STATE OF SOUTH DAKOTA
Richard Kneip, Governor

SOUTH DAKOTA GEOLOGICAL SURVEY
Duncan J. McGregor, State Geologist

Special Report 52

WATER INVESTIGATION FOR THE CITY OF PIERRE

by

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Science Center
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Vermillion, South Dakota
1971

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INTRODUCTION

Present Investigation

This report contains the results of a special investigation conducted by the South Dakota Geological Survey from June 3 to July 3, 1969 in and around the city of Pierre, Hughes County, South Dakota (fig. 1). The purpose of the investigation was to assist the city in locating an additional municipal water supply. The city presently receives its water from seven shallow wells in the northwestern part of town along the Missouri River (fig. 2).

A survey to determine the shallow ground-water possibilities was conducted in the Pierre area. Included in this survey were: (1) a review of the geology as mapped by Crandell (1954), (2) the drilling of 32 auger test holes, (3) the construction of 14 temporary shallow wells for observation of water level and collection of water samples, (4) the collection of 40 water samples for chemical analysis.

The results of the investigation indicate three areas for additional water supply for the city of Pierre; these are: (1) the expansion of their present well field in the northwest section of the city, (2) the development of a new well field in the alluvium of Laframboise Island, and (3) the drawing of water from the Missouri River.

The cooperation of the residents of Pierre, especially former Mayor Godfrey M. Roberts, Jr., Director of Public Works, David Padgett, and former City Water Commissioner, Donald Gerlach, is greatly appreciated.

The project was financed by the city of Pierre, Oahe Conservancy Sub-District, and the South Dakota Geological Survey.

Location and Extent of the Area

The Pierre area, as used in this report, covers an area along the Missouri River floodplain from the northwest section to the southwest section of Pierre and Laframboise Island which is located south of Pierre (fig. 1 and 3).

Topography and Drainage

Pierre is located partly on the floodplain of the Missouri River (fig. 3) which is flat-lying to gently sloping having 20 to 30 feet of relief. The remainder of the city occupies the shale bluffs along the river which rise as much as 160 feet above the floodplain.

A network of small intermittent streams drains the area into the Missouri River.

GENERAL GEOLOGY

Surficial Deposits

Surficial deposits in the Pierre area are the result of glaciation (Wisconsin in age), and recent stream deposition by the Missouri River since the retreat of the last Wisconsin ice sheet. These deposits consist of glacial outwash and alluvium respectively (fig. 3).

Alluvium, as used in this report, is a combination of floodplain alluvium and terrace alluvium, and is designated as one unit because of similar characteristics. Crandell (1954) differentiated the alluvium into two separate units based on differences in elevation. The alluvium (Qal., fig. 3) consists of stream deposits of reworked glacial material, shale detritus, and sand and gravel of nonglacial sources. The deposits range from a few feet up to 76 feet in thickness and consist of silt-to pebble-size fragments (app., test hole 16, and fig. 4).

Glacial outwash (Qwo, fig. 3) consists of coarse sand to cobble-size gravel. Thickness of this deposit, within the Pierre study area is not known, but the deposit lies unconformably on the shale bluffs adjacent to the Missouri River floodplain.

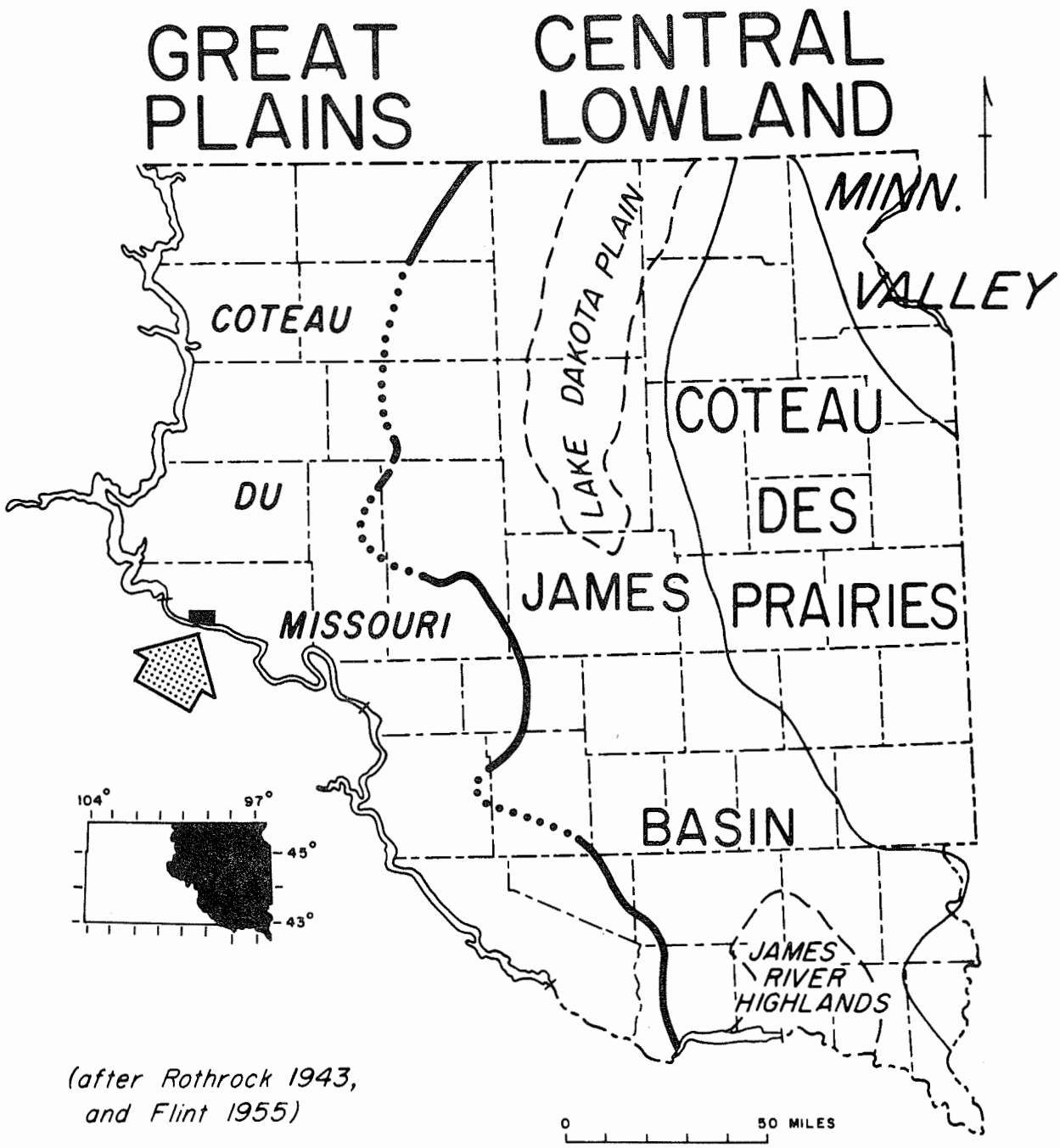


Figure 1. Map of eastern South Dakota showing the major physiographic divisions and location of the Pierre area.

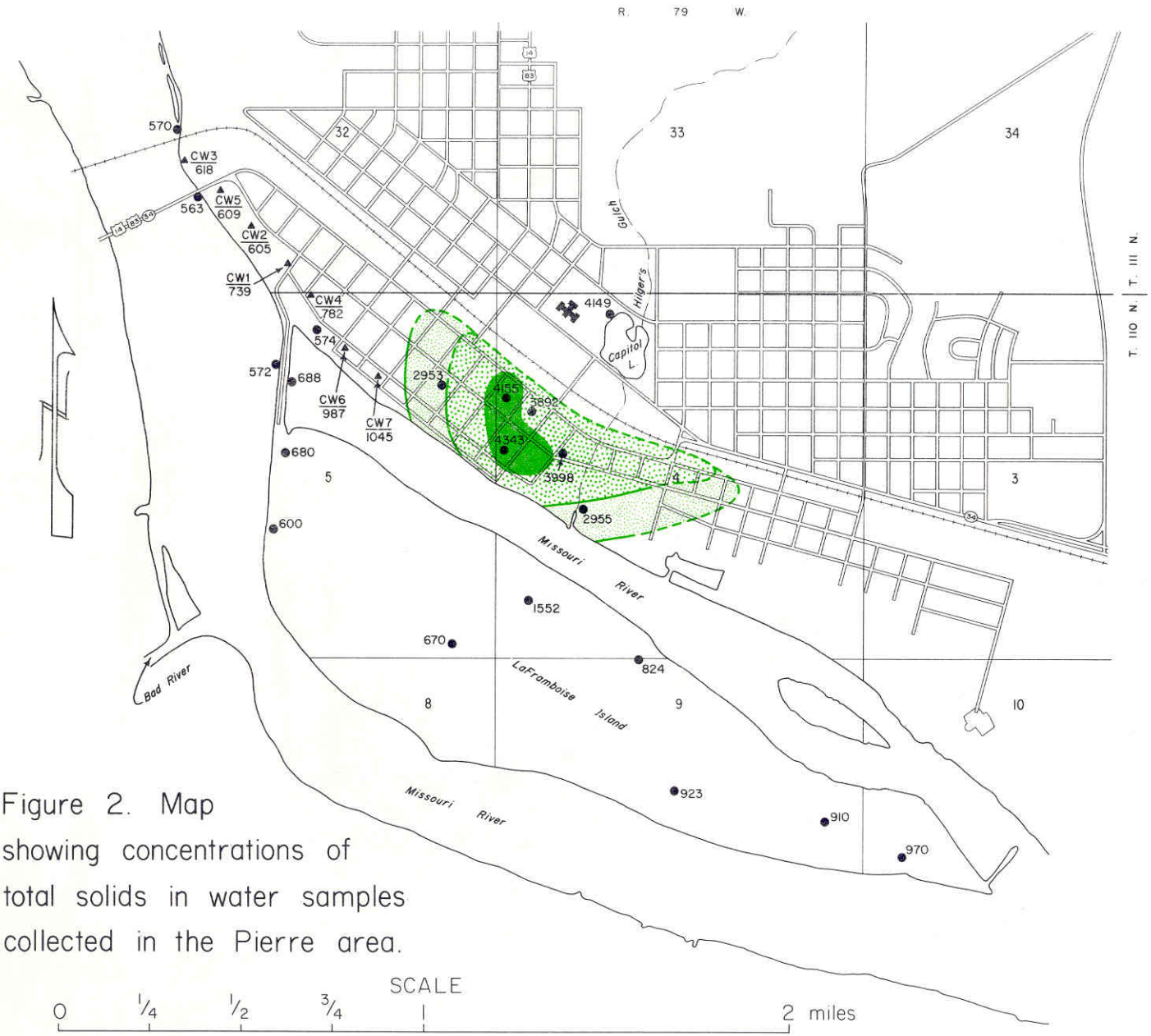


Figure 2. Map showing concentrations of total solids in water samples collected in the Pierre area.

SCALE

0 1/4 1/2 3/4 1 2 miles

EXPLANATION

Area 1
Total solids concentration above 4000 parts per million

Area 2
3000 to 4000 ppm

Area 3
2000 to 3000 ppm

below 2000 ppm

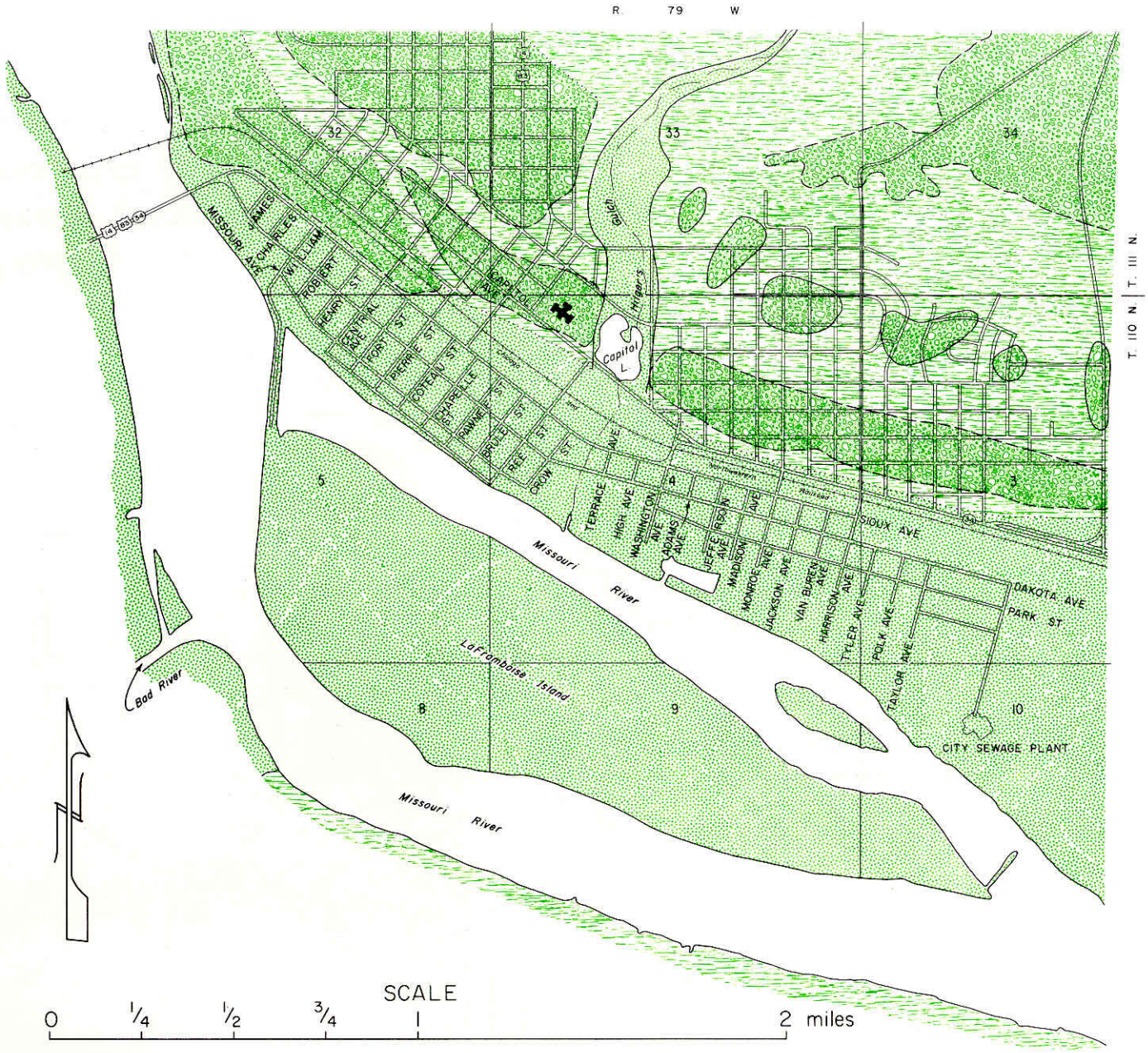
670● Water sample, number represents concentration of dissolved solids in ppm.

▲ CW3/618 City well water sample, upper number is well number; lower number is concentration of dissolved solids in ppm.

Where more than one sample was taken the number is an average of the analyses.

The patterns show total solids concentration in shallow ground water only and do not include the Capitol Lake flowing well.

by Dwight Brinkley, 1970



EXPLANATION

QUATERNARY	Qal	RECENT	Alluvium
	Qwo	PLEISTOCENE	Outwash
CRETACEOUS	Kp	UPPER CRETACEOUS	Shale

Contact

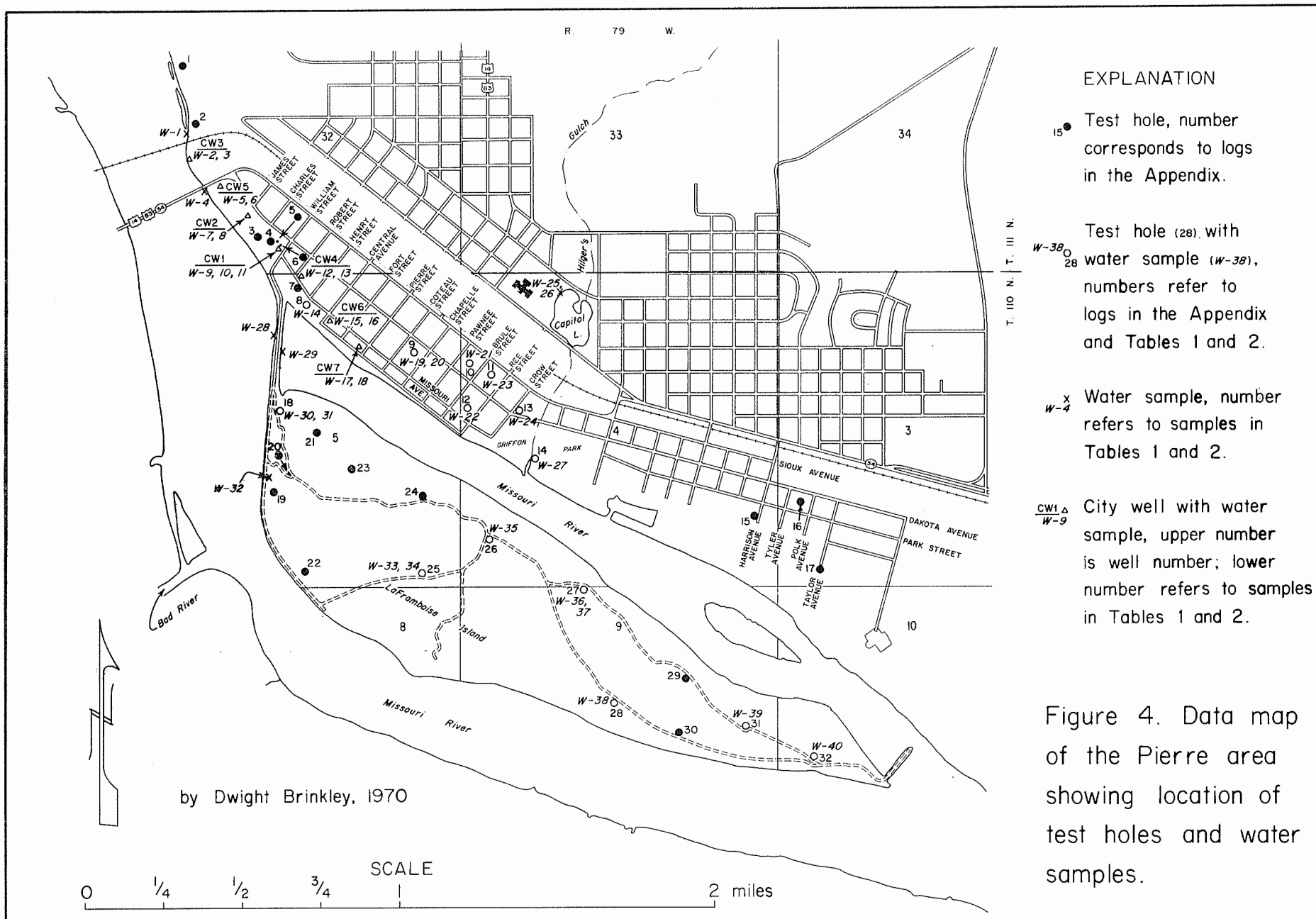
Gradational contact

Concealed contact

by Dwight Brinkley, 1970

drafted by D. W. Johnson

Figure 3. Generalized geologic map of the Pierre area. *(modified from D. R. Crandell, 1954).*



EXPLANATION

15 ● Test hole, number corresponds to logs in the Appendix.

W-38 28 ○ Test hole (28) with water sample (W-38), numbers refer to logs in the Appendix and Tables 1 and 2.

W-4 X Water sample, number refers to samples in Tables 1 and 2.

CW1 / W-9 △ City well with water sample, upper number is well number; lower number refers to samples in Tables 1 and 2.

Figure 4. Data map of the Pierre area showing location of test holes and water samples.

Exposed Bedrock

Two members of the Pierre Formation of Cretaceous age are exposed along the bluffs of the Missouri River in the Pierre area (Crandell, 1954): the Verendrye Member, which consists of olive-gray mudstone and siltstone, and the DeGrey Member, which consists of siliceous shale and claystone with bentonite beds. These two members are not differentiated on the geologic map (fig. 3) and will not be discussed because they have no bearing on the shallow ground-water prospects of the area.

Subsurface Bedrock

Sedimentary rocks of Cretaceous age are present beneath the exposed bedrock, and in descending order are: Pierre Shale, Niobrara Marl, Carlile Shale, Greenhorn Limestone, Graneros Shale, Dakota Formation, Skull Creek Shale, and the Inyan Kara Group (Fall River and Lakota Sandstones). The Sundance Formation (Jurrassic in age) underlies the Lakota Sandstone. Below the Sundance Formation are Paleozoic rocks that overlie Precambrian basement rocks. See stratigraphic column (fig. 5).

OCCURRENCE OF GROUND WATER

Principles of Occurrence

(Refer to fig. 6.)

Contray to popular belief, ground water does not occur in "veins" that crisscross the land at random. Instead, it can be shown that water is found everywhere beneath the surface, but at varying depths.

Ground water is defined as that water contained in the voids or openings within rocks or sediments below the water table. The water table is the upper surface of the zone of saturation which is under atmospheric pressure. Below this surface practically all open spaces in the rocks are filled with water. Rocks (including the soil) that lie above the water table are in the zone of aeration. Some of the interstices in this zone are also filled with water, but the water is either held by molecular attraction, or is moving downward toward the zone of saturation under the influence of gravity. In the saturated zone, water moves in a direction determined by the hydraulic gradient.

Nearly all ground water is derived from precipitation in the form of rain, melting snow, or ice. This water either evaporates, 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 into the rocks.

Recharge is the addition of water to an aquifer (a formation having structures that permit appreciable water to move through it under ordinary field conditions), and is accomplished in four main ways: (1) by downward percolation of precipitation from the ground surface, (2) by downward percolation from surface bodies of water, (3) by lateral underflow of water in transient storage, and (4) by artificial recharge, which takes place from excess irrigation, seepage from canals, and water purposely applied to augment ground-water supplies.

Discharge of ground water from an aquifer is accomplished in four main ways: (1) by evaporation and transpiration of plants, (2) by seepage upward and laterally into surface bodies of water, (3) by lateral movement of water in transient storage, and (4) by pumping from wells, which constitutes the major artificial discharge of ground water.

For a description and explanation of porosity and permeability, the factors that control the storage and movement of ground water, refer to figure 7.

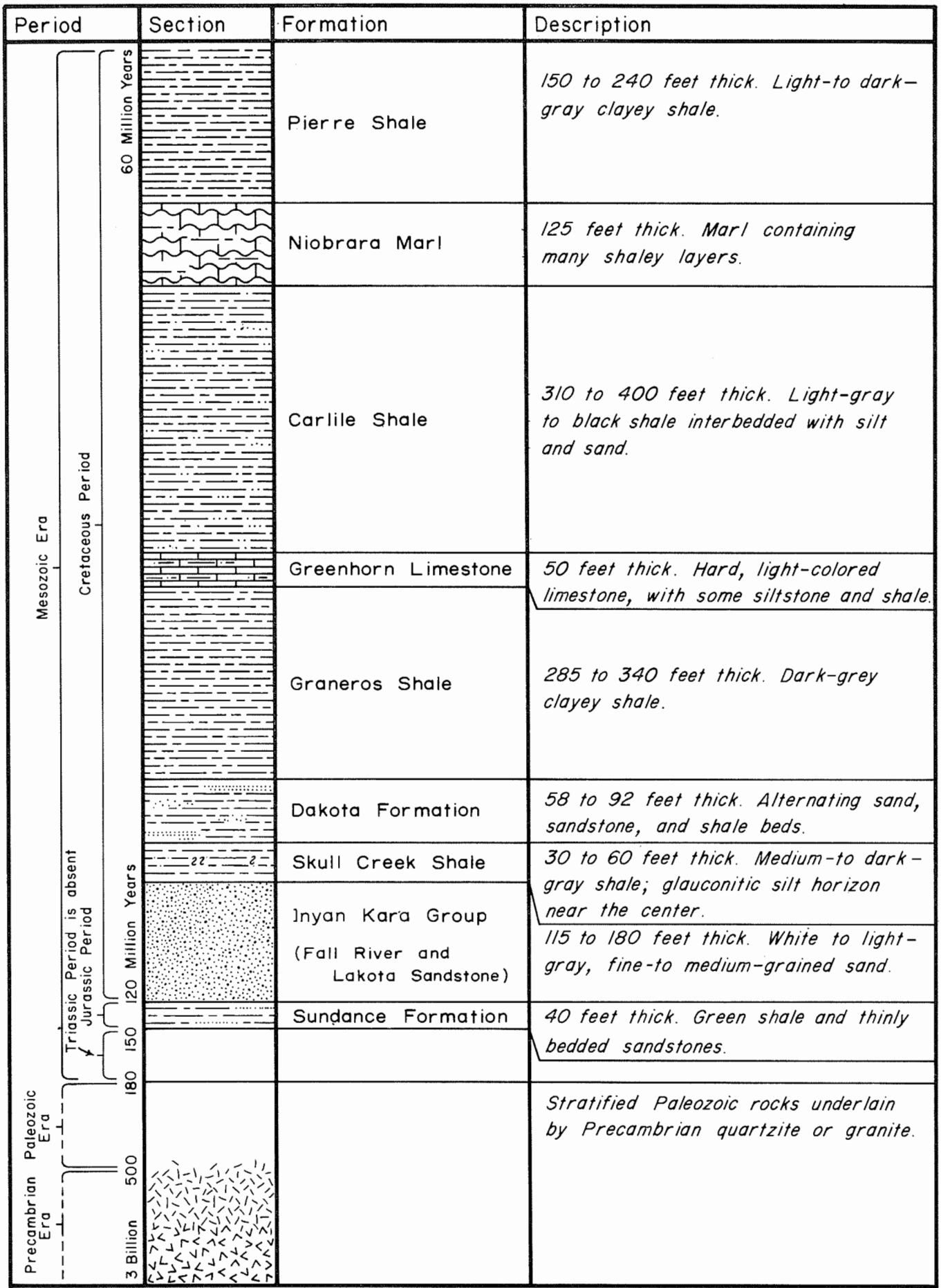


Figure 5. Stratigraphic column of the subsurface bedrock in the Pierre area.

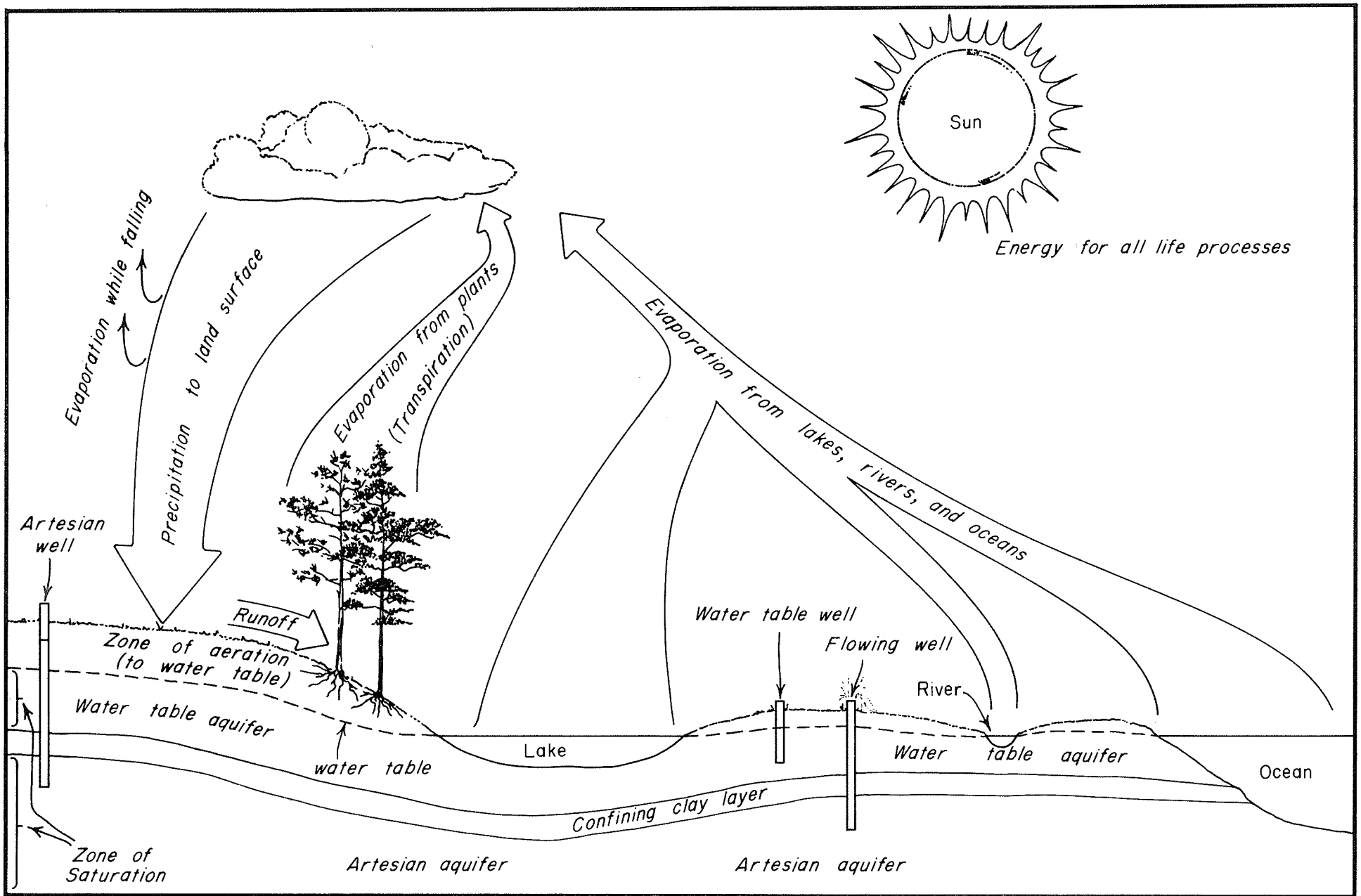
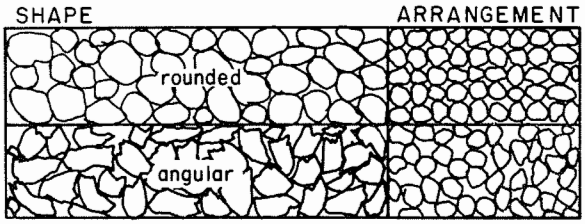


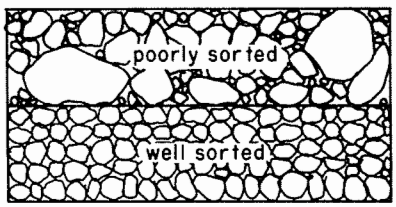
Figure 6. Illustrated hydrologic cycle. *(Modified from Ground Water and Wells, 1966).*

The porosity of a rock or soil is a measure of the contained open pore spaces, and it is expressed as the percentage of void space to the total volume of the rock. The porosity of a sedimentary deposit depends chiefly on:



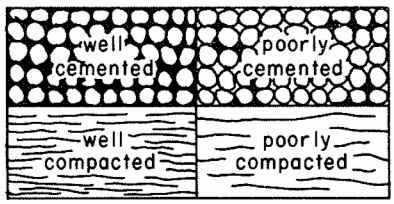
1.

The shape and arrangement of its constituent particles.



2.

The degree of sorting of its particles.

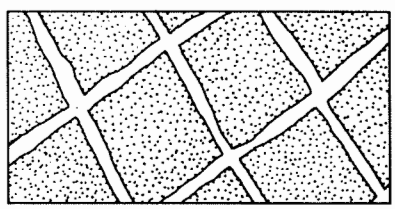


3.

The cementation and compaction to which it has been subjected since its deposition.

4.

Removal of mineral matter through solution by percolating water.



5.

The fracturing of rock resulting in joints and other openings.

Thus the size of the material has little or no effect on porosity if all other factors are equal. The permeability of a rock is its capacity for transmitting a fluid. Water will pass through a material with interconnected pores (see block 1), but will not pass through material with unconnected pores (see block 3), even if the latter material has a higher porosity. Therefore, permeability and porosity are not synonymous terms.

Figure 7. Illustration of porosity and permeability.

Ground Water in Alluvium

Alluvial deposits along the Missouri River (Qal., fig. 3) are made up of silt-to gravel-size particles. These deposits are predominantly sand with some beds of gravel which form a suitable aquifer. The maximum thickness of alluvial deposits below the water table was 64 feet in test hole 16 (app., fig. 4 and fig. 8) with an average saturated thickness of 48 feet in the study area.

Ground Water in Glacial Deposits

Glacial outwash deposits (fig. 3) within the city of Pierre are used as a source of gravel. These surface outwash deposits are not very large in areal extent or depth, and do not contain enough water to be considered for a municipal supply.

The only glacial outwash deposit in the Pierre area with the potential to yield an appreciable supply of ground water, is the gravel near the bottom of the alluvium in the Missouri River floodplain. It is believed that this gravel may be outwash material deposited during the formation of the Missouri River (Tipton, 1960). Whether this deposit is outwash or alluvial gravels cannot be determined without extensive laboratory tests. The maximum saturated thickness penetrated in this glacial outwash deposit was 23 feet in test hole 31 (app., and fig. 4).

Ground Water in Bedrock

The Dakota Formation and the Inyan Kara Group (Fall River and Lakota Sandstones) are the two major bedrock aquifers in the Pierre area. The Dakota Formation is at a depth of approximately 1100 feet and, as mentioned earlier, is composed of alternating layers of sand, sandstone, and shale beds that are approximately 58 to 92 feet in thickness. The water in this formation is under pressure and flows from wells penetrating it in the Pierre area. In addition, methane gas is present in the water from this formation.

The Inyan Kara Group as previously described is approximately 115 to 180 feet thick and is a white-to light-gray, fine-to medium-grained sand. This formation is approximately 1220 feet below the surface in the Pierre area. The water in this formation is also under pressure and flows from wells drilled into it.

QUALITY OF GROUND WATER

Ground water always contains dissolved chemical substances in various amounts. Contained chemicals are derived from: (1) the atmosphere as water condenses and falls, (2) the soil and underlying deposits as the water moves downward to the water table, and (3) the rock deposits below the water table where the water is circulating. In general, the more chemical substances that a water contains, the poorer its quality.

Table 1 and 2 show the quality of water from the Pierre area as compared with the limits (sample A, tables 1 and 2) recommended by the U. S. Department of Public Health (1962) and modified by the South Dakota Department of Health.

Samples w-1, w-4, w-28, and w-29 were collected from the Missouri River, samples w-25 and w-26 were obtained from the Capitol Lake flowing well the source of which is the Dakota Formation. All remaining samples in table 1 were collected from test holes and wells drilled in the alluvium within the city of Pierre.

Comparison of samples w-1 to w-17 in table 1 with the South Dakota Department of Health Standards (sample A in table 1) shows that these samples are within chemical limits as shown in the standard. There are two exceptions: (1) high iron in sample w-14, and (2) high manganese and low fluoride in all samples analyzed for these chemicals.

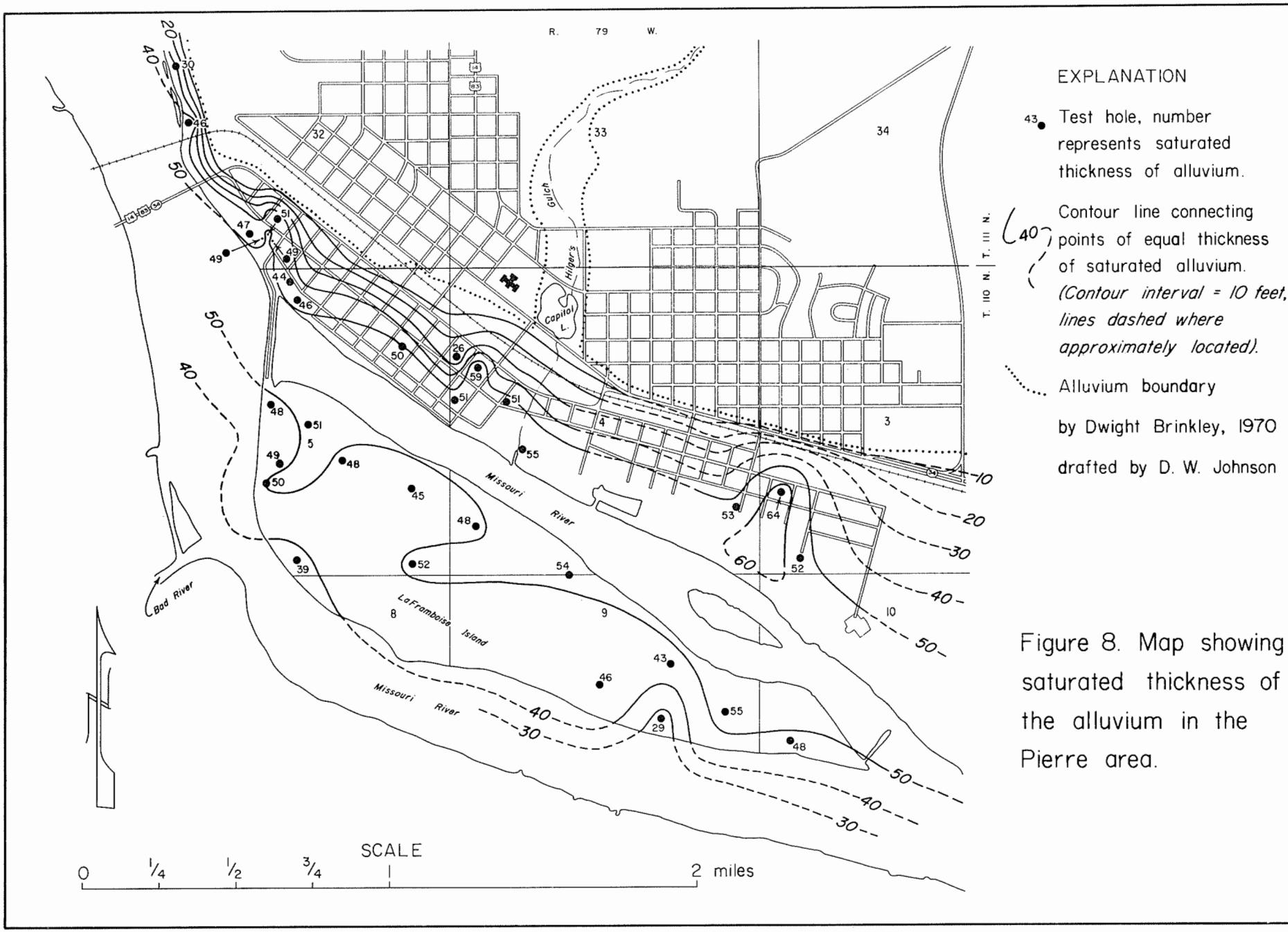


Figure 8. Map showing saturated thickness of the alluvium in the Pierre area.

Table 1 – Chemical analyses of water samples collected within the city of Pierre and from the Missouri River.

Sample	Source [3]	Parts Per Million											
		Calcium	Sodium	Magnesium	Chlorides	Sulfate	Iron	Manganese	Nitrate Nitrogen	Fluoride	pH	Hardness $CaCO_3$	Total Solids
A*		---	---	---	250	500[1]	0.3	0.005[1]	10.0	0.9–1.7 [2]	---	---	1000[1]
w-1	I	66		18	4.6	200	0.10				7.9	240	570
w-2	II	68		22	9.2	253	0.03				7.5	260	608
w-3	II	65		24	10	250	0.10				7.7	260	628
w-4	I	64		23	13	225	0.10				8.0	260	563
w-5	II	64		39	7.3	263	0.08				7.9	270	588
w-6	II	68		25	12	250	0.10				7.6	270	630
w-7	II	64		18	11	245	0.08				8.0	230	580
w-8	II	80		16	13	230	0.12				7.5	260	619
w-9	II	72	100	41	16	274	0.2	2.2	0.5	0.4	7.7	350	708
w-10	II	90		25	13	275	0.08				7.7	325	739
w-11	II	96		33	14	290	0.08				7.8	370	770
w-12	II	104		22	18	345	0.06				7.7	350	779
w-13	II	100		26	23	300	0.10				7.7	355	785
w-14	II	61	71	26	9	232	0.5	1.0	0.4	0.4	7.3	257	574
w-15	II	80		34	59	388	0.10				7.5	340	974
w-16	II	85		27	62	400	0.10				7.6	320	1000
w-17	II	91	200	49	114	414	none	2.4	0.4	1.4		430	1054
w-18	II	88		45	100	225	0.12				7.5	400	1037
w-19	II	147	950	241	1152	1134	10.7	5.0	14.0	0.4	7.7	1360	4020
w-20	II	25	640	66	429	476	2.4	1.8	1.0	0.4	8.0	334	1886
w-21	II	317		127	645	2300	0.08				7.8	1310	4155
w-22	II	309		95	737	2000	0.06				7.7	1160	4343
w-23	II	227	900	231	107	1672	1.0	1.8	0.6	0.8	7.9	1266	3892
w-24	II	280		40	691	1600	0.13				7.8	860	3998
w-25	III	17		11	1948	10	0.13				8.0	89	3498
w-26	III	44		10	1843	none	0.08				7.7	145	4800
w-27	II	200		25	553	1050	0.10				7.9	800	2955
w-28	I	36		38	7.3	280	0.03				7.6	250	572
w-29	I	84		23	13	350	0.2				7.9	310	688

All chemical analyses were determined by the South Dakota Geological Survey Water Quality Laboratory except samples 9, 14, 17, 19, 20, 23, and 25 which were analyzed by the State Chemical Laboratory in Vermillion. The pH of samples 9, 14, 19, 20, 23, and 25 were determined by the State Geological Survey.

*Sample A: Drinking Water Standards set by the U. S. Department of Public Health Service, 1962.

[1] Modified for South Dakota by the State Department of Health (written communication Water Sanitation Section, March 20, 1968).

[2] 1.2 is optimum for South Dakota.

[3] Source: I, Missouri River; II, Alluvium; III, Capitol Lake flowing well.

Location of Water Samples for Table 1

(For map location, see fig. 4.)

A. Drinking Water Standard, U. S. Public Health Service (1962).
w- 1. Missouri River, north of city well No. 3, date collected, 6-23-69.
w- 2. Pierre City Well No. 3, 62 feet deep, date collected, 6-10-69.
w- 3. Pierre City Well No. 3, 62 feet deep, date collected, 6-29-69.
w- 4. Missouri River, collected at State Highway 34 Bridge, date collected, 7-1-69.
w- 5. Pierre City Well No. 5, 60 feet deep, date collected, 6-14-69.
w- 6. Pierre City Well No. 5, 60 feet deep, date collected, 7-1-69.
w- 7. Pierre City Well No. 2, 60 feet deep, date collected, 6-9-69.
w- 8. Pierre City Well No. 2, 60 feet deep, date collected, 7-1-69.
w- 9. Pierre City Well No. 1, 63 feet deep, date collected, 6-9-69.
w-10. Pierre City Well No. 1, 63 feet deep, date collected, 6-20-69, (during high river stage).
w-11. Pierre City Well No. 1, 63 feet deep, date collected, 6-22-69, (during low river stage).
w-12. Pierre City Well No. 4, 64 feet deep, date collected, 6-14-69.
w-13. Pierre City Well No. 4, 64 feet deep, date collected, 6-30-69.
w-14. City of Pierre, test hole No. 8, 200 feet SW of intersection of Henry Street and Missouri Avenue, sample taken from 48 feet to 51 feet.
w-15. Pierre City Well No. 6, 60 feet deep, date collected, 6-10-69.
w-16. Pierre City Well No. 6, 60 feet deep, date collected, 7-1-69.
w-17. Pierre City Well No. 7, 63 feet deep, date collected, 6-10-69.
w-18. Pierre City Well No. 7, 63 feet deep, date collected, 7-1-69.
w-19. Test hole No. 9, in alley SE of Coteau Street and SW of Dakota Avenue, sample taken from 48 feet to 51 feet.
w-20. Test Hole No. 9, in alley SE of Coteau Street and SW of Dakota Avenue, sample taken from 31 feet to 34 feet.
w-21. City of Pierre, test hole No. 10, in alley SE of Pawnee Street and SW of Sioux Avenue, sample taken from 32 feet to 35 feet.
w-22. City of Pierre, test hole No. 12, in alley SE of Brule Street and SW of Dakota Avenue, sample taken from 30 feet to 33 feet.
w-23. City of Pierre, test hole No. 11, in alley SE of Brule Street and SW of Sioux Avenue, sample taken from 59 feet to 62 feet.
w-24. City of Pierre, test hole No. 13, NE corner of intersection of Crow Street and Dakota Avenue, sample taken from 60 feet to 63 feet.
w-25. City of Pierre, State Capitol flowing well, depth 1228 feet, date collected, 6-18-69.
w-26. City of Pierre, State Capitol flowing well, depth 1228 feet, date collected, 7-2-69.
w-27. City of Pierre, test hole No. 14, 100 feet west of Griffin Park Baseball Field, sample taken from 28 feet to 31 feet.
w-28. Missouri River, west side of causeway to Laframboise Island by boat ramp, date collected, 6-14-69.
w-29. Missouri River, east side of causeway to Laframboise Island, date collected, 6-8-69.

Table 2–Chemical analyses of water samples from the alluvium of Laframboise Island.

Sample	Parts Per Million											
	Calcium	Sodium	Magnesium	Chloride	Sulfate	Iron	Manganese	Nitrate Nitrogen	Fluoride	pH	Hardness $CaCO_3$	Total Solids
A*	---	---		250	500[1]	0.3	0.005[1]	10.0	0.9-1.7[2]	---	---	1000[1]
w-30	32		15	9.5	310	0.08				7.8	140	728
w-31	76		25	9.0	220	0.06				8.2	290	631
w-32	63	80	39	7	200	none	2.8	0.8	0.4		316	600
w-33	44	90	27	10	244	2.2	3.0	1.0	0.6	7.6	222	562
w-34	88		32	12	290	0.10				7.5	350	777
w-35	122	240	69	276	562	1.4	1.2	none	none	7.7	584	1552
w-36	77	180	35	124	376	1.2	2.6	0.5		7.8	333	1014
w-37	67	74	28	25	238	2.2	3.4	3.0	0.4	7.1	310	634
w-38	48		24	12	435	0.12				6.9	220	923
w-39	76		25	24	550	0.16				7.7	291	910
w-40	60	190	40	18	490	1.8	2.6	1.0	0.4	7.3	316	970

All chemical analyses were determined by the Water Quality Laboratory of the State Geological Survey except samples 32, 33, 35, 36, 37, and 40 which were analyzed by the State Chemical Laboratory in Vermillion. The pH of samples 33, 35, 36, 37, and 40 were determined by the State Geological Survey Water Quality Laboratory.

*Sample A: Drinking Water Standards set by the U. S. Department of Public Health Service, 1962.

[1] Modified for South Dakota by the State Department of Health (written communication, Water Sanitation Section, March 20, 1968).

[2] 1.2 is optimum for South Dakota.

Location of Water Samples for Table 2

(For map location, see fig. 4.)

A. Drinking Water Standard, U. S. Public Health Service (1962).
w-30. Laframboise Island, test hole No. 18, sample taken from 51 feet to 54 feet.
w-31. Laframboise Island, test hole No. 18, sample taken from 22 feet to 25 feet.
w-32. Laframboise Island, sample taken from existing well along west side of Island, depth unknown.
w-33. Laframboise Island, test hole No. 25, sample taken from 48 feet to 51 feet.
w-34. Laframboise Island, test hole No. 25, sample taken from 30 feet to 33 feet.
w-35. Laframboise Island, test hole No. 26, sample taken from 31 feet to 34 feet?
w-36. Laframboise Island, test hole No. 27, sample taken from 50 feet to 53 feet.
w-37. Laframboise Island, test hole No. 27, sample taken from 25 feet to 28 feet.
w-38. Laframboise Island, test hole No. 28, sample taken from 30 feet to 33 feet?
w-39. Laframboise Island, test hole No. 31, sample taken from 50 feet to 53 feet?
w-40. Laframboise Island, test hole No. 32, sample taken from 48 feet to 51 feet.

Results of analyses of water samples w-17 to w-28 show: (1) high chloride in samples except in w-17, w-18, and w-23, (2) high sulfate over the recommended limits in samples except for w-17, w-18, w-20, w-25, and w-26, (3) high total solids in samples w-17 to w-28, (4) higher manganese content which is over the limits in those samples analyzed for this element, (5) fluoride content was lower than the limits in the samples analyzed for these chemicals (except for sample w-17), (6) iron content in samples w-19 and w-20 were higher than the recommended limits as set forth in the standard.

The analyzed chemicals in samples w-28 and w-29 are within the limits set by the State Department of Health.

Table 2 shows the results of water analyzed from the alluvium of Laframboise Island. Comparison of these samples with the State Health Standards in sample A show that: (1) except for high sulfate in w-35, w-39, (2) high iron in samples w-33, w-35, w-36, w-37, w-40, (3) high total solids in samples w-35, w-36, and (4) high manganese and low fluoride in the samples analyzed for these chemicals. The remaining chemical elements are within the limits set forth by the South Dakota Department of Health. Comparison of table 1 with table 2 shows that the water quality from the west end of Laframboise Island is comparable with the water from the city's present well field.

Table 3 shows the significance of some chemical and physical properties of drinking water.

From the year 1889 to the 1930's approximately 10 flowing wells were drilled from 1100 to 1300 feet deep into the Dakota Formation to tap the methane gas (Gries, 1940). The gas was used to supply fuel to the city of Pierre. The greatest number of wells were drilled along Sioux Avenue between Brule Street and Crow Street. From the 1920's into the 1950's these wells were plugged except for the Capitol Lake flowing well. Apparently these wells, or well, have not been properly plugged allowing water from the Dakota Formation to infiltrate the alluvium causing high concentrations of dissolved solids in this area.

Figure 2 on page 3 is a map showing the concentration of total solids in water samples collected from the Pierre area (tables 1 and 2). The number beside each point represents the amount of total solids contained in that water sample; where more than one sample was taken, the number beside that point represents the average of the contained chemicals.

Three distinct areas are shown on figure 2 and each area is designated by a different pattern to represent a different concentration of total solids. Area 1 has the highest concentration of total solids which is above 4000 ppm. This area is closest to the old abandoned flowing wells. Area 2 ranges from 3000 to 4000 ppm total solids, and transgresses into Area 3 which has between 2000 and 3000 ppm total solids. Outward from Area 3, the quality of water improves in shallow ground water.

CONCLUSIONS AND RECOMMENDATIONS

Two shallow sources of water exist in the Pierre study area which the city could utilize for an additional municipal water supply; these are: (1) the Missouri River alluvium (fig. 3), and (2) the Missouri River water (fig. 3). From these two sources the most desirable sites for additional water development are: (1) expansion of their present well field within the Missouri River alluvium, (2) well development in the Missouri River alluvium of Laframboise Island, and (3) water from the Missouri River between city well three and city well one (fig. 2).

Selection of the best locality for additional water development in the Pierre area is based on: (1) quality of the water, (2) quantity of water, and (3) feasibility of production. Based on the above three criteria the recommendations listed below are in order of preference.

1. Chemical analyses of the water from the alluvium in which the present city wells are located indicate that this water is high in manganese and low in fluoride. Chemical analyses of the water from city well number seven shows that it is also high in total solids (table 1,

Table 3.–Significance of some chemical and physical properties of drinking water.

Chemical Constituents	Significance	Recommended Limits (ppm)[1]
Calcium (Ca) and Magnesium (Mg)	Cause most of the carbonate hardness and scale-forming properties of water by combining with carbonate and bicarbonate present in the water. Seldom can be tasted except in extreme concentrations.	Ca–None Mg–None
Sodium (Na)	Large amounts in combination with chloride will give water a salty taste. Large amounts will limit water for irrigation and industrial use.	None
Chloride (Cl)	Large amounts in combination with sodium give water a salty taste. Large quantities will also increase corrosiveness of water.	250
Sulfate (SO_4)	Large amounts of sulfate in combination with other ions give a bitter taste to water and may act as a laxative to those not used to drinking it. Sulfates of calcium and magnesium will form hard scale. U. S. Public Health Service recommends 250 ppm maximum concentration.	500[2]
Iron (Fe) and Manganese (Mn)	In excess will stain fabrics, utensils, and fixtures and produce objectionable coloration in the water. Both constituents in excess are particularly objectionable.	Fe–0.3 Mn–0.005[2]
Nitrogen (N)	In excess may be injurious when used in infant feeding. The U. S. Public Health Service regards 45 ppm as the safe limit of nitrate (NO_3) or 10 ppm nitrogen (N).	10
Fluoride (F)	Reduces incidence of tooth decay when optimum fluoride content is present in water consumed by children during period of tooth calcification. Excessive fluoride in water may cause mottling of enamel.	0.9-1.7[3]
pH	A measure of the hydrogen ion concentration; pH of 7.0 indicates a neutral solution, pH values lower than 7.0 indicate acidity, pH values higher than 7.0 indicate alkalinity. Alkalinity tends to aid encrustation and acidity tends to aid corrosion.	None
Hardness	Hardness equivalent to carbonate and bicarbonate is called carbonate hardness. Hardness in excess of this amount is noncarbonate hardness. Hardness in water consumes soap and forms soap curd. Will also cause scale in boilers, water heaters, and pipes. Water containing 0-60 ppm hardness considered soft; 61-120 ppm moderately hard; 121-180 ppm hard, and more than 180 ppm very hard. Good drinking water can be very hard.	None
Total Solids	Total of all dissolved constituents. U. S. Public Health Department recommends 500 ppm maximum concentration. Water containing more than 1000 ppm dissolved solids may have a noticeable taste; it may also be unsuitable for irrigation and certain industrial uses.	1000[2]

Modified from Jorgensen (1966).
[1] (ppm) parts per million.
[2] Modified for South Dakota by the South Dakota Department of Health (written communcation, Water Sanitation Section, March 20, 1968).
[3] 1.2 is optimum for South Dakota.

samples w-17 and w-18). If the city should decide to expand their present well field it is recommended that they drill northwest of city well number seven and south of Dakota Avenue because the water in that area has less dissolved chemicals (fig. 2). It is further recommended that no wells be drilled north of city well number three because the alluvium in that direction has a considerable amount of clay (app., test holes 1 and 2). Wells drilled and developed at or near test holes three and eight (fig. 4) should yield about the same quality and quantity of water that the present city wells are now producing. Observation of the drawdown in the observation wells next to city well one indicates that additional well development may be possible between city well two and city well five; however, more information would be required to make this recommendation.

2. The alluvium of Laframboise Island is a suitable aquifer that the city of Pierre could utilize as a municipal water supply. The best quality water from the island is in the northwest corner, but this water has more dissolved chemicals than the recommended limits in manganese and is below the standards in fluoride (fig. 4 and table 2, samples w-30, w-31, and w-32). If the city should decide to drill a well in the northwest corner at or near test hole eighteen (fig. 4) they can expect about the same quality of water that they are now receiving from their present city wells. The new well could be connected to their present well field by a pipeline across the Laframboise Island causeway. The city officials should inquire about obtaining water rights to Laframboise Island from the Federal Government.

Before additional testing is undertaken, the city should hire a consulting engineer licensed in South Dakota to plan and coordinate any additional testing. On the basis of the engineer's recommendation a commercial well drilling company should be engaged to drill additional test holes. This would allow location of the best site in the northwest corner of Laframboise Island for installation of a test well. The test well should be used to determine quality, safe yield, drawdown, and recovery data. Based on the results from the pump test a safe distance between the future wells can be determined. The pump test should be conducted by a qualified hydrologist or engineer and run for a minimum of 72 hours.

3. Water drawn from the Missouri River would more than meet the future demands of Pierre as a municipal water supply; although water from the river would require a filtration plant. Chemical analyses of the water from the Missouri River indicate that this water is within the recommended limits set by the South Dakota Department of Health (table 1, samples w-1, w-4, w-28, and w-29), but these water samples were not tested for manganese, nitrate, and fluoride. The water quality of the river is comparable to the water from the alluvium, and some seasonal change of the water temperature and quality from the river should be expected.

Before constructing a permanent city well, the city officials should consult with the South Dakota Water Resources Commission with regard to obtaining a water right and a permit to drill a city well, and the South Dakota Department of Health with regard to the biological and chemical suitability of the water.

GLOSSARY

Definitions of terms taken from Glossary of Geology and Related Sciences, 1966.

Alluvium: Sand and gravel, and stones and other transported matter which has been washed away and deposited by rivers, floods, and other causes, upon land not permanently submerged beneath the waters of lakes and seas.

Aquifer: A formation having structures that permit appreciable water to move through it under ordinary field conditions.

Artesian Well: One in which the water level rises above the top of the aquifer, whether or not the water flows at the land surface.

Flowing Well: A well in which pumping is not necessary to bring the water to the surface.

Ground Water: That part of the subsurface water which is in the zone of saturation.

Hydraulic Gradient: As applied to an aquifer it is the rate of change of pressure head per unit of distance of flow at a given point and in a given direction.

Hydrologic Cycle: The complete cycle of phenomena through which water passes, commencing as atmospheric water vapor, passing into liquid and solid form as precipitation, thence along or into the ground surface, and finally again returning to the form of atmospheric water vapor by means of evaporation and transpiration.

Interstices: Pore; void

Outwash: Stratified drift deposited by meltwater streams beyond active glacier ice (usually sand and gravel).

Permeability: The permeability of rock is its capacity for transmitting a fluid. Degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the latter. It is measured by the rate at which a fluid of standard viscosity can move a given distance through a given interval of time.

Porosity: The porosity of a rock or soil is a measure of the contained open pore spaces, and it is expressed as the percentage of void space to the total volume of the rock.

Sorting: The dynamic process by which material having some particular characteristic, such as similar size, shape, specific gravity, or hydraulic value, is selected from a larger heterogeneous mass.

Transpiration: The process by which water vapor escapes from a living plant and enters the atmosphere.

Unconformity: A surface of erosion or nondeposition, usually the former that separates younger strata from older rocks.

Water Table: The upper surface of a zone of saturation which is under atmospheric pressure. Below this surface practically all open spaces are filled with water.

Zone of Aeration: Rocks that lie above the water table. Some of the interstices in this zone are also filled with water, but the water is either held by molecular attraction, or is moving downward toward the zone of saturation under the influence of gravity.

Zone of Saturation: The zone in which the functional permeable rocks are saturated with water.

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APPENDIX

Logs of test holes in the Pierre area

(For location see fig. 4.)

Test Hole 1
Location: SE¼NW¼SW¼NW¼ sec. 32, T. 111 N., R. 79 W., (1000 feet north of Chicago and Northwestern railroad bridge over the Missouri River
Depth to water: 12 feet.

0-10	Sand, brown, very fine; silt
10-42	Clay, gray; sand, coarse; some gravel
42-47	Clay, bluish-gray, compact, (shale)

* * * *

Test Hole 2
Location: NW¼NE¼NW¼SW¼ sec. 32, T. 111 N., R. 79 W., (300 feet north of Chicago and Northwestern railroad bridge over the Missouri River
Depth to water: 8 feet

0- 4	Sand, light-brown, very fine
4-10	Clay, brown; sand, fine
10-15	Sand, brownish-black, coarse; some clay
15-16	Clay, dark-gray
16-18	Sand, brownish-black, coarse; some pea gravel; much clay
18-26	Sand, dark-brown, medium to coarse; some pea gravel; coal pebbles; much clay
26-37	Sand, brown, fine to medium; gravel; some clay
37-46	Sand, brown, medium; much clay
46-54	Sand, blackish-gray, fine to medium
54-55	Rock, abandoned hole

* * * *

Test Hole 3
Location: NE¼SW¼SE¼SW¼ sec. 32, T. 111 N., R. 79 W., (417 feet west of City Well No. 1)
Depth to water: 12 feet

0- 7	Sand, light-brown, medium
7- 8	Sand, gray, fine; much clay
8-15	Sand, gray, medium; some clay
15-18	Sand, light-brown, medium to coarse
18-23	Sand, light-brown, coarse to very coarse; some pea gravel
23-33	Sand, light-brown, very coarse; pea gravel
33-39	Sand, light-gray, coarse to very coarse; some pea gravel
39-52	Sand, brown, very coarse; some pea gravel
52-59	Sand, light-gray, very coarse; pea gravel
59-62	Clay, bluish-gray, compact, (shale)

* * * *

Test Hole 4
Location: NW¼SE¼SE¼SW¼ sec. 32, T. 111 N., R. 79 W., (150 feet west of City Well No. 1)
Depth to water: 12 feet

0- 5	Sand, light-brown, fine
5- 9	Clay, blackish-brown
9-15	Sand, dark-brown, coarse to very coarse; much clay
15-19	Sand, dark-brown, coarse to very coarse; some pea gravel; some clay
19-24	Sand, light-brown, coarse to very coarse; some pea gravel
24-36	Sand, brownish-gray, very coarse; pea gravel
36-45	Sand, light-gray, very coarse; pea gravel; coal
45-50	Sand, dark-brown, medium to coarse; some pea gravel
50-61	Sand, light-gray, very coarse; pea gravel
61-62	Clay, bluish-gray, compact, (shale)

* * * *

Test Hole 5
Location: NW¼SE¼SE¼SW¼ sec. 32, T. 111 N., R. 79 W., (100 feet northwest of City Well No. 1)
Depth to Water: 12 feet

0- 5	Sand, light-brown, very fine
5-10	Sand, brown, fine; clay
10-16	Sand, dark-brown, very coarse; some clay
16-33	Sand, dark-brown, very coarse; some pea gravel
33-42	Sand, light-brown, coarse to very coarse; some pea gravel
42-47	Sand, light-gray, very coarse
47-54	Sand, greenish-gray, fine to medium
54-55	Sand, light-greenish-gray, medium; some pea gravel
55-63	Sand, light-gray, very coarse; gravel
63-65	Clay, bluish-gray, compact, (shale)

* * * *

Test Hole 6
Location: NW¼SE¼SE¼SW¼ sec. 32, T. 111 N., R. 79 W., (41 feet northwest of City Well No. 1)
Depth to water: 13 feet

0- 4	Sand, brown, very fine; silt
4-15	Sand, brown, very fine; some clay
15-19	Sand, light-brown, coarse
19-29	Sand, light-brown, coarse; some pea gravel
29-42	Sand, light-brown, medium to coarse
42-47	Sand, light-gray, very coarse; some coal
47-53	Sand, brown, very coarse
53-62	Clay, dark-gray; some gravel, (reworked shale)
62-	Rock, abandoned hole

* * * *

Test Hole 7
Location: NE¼NE¼NE¼NW¼ sec. 5, T. 110 N., R. 79 W., (140 feet south of City Well No. 4)
Depth to water: 12 feet

Test Hole 7 -- continued.

0- 7	Sand, brown, very fine
7-10	Sand, dark-brown, medium; some clay
10-14	Sand, brown, coarse; some clay
14-21	Sand, brown, coarse, well sorted
21-25	Sand, dark-brown, very coarse
25-30	Sand, dark-brown, very coarse; some pea gravel
30-35	Sand, gray, fine to medium
35-40	Sand, gray, coarse
40-43	Sand, brown, medium
43-54	Sand, dark-grayish-brown, very coarse; some pea gravel; some clay
54-56	Sand, grayish-brown, very coarse; some gravel; coal pebbles
56-60	Clay, dark-gray; some gravel intermixed, (reworked shale)
60-61	Clay, bluish-gray, compact, (shale)

* * * *

Test Hole 8
Location: SW¼SW¼NW¼NE¼ sec. 5, T. 110 N., R. 79 W., (200 feet southwest of intersection of Henry street and Missouri Avenue)
Depth to water: 8 feet

0- 3	Clay, brown; some gravel
3-13	Clay, brown; sand, fine to medium
13-18	Sand, dark-brown, coarse; much clay
18-19	Clay, brown
19-33	Sand, blackish-brown, coarse; some clay
33-34	Sand, dark-brown, medium to coarse; some clay
34-41	Sand, brown, coarse
41-42	Sand, greenish-gray, fine
42-45	Sand, brown, coarse
45-54	Sand, dark-brown, coarse; some pea gravel
54-58	Clay, bluish-green, compact, (shale)

* * * *

Test Hole 9
Location: NE¼NW¼SE¼NE¼ sec. 5, T. 110 N., R. 79 W., (In alley SE of Coteau Street and SW of Dakota Avenue)
Depth to water: 11 feet

0- 5	Clay, dark-brown; sand, very fine
5- 7	Clay, light-brown
7-17	Sand, light-brown, medium to coarse; some clay
17-23	Sand, dark-brown, coarse to very coarse; coal pebbles
23-30	Sand, dark-brown, medium to coarse
30-38	Sand, dark-brown, coarse to very coarse; coal pebbles; some clay
38-41	Sand, grayish-green, medium to coarse
41-47	Sand, blackish-gray, medium to coarse
47-48	Sand, grayish-green, medium to coarse
48-54	Sand, grayish-brown, coarse to very coarse
54-57	Sand, grayish-brown, coarse to very coarse; many coal pebbles
57-61	Sand, grayish-brown, very coarse; pea gravel; clay
61-62	Clay, bluish-gray, compact, (shale)

* * * *

Test Hole 10
Location: NW¼NW¼SW¼NW¼ sec. 4, T. 110 N., R. 79 W., (In alley SE of Pawnee Street and SW of Sioux Avenue)
Depth to water: 11 feet

0- 3	Road bed
3- 5	Sand, light-brown, very fine
5-15	Clay, gray; sand, very fine
15-24	Clay, gray; fine sand
24-28	Sand, gray, very coarse; pea gravel; much clay
28-31	Sand, brown, very coarse
31-35	Sand, light-brown, coarse
35-37	Sand, blackish-gray, fine to medium
37-40	Clay, gray, compact, (shale?)

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Test Hole 11
Location: SE¼NW¼SW¼NW¼ sec. 4, T. 110 N., R. 79 W., (In alley SE of Brule Street and SW of Sioux Avenue)
Depth to water: 11 feet

0- 3	Sand, brown, medium; silt
3- 9	Clay, light-brown; sand, very fine
9-12	Clay, brown
12-18	Sand, light-brown, very fine; clay
18-29	Sand, light-brown, fine to medium; some clay
29-44	Sand, blackish-gray, fine to medium; some clay
44-54	Sand, brown, medium to coarse; clay
54-70	Sand, brown, medium to coarse; some gravel
70-74	Clay, blackish-gray, compact, (shale)

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Test Hole 12
Location: NW¼SW¼SW¼NW¼ sec. 4, T. 110 N., R. 79 W., (In alley SE of Brule Street and SW of Dakota Avenue)
Depth to water: 12 feet

0- 2	Road bed
2- 5	Clay, brown; sand, fine; silt
5- 8	Clay, light-brown; sand, fine
8-15	Sand, light-brown, coarse; some clay
15-19	Sand, light-brown, very coarse; some clay
19-27	Sand, brown, very coarse, sorted; pea gravel
27-33	Sand, blackish-gray, coarse
33-35	Sand, dark-brown, coarse
35-44	Sand, blackish-gray, fine to medium
44-49	Sand, blackish-gray, fine to coarse; coal pebbles; some clay
49-59	Clay, bluish-gray; some sand, coarse, and gravel intermixed
59-63	Sand, brown, very coarse; some gravel
63-64	Clay, bluish-gray, compact, (shale)

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Test Hole 13
Location: SW¼SE¼SW¼NW¼ sec. 4, T. 110 N., R. 79 W., (NE corner of intersection of Crow Street and Dakota Avenue)
Depth to water: 13 feet

0- 5	Clay, brown
5-11	Clay, light-brown
11-17	Clay, light-brown; sand, very fine
17-21	Clay, light-brown; sand, coarse
21-29	Sand, brown, medium; coal pebbles; some clay
29-36	Clay, brownish-gray; some gravel
36-44	Clay, bluish-gray
44-55	Clay, bluish-gray; sand, very fine
55-58	Sand, dark-gray, medium; much clay
58-60	Sand, brownish-gray, medium; much clay; some pea gravel
60-64	Sand, brown, very coarse; gravel
64-70	Clay, bluish-gray, compact, (shale)

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Test Hole 14
Location: SE¼NE¼NW¼SW¼ sec. 4, T. 110 N., R. 79 W., (100 feet west of Griffin Park Baseball Field)
Depth to water: 9 feet

0- 6	Sand, light-brown, fine; clay
6- 9	Sand, brown, fine to medium
9-18	Sand, brown, medium to coarse
18-26	Sand, blackish-brown, medium to coarse
26-29	Sand, brown, coarse to very coarse; some pea gravel
29-31	Sand, brown, very coarse; some gravel; some clay
31-34	Sand, brown, coarse to very coarse; some pea gravel
34-36	Sand, gray, medium
36-44	Clay, bluish-gray; some gravel
44-52	Clay, gray
52-56	Clay, bluish-gray
56-64	Clay, gray; sand, fine to medium
64-66	Clay, bluish-gray, pebbly, (reworked shale)
66-72	Clay, bluish-gray, compact, (shale)

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Test Hole 15
Location: NW¼NE¼SE¼SE¼ sec. 4, T. 110 N., R. 79 W., (South end of Harrison Avenue)
Depth to water: 8 feet

0- 5	Sand, light-brown, very fine
5- 6	Sand, brown, fine
6- 9	Sand, brown, fine; clay
9-13	Sand, light-brown, medium to coarse; some clay
13-15	Clay, gray; sand, fine to medium
15-25	Clay, bluish-gray
25-42	Clay, gray; some sand, fine
42-45	Sand, blackish-gray, fine to medium; some clay
45-50	Sand, blackish-gray, medium to coarse; some clay
50-53	Sand, blackish-gray, medium to coarse; some clay; coal
53-57	Sand, brown, very coarse; some pea gravel

Test Hole 15 -- continued.

57-61	Sand, brown, very coarse; gravel
61-62	Clay, bluish-gray, compact, (shale)

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Test Hole 16
Location: SE¼SW¼NW¼SW¼ sec. 3, T. 110 N., R. 79 W., (In alley SE of Tyler Avenue and SW of Dakota Avenue)
Depth to water: 12 feet

0- 7	Clay, brown
7-41	Clay, light-brown; sand, fine
41-69	Clay, bluish-gray
69-73	Sand, brown, coarse to very coarse
73-76	Clay, brown; some gravel
76-80	Clay, bluish-gray, compact, (shale)

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Test Hole 17
Location: SW¼SE¼SW¼SW¼ sec. 3, T. 110 N., R. 79 W., (South end of Taylor Avenue)
Depth to water: 9 feet

0- 6	Sand, light-brown, very fine; some clay
6-13	Sand, light-brown, fine
13-17	Sand, brown, medium; clay
17-24	Sand, brown, very coarse
24-34	Sand, brown, very coarse; some pea gravel; coal
34-39	Sand, brown, very coarse
39-44	Sand, gray, fine to coarse; some clay
44-54	Sand, gray, very fine; much clay
54-61	Sand, brown, very coarse; large gravel
61-64	Clay, bluish-gray, compact, (shale)

* * * *

Test Hole 18
Location: NW¼SE¼SE¼NW¼ sec. 5, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 10 feet

0- 9	Sand, light-brown, fine
9-13	Sand, gray, very coarse; some clay
13-21	Sand, brown, very coarse; coal pebbles; pea gravel; some clay
21-24	Sand, dark-brown, very coarse; pea gravel; coal pebbles
24-26	Sand, grayish-brown, medium to coarse; some clay
26-27	Clay, grayish-brown; sand, fine
27-30	Sand, grayish-brown, medium to coarse; some clay
30-33	Sand, dark-grayish-brown, very coarse; pea gravel; some clay
33-42	Sand, light-brown, fine to medium
42-49	Sand, grayish-brown, coarse to very coarse; some clay
49-52	Sand, dark-brown, very coarse; pea gravel; some clay
52-58	Sand, blackish-gray, medium to coarse; coal pebbles
58-64	Clay, bluish-gray, compact, (shale)

* * * *

Test Hole 19
Location: SW¼SE¼NE¼SW¼ sec. 5, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 11 feet

0- 5	Sand, light-brown, fine
5-10	Sand, light-brown, fine; some clay
10-20	Sand, dark-brown, medium to coarse
20-27	Sand, dark-gray, fine
27-42	Sand, dark-gray, very coarse; some pea gravel; some clay
42-46	Sand, dark-gray, fine to medium
46-48	Clay, gray
48-55	Sand, gray, fine to medium
55-57	Clay, dark-gray
57-61	Sand, brown, coarse to very coarse; some pea gravel
61-62	Clay, bluish-gray, compact, (shale)

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Test Hole 20
Location: NE¼SE¼NE¼SW¼ sec. 5, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 9 feet

0- 4	Sand, light-brown, fine
4- 9	Sand, dark-brown, fine; clay
9-14	Sand, dark-brown, coarse; shale pebbles
14-25	Sand, dark-brown, coarse to very coarse; pea gravel
25-29	Sand, gray, fine to very coarse; some clay
29-34	Sand, gray, fine to coarse; clay
34-42	Sand, dark-gray, coarse to very coarse; some clay
42-47	Sand, light-gray, medium to coarse
47-51	Sand, blackish-gray, coarse; some coal
51-58	Sand, grayish-brown, very coarse; gravel
58-	Rock, abandoned hole

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Test Hole 21
Location: NW¼NW¼NW¼SE¼ sec. 5, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 7 feet

0- 6	Sand, light-brown, very fine to fine
6-10	Sand, brown, coarse to very coarse
10-17	Sand, brown, very coarse; some pea gravel
17-21	Sand, blackish-brown, very coarse
21-31	Sand, blackish-brown, medium to coarse
31-35	Sand, blackish-brown, very fine; much clay; some gravel
35-40	Clay, blackish-brown; coal pebbles
40-42	Clay, brown; sand, very coarse; some gravel
42-48	Sand, brown, coarse
48-52	Sand, dark-brown, medium to coarse
52-58	Sand, light-brown, very coarse; some pea gravel
58-60	Clay, bluish-gray, compact, (shale)

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Test Hole 22
Location: SW¼SW¼SW¼SE¼ sec. 5, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 8 feet

0- 8	Clay, brown; sand, very fine; silt
8-19	Sand, brown, coarse to very coarse; some pea gravel
19-25	Sand, gray, very coarse; some clay
25-33	Sand, light-brown, medium to coarse; some pea gravel; coal pebbles
33-37	Sand, light brown, very coarse; some clay
37-45	Sand, light-brown, very coarse; gravel; some clay
45-47	Sand, light-brown, very coarse; gravel; more clay
47-48	Clay, bluish-gray, compact, (shale)

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Test Hole 23
Location: SW¼NE¼NW¼SE¼ sec. 5, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 8 feet

0- 9	Clay, light-brown
9-15	Sand, dark-brown, coarse; some clay
15-20	Sand, blackish-brown, very coarse
20-24	Sand, blackish-brown, very coarse; organic material
24-31	Sand, blackish-brown, medium; organic material; some clay
31-44	Sand, blackish-brown, medium; some gravel; much clay
44-53	Sand, blackish-brown, very fine; clay
53-56	Sand, blackish-brown, very coarse; much clay
56-59	Clay, bluish-gray, pebbly, (reworked shale)
59-64	Clay, bluish-gray, compact, (shale)

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Test Hole 24
Location: SW¼SE¼NE¼SE¼ sec. 5, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 12 feet

0- 4	Sand, dark-brown, very fine to fine
4-12	Clay, brownish-gray
12-19	Sand, brownish-gray, very fine to medium
19-31	Sand, light-gray, medium to very coarse
31-41	Sand, light gray, very fine to medium; some clay
41-57	Sand, dark-brown, medium to very coarse
57-64	Clay, bluish-gray, compact, (shale)

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Test Hole 25
Location: SW¼SE¼SE¼SE¼ sec. 5, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 7 feet

0- 4	Sand, light-brown, very fine
4- 7	Sand, light-brown, very fine; clay
7-11	Sand, dark-brown, medium to coarse
11-15	Sand, brown, medium to very coarse
15-20	Sand, brown, medium to very coarse; some pea gravel
20-28	Sand, brown, medium to very coarse; some pea gravel; some clay
28-33	Sand, brown, medium to coarse; coal pebbles; some clay

Test Hole 25 -- continued.

33-38	Sand, brown, coarse to very coarse; some pea gravel; some clay
38-46	Sand, light-gray, coarse to very coarse
46-57	Sand, light-brown, very coarse; pea gravel
57-59	Sand, light-brown, very coarse; pea gravel; clay
59-60	Clay, bluish-gray, compact, (shale)

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Test Hole 26
Location: SE¼NW¼SW¼SW¼ sec. 4, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 10 feet

0- 3	Sand, light-brown, fine
3-20	Sand, dark-brown, coarse to very coarse; some pea gravel
20-25	Sand, dark-brown, fine to medium; some pea gravel; some clay
25-26	Gravel, dark-brown, fine; coal
26-34	Sand, dark-brown, medium
34-38	Sand, blackish-gray, very coarse; organic material
38-43	Sand, brown, fine to medium
43-46	Sand, blackish-gray, fine to medium; organic material
46-56	Sand, blackish-gray, very fine to fine
56-57	Sand, blackish-gray, medium to coarse
57-58	Sand, brown, very coarse; pea gravel
58-	Clay, bluish-gray, pebbly, (reworked shale), abandoned hole because of tightness

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Test Hole 27
Location: NW¼NE¼NE¼NW¼ sec. 9, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 9 feet

0- 1	Topsoil
1- 7	Sand, light-brown, very fine; silt
7- 9	Clay, brown; sand, fine silty
9-14	Sand, grayish-brown, coarse to very coarse
14-21	Sand, light-brown, medium to coarse
21-30	Sand, light-brown, coarse to very coarse; some clay
30-35	Sand, light-gray, coarse to very coarse
35-42	Sand, light-gray, coarse to very coarse; some gravel; some clay
42-47	Sand, light-gray, medium to coarse
47-52	Sand, light-brown, medium to coarse; pea gravel
52-61	Sand, light-brown, coarse to very coarse; medium to pea sized gravel
61-63	Sand, light-brown, coarse to very coarse; pea gravel; clay layers
63-66	Clay, bluish-green, compact, (shale)

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Test Hole 28
Location: NE¼SE¼SE¼NW¼ sec. 9, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 8 feet

0- 4	Sand, brown, fine
4-11	Sand, brown, fine; some clay

Test Hole 28 – continued.

11-13	Sand, brown, medium to coarse; some clay
13-20	Sand, gray, coarse; clay; coal
20-30	Sand, gray, coarse to very coarse; coal; some pea gravel
30-35	Sand, gray, medium to coarse
35-38	Sand, gray, medium to coarse; some pea gravel
38-54	Sand, gray, very coarse; pea gravel; (clay from 47-48)
54-55	Clay, dark-greenish-gray, compact, (shale)

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Test Hole 29
Location: NE¼NE¼SW¼NE¼ sec. 9, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 10 feet

0- 8	Sand, brown, very fine; some clay
8-14	Sand, brown, very fine to medium; some clay
14-20	Sand, brown, very coarse; pea gravel
20-25	Sand, blackish-gray, coarse to very coarse; coal with organic material
25-34	Sand, blackish-gray, coarse to very coarse
34-40	Sand, blackish-gray, medium to coarse; some pea gravel
40-47	Sand, brown, very coarse; pea gravel
47-50	Sand, gray, very coarse; some pea gravel; some clay
50-53	Sand, brown, very coarse; gravel
53-54	Clay, grayish-green, compact, pebbly, (reworked shale)

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Test Hole 30
Location: SE¼SE¼SW¼NE¼ sec. 9, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 8 feet

0- 5	Sand, light-brown, very fine
5-10	Sand, light-brown, fine; clay
10-30	Sand, dark-gray, very coarse; some clay
30-34	Clay, whitish-gray; gravelly
34-37	Sand, brown, very coarse; some gravel
37-53	Clay, bluish-gray, compact, (shale)

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Test Hole 31
Location: SW¼SE¼SE¼NE¼ sec. 9, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 6 feet

0- 9	Sand, brown, very fine; clay
9-14	Sand, brown, coarse to very coarse; some pea gravel
14-22	Sand, brown, fine to coarse; some pea gravel
22-33	Sand, brown, very coarse
33-35	Gravel, brown; sand, coarse to very coarse
35-56	Gravel, brown, medium to coarse; some clay
56-59	Sand, gray, medium to coarse; some clay
59-61	Sand, gray, coarse; gravel, medium
61-64	Clay, bluish-gray, compact, (shale)

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Test Hole 32
Location: NE¼NW¼NW¼SW¼ sec. 10, T. 110 N., R. 79 W., (Laframboise Island)
Depth to water: 7 feet

0- 3	Sand, light-brown, very fine
3- 6	Clay, light-brown; sand, very fine
6-16	Sand, brown, coarse to very coarse
16-23	Sand, brown, coarse to very coarse; some pea gravel
23-28	Sand, dark-brown, very coarse; coal pebbles
28-32	Sand, dark-brown, very coarse; pea gravel
32-51	Gravel, grayish-brown
51-55	Sand, dark-brown, coarse to very coarse
55-57	Clay, bluish-gray, pebbly, (reworked shale)
57-61	Clay, dark-bluish-gray, compact, (shale)

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