STATE OF SOUTH DAKOTA
Ralph Herseth, Governor

STATE GEOLOGICAL SURVEY
Allen F. Agnew, State Geologist

SPECIAL REPORT 4

SHALLOW WATER SUPPLY

NEAR HURON, SOUTH DAKOTA

by

M. J. Tipton

UNION BUILDING
UNIVERSITY OF SOUTH DAKOTA
VERMILLION, SOUTH DAKOTA
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INTRODUCTION

Purpose and Present Investigation

The city of Huron has been drawing most of its water for municipal use from a dam on the James River, just east of the city (Plate 1). Until recently, the river has been an adequate source of water except for a short period in the early 1930's when shallow wells west of the city were used to supplement the water from the river. However, in the past few years the river has not provided sufficient water for the city's needs, owing to increased usage and lower than normal precipitation. For this reason the City Engineer, in June of 1959, requested that the State Geological Survey make a study of the area around Huron to attempt to find a supplementary source of shallow ground water. Unfortunately, the State Survey had already programed its summer work and did not have test drilling rigs available for such a study; consequently an agreement was made with the City whereby the City contracted with a commercial drilling company for the test drilling. Bids were let and the contract was awarded to the Grimshaw Drilling Company of Sioux Falls, South Dakota; Grimshaw sub-contracted the job to the Grosch Drilling Company of Silver Creek, Nebraska. The geologic study was begun by the State Geological Survey in August of 1959. The State Survey provided the writer as geologist, an earth-resistivity team of Clark Mulliner and Lamonte Sorenson under the supervision of geophysicist Dan Lum, and a surveying team of Charles Mickel and Roy Rymill; the United States Geological Survey provided geophysicist-hydrologist Lewis Howells, a survey team of Herbert Bandleman and Dale Lewis, and the supervision and facilities of the Huron office.

Acknowledgments

The preparation of this report was greatly facilitated by the cooperation of the people in and around Huron, especially City Engineer Harlan Meyers, City Water Commissioner Morgan Sanford, and the Water Treatment Plant Manager Al Ross. Special thanks are due to District Engineer John Powell of the United States Geological Survey Office in Huron for his help and encouragement, and to Jim Wynn of the Hasz Drilling Company of Huron, for making drilling records available. The study was performed under the supervision of Dr. Allen F. Agnew, State Geologist.

Previous Investigation

Several attempts have been made in the past to find additional water supplies at Huron. In the early 1930's, when the James River was too low to be used as a source of water for the city, several test holes were put down west of town in a buried outwash deposit that had been found by local drillers. This led to the installation of several wells in sec. 9, T. 110 N., R. 62 ., and the construction of a pipeline to the city. These wells were used until

SIMPLIFIED GEOLOGIC MAP of HURON and VICINITY

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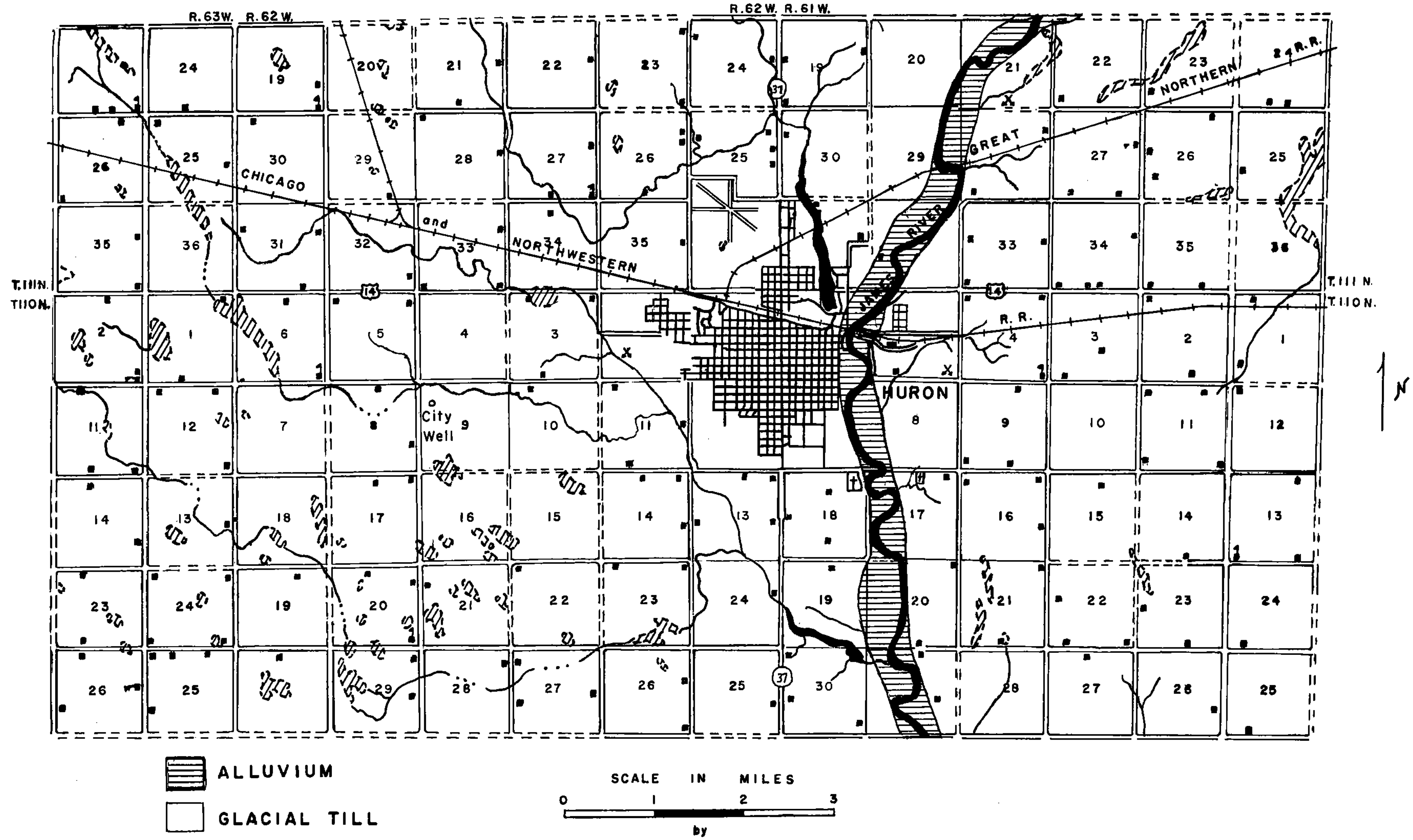

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the late 1930's, when the supply from the James River was again adequate.

The Layne-Minnesota Drilling Company and several local drillers have made tests west of town and also along the James River bottom east of town in the past twenty years.

The South Dakota Geological Survey performed a resistivity survey of the reservoir west of town in the summer of 1935. This survey was done by E. P. Rothrock and B. C. Petsch (1935) with a "home made" resistivity machine, and marked the first time that a resistivity survey was made in the State. Since then the United States Bureau of Reclamation has made resistivity studies and has test-drilled larger areas which included the City of Huron; however, they were not done specifically with a water supply for the City in mind.

In 1956 another well was drilled in the well field west of Huron and has been used intermittently since, to supplement the river supply.

GENERAL GEOLOGY

All of the surface deposits in the Huron area, with the exception of the alluvium along the floodplain of the James River, were deposited by the last glacial ice sheet to cover Eastern South Dakota during the Pleistocene Epoch. This Cary glacier retreated about 12,000 years ago, and was preceded by five other glaciers which deposited material in this area before the Cary deposits were laid down. These deposits, called drift, are divided into till and outwash. Till is material that was deposited directly by the ice and consequently is a jumbled mass of unsorted clay, silt, sand, gravel, and boulders. Till generally does not produce much water. Outwash deposits are material that was laid down by the meltwaters of the retreating glacier, and consists principally of sand and gravel from the original till material. These outwash sands and gravels contain large amounts of water and transmit it readily.

Besides glacial drift, the only other surficial material in the area is alluvium, which consists of clays and silts deposited in Recent time by the James River. These alluvial deposits are confined to the present flood plain of the James River, and are not considered a potential source of ground water because of their poor transmissibility. In the Huron area these alluvial deposits are unusually thick, averaging about 40 feet.

The surface deposits on both sides of the James River flood plain consist of Cary till except for a few isolated pockets of outwash deposits that are shown by gravel pits on Plate 1. In the area studied, this till ranges from ten to at least 50 feet in thickness, and in most places is underlain by outwash deposits that range from a few feet to more than 90 feet in thickness. These outwash deposits are believed to be part of a large pre-Cary outwash plain or plains that once filled most of the old James River Valley. However, because the outwash deposits are buried beneath till, they are very difficult to trace; although present information shows that they extend from about 90 miles north of Huron (fig. 1) at least as far south as Huron (U.S.G.S. open file map), it is believed they are even more extensive. In places these outwash deposits are as much as 30 miles wide (fig. 1); in the Huron area they are probably about 20 miles wide, extending an equal distance east and west of the city. The outwash deposits range in thickness up to 90 feet, and in most places the sand and gravels are separated by one or more layers of till (called "clay" in the logs of the test holes in the Appendix); thus they may

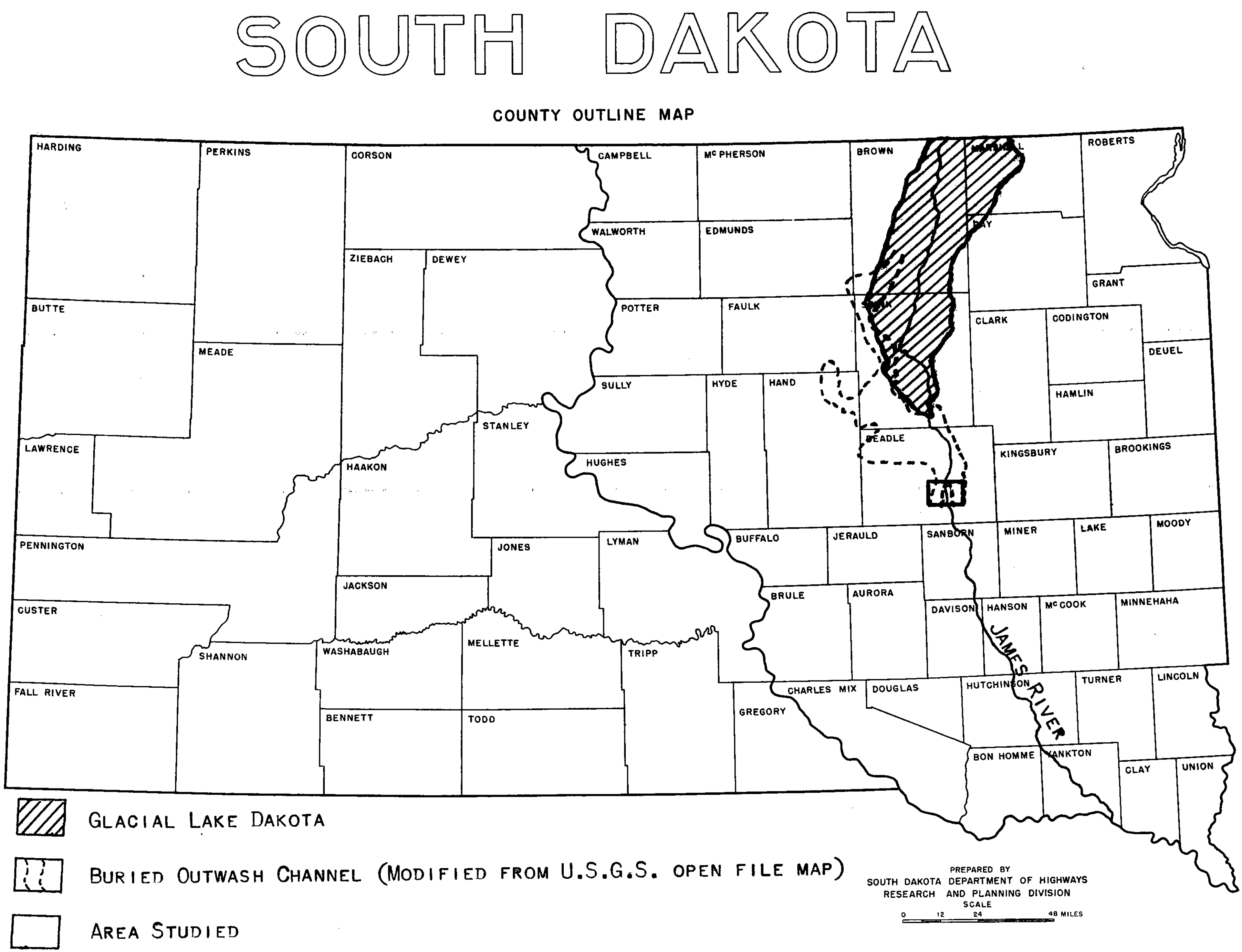

FIGURE I INDEX MAP

represent more than one age of deposition. It is believed these deposits were even more extensive in pre-Cary time, but were partially removed by the advancing Cary ice. As the Cary ice melted and retreated, its waters filled a natural depression in northeastern South Dakota and the adjoining part of North Dakota, forming glacial Lake Dakota (fig. 1); this lake covered 1800 square miles in South Dakota. When this large but shallow lake was drained to the south, it cut a deep, narrow trench to its mouth, and removed the till and outwash deposits from the trench and deposited in their place large amounts of alluvial lake silts. This probably explains why the alluvial deposits are thicker along the James River than along other major rivers in eastern South Dakota, and also explains why extensive outwash deposits, which are buried beneath the floodplains of all of the other major rivers of Eastern South Dakota, are lacking below the floodplain of the James River.

In the Huron area the glacial deposits are underlain by bedrock which in some places is Pierre shale and in others Niobrara chalk. The glacial drift is as little as 68 feet thick in places, as shown in test hole 2 (Appendix); thus the bedrock is generally near the surface.

SHALLOW GROUND WATER

Occurrence and Movement

Despite the common belief that ground water is found only in veins, which crisscross the country in a disconnected maze, it can be shown that water occurs almost everywhere in the ground, at a depth below the surface which varies from a few feet to several tens or even hundreds of feet. The top of this water-saturation is known as the water table, and in the Huron area it is 10 to 30 feet below the surface. The type of deposit in which this water is contained governs the amount of water which can be withdrawn from the deposit and, in part, how rapidly it can be recharged. For instance, a sand or gravel (such as that in the buried outwash channel) will yield more water to a well than will till or shale because of the size and shape of the particles which make up these deposits. Therefore the main efforts of this geologic study were directed toward finding the places in this buried channel which contain the least till and the most sand and gravel.

These buried outwash channels had to be located by resistivity or test drilling, as they have no surface expression. Resistivity is a geophysical method whereby electrical currents are induced into the ground, and measurements are taken of the resistance that the underlying materials offer to the current. Sand and gravel containing water offers more resistance to the electrical current than water-saturated clay. Resistivity traverses were run in this area, consisting of stations with quarter-mile spacing; readings were taken at electrode spacings (equal to depths) of 30, 65, 80, and sometimes 130 feet. Although maps plotted for each of these spacings were generally similar, only the 65 foot spacing was used to compile the resistivity map (Plate 2), because these readings best outlined the buried outwash channel.

As had been stated previously, a buried outwash channel west of town was known from a resistivity survey that had been made in 1935. The results of this survey were checked by drilling ten test holes in the area (Plates 2 and 3), and were found to be fairly accurate although the resistivity survey shows more sand and gravel in some places than was recorded by the drill. This test drilling was done during June of 1959, under the direction of City

PLATE 2

ISOPACH AND ISO-RESISTIVITY MAP OF OUTWASH DEPOSITS NEAR HURON

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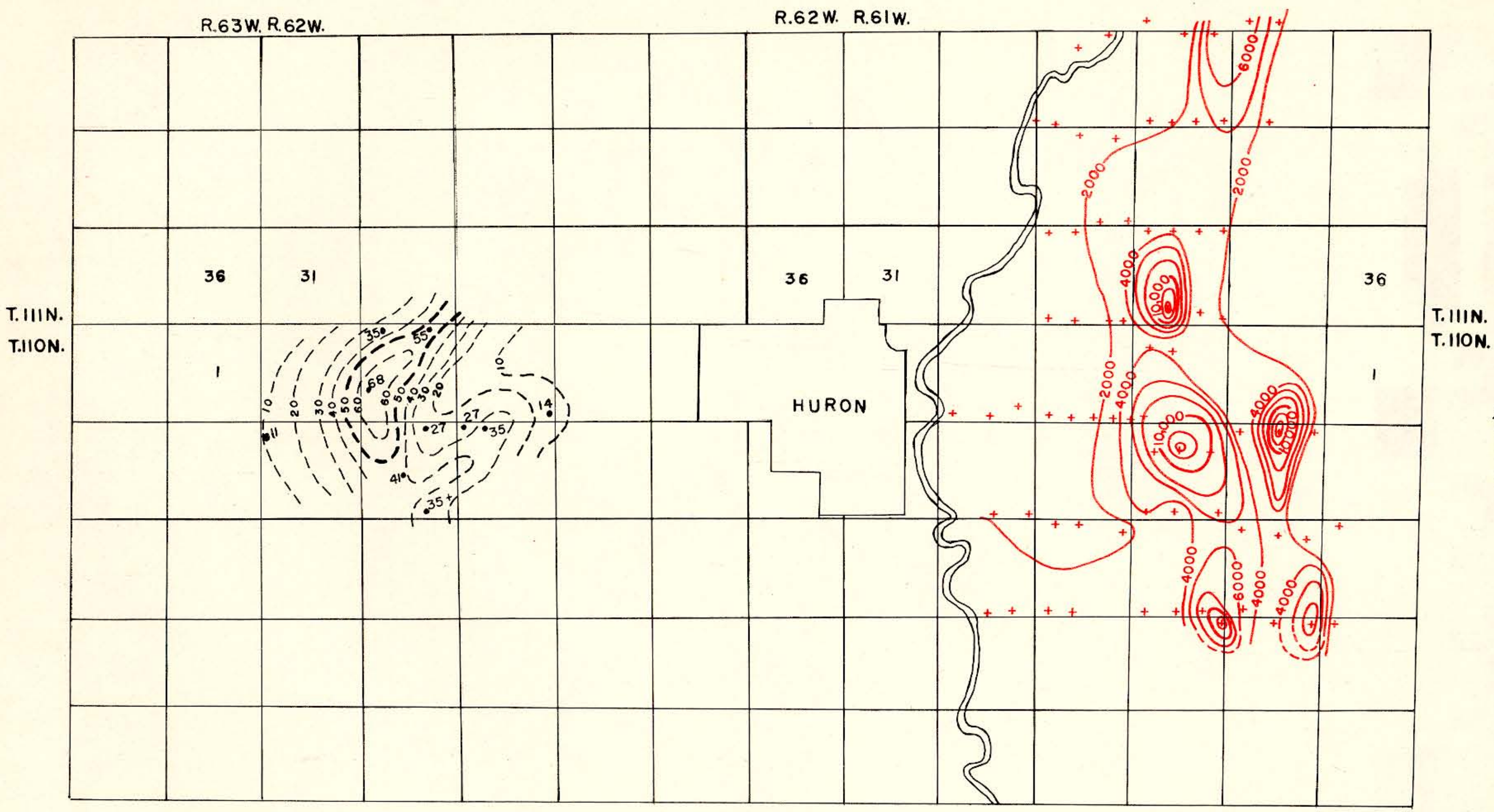

•55 DRILL HOLE (giving sand thickness)

THICKNESS CONTOUR (interval 10 feet)

SCALE 0 1 2 3 MILES

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\+ RESISTIVITY STATION (sta. no. given on plate 3)

ISO-RESISTIVITY CONTOURS
INTERVAL = 2000 OHM-CM.

Survey by C. Mulliner, C. Mickel; supervised by D. Lum

DATA MAP of HURON AREA

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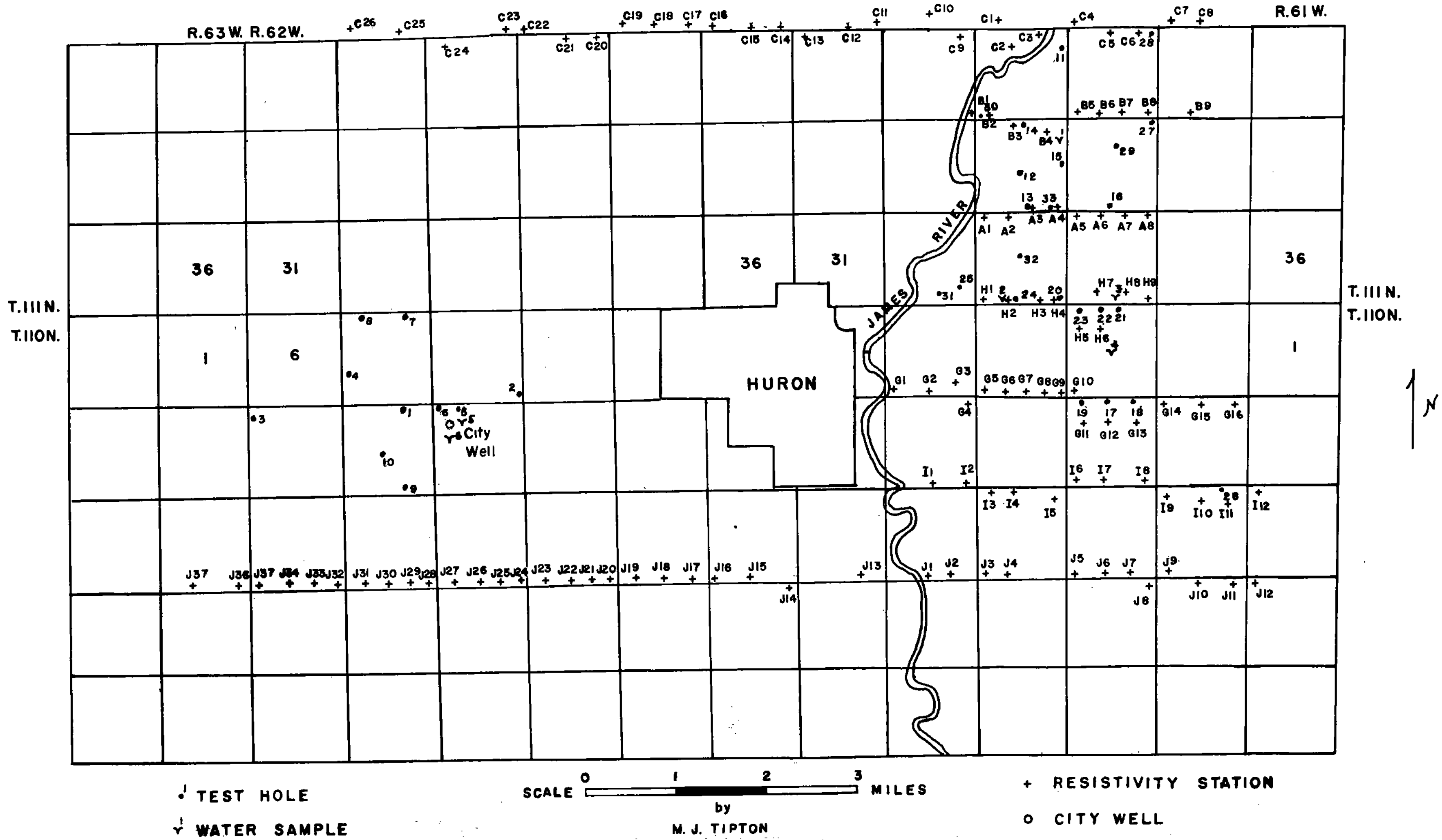

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Engineer Harlan Meyers. Although some water could be obtained from this area, the possibility of other potential sources was investigated. A well inventory of the farms east of town showed that some sand and gravel deposits exist about two miles east of the city, suggesting a buried north-south channel. A resistivity survey was made (Plates 2 and 3) and the presence of an outwash channel was confirmed. The channel was then test-drilled (Plate 3) and a location was selected (SW¼ sec. 3, T. 110 N., R. 61 W.) for a well to be drilled and a pump test made. At this date (December 15, 1959) the well had not been drilled, but two wells were put down in sec. 28, T. 111 N., R. 61 W. at the edge of the buried channel. One is producing about 450 gallons of water per minute, so that if the State Geological Survey's interpretation that these wells are near the edge of the buried channel is correct, then a well in the central part of the outwash will produce a large quantity.

Hydrologic Properties of the Outwash Deposits

As stated earlier, more water can be pumped from sand and gravel (outwash) than from shale or from a mixture of clay, silt, sand, and gravel (till). This is due to the higher porosity (percentage of pore space) and permeability (ability of the material to permit a fluid to pass through its pores) of the sands and gravels. Because of the many variable factors involved and the lack of equipment needed to determine the porosity and permeability, it is impossible to compute accurately these values of the outwash in question. However, it is generally true that coarser material will yield more water, other conditions being equal. Therefore, the coarsest and thickest parts of the outwash channel will yield the most water.

Recharge

Recharge to the buried outwash deposits comes either directly or indirectly from precipitation in the form of rain or snow. If the recharge is obtained directly, this means that a portion of any precipitation which falls on the James River Basin south of the Lake Dakota deposits and north of Huron has the ability to recharge the outwash channels at Huron. The silty and clayey nature of the Lake Dakota deposits will probably prohibit direct recharge to the outwash. Whether this precipitation actually does provide much recharge to the outwash is difficult to determine because the outwash deposit is buried. If the only recharge to the buried channels from direct precipitation is that which seeps through the overlying till, the recharge is very slow and the water in the outwash sands and gravels could be exhausted in a short period of time by the present water supply demands of the city. However, if the sands and gravels are being recharged directly by the James River and its tributaries at some places upstream from Huron, the water in the outwash sands and gravels will probably not be exhausted by the city demands because of the large volume of water carried by the James River. Records of average annual discharge for the James River for the past 20 years show 115 cfs at Colombia (100 miles north of Huron) and 238 cfs at Huron (U.S.G.S., 1960).

Another possibility of recharge is through seepage upward from underlying bedrock formations. These underlying formations contain such large volumes of water that they are less affected by local periods of low precipitation.

It is possible to determine which of the above sources are recharging the outwash materials, by making pump tests at selected locations in the outwash materials. It is strongly recommended that such pump tests be made before the city of Huron goes ahead with any well-development program.

Discharge

Discharge from the outwash reservoir is accomplished in several ways: (1) by down-gradient underflow through the outwash material, (2) by pumping from wells and, (3) by natural discharge at the surface through processes of surface runoff, evaporation, and transpiration.

It is difficult to determine how much discharge is accounted for by underflow, but it is probably a significant amount of the total discharge because of the relatively high permeability of the deposits. Most of the discharge by pumping is from irrigation wells located north of Huron in the outwash channel, and a smaller amount is accounted for by the domestic farm wells in the same area.

Springs along the James River account for some of the discharge from the reservoir. These springs originate along the bluffs of the river where it has cut below the top of the buried channel material. How many of these springs are discharging into the river is unknown, but from Huron northward to the Spink County line (fig. 1) at least thirty were mapped. Such springs may account for a large amount of discharge.

Evaporation and transpiration in the Huron area are probably only small factors in the total discharge, because of the covering of till on the outwash materials, which provides an effective seal against upward movement of water.

Chemical Quality of the Water

All ground water contains minerals which are obtained (1) from the atmosphere as the water vapor condenses and falls, (2) from soil and underlying deposits as the water moves downward to the water table, and (3) from deposits below the water table, in which the water is circulating. In general, the more minerals that a water contains, the poorer its quality.

The United States Department of Public Health has established standards for public drinking water (table 1), which show the maximum concentrations of chemical constituents that are permitted.

Table 1 shows the analyses of seven water samples taken from the Huron area. Samples 1-4 are from the buried outwash channel east of Huron, samples 5 and 6 are from the buried outwash channel west of Huron, and sample 7 is James River water. The table shows that samples 1 and 4 contain large amounts of most of the chemical constituents, making them almost prohibitive for use. The rest of the samples, although they exceed the Public Health standards for a few of the chemical constituents, are generally good and could be used. It should also be kept in mind that the city of Huron has an excellent water treatment plant which can eliminate some of the undesirable constituents from the water.

Table 1. Chemical Analyses of Water Samples in Huron Area

Water Sample No. (for location see Plate 3)	Depth of Well	Parts per Million									Hard-ness $CaCo_3$	Total Solids
		Ca	Na	Mg	Cl	SO_4	Fe	Mn	N	F		
U.S.Dept. of Public Health, Drinking Water Standards*	--	--	--	125	250	250	0.3	--	10	1.5	--	500 to 1000
1 (east channel)	39'	879	83	248	304	1563	0.8	0	--	--	3213	5034
2 (east channel)	50'	169	70	40	13	485	1.4	Tr	--	--	586	1106
3 (east channel)	65'	125	8	33	14	172	0	0	--	--	449	642
4 (east channel)	51'	306	284	175	84	284	0	1.6	--	--	1484	3000
5 (west channel)	50'	60	--	18	36	336	0.3	--	--	0.8	224	1100
6 (west channel)	50'	58	--	13	35	351	1.5	0.3	--	0.8	201	1108
7 (James River)	--	76	--	37	46	326	0.3	1.3	--	0.6	342	771

*not to exceed

Samples 1-4 were analyzed by the South Dakota State Chemical Laboratory, Vermillion.
Samples 5-7 by the South Dakota State Department of Health, Pierre.

POSSIBLE SOURCES FOR A CITY WATER SUPPLY

The study of the area around Huron shows that there are two possible sources from which the city can draw its shallow water supply, in addition to the James River which is now being used: (1) the buried outwash channel just east of town (pl. 2), discovered during the present survey, and (2) the buried outwash channel a few miles west of town (pl. 2) where the city has a well at the present time. It is believed that either or both of these channels, if developed properly, can provide enough water for the city of Huron to supplement the James River supply. In 1958, the city of Huron used 594 million gallons of water (table 2), almost all of which came from the James River. Two wells, each with a capacity of 1000 gallons per minute, pumped 50 percent of the time, could produce more than 525 million gallons of water per year; this would amply supplement the river water supply at present rate of water use in Huron.

The sands and gravels in the western channel are thinner than those in the eastern channel, averaging about 35 feet in thickness with a maximum of about 68 feet. The thicker eastern channel averages about 49 feet in thickness, with a maximum of about 90 feet. Also, the eastern channel has generally much coarser material than the western channel which usually insures a more rapid recharge rate. This means that fewer wells would have to be drilled in the eastern channel, and they could be spaced more closely. However, the quality of the water in the western channel is better than that in the eastern channel (table 1); thus, treatment costs would be less for water from the west channel.

Another factor which has to be taken into consideration is that the water treatment plant is located on the eastern edge of the city, and is only about 2 miles from the eastern outwash channel. This means that only about two miles of pipeline would have to be laid to connect the eastern channel with the water plant. In the western outwash channel, even though a pipeline has already been laid from the present wells to the west edge of town, it would still take about four miles of pipeline from there around the city to the water plant; in addition, more gathering lines would be needed in the well field of the western channel because of the wider spacing between wells.

Of the two possible sources of shallow ground water, the eastern channel is recommended even though water contained in it is inferior in quality to that in the western channel. The eastern channel does have thicker deposits and coarser material than the west channel, which should insure more rapid recharge; however, as stated previously, these interpretations should be verified by pump test.

From the iso-resistivity map (pl. 3) the best locations for city wells in the eastern outwash channel appear to be in sec. 34, T. 111 N., R. 61 W. and in secs. 2, 3, 10, and 11, T. 110 N., R. 61 W. This is substantiated by the thick, coarse gravels in test holes 17, 19, and 22 (Appendix). Test holes 12, 15, 24, and 33 (Appendix) also show good thicknesses of sand and gravel, but appear to be near the edge of the channel as shown on the iso-resistivity map. This may partially explain why the two wells drilled near test holes 12 and 15 by the City did not yield more than 450 gallons per minute. Before additional city wells are drilled, test wells should be placed in the more favorable locations recommended above, and pump tests should be made of them to determine if wells at these locations would yield larger quantities of water.

It is further recommended that the city hire a consulting engineering firm to study the data presented herein and to evaluate the cost of obtaining water from both the eastern and the western outwash channels before a decision is

Table 2

Rate of water use in the city of Huron, 1952-1958, (millions of gallons)

	1952	1953	1954	1955	1956	1957	1958
Jan.	25	27	32	33	36	28	33
Feb.	23	26	27	30	34	25	31
Mar.	24	29	29	34	36	27	33
Apr.	24	28	33	41	38	29	33
May	39	32	44	65	55	38	59
June	46	35	37	43	94	32	52
July	50	47	72	71	68	84	69
Aug.	39	53	59	86	54	76	103
Sept.	42	50	38	65	56	41	64
Oct.	24	41	30	46	47	34	50
Nov.	21	31	31	33	27	31	33
Dec.	23	31	33	3[illegible]	28	32	29
Total	385	435	470	589	577	484	594

reached as to where to develop the city water supply. The city officials should also consult the State Water Resources Commission to see if water rights are available, and also the State Board of Health with regard to the construction of the water system, and for bacteriological and further chemical analyses of the water. It is also recommended that the city do more test drilling in the areas suggested herein.

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Rothrock, E. P. and Petsch, B. C., 1935, A Shallow Water Supply for Huron, South Dakota: S. Dak. Geol. Survey, Rept. Invest. No. 24, 9 p.

U. S. G. S., 1960, South Dakota, in Surface water resources of the United States: Select Comm. National Water Resources, U. S. Senate, 86th Cong., 2nd Sess., Comm. Print No. 4, p. 76-77.

APPENDIX A

LOGS* OF TEST HOLES IN THE HURON AREA

(for location see Plate II)

Test No. 1

0 - 9 brown clay
9 - 12 blue clay
12 - 14 sand
14 - 15 boulder
15 - 30 soft blue clay
30 - 35 blue clay
35 - 36 sand
36 - 48 blue clay
48 - 72 sand and coal layers
72 - 78 shale

Test No. 2

0 - 16 top soil and brown clay (boulder at 15')
16 - 24 blue clay
24 - 29 sand and soft shale
29 - 32 blue clay
32 - 35 sand
35 - 47 blue clay
47 - 49 sand
49 - 54 blue clay
54 - 57 sand
57 - 59 blue clay
59 - 60 sand
60 - 68 blue clay
68 - 90 shale

Test No. 3

0 - 24 top soil and brown clay
24 - 38 blue clay
38 - 40 sand
40 - 46 blue clay
46 - 48 sand and gravel
48 - 49 blue clay
49 - 52 sand and gravel
52 - 54 blue clay
54 - 57 sand and gravel
57 - 68 blue clay
68 - 69 sand and gravel
69 - 75 blue clay
75 - 90 shale

Test No. 4

0 - 14 top soil and brown clay
14 - 24 blue clay
24 - 27 sand
27 - 28 blue clay
28 - 29 sand
29 - 31 blue clay
31 - 56 sand (rock at 39')
56 - 59 brown clay
59 - 89 sand and coal layers
89 - 90 blue clay
90 - 99 sand (rock at 96')
99 - 105 shale

Test No. 5

0 - 12 top soil and brown clay
12 - 18 blue clay
18 - 21 sand
21 - 33 blue clay
33 - 35 sand
35 - 39 blue clay
39 - 40 rock
40 - 42 blue clay
42 - 72 sand and coal layers
72 - 90 blue clay
90 - 93 shale

Test No. 6

0 - 8 top soil and clay
8 - 11 sand & boulders mixed with clay
11 - 28 blue clay
28 - 30 rock
30 - 36 blue clay
36 - 41 clay
41 - 46 blue clay
46 - 68 sand and coal layers
68 - 87 blue clay
87 - 93 shale

*Driller's terms are used in all logs.

Test No. 7

0 - 9 top soil and brown clay
9 - 14 blue clay
14 - 17 sand, gravel and boulders
17 - 26 blue clay
26 - 51 hard pan & gravel embedded blue clay
51 - 78 sand (rock at 51')
78 - 90 blue clay
90 - 93 shale

Test No. 8

0 - 9 top soil and brown clay
9 - 14 blue clay
14 - 17 sand and gravel
17 - 20 blue clay
20 - 22 sand and gravel
22 - 31 blue clay
31 - 33 sand and gravel
33 - 38 boulder and hard pan clay
38 - 44 sand
44 - 47 blue clay
47 - 69 sand with thin clay layers
69 - 83 blue clay
83 - 90 blue shale

Test No. 9

0 - 14 top soil and brown clay
14 - 36 hard pan clay
36 - 47 blue clay
47 - 48 hard
48 - 53 blue clay
53 - 60 sand
60 - 67 blue clay
67 - 71 loose sand
71 - 75 blue clay
75 - 92 coarse sand & gravel (lost circulation - couldn't continue drilling)

Test No. 10

0 - 11 top soil and clay
11 - 16 blue clay
16 - 18 sand and gr vel
18 - 50 blue clay
50 - 51 rock
51 - 60 blue clay

Test No. 10 (con't)

60 - 89 sand
89 - 95 blue clay
95 - 105 sand
105 - 108 blue clay
108 - 120 blue shale

Test No. 11

0 - 11 top soil and clay
11 - 14 gravel (boulder at 13')
14 - 18 fine sand
18 - 25 clay
25 - 44 good sand
44 - 48 rock and coal layers
48 - 70 hard clay
70 - 72 sand
72 - 99 clay
99 - 100 shale

Test No. 12

0 - 6 top soil and sand
6 - 17 clay
17 - 95 sand, fine
95 - 116 clay
116 - 120 sand
120 - 135 clay with sand layers
135 - 138 shale

Test No. 13

0 - 12 top soil and clay
12 - 20 sand, gravel and boulders
20 - 24 sand mixed with clay
24 - 30 clay
30 - 60 coarse sand
60 - 78 sand mixed with clay (hit rock, could not continue)

Test No. 14

0 - 8 top soil and sand
8 - 18 clay (boulder at 10')
18 - 38 fine sand
38 - 45 clay
45 - 53 sand and gravel
53 - 56 clay

Test No. 14 (con't)

56 - 65 sand and gravel
65 - 70 clay
70 - 71 sand
71 - 72 clay
72 - 90 sand and gravel

Test No. 15

0 - 9 top soil and clay
9 - 12 sand and gravel
12 - 20 clay and boulders
20 - 32 fine sand
32 - 36 clay
36 - 61 sand and gravel
61 - 85 clay
85 - 87 sand
87 - 92 clay with thin sand layers
92 - 96 sand and gravel
96 - 102 clay
102 - 137 sand and gravel
137 - 138 clay

Test No. 16

0 - 5 top soil, sand & gravel
5 - 28 clay
28 - 33 sand and gravel
33 - 52 fine sand with thin clay layers
52 - 72 clay
72 - 73 sand
73 - 87 clay
87 - 90 sand
90 - 93 clay

Test No. 17

0 - 7 top soil and clay
7 - 8 rock
8 - 12 yellow clay chalk
12 - 20 blue shale
20 - 24 sand
24 - 26 clay
26 - 69 sand and gravel (could drill no further, lost circulation)

Test No. 18

0 - 8 top soil and clay
8 - 15 yellow clay chalk
15 - 21 blue shale
21 - 63 hard clay
63 - 81 shale and chalk
81 - 93 shale

Test No. 19

0 - 7 top soil and clay
7 - 9 boulders and clay
9 - 13 sand
13 - 22 sand and gravel with embedded clay
22 - 24 clay
24 - 30 sand and gravel
30 - 33 clay
33 - 74 sand and gravel
74 - 105 sand and clay layers

Test No. 20

0 - 9 top soil and clay
9 - 15 sand and gravel
15 - 27 sand and gravel with clay (boulders at 22 & 26 feet)
27 - 35 sand & gravel (could not continue because of rocks)

Test No. 21

0 - 25 top soil and clay
25 - 27 sand
27 - 29 clay
29 - 31 sand and gravel
31 - 37 clay
37 - 40 sand
40 - 86 clay
86 - 92 sand and clay layers
92 - 99 clay
99 - 105 hard clay

Test No. 22

0 - 10 clay
10 - 30 sand
30 - 59 good gravel and sand
59 - 64 sand and gravel with some clay (boulder at 64 feet)
64 - 78 medium and coarse sand (could not continue because of rocks)

Test No. 23

0 - 12 top soil and clay (boulders)
12 - 15 sand and gravel (boulders)
15 - 18 sand and gravel embedded in clay (hit boulder at 18')

Test No. 24

0 - 3 top soil and clay
3 - 21 sand and gravel
21 - 22 boulders
22 - 45 clay
45 - 54 sand and gravel
54 - 63 clay
63 - 105 fine sand and gravel; still in good gravel but pump would not work

Test No. 25

0 - 2 top soil and clay
2 - 14 sand and gravel
14 - 33 clay and boulders
33 - 48 clay
48 - 54 sand and gravel
54 - 90 clay

Test No. 26

0 - 33 top soil and clay
33 - 39 sand
39 - 54 clay
54 - 60 fine sand
60 - 69 clay

Test No. 26 (con't)

69 - 87 sandyclay
87 - 105 clay
105 - 103 hard clay

Test No. 27

0 - 12 top soil and clay
12 - 20 sand and gravel, red
20 - 24 clay
24 - 36 sand and gravel, red
36 - 60 clay
60 - 63 sand and clay layers
63 - 67 clay
67 - 72 sand and clay layers
72 - 83 sand and gravel
83 - 87 clay
87 - 93 shale

Test No. 28

0 - 14 top soil and clay
14 - 26 sand and gravel
26 - 29 clay
29 - 38 sand and gravel with boulders
38 - 78 clay
78 - 81 fine sand
81 - 96 clay
96 - 117 sand and gravel with thin clay layers
117 - 123 clay

Test No. 29

0 - 5 top soil and clay
5 - 6 sand and gravel
6 - 27 clay with few boulders
27 - 30 clay
30 - 48 sand and gravel
48 - 75 clay
75 - 102 sand and gravel with boulders
102 - 104 clay
104 - 112 sand and gravel with boulders
112 - 120 clay

Test No. 30

0 - 27 top soil and clay
27 - 39 sand
39 - 45 rock, sand, thin clay
layers and sea shells
45 - 90 clay
90 - 93 hard shale

Test No. 31

0 - 21 top soil, clay and boulder
21 - 24 sand and gravel with boulders
24 - 45 clay and boulders
45 - 62 fine sand
62 - 72 clay
72 - 84 sand, boulders
84 - 105 clay, hard

Test No. 32

0 - 4 top soils, clay and
boulders
4 - 7 sand and gravel
7 - 10 clay and boulders
10 - 24 clay
24 - 27 sand and gravel
27 - 31 hard clay
31 - 33 clay
33 - 38 sand, gravel, boulders
38 - 49 hard clay and boulders
49 - 120 hard clay

Test No. 33

0 - 23 top soil and clay with
few boulders
23 - 30 fine sand
30 - 32 clay
32 - 51 fine sand
51 - 57 clay
57 - 110 coarse sand
110 - 123 clay

APPENDIX B

Resistivity Readings Used in Compiling Plate 2
(for location of stations, see plate 3)

Sta. No.	Ohm-Cm.*	Sta. No.	Ohm-Cm.*	Sta. No.	Ohm-Cm.*
A1	2220	C23	1700	I11	1000
A2	1400	C24	2100	I12	1150
A3	3770	C25	940	J1	3500
A4	1180	C26	510	J2	2750
A5	3770	G1	1100	J3	2650
A6	3500	G2	1000	J4	2400
A7	2120	G3	1700	J5	2550
A8	2050	G4	1000	J6	3550
B1	1350	G5	1680	J7	9300
B2	1200	G6	1650	J8	13100
B3	850	G7	1340	J9	5800
B4	1600	G8	3200	J10	2540
B5	1150	G9	5900	J11	10000
B6	1220	G10	8000	J12	1240
B7	3530	G11	10000	J13	1100
B8	4450	G12	14700	J14	1650
B9	1250	G13	10000	J15	1400
C1	1320	G14	2070	J16	1000
C2	1450	G15	15000	J17	2300
C3	1100	G16	800	J18	1220
C4	850	H1	4450	J19	1620
C5	1380	H2	2330	J20	400
C6	8350	H3	1800	J21	340
C7	8000	H4	3750	J22	610
C8	2350	H5	4000	J23	---
C9	460	H6	1000	J24	900
C10	1650	H7	14500	J25	480
C11	1280	H8	970	J26	100
C12	860	H9	2000	J27	150
C13	920	I1	1770	J28	1550
C14	820	I2	1250	J29	440
C15	800	I3	1100	J30	490
C16	920	I4	950	J31	870
C17	1240	I5	1750	J32	820
C18	1200	I6	4220	J33	1000
C19	1280	I7	3400	J34	1370
C20	1850	I8	7500	J35	2200
C21	1400	I9	4850	J36	1200
C22	2000	I10	3100	J37	770

*All values represent readings taken for effective depth penetration of 65 feet