-29	sand, medium to coarse, some clay
29-89	sand, medium to coarse, less clay
89-99	clay, blue

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Test Hole No. 11
Surface elevation: 1,734 feet
Depth to water: 4 feet

0-11	clay, brown, gravel, unsorted
11-29	gravel, coarse, some clay
29-44	gravel, less clay
44-49	gravel, more clay
49-54	clay, blue

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Test Hole No. 12
Surface elevation: 1,739 feet
Depth to water: 15 feet

0-14	clay, sand, gravel, poorly sorted
14-54	sand, coarse, gravel, fine
54-64	sand and gravel, more silty

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Test Hole No. 13
Surface elevation: not taken
Depth to water: 13 feet

0-19	clay, sand, gravel, poorly sorted
19-39	clay, brown, little sand
39-49	clay, blue

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Test Hole No. 14
Surface elevation: 1,765 feet
Depth to water: 18 feet

0-19	sand, brown, medium, clay
19-24	sand, fine, clay
24-49	till, blue

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Test Hole No. 15
Surface elevation: 1,721 feet
Depth to water: 17 feet

0-9	clay, brown, sand
9-24	till, blue
24-49	till, brown

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Test Hole No. 16
Surface elevation: 1,748 feet
Depth to water: 9 feet

0-9	clay, brown, some sand and gravel
9-24	sand, some clay
24-59	clay, blue, some sand

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Test Hole No. 17
Surface elevation: not taken
Depth to water: not measured

0-4	road fill
4-34	silt, clayey, sandy
34-54	silt, sandy

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Test Hole No. 18
Surface elevation: 1,736 feet
Depth to water: 4 feet

0-6	topsoil and clay
6-19	sand, medium, gravel, fine
19-59	sand, gravel
59-64	sand, gravel, more clay
64-74	clay, brown

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Test Hole No. 19
Surface elevation: 1,939 feet
Depth to water: 3 feet

0-5	clay, brown, gravel, fine
5-34	sand and gravel, some clay
34-49	sand and gravel, more clay
49-54	clay, blue

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Test Hole No. 20
Surface elevation: 1,750 feet
Depth to water: not measured

0-17	gravel, fine to medium, some sand
17-44	clay, brown
44-49	clay, brown, some sand
49-54	clay, blue

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Test Hole No. 21
Surface elevation: 1,747 feet
Depth to water: 22 feet

0-29	clay, red, sand
29-39	sand, brown, clay
39-49	sand, more clay
49-59	clay, gray

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Test Hole No. 22
Surface elevation: not taken
Depth to water: 14 feet

0-4	topsoil
4-16	alluvium
16-19	clay, some sand
19-34	clay, some sand
34-64	clay, brown
64-74	till, blue

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Test Hole No. 23
Surface elevation: not taken
Depth to water: 10 feet

0-14	sand and gravel, some clay
14-19	sand and gravel
19-24	sand and gravel, more clay
24-29	till, brown
29-37	till, blue

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Test Hole No. 24
Surface elevation: not taken
Depth to water: 4 feet

0-16	alluvium
16-19	alluvium, little sand

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Test Hole No. 25
Surface elevation: not taken
Depth to water: 6 feet

0-9	sand, fine to coarse, some clay
9-29	sand, some clay
29-44	till, blue

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Test Hole No. 26
Surface elevation: 1,724 feet (approximately)
Depth to water: 5 feet

0-9	clay, black, sandy
9-37	gravel, fine to pea-size, hit rock, couldn't penetrate

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Test Hole No. 27
Surface elevation: 1,724 feet
Depth to water: 9 feet

0-9	clay, sandy
9-29	sand, some clay
29-44	till, blue

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Test Hole No. 28
Surface elevation: 1,726 feet
Depth to water: 9 feet

0-9	sand, gravel, some clay
9-39	sand, gravel
39-64	till, brown

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Test Hole No. 29
Surface elevation: 1,720 feet
Depth to water: 4 feet

0-4	sand, coarse, some clay
4-22	sand, coarse
22-64	clay, blue
64-74	clay, brown

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Test Hole No. 30
Surface elevation: not taken
Depth to water: 9 feet

0-4	topsoil, unsorted sand and gravel
4-12	clay, gray, moist
12-39	clay, blue

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Test Hole No. 31
Surface elevation: not taken
Depth to water: 14 feet

0-14	clay, dark brown, some sand
14-44	clay, dark brown
44-54	clay, blue
54-74	clay, brown

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Test Hole No. 32
Surface elevation: not taken
Depth to water: dry

0-34	clay, brown

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Test Hole No. 33
Surface elevation: not taken
Depth to water: 17 feet

0-29	clay, brown, some sand
29-49	sand, some clay
49-54	till, brown

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Test Hole No. 34
Surface elevation: 1,721 feet
Depth to water: 4 feet

0-17	sand, clay, poorly sorted
17-39	sand, some clay
39-59	clay, gray, sandy
59-64	clay, blue
64-69	till, brown

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Test Hole No. 35
Surface elevation: not taken
Depth to water: dry

0-74	clay, dark

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Test Hole No. 36
Surface elevation: 1,733 feet
Depth to water: not measured

0-14	sand, brown, unsorted, clay
14-29	sand, medium, some clay
29-44	clay, brown
44-59	clay, brown

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Test Hole No. 37
Surface elevation: not taken
Depth to water: not measured

0-19	clay, yellow
19-49	till, brown

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Test Hole No. 46--continued

4-25	clay, blue
45-52	gravel, some blue clay
52-69	silt

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Test Hole No. 47
Surface elevation: not taken
Depth to water: dry

0-19	sand, gravel, poorly sorted
19-	drilled too hard

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Test Hole No. 48
Surface elevation: not taken
Depth to water: 19 feet

0-4	gravel
4-14	till, brown
14-24	till, brown
24-44	clay, dark brown

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Test Hole No. 49
Surface elevation: not taken
Depth to water: not measured

0-14	sand, gravel, clay, poorly sorted
14-29	sand, fine, clean
29-44	sand, some clay
44-69	clay, brown, some sand
69-89	till, blue

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Test Hole No. 50
Surface elevation: not taken
Depth to water: 34 feet

0-4	topsoil
4-36	clay, sand, gravel, poorly sorted
36-79	clay, sand and gravel
79-84	clay, blue

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Test Hole No. 51
Surface elevation: not taken
Depth to water: 19 feet

0-9	clay, brown
9-14	sand, some clay
14-20	clay, sandy
20-39	clay, sandy
39-84	sand, coarse, silty

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Test Hole No. 52
Surface elevation: not taken
Depth to water: not measured

0-24	gravel, fine
24-84	gravel, sand, high clay content
84-99	clay, sandy

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Test Hole No. 53
Surface elevation: not taken
Depth to water: 9 feet

0-9	sand, poorly sorted, silty
9-34	clay, buff, sandy
34-69	till, dark brown

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Test Hole No. 54
Surface elevation: not taken
Depth to water: 4 feet

0-8	clay, sandy
8-14	clay, sandy
14-29	gravel, clean
29-40	drills like clay, no cuttings
40-69	drills like gravel, no cuttings

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Test Hole No. 55
Surface elevation: not taken
Depth to water: 19 feet

0-20	sand, gravel, clay

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Test Hole No. 55--continued

20-29	sand, gravel
29-49	clay content increasing
49-54	till, brown
54-64	clay, buff

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Test Hole No. 56
Surface elevation: not taken
Depth to water: 14 feet

0-39	sand, medium, clay increases downward
39-44	clay, brown, some sand
44-54	drills like till
54-69	clay, little sand
69-74	clay, blue

* * * * *

Test Hole No. 57
Surface elevation: not taken
Depth to water: 19 feet

0-19	topsoil and clay
19-24	gravel, fine, silty
24-84	till, brown
84-94	clay, buff
94-98	clay, blue

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Test Hole No. 58
Surface elevation: 1,722 feet
Depth to water: 9 feet

0-4	topsoil
4-10	gravel, poorly sorted, some clay
10-49	gravel, fine, cleaner
49-59	till, blue

* * * * *

Test Hole No. 59
Surface elevation: not taken
Depth to water: 21 feet

0-19	clay, some sand

(continued on next page)

Test Hole No. 59--continued

19-39	clay, brown
39-49	till, blue

* * * * *

Test Hole No. 60

Surface elevation: not taken
Depth to water: 9 feet

0-9	sand, gravel, clay, poorly sorted
9-14	sand, gravel
14-34	sand, gravel, clay increasing, hit rock

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Test Hole No. 61

Surface elevation: 1,715 feet
Depth to water: 4 feet

0-4	sand, clayey
4-34	sand, coarse to medium, clean
34-59	sand, blue, clay content increasing
59-104	sand, brown, clay

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Test Hole No. 62

Surface elevation: 1,718 feet
Depth to water: 6 feet

0-4	topsoil, sandy, black
4-14	sand, brown to gray, pea gravel, some clay
14-20	sand and gravel
20-24	till, gray
24-39	sand, fine, clayey
39-44	till, gray

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Test Hole No. 63

Surface elevation: 1,712 feet
Depth to water: 8 feet

0-6	till, black
6-14	sand, poorly sorted, brown
14-19	pea-sized gravel

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Test Hole No. 63--continued

19-44	sand and pea-sized gravel
44-59	till? no cuttings

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Test Hole No. 64
Surface elevation: 1,724 feet
Depth to water: not measured

0-4	topsoil, black, some pebbles
4-34	sand, brown, coarse, poorly sorted
34-44	sand, gray, medium to coarse
44-49	sand, medium to coarse
49-64	silt, gray, sandy, clayey

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Test Hole No. 65
Surface elevation: 1,707 feet
Depth to water: 4 feet

0-6	alluvium, some sand and gravel
6-19	alluvium
19-84	sand, coarse, water flowed at about 50 feet
84-89	till, yellow

* * * * *

Test Hole No. 66
Surface elevation: 1,709 feet
Depth to water: 5 feet

0-4	topsoil
4-10	sand, gravel
10-44	sand, gray to brown, gravel, medium
44-99	sand, brown, silty, fine grained, clayey

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