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DEPARTMENT OF ENVIRONMENT AND NATURAL RESOURCES
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DIVISION OF GEOLOGICAL SURVEY
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Open-File Report 49-UR

**GROUND-WATER STUDY FOR THE CITY OF
MADISON, SOUTH DAKOTA**

by

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INTRODUCTION

This report contains the results of a ground-water investigation conducted by the South Dakota Geological Survey (SDGS) for the city of Madison, Lake County, South Dakota (fig. 1). In 1981, the Madison City Council and the Industrial Development Committee asked the South Dakota Geological Survey to investigate the potential of the Howard aquifer to supply future industrial development and municipal water needs. Field work was conducted during the months of July, August, September, and October, 1982. The investigation included the drilling of 18 test holes (fig. 2, app. A), construction of 8 observation wells (fig. 2), collecting and analyzing 37 water samples (fig. 3, app. B), and conducting an aquifer test from March 23 to 26, 1982.

The investigation was funded by the South Dakota Geological Survey, the East Dakota Conservancy Sub-District, and the city of Madison.

Acknowledgements

William Heyer, City Engineer, and Dale Carlson, City Water and Waste Superintendent, were invaluable in providing extensive data on the municipal water system. Their assistance and cooperation throughout the course of the investigation was greatly appreciated.

Present Madison Water Supply

The city of Madison obtains its water from wells located near the municipal water treatment facility (fig. 2). Municipal wells 1, 3, 8, and 9 produce water from the Northern Skunk Creek management unit of the Big Sioux aquifer, a shallow aquifer located near the land surface. Municipal wells 10 and 11 produce water from the Howard aquifer, a confined buried aquifer located at an approximate depth of 220 feet below land surface. The quality of water from all the municipal wells is presented in table 1. High iron, manganese, sulfate, and dissolved-solids concentrations are found in water from the Northern Skunk Creek management unit and high sulfate, dissolved-solids, and hardness concentrations are found in water from the Howard aquifer.

HYDROGEOLOGIC SETTING

The study area is underlain by Quaternary drift (Tipton, 1959; Tomhave, 1987). The drift is directly underlain by bedrock, either Cretaceous Pierre Shale or Niobrara Formation.

Drift is composed of till and outwash, both of which are present in the study area. Till, consists of a heterogeneous mixture of boulders, gravel, sand, clay, and silt. The till matrix is composed predominantly of clay and silt. Outwash consists primarily of sand and gravel that has been washed, sorted, and deposited by flowing glacial meltwater. Varying amounts of less permeable material, silt and clay, are found dispersed throughout the outwash matrix. Two particular outwash units, the Northern Skunk Creek management unit of the Big Sioux aquifer and the Howard aquifer, provide water for the city of Madison.

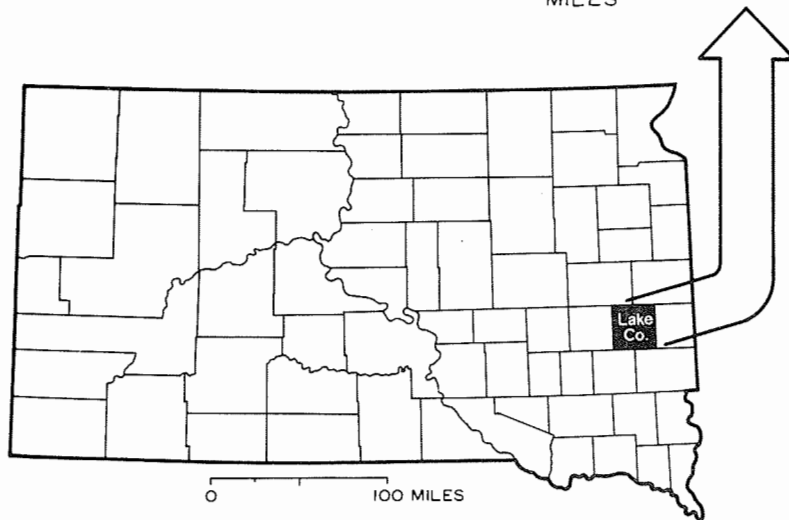
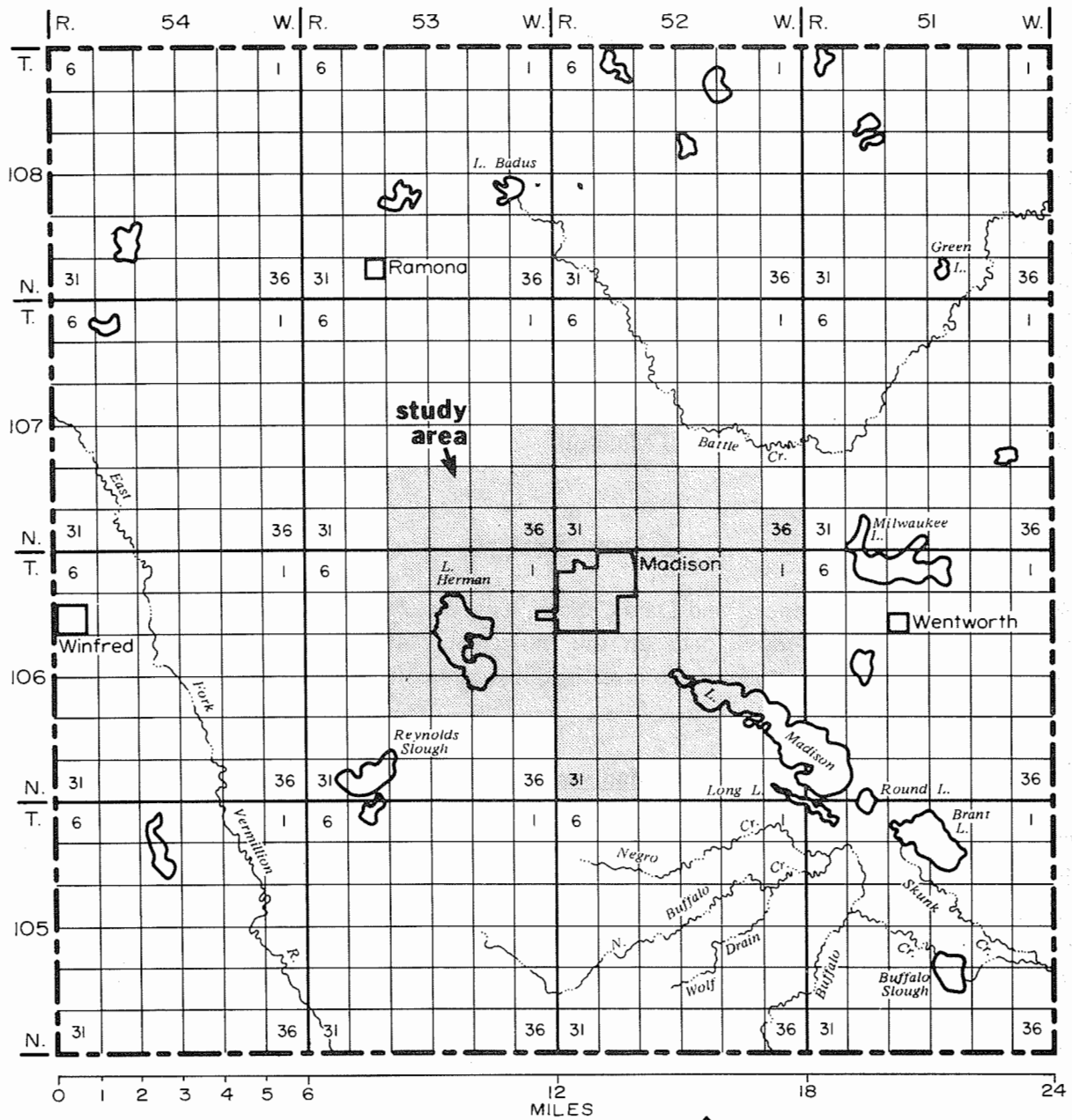
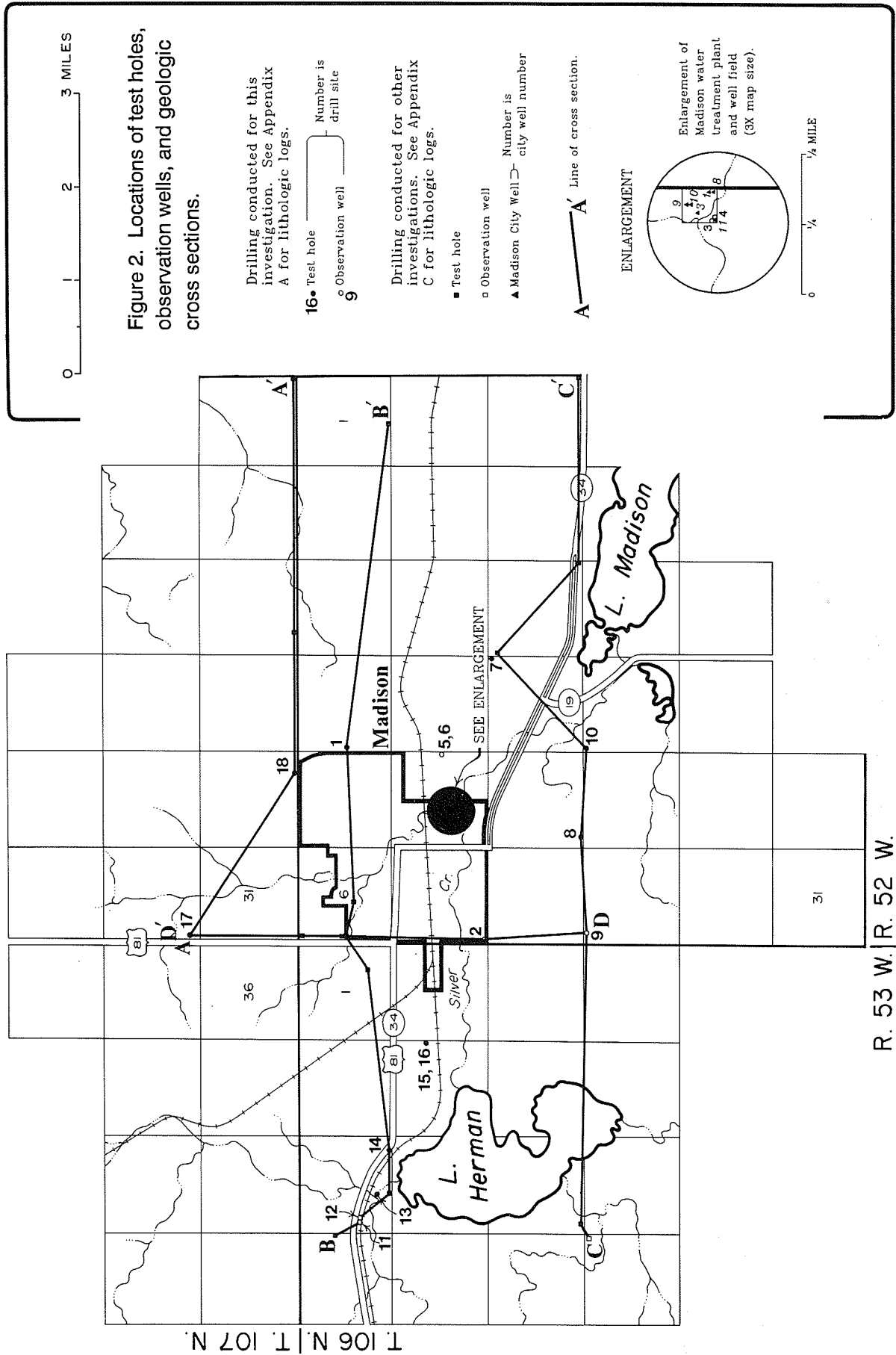


Figure 1.
Location of
study area.



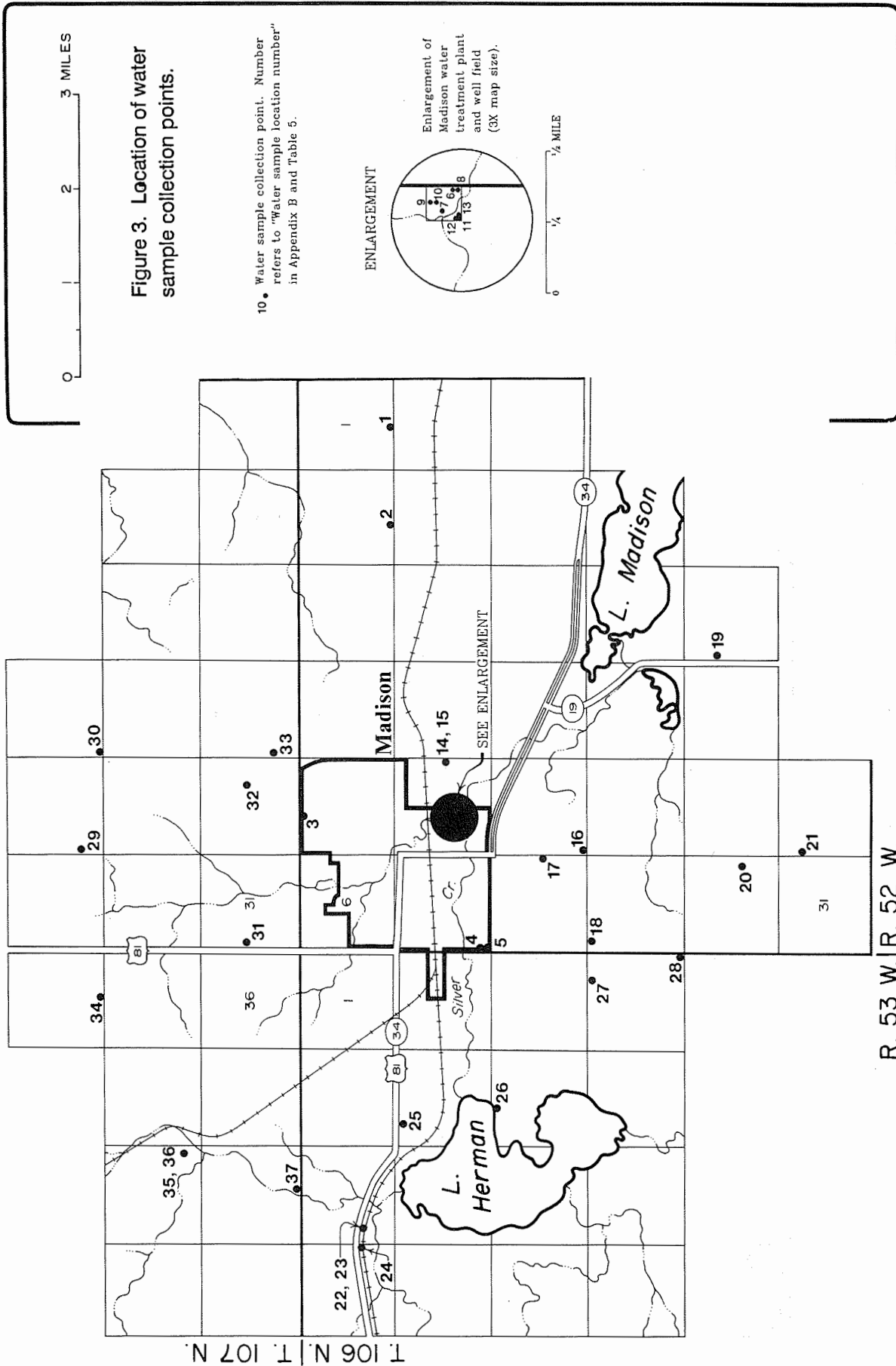
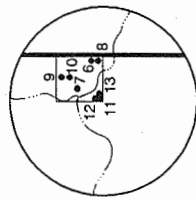


Figure 3. Location of water sample collection points.

10. Water sample collection point. Number refers to "Water sample location number" in Appendix B and Table 5.

ENLARGEMENT



Enlargement of Madison water treatment plant and well field (3X map size).

0 1/4 1/2 MILE

T. 106 N. | T. 107 N.

R. 53 W. | R. 52 W.

TABLE 1. Chemical analyses of water from Madison municipal wells

City Well No.	Aquifer ²	Well depth (ft)	Conduc-tivity (mmhos) ³	Concentrations in milligrams per liter ¹												
				DS	Hard-ness as CaCO ₃	Fe	Mn	SO ₄	NO ₃ -N	Na	Ca	Mg	Cl	F		
--	---	-----	-----	500 ⁴	-----	0.3 ⁴	0.05 ⁴	250 ⁴	10 ⁵	--	--	--	250 ⁴	2.4 ⁵		
1	NSC	34	1730	1240	798	1.26	1.87	538	<0.10	108	207	68.7	176.0	0.14		
3	NSC	47	2474	1510	693	0.69	2.04	378	<0.10	299	172	64.3	770.0	0.20		
8	NSC	35	2375	2030	1537	2.21	5.35	1060	<0.10	105	475	86.1	154.0	0.09		
9	NSC	51	1710	1330	865	0.65	1.71	610	<0.10	114	211	82.7	172.0	0.25		
NSC Averages ...			2072	1528	973	1.20	2.74	647	...	157	266	75.5	318.0	0.17		
10	HO	257	1860	1400	1231	<0.05	0.42	1100	<0.10	126	296	120.2	20.0	0.60		
11	HO	254	1780	1640	989	0.02	0.33	930	<0.10	94	242	94.1	13.2	0.69		
HO Averages ...			1820	1520	1110	...	0.38	1015	...	110	269	107.2	16.6	0.65		
Treated water supply ⁶			---	---	1581	1156	582	0.23	<0.02	578	<0.10	105	118	69.9	124.0	1.68

¹ DS - dissolved solids; Fe - iron; Mn - manganese; SO₄ - sulfate; NO₃-N - nitrate nitrogen; Na - sodium; Ca - calcium; Mg - magnesium; Cl - chloride; F - fluoride.

² The abbreviation represents the aquifer from which the sample was collected:
 NSC - Northern Skunk Creek management unit of the Big Sioux aquifer
 HO - Howard aquifer

³ mmhos - micromhos.

⁴ U.S. Environmental Protection Agency national secondary drinking water regulations (U.S. Environmental Protection Agency, 1985b).

⁵ U.S. Environmental Protection Agency national interim primary drinking water regulations (U.S. Environmental Protection Agency, 1985a).

⁶ "Treated water supply" is a composite sample consisting of water from city wells 3, 8, 9, 10 and 11. Analysis date: April 21, 1982. South Dakota Public Water System Data, 1983, Office of Drinking Water, South Dakota Department of Environment and Natural Resources.

See appendix B for other water sample information.

The bedrock formations in the Madison area are represented by Cretaceous sedimentary rocks and the Precambrian Sioux Quartzite. If all commonly encountered bedrock units in the study area were present at one location, they would be encountered in descending order (from youngest to oldest) as follows: Cretaceous Pierre Shale, Niobrara Formation, Carlile Shale, Greenhorn Limestone, Graneros Shale, and Dakota Formation followed by weathered quartzite and Precambrian Sioux Quartzite.

RESULTS OF INVESTIGATION

Northern Skunk Creek Management Unit

The Northern Skunk Creek management unit of the Big Sioux aquifer is the major surficial aquifer in the Madison area. Prior investigations by Tipton (1959), Adolphson and Ellis (1964), and Ellis and Adolphson (1969), describe the aquifer to consist of poorly-sorted, sandy gravel with varied amounts of fine sand, silt, and clay (outwash). The outwash was deposited in two channels (fig. 4): the main outwash channel extends eastward from Lake Herman and passes through the southern half of Madison; a minor channel originates northwest of Madison and passes southeasterly through the city, joining the main channel near the central sector of the city. From the confluence of the outwash channels, the outwash body trends southeasterly through Lake Madison (Tipton, 1959).

Since the main emphasis of the study was to explore the potential of the Howard aquifer, drilling in the Northern Skunk Creek management unit consisted of only four test holes, (drill sites 13, 14, 15, and 16; fig. 2 and app. A), and one observation well (drill site 5; fig. 2 and app. A). Five other observation wells penetrated this aquifer (drill sites 3, 4, 6, 11, and 12) but were screened in the deeper Howard aquifer and they are discussed later in this report. Water-quality data were collected from an observation well, municipal wells and private wells and are represented by water samples 4, 6, 7, 8, 9, 14, and 24 (app. B).

Water samples collected from the Northern Skunk Creek management unit for this investigation have an average hardness concentration of 932 milligrams per liter (mg/L), and average concentrations of iron, 2.57 mg/L; manganese, 2.24 mg/L; and sulfate, 627 mg/L (table 2, app. B). Iron, manganese, sulfate, and dissolved-solids concentrations exceed the recommended limits set by the U.S. Environmental Protection Agency (1985b).

Pleistocene Series Aquifers

Pleistocene Series aquifers consist of outwash deposits that are not interpreted to be part of the Northern Skunk Creek management unit or the Howard aquifer. The outwash consists of lenses of varying thickness of fine sand to fine-pebble gravel. Chemical analyses of water classified under this heading (water samples 19, 23, 27, 28, 29, and 35, app. B) do not indicate a uniformity in water type because the outwash bodies are individual isolated units. Pleistocene Series aquifers account for only a minor fraction of the water resources in the Madison area since the isolated outwash bodies are only capable of supplying sufficient water for domestic and stock usage.

TABLE 2. Comparison of water quality between nonbedrock and bedrock aquifers

		Concentrations in milligrams per liter ¹												
Aquifer ²	Number of samples ³	Average well depth (ft)	Conductivity (mmhos) ⁴	DS	Hardness as CaCO ₃	Fe	Mn	SO ₄	NO ₃ -N	Na	Ca	Mg	Cl	F
---	----	-----	-----	500 ⁵	-----	0.3 ⁵	0.05 ⁵	250 ⁵	10 ⁶	----	----	----	250 ⁵	2.4 ⁶
NSC	7	49	1940	1447	932	2.57	2.24	627	...	133	246	77.6	187.4	0.28
HO	20	210	2069	1654	1107	...	...	1025	...	127	283	97.8	14.1	...
Kcc	2	628	2917	2195	540	...	0.12	1130	0.90	498	146	42.9	62.0	1.30
Kd	1	1100	3026	2210	299	4.75	0.33	1240	<0.10	612	56	38.9	43.0	0.33

¹ DS - dissolved solids; Fe - iron; Mn - manganese; SO₄ - sulfate; NO₃-N - nitrate nitrogen; Na - sodium; Mg - magnesium; Cl - chloride; F - fluoride.

² The abbreviation represents the aquifer.

Non-bedrock aquifers:

NSC - Northern Skunk Creek management unit of the Big Sioux aquifer

HO - Howard aquifer

Bedrock aquifers:

Kcc - Codell Sandstone Member of the Carlile Shale

Kd - Dakota Formation

³ This is the number of chemical analyses used to calculate average values for well depth, conductivity, and the various chemical parameters. See appendix B for individual analyses.

⁴ mmhos - micromhos.

⁵ U.S. Environmental Protection Agency national secondary drinking water regulations (U.S. Environmental Protection Agency, 1985b).

⁶ U.S. Environmental Protection Agency national interim primary drinking water regulations (U.S. Environmental Protection Agency, 1985a).

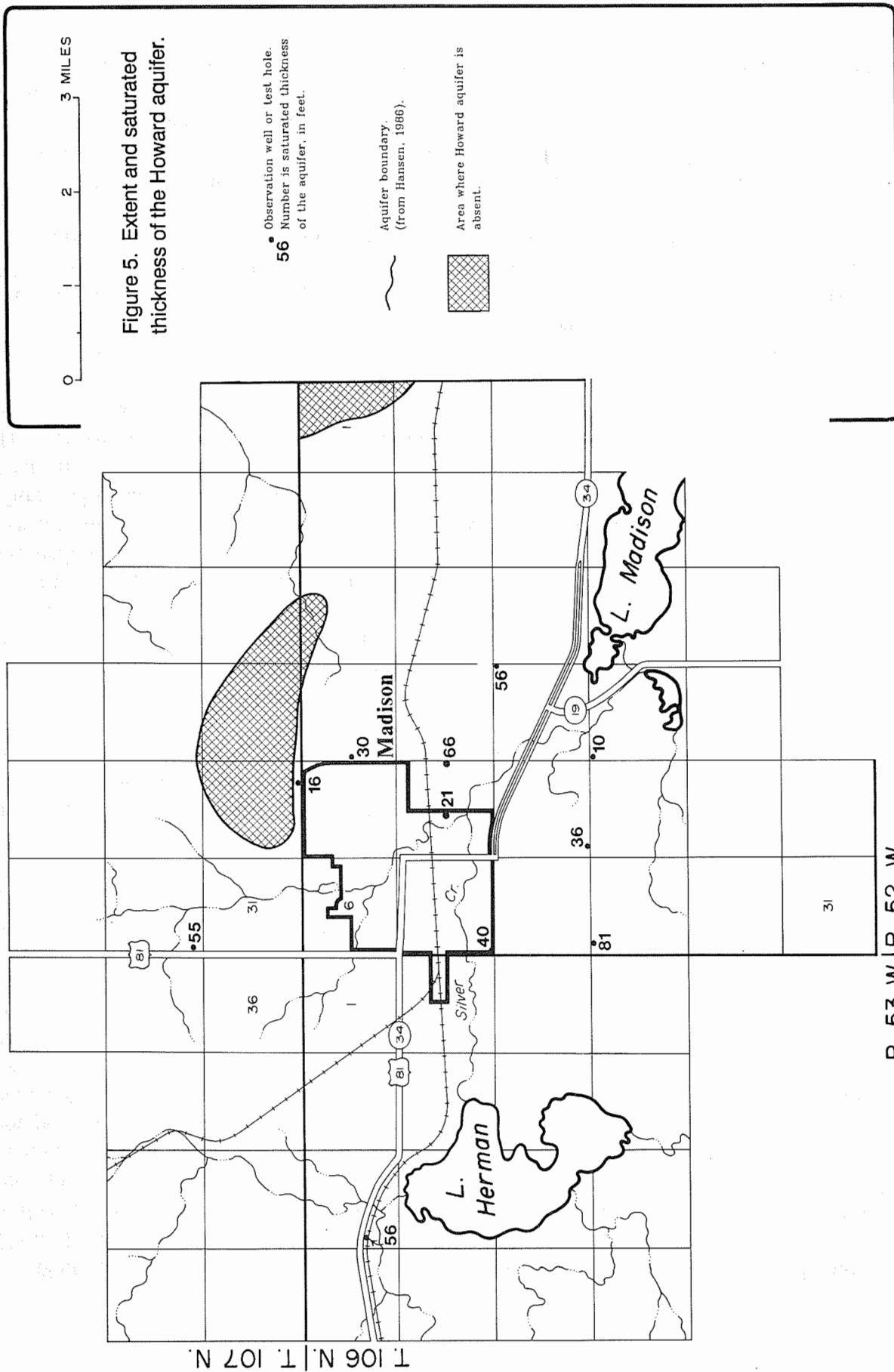
Howard Aquifer

Water from the Howard aquifer is used by the city of Madison to supplement the city supply. The Howard aquifer is a confined basal aquifer that underlies much of the study area (fig. 5) and ranges in thickness from 10 feet (drill site 10) to 81 feet (drill site 9). In the immediate vicinity of Madison the aquifer is composed of white, well-rounded, fine sand to fine-pebble gravel (drill sites 1, 2, 3, 4, 6, 7, 8, 9, and 10; fig. 2) while in the northern and western fringe of the study area the aquifer is composed of white to brown, medium to coarse sand (drill sites 11, 17, and 18; fig. 2). The white sand is thought to be derived from a river whose course ran from the western part of the state toward the east during Quaternary time. Sometime after the sediments were deposited, glacial meltwaters retransported and redeposited the "western-derived" sand as well as incorporated outwash sediments (drill sites 1, 2, 3, 4, 6, 7, 8, 9, and 10).

The depth to water in observation wells installed in the Howard aquifer for this investigation, was measured on eight occasions (table 3). When this information is plotted on figure 6, it becomes evident that more data are needed in order to describe adequately the potentiometric surface of the Howard aquifer in the study area. An observation well at drill site 11 shows an anomalous water level elevation and according to the lithologic log, this well is installed in the Howard aquifer. Water-level and chemistry data, however, suggest that the well is reflective of conditions in the underlying Niobrara Formation. Consequently, additional data are needed to better understand and describe the hydrogeology of this area.

The dominant chemical constituents of the Howard aquifer are sulfate and calcium. Average hardness for the aquifer is 1,107 mg/L (table 2) and dissolved-solids concentrations range from 964 mg/L to 2,640 mg/L (water samples 5 and 33; fig. 3 and app. B). Generally, iron concentrations are relatively low, however, several private wells (app. B) have concentrations well above the Environmental Protection Agency (EPA) recommended limit of 0.3 mg/L (U.S. Environmental Protection Agency, 1985b) and with one exception (water sample 17), manganese concentrations are elevated and above the EPA regulation of 0.05 mg/L (U.S. Environmental Protection Agency, 1985b). Nitrate-nitrogen concentrations are well below the EPA limit of 10 mg/L (U.S. Environmental Protection Agency, 1985a). Table 4 shows a chemical analyses of water from the Howard aquifer. This sample was collected from municipal well 11 and sent to the State Health Laboratory in Pierre, South Dakota, for chemical analyses.

Water quality in the Howard aquifer may be influenced by the occurrence of Cretaceous bedrock directly underlying the aquifer (figs. 7, 8, and 9). Table 5 shows a comparison of water quality within the Howard aquifer where the aquifer is underlain by the Pierre Shale or where it is underlain by the Niobrara Formation. Information in table 5 suggests that the areas where the Pierre Shale underlies the Howard aquifer have generally better water quality than where the Howard aquifer is underlain by the Niobrara Formation. It may be that the Pierre Shale acts as a confining layer or barrier to the movement of water from the Niobrara Formation into the Howard aquifer. However, the anomalous water level on figure 6, which has previously been attributed to the Niobrara Formation, would indicate a potential for water movement from the Howard to the Niobrara when compared to other water levels from the Howard aquifer. In either case, more data are needed in order to understand the hydraulic relationships between the Howard aquifer and the underlying Cretaceous sediments.



R. 53 W. | R. 52 W.

TABLE 3. Water levels in Howard aquifer observation wells

Drill Site	Location ²	Well Name	Casing Top Elevation ³	Depth to water and date of measurement ⁴							
				07-23-81	07-24-81	03-23-82	04-01-82	04-06-82	06-03-82	07-28-82	08-05-82
2	106N-52W-07C000	MD-81-01	1685.54 I	----	----	106.22	107.20	108.95	108.06	109.22	109.92
3	106N-52W-08CADB 1	MD-81-14	1657.01 I	----	----	81.20	82.25	81.77	80.74	82.21	82.96
4	106N-52W-08CADB 2	MD-81-16	1657.00 I	----	----	81.28	82.41	81.68	80.65	82.23	82.95
6	106N-52W-08DAAA 2	MD-81-08	1656.39 I	82.60	----	80.30	80.42	80.71	80.12	80.67	80.74
9	106N-52W-19BBBA	MD-81-02	1713.56 I	----	149.00	135.63	136.20	136.16	135.27	136.25	136.67
11	106N-53W-03CBCA	R1-82-88	1695 T	----	----	----	----	----	----	181.34	181.44
	106N-52W-08CAAA	City No. 10	1660 T	----	----	83.33	84.45	----	----	----	----
	106N-52W-08CADB	City No. 11	1656 T	----	----	80.00	81.10	80.62	----	----	----

¹ Drill Site - corresponds to number on figure 2 and in appendix A.

² See appendix A for explanation of location format.

³ Presented in feet above mean sea level; T = the estimated ground-surface elevation from a topographic map plus the length of casing extending above ground surface; I = elevation surveyed with instrument; see lithologic logs in appendix A. **Note:** the casing extending above ground surface at Drill Site 11 is unknown, therefore, the ground-surface elevation was used for this table.

⁴ All water levels are presented in feet below top of casing.

T. 106 N. | T. 107 N.

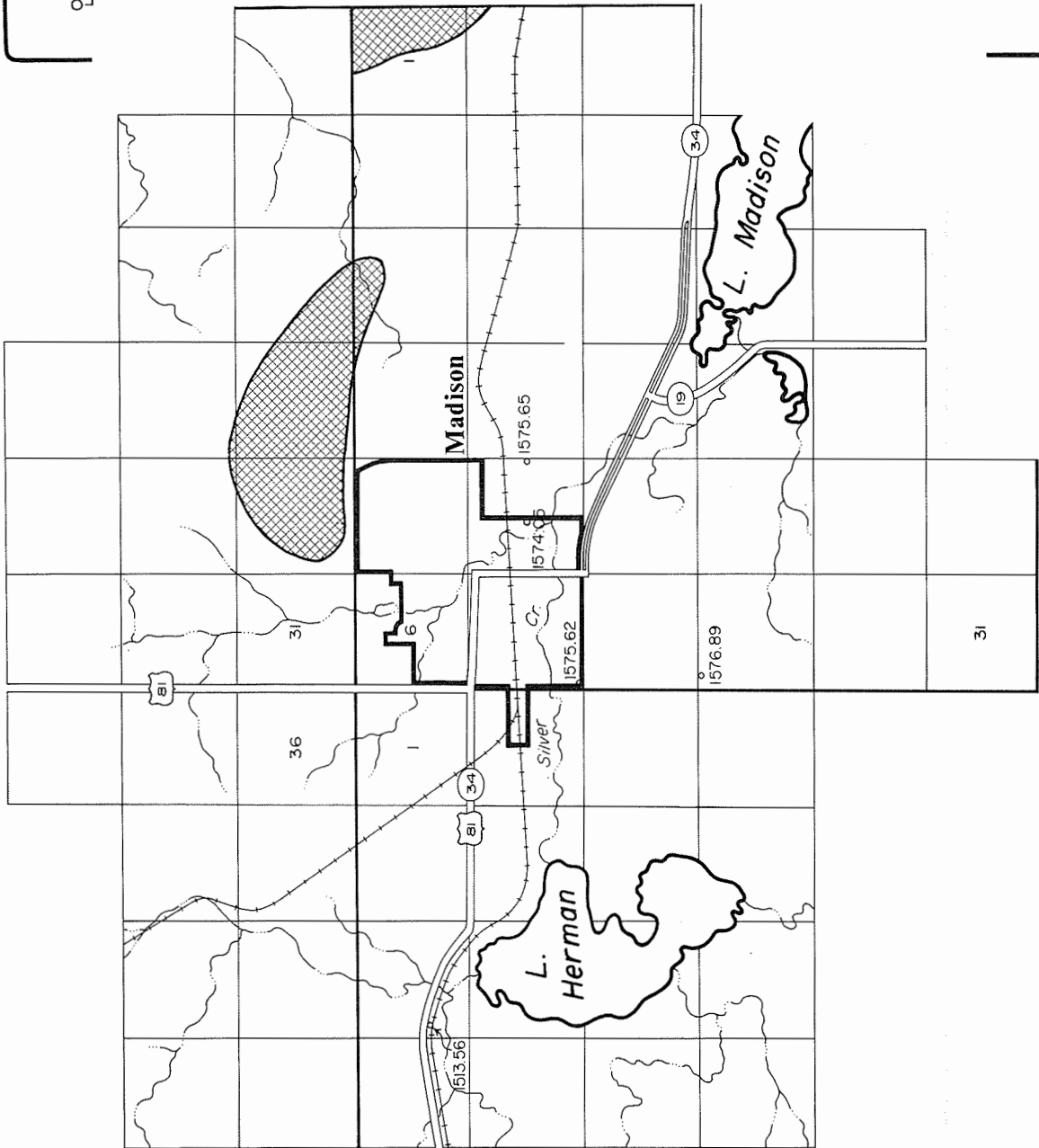


Figure 6. Water-level elevations in the Howard aquifer on August 5, 1982.

Observation well. Number indicates elevation of water in the well, in feet. See Table 3 for water-level measurement.

Aquifer boundary. (from Hansen, 1986).

Area where Howard aquifer is absent.

R. 53 W. | R. 52 W.

TABLE 4. Chemical analyses of water from the Howard aquifer
(Municipal well 11, April 30, 1982, see fig. 2)

Analyzed by the State Health Laboratory and financed by the Office of Drinking Water, South Dakota Department of Environment and Natural Resources.

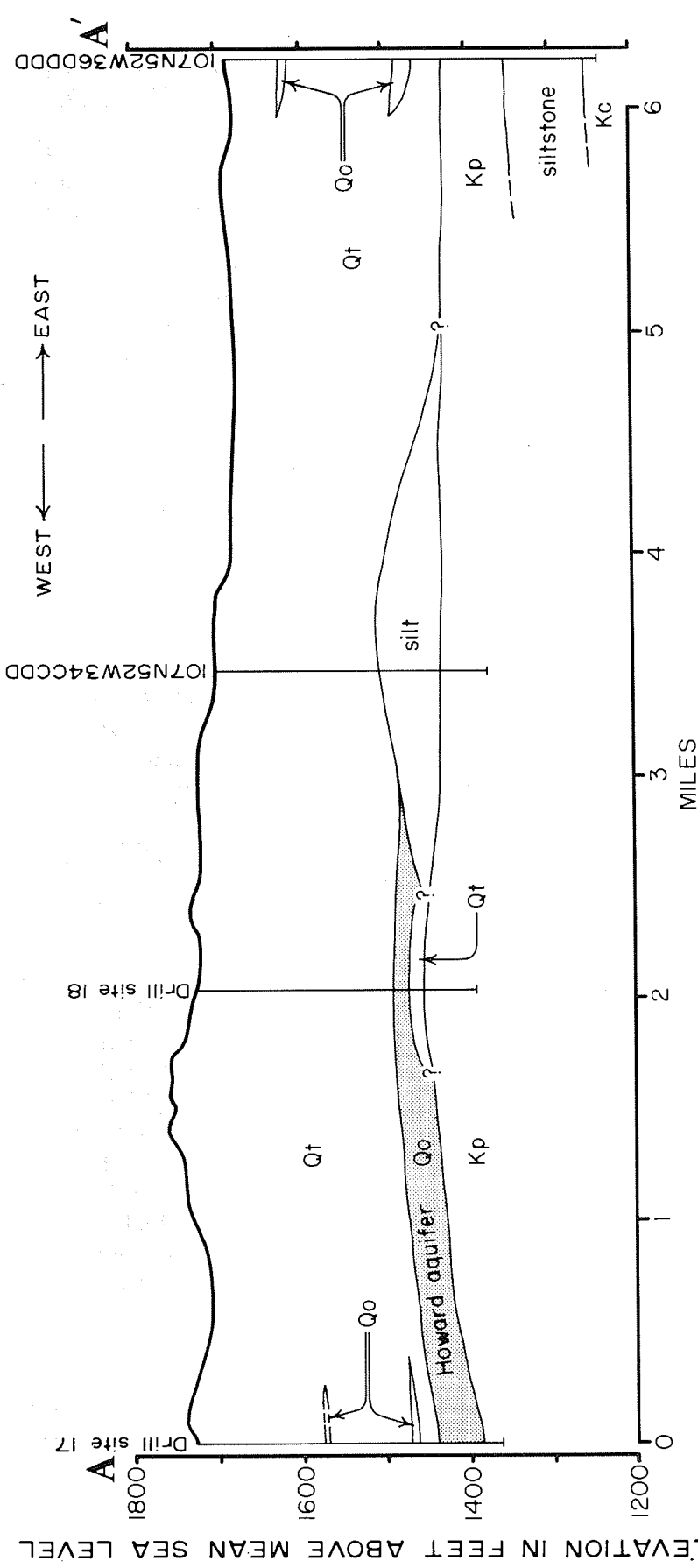
<u>PARAMETER</u>	<u>MAXIMUM LIMIT</u> ¹	<u>RESULTS</u>
Arsenic	50 ug/L	7.8
Barium	1000 ug/L	14
Cadmium	10 ug/L	<1.0
Chromium	50 ug/L	<1.0
Lead	50 ug/L	<1.0
Mercury	2 ug/L	<0.20
Nitrate (as N)	10 mg/L	0.7
Selenium	10 ug/L	2.9
Silver	50 ug/L	<1.0
Fluoride	2.4 mg/L	0.60
Gross alpha	15 pCi/L	19.4 ± 5.7

* * * * *

<u>PARAMETER</u>	<u>SUGGESTED LIMIT</u> ²	<u>RESULTS</u>
Chloride (Cl)	250 mg/L	9.5
Copper (Cu)	1 mg/L	0.007
Iron (Fe)	0.3 mg/L	0.04
Manganese (Mn)	0.05 mg/L	0.44
Sulfate (SO ₄)	250 mg/L	835
Zinc (Zn)	5 mg/L	0.010
Dissolved Solids (DS)	500 mg/L	1598
pH	6.5-8.5	7.42
Alkalinity (T) (CaCO ₃)	--- mg/L	269
Alkalinity (P) (CaCO ₃)	--- mg/L	0
Bicarbonate (HCO ₃)	--- mg/L	328
Carbonate (CO ₃)	--- mg/L	0
Spec. Conductivity	25°C mmhos/cm	1924
Calcium (Ca)	--- mg/L	247
Magnesium (Mg)	--- mg/L	88.7
Hardness (CaCO ₃)	--- mg/L	982
Sodium (Na)	--- mg/L	83.1
Potassium (K)	--- mg/L	20.0

mg/L = milligrams per liter = parts per million (ppm)
 ug/L = micrograms per liter = parts per billion (ppb)
 pCi/L = picocuries per liter

¹ U.S. Environmental Protection Agency recommended maximum limit (U.S. Environmental Protection Agency, 1985b).
² U.S. Environmental Protection Agency enforceable maximum limit (U.S. Environmental Protection Agency, 1985a).



See figure 2 for location of cross section.

Vertical exaggeration = 20X.

- Quaternary { Qt Glacial till (primarily clay and silt)
- { Qo Glacial sand and gravel
- Cretaceous { Kp Pierre Shale
- { Kc Carlile Shale

--- Lithologic contact. Dashed where approximate.

⊥ A question mark (?) indicates that lateral extent is uncertain.

⊥ For explanation of drill-site number and location format see Appendix A.

Figure 7. Geologic cross section A - A'.

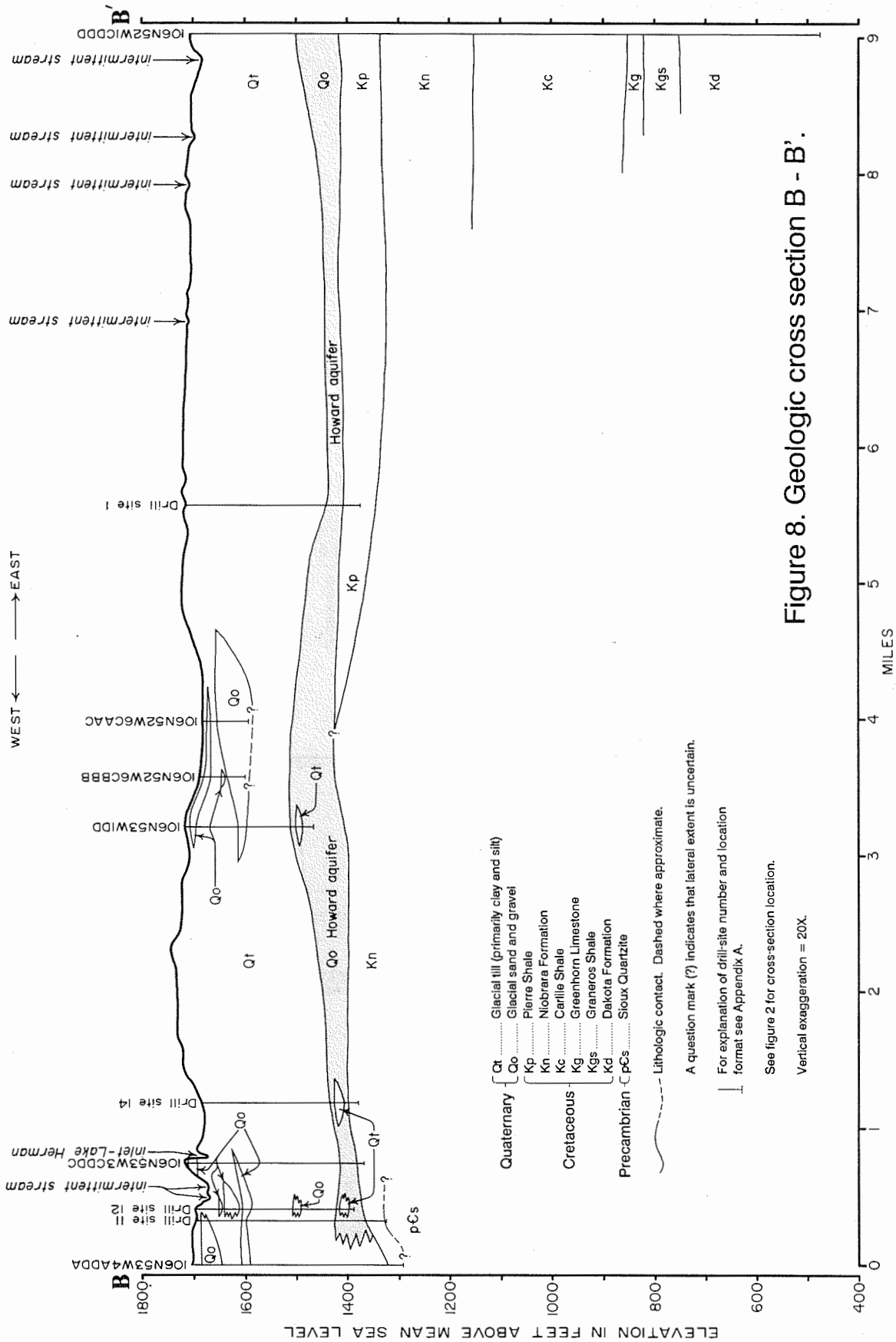
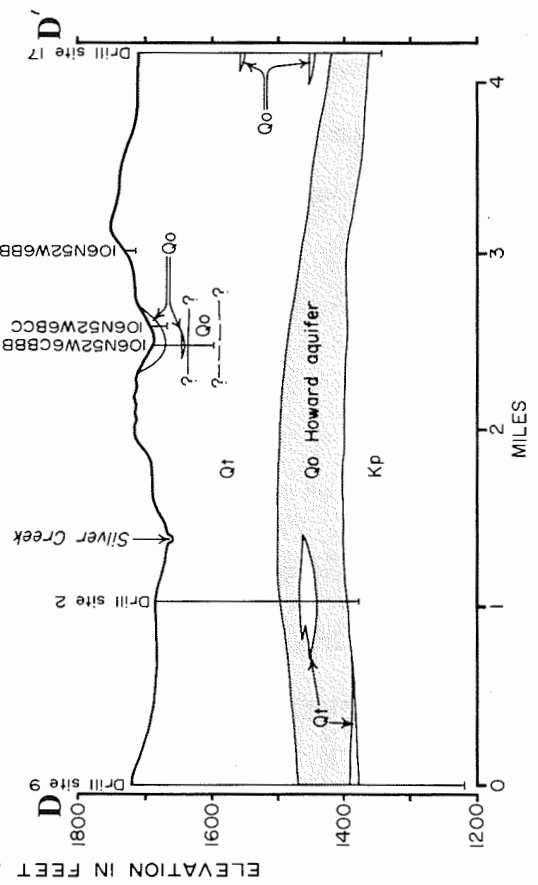
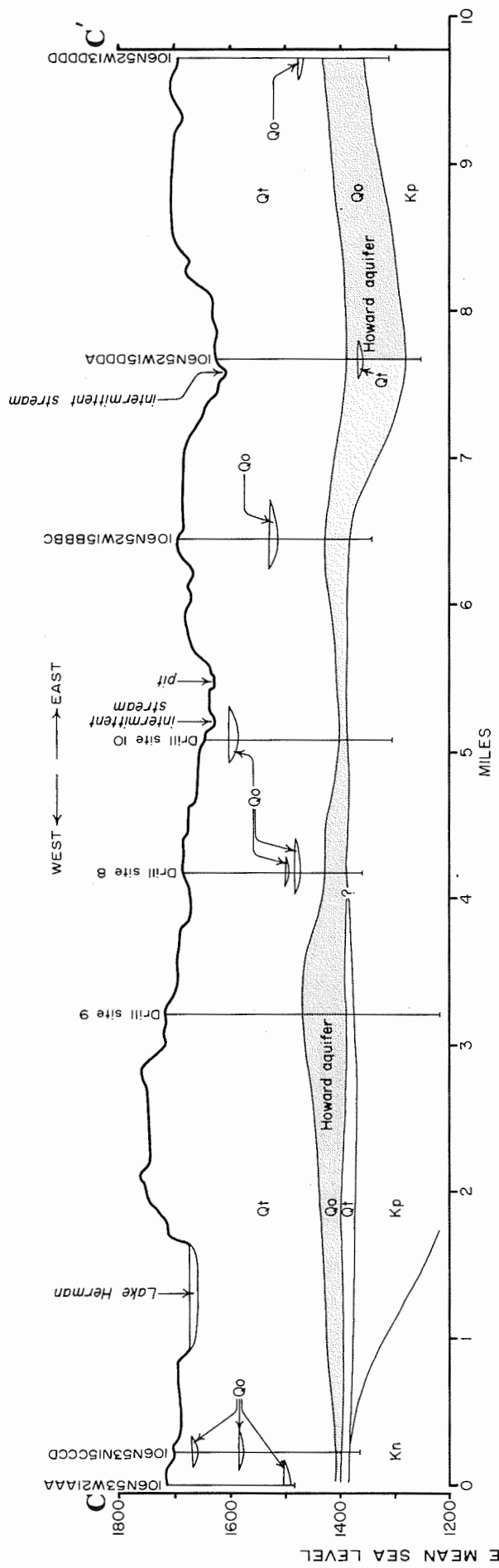


Figure 8. Geologic cross section B - B'.



Quaternary { Qt Glacial till (primarily clay and silt)
 Qo Glacial sand and gravel

Cretaceous { Kp Pierre Shale
 Kn Niobrara Formation

----- Lithologic contact. Dashed where approximate.
A question mark (?) indicates that lateral extent is uncertain.
┆ For explanation of drill-site number and location format see Appendix A.
See figure 2 for cross-section location.
Vertical exaggeration = 20X.

Figure 9. Geologic cross sections C - C' and D - D'.

TABLE 5. Comparison of water quality within the Howard aquifer where it is underlain by Pierre Shale or Niobrara Formation

Water Sample Location Number ²	Aquifer ³	Conduc-tivity (mmhos) ⁴	Concentrations in milligrams per liter ¹										
			DS	Hard-ness as CaCO ₃	Fe	Mn	SO ₄	NO ₃ -N	Na	Ca	Mg	Cl	F
--	---	----	500 ⁵	----	0.3 ⁵	0.05 ⁵	250 ⁵	10 ⁶	--	---	---	250 ⁵	2.4 ⁶
5	HO (Kp)	1552	964	702	<0.01	0.74	500	<0.10	78	173	66.0	8.0	0.61
10	HO (Kp)	1860	1400	1231	<0.05	0.42	1100	<0.10	126	296	120.2	20.0	0.60
11	HO (Kp)	1780	1640	989	0.02	0.33	930	<0.10	94	242	94.1	13.2	0.69
12	HO (Kp)	1995	1010	1087	0.17	0.56	925	<0.10	94	268	102.0	6.0	0.56
13	HO (Kp)	2007	1750	1092	<0.01	0.57	1025	<0.10	122	267	104.0	9.0	0.39
15	HO (Kp)	2150	1680	1011	<0.05	1.20	965	<0.10	215	259	89.0	20.0	0.60
18	HO (Kp)	1830	1330	876	<0.05	1.37	640	<0.10	190	230	74.0	13.0	0.43
Aver-ages for HO (Kp) ...		1882	1396	998	...	0.74	869	...	131	248	92.8	12.7	0.55
22	HO (Kn)	2410	2100	1179	0.03	3.76	1230	<0.10	156	325	90.0	19.0	<0.01

¹ DS - dissolved solids; Fe - iron; Mn - manganese; SO₄ - sulfate; NO₃-N - nitrate nitrogen; Na - sodium; Ca - calcium; Mg - magnesium; Cl - chloride; F - fluoride.

² Water sample location number corresponds to number on figure 3.

³ The abbreviation represents the aquifer, the Howard aquifer (HO) in this table, and whether or not the water sample was taken from a well where the aquifer overlies the Pierre Shale (Kp) or the Niobrara Formation (Kn). The sample from water sample location 18 is from a well where the aquifer is separated from the underlying Pierre Shale by a 12-foot thick clay layer.

⁴ mmhos - micromhos.

⁵ U.S. Environmental Protection Agency national secondary drinking water regulations (U.S. Environmental Protection Agency, 1985b).

⁶ U.S. Environmental Protection Agency national interim primary drinking water regulations (U.S. Environmental Protection Agency, 1985a).

From March 23 to 26, 1982, an aquifer test was conducted using municipal well 11 (see driller's log in app. C) as the pumping well. Well 11 was constructed in 1968 to a depth of 252.5 feet, with the lower 35 feet screened with stainless steel.

For the aquifer test, the well was pumped at a rate of 240.83 gallons per minute for a period of 65.82 hours. During this time, the water level was lowered 62.03 feet from a static water level of 80 feet (app. D). The monitoring network for the aquifer test consisted of six wells: five SDGS observation wells and municipal well 10. Observation wells drill sites 3 and 4, and municipal well 10 had drawdowns of 18.30, 15.81, and 9.78 feet, respectively. The other three observation wells (drill sites 6, 2, and 9) had minimal (less than 2 feet) drawdown.

Data obtained from the aquifer test were analyzed using the Theis and Cooper-Jacob methods for confined aquifers. The average transmissivity using the Theis method was calculated to be approximately 16,000 gallons per day per foot and the average storativity was approximately 0.00021. The Cooper-Jacob method produced comparable values. Basic data from the Howard aquifer test are found in appendix D.

Niobrara Formation

The Niobrara Formation consists of brown and white marls that range in thickness from 37 feet (drill site 11) in the western portion of the study area to 180 feet (private well - Eilertson, app. C) in the eastern part of the study area. The Niobrara Formation is highly fractured and contains numerous solution cavities Hansen (1986). Hansen found that the predominant chemical constituents in water from one observation well installed in the Niobrara Formation were calcium, sodium, and sulfate, with a dissolved-solids concentration of 1,840 mg/L and a hardness concentration of 850 mg/L (Hansen, 1986). For the present investigation, data show that the Niobrara Formation is hydrogeologically connected with the Howard aquifer based on driller's logs (drill sites 11 and 14) and geologic cross section B-B' (fig. 8).

Codell Sandstone Member of the Carlile Shale

No observation wells were drilled into the Codell Sandstone for this investigation, however, Hansen (1986) reports that the Codell Sandstone is a white to yellow-brown medium sandstone that, in Lake and Moody Counties, ranges in depth between 600 and 700 feet below land surface, and has a maximum thickness of 70 feet. Hansen (1986) has defined the water to be of sodium sulfate nature. Water samples 2 and 3 (fig. 3, and app. B) were collected from private wells installed in the Codell Sandstone in the eastern part of the study area. With an average hardness of 540 mg/L (table 2), this water appears to be softer than water from the surficial aquifers. The average value for dissolved solids is 2,195 mg/L (table 2).

Dakota Formation

The Dakota Formation consists of fine-grained sand and sandstones interbedded with shale. An

electric log taken from a domestic well shows the Dakota Formation at this site to be at least 163 feet thick with the top of the formation located approximately 940 feet below the land surface (see lithologic log, app. C). Water from this aquifer (water sample 1, fig. 3 and app. B) is characterized by high sodium and sulfate concentrations of 612 mg/L and 1,240 mg/L, respectively (table 2). The concentrations of dissolved solids and hardness were 2,210 mg/L and 299 mg/L, respectively.

SUMMARY AND RECOMMENDATIONS

The Howard aquifer underlies at least 50 square miles in the Madison area (fig. 5) and is thought to be both glacial (outwash) and fluvial ("western-derived" sand) in origin. A comparison of lithologic data (app. A) and water levels (table 3) shows that the aquifer is under confined conditions. The aquifer material consists of fine to coarse sand and fine-pebble gravel. The aquifer is overlain by a thick layer of till in excess of 150 feet. The aquifer thickness varies throughout the study area and ranges from approximately 10 to 81 feet (fig. 5). Areas devoid of the Howard aquifer are located northeast of the city of Madison (fig. 5). In the vicinity of the municipal well field, the Howard aquifer directly overlies the Pierre Shale with the top of the aquifer ranging from 194 (drill site 6) to 219 (drill sites 3 and 4) feet below land surface. In this same area, the aquifer has a thickness ranging from 21 to 66 feet (fig. 5).

Water from the Howard aquifer is predominantly a calcium-sulfate type. The high average calcium concentration (283 mg/L) is reflected in the high average hardness concentration (1,107 mg/L). Average sulfate (1,025 mg/L) and dissolved-solids (1,654 mg/L) concentrations are high while iron and manganese concentrations are generally low. Nitrate-nitrogen concentrations are well below EPA limits.

Howard aquifer water-quality data for the region is depicted in tables 2 and 5, and app. B. Water-quality data are limited in the area west of the city, and consequently, additional information might be needed in order to adequately determine if the water quality is suitable for industrial use in that area.

The portion of the Howard aquifer south, east and southeast of the city of Madison should be considered as a possible area for further investigation (drill sites 1, 2, 3, 4, 6, 7, 8, 9, and 10). This area of the Howard aquifer contains a white, well-rounded, fine sand to fine-pebble gravel ("western-derived" sand) which is thought to be fluvial in origin. The thickness of the Howard aquifer in this area (fig. 5) ranges from 10 feet (drill site 10) to 81 feet (drill site 9).

Water quality in this area is good with an average dissolved solids concentration of 1,347 mg/L; an average hardness concentration of 954 mg/L, and an average sulfate concentration of 1,025 mg/L. All of these values are lower than the average concentrations found in the Howard aquifer elsewhere in the study area. Iron concentrations in the area south, east, and southeast of the city range from <0.01 mg/L to 0.17 mg/L and manganese concentrations range from 0.56 mg/L to 1.37 mg/L.

Based on the available data, the Howard aquifer could produce additional water for industrial and municipal use. However, because the Howard aquifer varies in thickness and sediment characteristics, it is recommended that before a production well is drilled test wells be drilled in the areas where the

aquifer has the greatest thickness (fig. 5). After the drilling has been completed, an aquifer test should be conducted to determine the local hydraulic characteristics of the aquifer.

Before a permanent well is constructed, information regarding the appropriation of water from the Howard aquifer should be obtained from the Division of Water Rights, Department of Environment and Natural Resources, Pierre, South Dakota.

REFERENCES

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- Hansen, D. S., 1986, *Major aquifers in Lake and Moody Counties, South Dakota*: South Dakota Geological Survey Information Pamphlet 31, 12 p.
- Tipton, M. J., 1959, *Geology of the shallow water supply at Madison, South Dakota*: South Dakota Geological Survey Special Report 2, 12 p.
- Tomhave, D. W., 1987, *Sand and gravel resources in Lake County, South Dakota*: South Dakota Geological Survey Information Pamphlet 32, 51 p.
- U.S. Environmental Protection Agency, 1985a, *National interim primary drinking water regulations - maximum contaminant levels for inorganic chemicals*: Code of Federal Regulations, Title 40, Part 141, Section 141.11, p. 523-524.
- _____, 1985b, *National secondary drinking water regulations - secondary maximum contaminant levels*: Code of Federal Regulations, Title 40, Part 143, Section 143.3, p. 584.

APPENDIX A

Logs of Test Holes and Observation Wells Drilled by the South Dakota Geological Survey For This Investigation

DRILL SITE

A number arbitrarily assigned to the log according to the order in which it is listed (see **LEGAL LOCATION** and **LOCATION**). This number corresponds to the numbers listed on figure 2.

LEGAL LOCATION and LOCATION

The logs are listed by smallest township number, then the smallest range number, the smallest section number, and then by quarter section: NE = A; NW = B; SW = C; SE = D. A comparison of **LEGAL LOCATION** and **LOCATION** is as follows. A **LEGAL LOCATION** of NW $\frac{1}{4}$ SE $\frac{1}{4}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 8, T. 106 N., R. 52 W. is the same as a **LOCATION** of 106N-52W-08CADB. In several **LOCATIONS**, the smallest quarter section is followed by the number 1 or 2 which indicates that more than one log may exist for that particular location.

LATITUDE and LONGITUDE

The format is DD.MMSS where D is degrees, M is minutes, and S is seconds.

DRILLING COMPANY

SDGS is an abbreviation for South Dakota Geological Survey.

TOTAL DRILL HOLE DEPTH, SCREEN LENGTH, TOTAL CASING AND SCREEN, and CASING STICK-UP

The numbers are presented in feet.

SCREEN TYPE and CASING TYPE

PVC is an abbreviation for polyvinyl chloride. MFG. is an abbreviation for manufactured and indicates a product that is commercially available.

CASING DIAMETER

The numbers are presented in inches.

CASING TOP ELEVATION and GROUND SURFACE ELEVATION

The numbers are presented in feet above mean sea level. I - the elevation was determined using a surveying instrument. T - the elevation was estimated from a 7.5 minute series topographic map.

County: LAKE
 Drill Site: 1
 Legal Location: NW NW NW SW sec. 04, T. 106 N., R. 52 W.
 Latitude: 44.0042
 Land Owner:
 Project: MADISON CITY STUDY
 Drilling Company: SDGS
 Driller: L. HELSETH
 Geologist: S. GREEN
 Date Drilled: 07-30-1981
 Ground Surface Elevation: 1710.00 T
 Total Drill Hole Depth: 337
 USGS Hydrological Unit Code: 10170203
 Electric Log Information:
 Spontaneous Potential: X
 Natural Gamma: X
 Samples:

Location: 106N-52W-04CBBB
 Longitude: 97.0520
 Driller's Log:
 Geologist's Log: X
 Drilling Method: ROTARY
 Test Hole Number: MD-81-9
 Single Point Resistivity: X
 Extra:

0	-	37	Clay, yellow-brown, silty, sandy, pebbly (till)
37	-	82	Clay, gray, silty, pebbly (till)
82	-	98	Clay, gray, very silty
98	-	144	Clay, gray, silty, pebbly (till)
144	-	160	Clay, buff, very silty; some sand
160	-	206	Clay, buff to brown, silty, pebbly
206	-	218	Clay, gray, silty, slightly pebbly (till)
218	-	246	Clay, yellow-brown, silty, pebbly (till)
246	-	272	Clay, yellow-brown, silty, sandy; some gravel (till)
272	-	302	Sand and gravel, fine to medium sand and fine gravel; some clay (western sand?)
302	-	337	Shale, gray (Pierre Shale)

* * * *

County: LAKE
 Drill Site: 2
 Legal Location: SW SW SW SW sec. 07, T. 106 N., R. 52 W.
 Latitude: 43.5938
 Land Owner:
 Project: MADISON CITY STUDY
 Drilling Company: SDGS
 Driller: M. JARRETT
 Geologist: S. GREEN
 Date Drilled: 07-13-1981
 Ground Surface Elevation: 1683.14 I
 Total Drill Hole Depth: 305
 Water Rights Well:
 Other Well Name:
 Basin: BIG SIOUX
 Management Unit:
 Screen Type: PVC, MFG.
 Casing Type: PVC
 Casing Top Elevation: 1685.54 I
 Casing Stick-up: 2.40
 Well Maintenance Date:

Location: 106N-52W-07CCCC
 Longitude: 97.0743
 Driller's Log:
 Geologist's Log: X
 Drilling Method: ROTARY
 Test Hole Number: MD-81-1
 SDGS Well Name: MD-81-1
 Aquifer: HOWARD
 Screen Length: 6.0
 Casing Diameter: 2.0
 Total Casing and Screen: 286.0

USGS Hydrological Unit Code: 10170203

Electric Log Information:

Spontaneous Potential:

Natural Gamma: X

Samples:

Single Point Resistivity: X

Extra:

Depth to water: 106.22 feet on 3-23-1982, 107.20 feet on 4-1-1982, 108.95 feet on 4-6-1982 (2.01 foot extension added), 108.06 feet on 6-3-1982, 109.22 feet on 7-28-1982, 109.92 feet on 8-5-1982.

0	-	1	Topsoil, black
1	-	9	Clay, yellow-brown, sandy (till)
9	-	20	Clay, brown, sandy, pebbly (till)
20	-	172	Clay, gray, sandy, gravelly (till)
172	-	188	Clay, yellow-brown, sandy, pebbly; calcareous (till)
188	-	200	Gravel, medium to coarse
200	-	216	Sand, gray; medium
216	-	232	Clay, yellow-white; some gravel, calcareous
232	-	246	Clay, yellow-white, silty, sandy, pebbly; calcareous
246	-	286	Sand, white, medium, well-sorted; rounded (western sand?)
286	-	305	Shale, gray (Pierre Shale)

* * * *

County: LAKE

Drill Site: 3

Legal Location: NW SE NE SW sec. 08, T. 106 N., R. 52 W.

Latitude: 43.5955

Land Owner: CITY OF MADISON

Project: MADISON CITY STUDY

Drilling Company: SDGS

Driller: M. JARRETT

Geologist: S. GREEN

Date Drilled: 10-01-1981

Ground Surface Elevation: 1653.81 I

Total Drill Hole Depth: 260

Water Rights Well:

Other Well Name:

Basin: BIG SIOUX

Management Unit:

Screen Type: PVC, MFG.

Casing Type: PVC

Casing Top Elevation: 1657.01 I

Casing Stick-up: 3.20

Well Maintenance Date:

USGS Hydrological Unit Code: 10170203

Electric Log Information:

Spontaneous Potential:

Natural Gamma: X

Samples:

Location: 106N-52W-08CADB 1

Longitude: 97.0610

Driller's Log:

Geologist's Log: X

Drilling Method: ROTARY

Test Hole Number: MD-81-14

SDGS Well Name: MD-81-14

Aquifer: HOWARD

Screen Length: 5.0

Casing Diameter: 2.0

Total Casing and Screen: 265.0

Single Point Resistivity: X

Extra:

Depth to water: 81.20 feet on 3-23-1982, 82.25 feet on 4-1-1982, 81.77 feet (new coupler added) on 4-6-1982, 80.74 feet on 6-3-1982, 82.21 feet on 7-28-1982, 82.96 feet on 8-5-1982.

0	-	1	Topsoil, black
1	-	12	Clay, gray-brown, sandy, pebbly (till)
12	-	42	Gravel, fine to coarse; some coal
42	-	128	Clay, gray, sandy, pebbly, silty (till)
128	-	181	Clay, yellow-brown, sandy, pebbly; some sand stringers (till)
181	-	219	Silt, yellow-white, sandy
219	-	223	Sand, brown, medium
223	-	237	Silt, yellow-white, sandy
237	-	258	Sand, white, medium to coarse, rounded (western sand?)
258	-	260	Shale, gray (Pierre Shale)

* * * *

County: LAKE	Location: 106N-52W-08CADB 2
Drill Site: 4	
Legal Location: NW SE NE SW sec. 08, T. 106 N., R. 52 W.	
Latitude: 43.5955	Longitude: 97.0610
Land Owner: CITY OF MADISON	
Project: MADISON CITY STUDY	
Drilling Company: SDGS	
Driller: M. JARRETT	Driller's Log:
Geologist: S. GREEN	Geologist's Log: X
Date Drilled: 10-02-1981	Drilling Method: ROTARY
Ground Surface Elevation: 1654.70 I	
Total Drill Hole Depth: 260	Test Hole Number: MD-81-16
Water Rights Well:	SDGS Well Name: MD-81-16
Other Well Name:	
Basin: BIG SIOUX	Aquifer: HOWARD
Management Unit:	
Screen Type: PVC, MFG	Screen Length: 5.0
Casing Type: PVC	Casing Diameter: 2.0
Casing Top Elevation: 1657.00 I	
Casing Stick-up: 2.30	Total Casing and Screen: 265.0
Well Maintenance Date:	
USGS Hydrological Unit Code: 10170203	
Electric Log Information:	Single Point Resistivity:
Spontaneous Potential:	
Natural Gamma:	Extra:
Samples:	

Depth of water: 81.28 feet on 3-23-1982, 82.41 feet on 4-1-1982, 81.68 feet (new coupler added) on 4-6-1982, 80.65 feet on 6-3-1982, 82.23 feet on 7-28-1982, 82.95 feet on 8-5-1982.

0	-	1	Topsoil, black
1	-	13	Clay, gray-brown, sandy, pebbly (till)
13	-	33	Gravel, fine to coarse; some coal
33	-	132	Clay, gray, sandy, silty, pebbly (till)
132	-	175	Clay, yellow-brown, sandy, pebbly (till)
175	-	219	Silt, white, sandy, clayey
219	-	223	Sand, brown, medium
223	-	237	Silt, white, sandy, clayey

237 - 258 Sand, white, medium to coarse, rounded (western sand?)
258 - 260 Shale, gray (Pierre Shale)

* * * *

County: LAKE	Location: 106N-52W-08DAAA 1
Drill Site: 5	
Legal Location: NE NE NE SE sec. 08, T. 106 N., R. 52 W.	
Latitude: 44.0001	Longitude: 97.0523
Land Owner:	
Project: MADISON CITY STUDY	
Drilling Company: SDGS	
Driller: D. IVERSON/M. JARRETT	Driller's Log:
Geologist: S. GREEN	Geologist's Log: X
Date Drilled: 07-16-1981	Drilling Method: ROTARY
Ground Surface Elevation: 1653.39 I	
Total Drill Hole Depth: 110	Test Hole Number: MD-81-7
Water Rights Well: LK-84B	SDGS Well Name: MD-81-7
Other Well Name:	
Basin: BIG SIOUX	Aquifer: BIG SIOUX
Management Unit: NORTHERN SKUNK CREEK	
Screen Type: PVC, MFG.	Screen Length: 5.0
Casing Type: PVC	Casing Diameter: 2.0
Casing Top Elevation: 1655.29 I	
Casing Stick-up: 1.90	Total Casing and Screen: 50.0
Well Maintenance Date:	
USGS Hydrological Unit Code: 10170203	
Electric Log Information:	
Spontaneous Potential:	Single Point Resistivity:
Natural Gamma:	Extra:
Samples:	

Depth to water: 17.73 feet on 4-6-1982, 17.02 feet on 6-3-1982, 15.42 feet on 7-28-1982, 15.24 feet on 8-5-1982.

0 - 1	Topsoil, black
1 - 10	Clay, brown, silty, sandy, pebbly (till)
10 - 50	Sand and gravel, coarse sand and fine to medium gravel; clean
50 - 110	Clay, gray, silty, sandy, pebbly (till)

* * * *

County: LAKE	Location: 106N-52W-08DAAA 2
Drill Site: 6	
Legal Location: NE NE NE SE sec. 08, T. 106 N., R. 52 W.	
Latitude: 44.0002	Longitude: 97.0524
Land Owner:	
Project: MADISON CITY STUDY	
Drilling Company: SDGS	
Driller: M. JARRETT/D. IVERSON	Driller's Log:
Geologist: S. GREEN	Geologist's Log: X

Date Drilled: 07-16-1981
Ground Surface Elevation: 1653.39 I
Total Drill Hole Depth: 335
Water Rights Well: LK-84A
Other Well Name:
Basin: BIG SIOUX
Management Unit:
Screen Type: PVC, MFG.
Casing Type: PVC
Casing Top Elevation: 1656.39 I
Casing Stick-up: 3.00
Well Maintenance Date:
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Natural Gamma: X
Samples:

Drilling Method: ROTARY
Test Hole Number: MD-81-8
SDGS Well Name: MD-81-8
Aquifer: HOWARD
Screen Length: 5.0
Casing Diameter: 2.0
Total Casing and Screen: 260.0
Single Point Resistivity:
Extra:

Depth to water: 82.60 feet on 7-23-1981, 80.30 feet on 3-23-1982, 80.42 feet on 4-1-1982, 80.71 feet on 4-6-1982, 80.12 feet on 6-3-1982, 80.67 feet on 7-28-1982, 80.74 feet on 8-5-1982.

0	-	1	Topsoil, brown
1	-	8	Clay, brown, silty, sandy, pebbly (till)
8	-	30	Gravel, medium to coarse, sandy
30	-	110	Clay, gray, pebbly, sandy (till)
110	-	117	Gravel, fine
117	-	194	Clay, brown-gray, pebbly; greasy (till)
194	-	214	Sand, white, fine, clayey (western sand?)
214	-	260	Sand, white, fine to medium, rounded (western sand?)
260	-	335	Shale, gray (Pierre Shale)

* * * *

County: LAKE
Drill Site: 7
Legal Location: NE NE NE NE sec. 16, T. 106 N., R. 52 W.
Latitude: 43.5938
Land Owner:
Project: MADISON CITY STUDY
Drilling Company: SDGS
Driller: M. JARRETT
Geologist: S. GREEN
Date Drilled: 08-03-1981
Ground Surface Elevation: 1690.00 T
Total Drill Hole Depth: 332
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Natural Gamma: X
Samples:

Location: 106N-52W-16AAAA
Longitude: 97.0413
Driller's Log:
Geologist's Log: X
Drilling Method: ROTARY
Test Hole Number: MD-81-12
Single Point Resistivity:
Extra:

0	-	1	Topsoil, black
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1	-	33	Clay, light-brown, silty, sandy, pebbly (till)
33	-	115	Clay, gray, sandy, pebbly (till)
115	-	126	Clay, light-brown, silty, sandy, pebbly (till)
126	-	138	Clay, pink-gray, silty
138	-	141	Clay, white, silty
141	-	188	Clay, yellow-brown, silty, pebbly (till)
188	-	220	Sand, buff, very fine
220	-	234	Silt, buff, sandy
234	-	238	Sand, white, fine, very silty
238	-	242	Clay, gray, sandy (till)
242	-	265	Sand, white, fine to medium, very silty (western sand?)
265	-	298	Sand, white, medium to coarse; some fine gravel (western sand?)
298	-	308	Clay, brown-gray, silty, sandy (till)
308	-	332	Shale, gray; greasy (Pierre Shale)

* * * *

County: LAKE	Location: 106N-52W-17CCCD
Drill Site: 8	
Legal Location: SE SW SW SW sec. 17, T. 106 N., R. 52 W.	
Latitude: 43.5844	Longitude: 97.0626
Land Owner:	
Project: MADISON CITY STUDY	
Drilling Company: SDGS	
Driller: M. JARRETT	Driller's Log:
Geologist: S. GREEN	Geologist's Log: X
Date Drilled: 07-14-1981	Drilling Method: ROTARY
Ground Surface Elevation: 1680.00 T	
Total Drill Hole Depth: 320	Test Hole Number: MD-81-3
USGS Hydrological Unit Code: 10170203	
Electric Log Information:	
Spontaneous Potential:	Single Point Resistivity: X
Natural Gamma: X	Extra:
Samples:	

0	-	2	Topsoil, black
2	-	5	Silt, yellow-brown-white
5	-	25	Clay, yellow-brown, sandy, pebbly (till)
25	-	185	Clay, gray, silty, sandy, pebbly; some gravel stringers (till)
185	-	188	Gravel, medium
188	-	200	Clay, gray, sandy, pebbly (till)
200	-	210	Gravel, medium
210	-	228	Clay, gray, sandy, pebbly (till)
228	-	258	Clay, yellow-brown, sandy, pebbly (till)
258	-	265	Gravel, medium
265	-	294	Sand, white, medium, well-rounded (western sand?)
294	-	320	Shale, gray (Pierre Shale)

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County: LAKE	Location: 106N-52W-19BBBA
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Drill Site: 9
 Legal Location: NE NW NW NW sec. 19, T. 106 N., R. 52 W.
 Latitude: 43.5843
 Land Owner:
 Project: MADISON CITY STUDY
 Drilling Company: SDGS
 Driller: D. IVERSON
 Geologist: S. GREEN
 Date Drilled: 07-14-1981
 Ground Surface Elevation: 1711.26 I
 Total Drill Hole Depth: 495
 Water Rights Well:
 Other Well Name:
 Basin: BIG SIOUX
 Management Unit:
 Screen Type: PVC, MFG.
 Casing Type: PVC
 Casing Top Elevation: 1713.56 I
 Casing Stick-up: 2.30
 Well Maintenance Date:
 USGS Hydrological Unit Code: 10170203
 Electric Log Information:
 Spontaneous Potential: X
 Natural Gamma: X
 Samples: X

Longitude: 97.0735

Driller's Log:
 Geologist's Log: X
 Drilling Method: ROTARY

Test Hole Number: MD-81-2
 SDGS Well Name: MD-81-2

Aquifer: HOWARD

Screen Length: 5.0
 Casing Diameter: 2.0

Total Casing and Screen: 315.0

Single Point Resistivity: X
 Extra:

Depth to water: 149.00 feet on 07-24-1981, 135.63 feet on 03-23-1982, 136.20 feet on 04-01-1982, 136.20 feet (new coupler added) on 04-06-1982, 135.27 feet on 06-03-1982, 136.25 feet on 07-28-1982, 136.67 feet on 08-05-1982.

0	-	1	Topsoil, black
1	-	13	Clay, brown, sandy (till)
13	-	28	Clay, brown, pebbly (till)
28	-	40	Clay, dark-brown, pebbly (till)
40	-	52	Clay, gray-brown, pebbly (till)
52	-	90	Clay, gray, sandy, pebbly (till)
90	-	125	Clay, gray (till)
125	-	162	Clay, gray, sandy, pebbly (till)
162	-	170	Clay, gray (till)
170	-	195	Clay, gray, pebbly; soft (till)
195	-	206	Clay, brown-gray, pebbly (till)
206	-	245	Clay, brown, sandy, pebbly (till)
245	-	276	Sand, medium; some brown clay stringers
276	-	326	Sand, white, fine to coarse, rounded; some gravel (western sand?)
326	-	338	Clay, gray, sandy
338	-	495	Shale, gray (Pierre Shale)

* * * *

County: LAKE
 Drill Site: 10
 Legal Location: NW NW NW NW sec. 21, T. 106 N., R. 52 W.
 Latitude: 43.5842

Location: 106N-52W-21BBBB
 Longitude: 97.0517

Land Owner:
Project: MADISON CITY STUDY
Drilling Company: SDGS
Driller: M. JARRETT/D. IVERSON
Geologist: S. GREEN
Date Drilled: 07-14-1981
Ground Surface Elevation: 1640.00 T
Total Drill Hole Depth: 338
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Natural Gamma: X
Samples:

0	-	1	Topsoil, black
1	-	10	Clay, yellow-brown, sandy, pebbly (till)
10	-	24	Clay, brown, sandy, pebbly (till)
24	-	42	Clay, gray, sandy, pebbly (till)
42	-	58	Sand and gravel, medium to coarse sand and fine gravel
58	-	130	Clay, gray, silty, sandy, pebbly (till)
130	-	156	Clay, gray, sandy (till)
156	-	190	Clay, gray, sandy; soft
190	-	242	Clay, gray, sandy (till)
242	-	252	Sand, white, medium, rounded (western sand?)
252	-	260	Clay, black (Pierre Shale)
260	-	338	Shale, gray (Pierre Shale)

* * * * *

County: LAKE
Drill Site: 11
Legal Location: NE SW NW SW sec. 03, T. 106 N., R. 53 W.
Latitude: 44.0047
Land Owner: MADISON COUNTRY CLUB
Project: MADISON CITY STUDY
Drilling Company: SDGS
Driller: R. GRAVHOLT/L. HELSETH
Geologist: S. GREEN
Date Drilled: 06-07-1982
Ground Surface Elevation: 1695.00 T
Total Drill Hole Depth: 371
Water Rights Well:
Other Well Name:
Basin: BIG SIOUX
Management Unit:
Screen Type: PVC, MFG.
Casing Type: PVC
Casing Top Elevation:
Casing Stick-up:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X

Driller's Log:
Geologist's Log: X
Drilling Method: ROTARY
Test Hole Number: MD-81-4
Single Point Resistivity: X
Extra:

Location: 106N-53W-03CBCA
Longitude: 97.1113

Driller's Log:
Geologist's Log: X
Drilling Method: ROTARY

Test Hole Number: R1-82-88
SDGS Well Name: R1-82-88

Aquifer: HOWARD

Screen Length: 5.0
Casing Diameter: 2.0

Total Casing and Screen: 318.3

Single Point Resistivity: X

Natural Gamma: X
Samples:

Extra:

Depth to water: 181.34 feet on 7-28-1982, 181.44 feet on 8-5-1982.

0 - 2	Topsoil, black
2 - 8	Clay, yellow-brown, silty, sandy, pebbly (till)
8 - 17	Sand and gravel, coarse sand and fine gravel
17 - 26	Sand and gravel, coarse sand and medium to coarse gravel
26 - 90	Clay, gray, sandy, pebbly, gravelly (till)
90 - 100	Sand and gravel, coarse sand and fine gravel; clayey
100 - 192	Clay, gray, sandy, pebbly; some coarse sand lenses (till)
192 - 274	Clay, gray, sandy, pebbly; some coarse sand and fine gravel lenses (till)
274 - 300	Sand, brown, coarse; some fine gravel, clay lenses
300 - 330	Sand, brown, coarse; some fine gravel
330 - 367	Limestone, brown, silty; calcareous, some white clay (Niobrara Formation)
367 - 371	Quartzite, pink; hard (boulder?/bedrock?)

* * * *

County: LAKE

Drill Site: 12

Legal Location: NW SE NW SW sec. 03, T. 106 N., R. 53 W.

Latitude: 44.0047

Land Owner: MADISON COUNTRY CLUB

Project: MADISON CITY STUDY

Drilling Company: SDGS

Driller: L. HELSETH/D. IVERSON

Geologist: S. GREEN

Date Drilled: 06-04-1982

Ground Surface Elevation: 1690.00 T

Total Drill Hole Depth: 305

Water Rights Well:

Other Well Name:

Basin: BIG SIOUX

Management Unit:

Screen Type: PVC, MFG.

Casing Type: PVC

Casing Top Elevation:

Casing Stick-up:

Well Maintenance Date:

USGS Hydrological Unit Code: 10170203

Electric Log Information:

Spontaneous Potential:

Natural Gamma: X

Samples: X

Location: 106N-53W-03CBDB

Longitude: 97.1108

Driller's Log:

Geologist's Log: X

Drilling Method: ROTARY

Test Hole Number: R1-82-87

SDGS Well Name: R1-82-87

Aquifer:

Screen Length: 5.4

Casing Diameter: 2.0

Total Casing and Screen: 105.0

Single Point Resistivity: X

Extra:

Depth to water: 21.41 feet on 7-28-1982, 21.53 feet on 8-5-1982.

0 - 18	Clay, yellow-brown, silty, pebbly (till)
18 - 22	Clay, gray, silty, pebbly (till)
22 - 26	Boulders
26 - 42	Clay, gray, silty, pebbly (till)

42 - 49	Sand and gravel, medium to coarse sand and medium gravel; some coal
49 - 55	Clay, gray, silty, sandy, pebbly (till)
55 - 82	Sand and gravel, medium to coarse sand and medium pebble gravel; some clay lenses, coal
82 - 88	Clay, gray, silty, sandy, pebbly (till)
88 - 104	Sand and gravel, medium to coarse sand and medium pebble gravel; some clay lenses, coal
104 - 108	Sand and gravel, medium to coarse sand and medium gravel; some clay lenses, coal
108 - 186	Clay, gray, gravelly (till)
186 - 200	Sand and gravel, medium to coarse sand and fine gravel
200 - 273	Clay, gray, gravelly (till?)
273 - 278	Sand, coarse; some clay
278 - 292	Clay, gray, sandy, gravelly (till?)
292 - 305	Sand, coarse; some fine gravel

* * * *

County: LAKE
 Drill Site: 13
 Legal Location: SW NE SE SW sec. 03, T. 106 N., R. 53 W.
 Latitude: 44.0035
 Land Owner: MADISON COUNTRY CLUB
 Project: MADISON CITY STUDY
 Drilling Company: SDGS
 Driller: M. JARRETT
 Geologist: S. GREEN
 Date Drilled: 10-01-1981
 Ground Surface Elevation: 1680.00 T
 Total Drill Hole Depth: 50
 USGS Hydrological Unit Code: 10170203
 Electric Log Information:
 Spontaneous Potential:
 Natural Gamma:
 Samples:

Location: 106N-53W-03CDAC
 Longitude: 97.1053

Driller's Log:
 Geologist's Log: X
 Drilling Method: ROTARY

Test Hole Number: MD-81-15

Single Point Resistivity:
 Extra:

0 - 6	Topsoil, black; some organic matter
6 - 11	Gravel, coarse
11 - 12	Rock
12 - 50	Clay, dark-gray, sandy, pebbly (till)

* * * *

County: LAKE
 Drill Site: 14
 Legal Location: SE SW SE SE sec. 03, T. 106 N., R. 53 W.
 Latitude: 44.0030
 Land Owner: MADISON COUNTRY CLUB
 Project: MADISON CITY STUDY
 Drilling Company: SDGS
 Driller: M. JARRETT
 Geologist: S. GREEN

Location: 106N-53W-03DDCD
 Longitude: 97.1023

Driller's Log:
 Geologist's Log: X

Date Drilled: 09-29-1981
Ground Surface Elevation: 1680.00 T
Total Drill Hole Depth: 305
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential:
Natural Gamma: X
Samples:

Drilling Method: ROTARY
Test Hole Number: MD-81-13
Single Point Resistivity: X
Extra:

Test hole was abandoned at 305 feet due to the loss of drilling fluid circulation.

0	-	2	Topsoil, dark-brown
2	-	5	Clay, light-brown, sandy (till)
5	-	7	Rock
7	-	21	Clay, gray-brown, sandy, pebbly; rock at 17 and 19 feet (till)
21	-	141	Clay, gray, sandy, pebbly (till)
141	-	249	Clay, gray, very sandy, pebbly (till)
249	-	253	Gravel, fine; some clay
253	-	278	Clay, gray, silty, sandy (till)
278	-	286	Sand(?); no sample
286	-	305	Chalk(?); no sample

* * * * *

County: LAKE
Drill Site: 15
Legal Location: SE NE SE NE sec. 11, T. 106 N., R. 53 W.
Latitude: 44.0008
Land Owner:
Project: MADISON CITY STUDY
Drilling Company: SDGS
Driller: M. JARRETT
Geologist: S. GREEN
Date Drilled: 07-31-1981
Ground Surface Elevation: 1669.00 T
Total Drill Hole Depth: 50
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Location: 106N-53W-11ADAD 1
Longitude: 97.0758
Driller's Log:
Geologist's Log: X
Drilling Method: ROTARY
Test Hole Number: MD-81-10
Single Point Resistivity:
Extra:

0	-	1	Topsoil, black
1	-	8	Clay, yellow-brown, silty, pebbly (till)
8	-	50	Gravel, fine to medium

* * * * *

County: LAKE
Drill Site: 16
Legal Location: SE NE SE NE sec. 11, T. 106 N., R. 53 W.

Location: 106N-53W-11ADAD 2

Latitude: 44.0008
Land Owner:
Project: MADISON CITY STUDY
Drilling Company: SDGS
Driller: M. JARRETT/L. HELSETH
Geologist: S. GREEN
Date Drilled: 07-31-1981
Ground Surface Elevation: 1669.00 T
Total Drill Hole Depth: 50
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

0	-	1	Topsoil, black
1	-	8	Clay, yellow-brown, silty, pebbly (till)
8	-	50	Gravel, fine to medium

* * * *

County: LAKE
Drill Site: 17
Legal Location: NW SW SW SW sec. 30, T. 107 N., R. 52 W.
Latitude: 44.0216
Land Owner:
Project: MADISON CITY STUDY
Drilling Company: SDGS
Driller: M. JARRETT
Geologist: S. GREEN
Date Drilled: 07-15-1981
Ground Surface Elevation: 1708.00 T
Total Drill Hole Depth: 362
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Natural Gamma: X
Samples:

0	-	1	Topsoil, black
1	-	2	Clay, red; some gravel
2	-	21	Clay, yellow-brown, sandy, pebbly (till)
21	-	34	Silt, gray-brown
34	-	153	Clay, gray, silty, sandy, pebbly (till)
153	-	155	Sand, gray, medium; some coal
155	-	254	Clay, gray, silty, sandy, pebbly (till)
254	-	262	Sand and gravel, medium sand and fine gravel
262	-	287	Clay, gray, sandy, pebbly (till)
287	-	342	Sand, brown, medium to coarse; some clay stringers
342	-	362	Shale, gray; greasy (Pierre Shale)

* * * *

Longitude: 97.0758

Driller's Log:
Geologist's Log: X
Drilling Method: ROTARY

Test Hole Number: MD-81-11

Single Point Resistivity:
Extra:

Location: 107N-52W-30CCCB

Longitude: 97.0742

Driller's Log:
Geologist's Log: X
Drilling Method: ROTARY

Test Hole Number: MD-81-5

Single Point Resistivity: X
Extra:

County: LAKE
Drill Site: 18
Legal Location: SW SW SE SE sec. 32, T. 107 N., R. 52 W.
Latitude: 44.0120
Land Owner:
Project: MADISON CITY STUDY
Drilling Company: SDGS
Driller: M. JARRETT/D. IVERSON
Geologist: S. GREEN
Date Drilled: 07-15-1981
Ground Surface Elevation: 1710.00 T
Total Drill Hole Depth: 335
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Natural Gamma: X
Samples:

0	-	1	Topsoil, black
1	-	14	Clay, yellow-brown, sandy (till)
14	-	19	Clay, brown, silty, sandy (till)
19	-	64	Clay, gray, sandy, pebbly (till)
64	-	140	Clay, gray, silty
140	-	200	Clay, gray
200	-	238	Clay, gray; soft (till)
238	-	254	Sand, brown; some gray-brown clay
254	-	270	Clay, brown; hard
270	-	335	Shale, gray (Pierre Shale)

* * * *

Location: 107N-52W-32DDCC

Longitude: 97.0535

Driller's Log:
Geologist's Log: X
Drilling Method: ROTARY

Test Hole Number: MD-81-6

Single Point Resistivity: X
Extra:

Appendix B. Chemical analyses of water samples

Water Sample Location Number ²	Location ³	Sample Date	Lab Id ⁴	Water Source ⁵	Well Controller ⁶	Aquifer ⁷	Well Depth (ft)	Conduc-tivity (mmhos) ⁸	Concentrations in milligrams per liter ¹										
									DS	Hardness as CaCO ₃	Fe	Mn	SO ₄	NO ₃ -N	Na	Ca	Mg	Cl	F
----	----	----	----	----	----	----	---	----	500 ⁹	----	0.3 ⁹	0.05 ⁹	250 ⁹	10 ¹⁰	---	---	---	250 ⁹	2.4 ¹⁰
Northern Skunk Creek management unit of the Big Sioux aquifer																			
4	106N-52W-07CCCB	07-14-81	MAD-81-5	Private	.....	NSC	...	1370	956	674	2.91	3.87	375	0.20	56	172	59.9	10.0	0.38
6	106N-52W-08CA	07-21-84	MAD-81-17	City no. 1	City	NSC	34	1730	1240	798	1.26	1.87	538	<0.10	108	207	68.7	176.0	0.14
7	106N-52W-08CA	07-21-81	MAD-81-19	City no. 3	City	NSC	47	2474	1510	693	0.69	2.04	378	<0.10	299	172	64.3	770.0	0.20
8	106N-52W-08CA	07-21-81	MAD-81-18	City no. 8	City	NSC	35	2375	2030	1537	2.21	5.35	1060	<0.10	105	475	86.1	154.0	0.09
9	106N-52W-08CA	07-21-81	MAD-81-16	City no. 9	City	NSC	51	1710	1330	865	0.65	1.71	610	<0.10	114	211	82.7	172.0	0.25
14	106N-52W-08DAAA 1	03-01-82	MAD-82-2	MD-81-7	SDGS	NSC	48	1783	1322	963	0.02	0.40	575	<0.10	94	225	98.0	14.0	0.64
24	106N-53W-04DAAD	03-25-82	MAD-82-6	Private	D. Laughlin	NSC	80	2140	1740	997	10.25	0.44	850	<0.10	154	263	83.2	16.0	0.28
AVERAGES							49	1940	1447	932	2.57	2.24	627	...	133	246	77.6	187.4	0.28
Howard aquifer																			
5	106N-52W-07CCCC	03-01-82	MAD-82-1	MD-81-1	SDGS	HO	284	1552	964	702	<0.01	0.74	500	<0.10	78	173	66.0	8.0	0.61
10	106N-52W-08CAAA	07-21-81	MAD-81-15	City no. 10	City	HO	257	1860	1400	1231	<0.05	0.42	1100	<0.10	126	296	120.2	20.0	0.60
11	106N-52W-08CADB	03-26-81	MAD-82-8	City no. 11	City	HO	254	1780	1640	989	0.02	0.33	930	<0.10	94	242	94.1	13.2	0.69
12	106N-52W-08CADB 1	03-02-82	MAD-82-3	MD-81-14	SDGS	HO	262	1995	1010	1087	0.17	0.56	925	<0.10	94	268	102.0	6.0	0.56
13	106N-52W-08CADB 2	03-02-82	MAD-82-4	MD-81-16	SDGS	HO	263	2007	1750	1092	<0.01	0.57	1025	<0.10	122	267	104.0	9.0	0.39
15	106N-52W-08DAAA 2	07-23-81	MAD-81-22	MD-81-8	SDGS	HO	257	2150	1680	1011	<0.05	1.20	965	<0.10	215	259	89.0	20.0	0.60
16	106N-52W-17CCCC	07-14-81	MAD-81-1	Private	M. Voeltz	HO	260	1760	1280	915	0.13	3.30	675	0.20	97	242	76.0	20.0	0.39
17	106N-52W-18DAAA	07-14-81	MAD-81-4	Private	R. Ellingson	HO	...	1760	1420	1051	<0.05	<0.05	781	<0.10	52	252	103.0	17.0	0.65
18	106N-52W-19BBBA	07-24-81	MAD-81-23	MD-81-2	SDGS	HO	313	1830	1330	876	<0.05	1.37	640	<0.10	190	230	74.0	13.0	0.43
20	106N-52W-30DAAC	07-14-81	MAD-81-6	Private	H. Booze	HO	...	2180	1890	1340	31.8	1.72	1750	<0.10	105	350	114.0	6.0	0.33
21	106N-52W-32BCBB	07-14-81	MAD-81-7	Private	L. Herr	HO	...	1720	1330	901	1.13	0.22	600	<0.10	77	210	92.0	12.0	0.51
22	106N-53W-03CBCA	06-30-82	MAD-82-13	R1-82-88	SDGS	HO	318	2410	2100	1179	0.03	3.76	1230	<0.10	156	325	90.0	19.0	<0.01
25	106N-53W-11BBAA	07-23-81	MAD-81-21	Private	Prairie Village	HO	230	2010	1540	1074	<0.05	4.95	822	0.40	175	281	91.0	12.0	0.29
30	107N-52W-21CCCC	07-15-81	MAD-81-9	Private	L. Wiseman	HO	...	2710	2210	849	0.44	2.10	1300	0.80	357	233	65.4	28.0	0.37
31	107N-52W-31BCCC	07-15-81	MAD-81-14	Private	F. Krueger	HO	338	2070	1087	1161	10.20	0.94	1085	<0.10	93	288	108.0	15.0	0.41
32	107N-52W-32ACDD	07-15-81	MAD-81-13	Private	.....	HO	...	2010	1760	1162	21.00	2.63	987	<0.10	85	280	113.0	15.0	0.59
33	107N-52W-33CBCC	07-15-81	MAD-81-12	Private	.....	HO	...	2740	2640	1773	4.30	2.25	1750	<0.10	102	410	183.0	17.0	0.65
34	107N-53W-24CDDD	03-23-82	MAD-82-7	Private	E. Hulscher	HO	437	2450	2180	1373	5.75	4.30	1210	<0.10	106	385	100.8	5.4	0.20
36	107N-53W-27DDAC	04-01-82	MAD-82-11	Private	O. Njus	HO	365	2225	1960	1213	4.50	2.22	1125	<0.10	109	339	89.8	16.0	0.32
37	107N-53W-34CDDD	03-02-82	MAD-82-5	Private	K. Nelson	HO	357	2170	1900	1151	1.95	3.30	1100	0.20	113	329	80.7	11.0	0.34
AVERAGES							210	2069	1654	1107	...	...	1025	...	127	283	97.8	14.1	...
Codell Sandstone Member of the Carlile Shale																			
2	106N-52W-02CDDC	04-02-82	MAD-82-9	Private	H. Braskamp	Kcc	655	2693	2010	564	5.25	0.12	1110	0.10	446	153	44.5	40.0	1.21
3	106N-52W-05BAAB	07-15-81	MAD-81-11	Private	B. Wagner	Kcc	600	3140	2380	515	<0.05	0.12	1150	1.70	550	139	41.2	84.0	1.39
AVERAGES							628	2917	2195	540	...	0.12	1130	0.90	498	146	42.9	62.0	1.30

Appendix B -- continued.

Water Sample Location Number ²	Location ³	Sample Date	Lab Id ⁴	Water Source ⁵	Well Controller ⁶	Aquifer ⁷	Well Depth (ft)	Conductivity (mmhos) ⁸	Concentrations in milligrams per liter ¹										
									DS	Hardness as CaCO ₃	Fe	Mn	SO ₄	NO ₃ -N	Na	Ca	Mg	Cl	F
----	----	----	----	----	----	----	---	----	500 ⁹	----	0.3 ⁹	0.05 ⁹	250 ⁹	10 ¹⁰	---	---	---	250 ⁹	2.4 ¹⁰
Dakota Formation																			
1	106N-52W-01CDDD	04-01-82	MAD-82-12	Private	K. Eilerjson	Kd	1100	3206	2210	299	4.75	0.33	1240	<0.10	612	56	38.9	43.0	0.33
Pleistocene Series aquifers																			
19	106N-52W-27BCAD	07-15-81	MAD-81-10	Private	C. Hidenshield	PS	210	1040	745	534	1.24	0.32	275	<0.10	35	145	42.1	10.0	0.43
23	106N-53W-03CBDB	06-30-82	MAD-82-4	R1-82-87	SDGS	PS	105	1760	1290	842	0.93	0.55	515	<0.10	119	244	57.0	12.0	0.08
27	106N-53W-24ABAA	07-14-81	MAD-81-2	Private	E. Hyink	PS	180	2960	672	515	0.70	0.60	300	<0.10	43	138	41.6	6.0	0.16
28	106N-53W-24DDDD	07-14-81	MAD-81-3	Private	D. Doerr	PS	186	832	508	398	3.20	0.30	140	<0.10	39	109	30.8	<2.0	0.17
29	107N-52W-20CCBB	07-15-81	MAD-81-8	Private	K. Klingbile	PS	80	1050	2460	1005	1.12	0.60	1300	0.40	366	269	81.6	34.0	0.32
35	107N-53W-27DDAC	04-01-82	MAD-82-10	Private	O. Njus	PS	65	4710	4550	3013	<0.01	0.18	2220	7.20	311	493	434.4	140.0	0.54
Surface water																			
26	106N-53W-14BAAC	07-23-81	MAD-81-20	Lake	.....	..	....	1453	1110	326	<0.05	0.10	488	<0.10	128	98	30.0	31.0	0.23

¹ DS - dissolved solids; Fe - iron; Mn - manganese; SO₄ - sulfate; NO₃-N - nitrate nitrogen; Na - sodium; Ca - calcium; Mg - magnesium; Cl - chloride; F - fluoride.

² Water sample location number corresponds to number on figure 3.

³ See appendix A for explanation of location format.

⁴ An identifier assigned by the laboratory which performed the chemical analysis.

⁵ Lake - surface-water sample; Private - private well; City - Madison city well; a format similar to MD-81-8 or R1-82-87 indicates the monitoring well name in appendix A.

⁶ SDGS - South Dakota Geological Survey; City - city of Madison.

⁷ The abbreviation represents the aquifer from which the sample was collected; NSC - Northern Skunk Creek management unit of the Big Sioux aquifer; PS - Pleistocene Series aquifers; HO - Howard aquifer; Kcc - Codell Sandstone Member of the Carlile Shale; Kd - Dakota Formation.

⁸ mmhos - micromhos.

⁹ U.S. Environmental Protection Agency national secondary drinking water regulations (U.S. Environmental Protection Agency, 1985b).

¹⁰ U.S. Environmental Protection Agency national interim primary drinking water regulations (U.S. Environmental Protection Agency, 1985a).

APPENDIX C

Logs of a Private Well, Madison Municipal Wells 10 and 11, and Additional Logs Used to Construct Geologic Cross Sections

LEGAL LOCATION and LOCATION

The logs are listed by smallest township number, then the smallest range number, the smallest section number, and then by quarter section: NE = A; NW = B; SW = C; SE = D. A comparison of **LEGAL LOCATION** and **LOCATION** is as follows. A **LEGAL LOCATION** of SW $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ SW $\frac{1}{4}$ sec. 6, T. 106 N., R. 52 W. is the same as a **LOCATION** of 106N-52W-06CAAC. In several **LOCATIONS**, the smallest quarter section is followed by the number 1 or 2 which indicates that more than one log may exist for that particular location.

LATITUDE and LONGITUDE

The format is DD.MMSS where D is degrees, M is minutes, and S is seconds.

DRILLING COMPANY

SDGS is an abbreviation for South Dakota Geological Survey.

TOTAL DRILL HOLE DEPTH, SCREEN LENGTH, TOTAL CASING AND SCREEN, and CASING STICK-UP

The numbers are presented in feet.

SCREEN TYPE and CASING TYPE

PVC is an abbreviation for polyvinyl chloride. MFG. is an abbreviation for manufactured and indicates a product that is commercially available. HM. is an abbreviation for homemade and indicates a hacksaw-slotted casing.

CASING DIAMETER

The numbers are presented in inches.

CASING TOP ELEVATION and GROUND SURFACE ELEVATION

The numbers are presented in feet above mean sea level. I - the elevation was determined using a surveying instrument. T - the elevation was estimated from a 7.5 minute series topographic map.

County: LAKE
Legal Location: SE SE SE SW sec. 01, T. 106 N., R. 52 W.
Latitude: 44.0033
Land Owner: K. EILERTSON
Project:
Drilling Company: TORGRUDE WELL DRILLING
Driller:
Geologist: R. SCHOON
Date Drilled: 08-18-1971
Ground Surface Elevation: 1699.00 T
Total Drill Hole Depth: 1103
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Natural Gamma:
Samples:

0 - 200	Drift, undifferentiated
200 - 285	Sand and gravel; with clay layers
285 - 365	Shale (Pierre Shale)
365 - 545	Chalk (Niobrara Formation)
545 - 630	Shale (Carlile Shale)
630 - 685	Sandstone (Codell sandstone member - Carlile Shale)
685 - 845	Shale (Carlile Shale)
845 - 875	Limestone (Greenhorn Limestone)
875 - 940	Shale (Graneros Shale)
940 - 1103	Sandstone (Dakota Formation)

Log written from electric log by R. Schoon, formation picked by R. Schoon.

* * * * *

County: LAKE
Legal Location: NW NW NW sec. 06, T. 106 N., R. 52 W.
Latitude: 44.0118
Land Owner:
Project: SKUNK CREEK-LAKE MADISON
Drilling Company: SDGS
Driller:
Geologist:
Date Drilled: 00-00-0000
Ground Surface Elevation: 1730.00 T
Total Drill Hole Depth: 14
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

0 - 4	Topsoil, black
4 - 9	Till, yellowish-gray
9 - 14	Till, tan

* * * * *

County: LAKE

Location: 106N-52W-01CDDD

Longitude: 97.0056

Driller's Log:
Geologist's Log: X
Drilling Method: ROTARY

Test Hole Number:

Single Point Resistivity: X
Extra:

Location: 106N-52W-06BBB

Longitude: 97.0743

Driller's Log:
Geologist's Log:
Drilling Method: AUGER

Test Hole Number:

Single Point Resistivity:
Extra:

Location: 106N-52W-06BCC

Legal Location: SW SW NW sec. 06, T. 106 N., R. 52 W.
Latitude: 44.0055
Land Owner:
Project: SKUNK CREEK-LAKE MADISON
Drilling Company: SDGS
Driller:
Geologist:
Date Drilled: 00-00-0000
Ground Surface Elevation: 1690.00 T
Total Drill Hole Depth: 24
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

0	-	4	Topsoil, black
4	-	9	Sand and gravel, medium sand, fine gravel
9	-	14	Sand, coarse
14	-	24	Till

* * * *

County: LAKE
Legal Location: SW NE NE SW sec. 06, T. 106 N., R. 52 W.
Latitude: 44.0047
Land Owner:
Project:
Drilling Company: S.T. BANNER AND ASSOC.
Driller:
Geologist:
Date Drilled: 10-20-1955
Ground Surface Elevation: 1680.00 T
Total Drill Hole Depth: 90
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

0	-	5	Topsoil, black
5	-	7	Clay, gray
7	-	10	Sand and gravel, hard sand, pea-sized gravel
10	-	15	Sand and gravel, medium sand, pea-sized gravel
15	-	27	Clay, blue
27	-	38	Sand, fine; hard
38	-	40	Sand, coarse
40	-	75	Sand, fine; hard
75	-	85	Sand, fine
85	-	90	Sand, fine; hard

* * * *

County: LAKE
Legal Location: NW NW NW SW sec. 06, T. 106 N., R. 52 W.

Longitude: 97.0742
Driller's Log:
Geologist's Log:
Drilling Method: AUGER
Test Hole Number:
Single Point Resistivity:
Extra:

Location: 106N-52W-06CAAC
Longitude: 97.0719
Driller's Log:
Geologist's Log:
Drilling Method:
Test Hole Number:
Single Point Resistivity:
Extra:

Location: 106N-52W-06CBBB

Latitude: 44.0052
Land Owner:
Project:
Drilling Company: S.T. BANNER AND ASSOC.
Driller:
Geologist:
Date Drilled: 10-19-1955
Ground Surface Elevation: 1685.00 T
Total Drill Hole Depth: 90
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Longitude: 97.0742

Driller's Log:
Geologist's Log:
Drilling Method:

Test Hole Number:

Single Point Resistivity:
Extra:

0	-	4	Topsoil, black
4	-	5	Clay, gray
5	-	10	Sand and clay
10	-	19	Sand and gravel, medium sand, pea-sized gravel
19	-	45	Clay, blue
45	-	47	Sand, fine
47	-	54	Clay, blue
54	-	55	Sand, medium
55	-	75	Sand, fine
75	-	80	Sand, medium
80	-	90	Sand, medium-fine

* * * * *

County: LAKE
Legal Location: NE NE NE SW sec. 08, T. 106 N., R. 52 W.
Latitude: 44.0000
Land Owner: CITY OF MADISON
Project:
Drilling Company: GRIMSHAW DRILLING
Driller:
Geologist:
Date Drilled: 03-09-1968
Ground Surface Elevation: 1657.00 T
Total Drill Hole Depth: 275
Water Rights Well:
Other Well Name: WELL 10
Basin: BIG SIOUX
Management Unit:
Screen Type: STAINLESS STEEL
Casing Type: PVC
Casing Top Elevation: 1659.36 I
Casing Stick-up: 2.36
Well Maintenance Date:
USGS Hydrological Unit Code: 10170205
Electric Log Information:
Spontaneous Potential:
Natural Gamma: X
Samples:

Location: 106N-52W-08CAAA

Longitude: 97.0601

Driller's Log: X
Geologist's Log:
Drilling Method: ROTARY

Test Hole Number:
SDGS Well Name:

Aquifer: HOWARD

Screen Length: 25.0
Casing Diameter: 8.0

Total Casing and Screen: 260

Single Point Resistivity: X
Extra:

0 - 1 Topsoil
 1 - 44 Sand and gravel
 44 - 120 Clay, gray; some rocks (till)
 120 - 130 Clay, yellow (till)
 130 - 131 Clay; hard (till)
 131 - 132 Rock
 132 - 134 Clay; hard (till)
 134 - 135 Rock
 135 - 143 Clay; hard (till)
 143 - 145 Rock
 145 - 180 Clay; hard (till)
 180 - 222 Clay; soft, some sand stringers (till)
 222 - 232 Sand, yellow-white, clayey; soft
 232 - 258 Sand; hard
 258 - 275 Shale, gray; hard (Pierre Shale)

* * * *

County: LAKE
 Legal Location: NW SE NE SW sec. 08, T. 106 N., R. 52 W.
 Latitude: 43.5955
 Land Owner: CITY OF MADISON
 Project:
 Drilling Company: GRIMSHAW DRILLING
 Driller:
 Geologist:
 Date Drilled: 04-06-1968
 Ground Surface Elevation: 1654.50 T
 Total Drill Hole Depth: 260
 Water Rights Well:
 Other Well Name: WELL 11
 Basin: BIG SIOUX
 Management Unit:
 Screen Type: STAINLESS STEEL
 Casing Type: IRON
 Casing Top Elevation: 1656.00 I
 Casing Stick-up: 1.50
 Well Maintenance Date:
 USGS Hydrological Unit Code: 10170205
 Electric Log Information:
 Spontaneous Potential:
 Natural Gamma:
 Samples:

Location: 106N-52W-08CADB

Longitude: 97.0610

Driller's Log: X
 Geologist's Log:
 Drilling Method: ROTARY

Test Hole Number:
 SDGS Well Name:

Aquifer:

Screen Length: 35.0
 Casing Diameter: 8.0

Total Casing and Screen: 254

Single Point Resistivity:
 Extra:

0 - 31 Sand and gravel
 31 - 50 Clay, dark-gray, silty (till)
 50 - 130 Clay, light-gray (till)
 130 - 190 Clay, yellow (till)
 190 - 200 Clay, yellow-white; soft
 200 - 215 Sand; some clay, soft
 215 - 230 Sand, fine
 230 - 240 Sand, medium to fine
 240 - 254 Sand
 254 - 260 Clay

* * * *

County: LAKE
 Legal Location: SE SE SE SE sec. 13, T. 106 N., R. 52 W.
 Latitude: 43.5845
 Land Owner:
 Project: LAKE-MOODY COUNTY STUDY
 Drilling Company: SDGS
 Driller: R. GRAVHOLT/D. IVERSON
 Geologist: R. HAMMOND
 Date Drilled: 07-28-1982
 Ground Surface Elevation: 1691.00 T
 Total Drill Hole Depth: 380
 Water Rights Well:
 Other Well Name:
 Basin: BIG SIOUX
 Management Unit:
 Screen Type: PVC, MFG.
 Casing Type: PVC
 Casing Top Elevation:
 Casing Stick-up: 3.00
 Well Maintenance Date:
 USGS Hydrological Unit Code: 10170203
 Electric Log Information:
 Spontaneous Potential: X
 Natural Gamma: X
 Samples: X

Location: 106N-52W-13DDDD
 Longitude: 97.0035

Driller's Log:
 Geologist's Log: X
 Drilling Method: ROTARY

Test Hole Number: R1-82-124
 SDGS Well Name: R1-82-124

Aquifer:

Screen Length: 5.0
 Casing Diameter: 2.0

Total Casing and Screen: 335

Single Point Resistivity: X
 Extra:

- 0 - 1 Topsoil, black
- 1 - 18 Clay, yellow-brown, pebbly (till)
- 18 - 133 Clay, gray, silty, pebbly (till)
- 133 - 153 Clay, yellow-brown, sandy, pebbly (till)
- 153 - 219 Clay, gray-brown, gray from 180 to 219 feet, sandy, pebbly; rock at 218 to 219 feet (till)
- 219 - 226 Sand, coarse, pebbly
- 226 - 258 Clay, gray and brown, mottled, sandy, pebbly; severely jointed (till)
- 258 - 334 Sand, green, coarse; abundant white quartz grains, clay lens at 270 to 278 feet
- 334 - 337 Shale, light-gray and tan; highly weathered
- 337 - 380 Shale, black; greasy, some thin light-green bentonite seams and chalky siltstone lenses (Pierre Shale)

* * * *

County: LAKE
 Legal Location: SW NW NW NW sec. 15, T. 106 N., R. 52 W.
 Latitude: 43.5950
 Land Owner:
 Project: LAKE-MOODY COUNTY STUDY
 Drilling Company: SDGS
 Driller: R. SNYDER
 Geologist: R. HAMMOND
 Date Drilled: 08-12-1980
 Ground Surface Elevation: 1690.00 T
 Total Drill Hole Depth: 350
 USGS Hydrological Unit Code: 10170203
 Electric Log Information:

Location: 106N-52W-15BBBC
 Longitude: 97.0410

Driller's Log:
 Geologist's Log: X
 Drilling Method: ROTARY

Test Hole Number: LM-19-80

Spontaneous Potential: X
Natural Gamma: X
Samples:

Single Point Resistivity: X
Extra:

0	-	1	Sand, yellow
1	-	26	Clay, yellow-brown, pebbly (till)
26	-	44	Clay, gray, pebbly; calcareous (till)
44	-	89	Silt, gray; calcareous
89	-	144	Clay, gray, pebbly; rocky from 89 to 94 feet (till)
144	-	158	Silt, reddish-brown; compact, calcareous
158	-	164	Clay, yellow and gray, mottled, sandy, pebbly (jointed till?)
164	-	177	Gravel, medium, very clayey
177	-	187	Clay, yellow, pebbly (till)
187	-	226	Silt, pink; with white, fine sand
226	-	264	Siltstone, gray, sandy
264	-	310	Sand, green, silty; well-rounded (western sand)
310	-	350	Shale, black; few bentonite beds (Pierre Shale)

* * * *

County: LAKE
Legal Location: NE SE SE SE sec. 15, T. 106 N., R. 52 W.
Latitude: 43.5800
Land Owner:
Project: LAKE-MOODY COUNTY STUDY
Drilling Company: SDGS
Driller: L. HELSETH
Geologist: R. HAMMOND
Date Drilled: 08-05-1982
Ground Surface Elevation: 1620.00 T
Total Drill Hole Depth: 365
Water Rights Well:
Other Well Name:
Basin: BIG SIOUX
Management Unit:
Screen Type: PVC, HM.
Casing Type: PVC
Casing Top Elevation:
Casing Stick-up: 3.00
Well Maintenance Date:
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Location: 106N-52W-15DDDA

Longitude: 97.0256

Driller's Log: X
Geologist's Log:
Drilling Method: ROTARY

Test Hole Number: R1-82-133
SDGS Well Name: R1-82-133

Aquifer:

Screen Length: 15.0
Casing Diameter: 2.0

Total Casing and Screen: 335

Single Point Resistivity:
Extra:

Screen slotted with circular saw.

0	-	2	Topsoil, black
2	-	19	Clay, yellow-brown, silty, pebbly (till)
19	-	50	Clay, gray, silty, pebbly (till)
50	-	63	Clay, gray, silty (lake clay)
63	-	127	Clay, gray, silty, pebbly (till)
127	-	233	Clay, tan, silty, pebbly (till)
233	-	255	Gravel, medium to coarse, sandy

255 - 260 Clay, gray (till)
 260 - 338 Gravel, medium to coarse, sandy
 338 - 365 Shale, dark-gray (Pierre Shale)

Very poor cuttings, suspect poor description and depth control below 260 feet.

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THIS LOG CONTAINS UNVERIFIED INFORMATION

County: LAKE
 Legal Location: SE SE sec. 01, T. 106 N., R. 53 W.
 Latitude: 44.0030
 Land Owner: L. YEAGER
 Project:
 Drilling Company: SIOUX WELL DRILLING
 Driller:
 Geologist:
 Date Drilled: 00-00-1984
 Ground Surface Elevation: 1715.00 T
 Total Drill Hole Depth: 250
 Water Rights Well:
 Other Well Name: PRIVATE
 Basin: BIG SIOUX
 Management Unit:
 Screen Type: PVC
 Casing Type: PVC
 Casing Top Elevation:
 Casing Stick-up:
 Well Maintenance Date:
 USGS Hydrological Unit Code: 10170203
 Electric Log Information:
 Spontaneous Potential:
 Natural Gamma:
 Samples:

Location: 106N-53W-01DD

Longitude: 97.0749

Driller's Log: X
 Geologist's Log:
 Drilling Method: ROTARY

Test Hole Number:
 SDGS Well Name:

Aquifer:

Screen Length: 10.0
 Casing Diameter: 5.0

Total Casing and Screen: 250

Single Point Resistivity:
 Extra:

Screen slot size .018. Static water level 104 feet.

0	-	1	Topsoil
1	-	10	Clay, yellow
10	-	22	Sand and gravel
22	-	75	Clay, gray
75	-	160	Clay, gray, sandy
160	-	205	Clay, yellow
205	-	220	Sand, fine
220	-	230	Clay
230	-	250	Sand, medium

* * * *

County: LAKE
 Legal Location: SW SE SE SW sec. 03, T. 106 N., R. 53 W.
 Latitude: 44.0027

Location: 106N-53W-03CDDC

Longitude: 97.1105

Land Owner:
 Project: LAKE-MOODY COUNTY STUDY
 Drilling Company: SDGS
 Driller: D. IVERSON
 Geologist: R. HAMMOND
 Date Drilled: 09-20-1982
 Ground Surface Elevation: 1718.00 T
 Total Drill Hole Depth: 350
 Water Rights Well:
 Other Well Name:
 Basin: BIG SIOUX
 Management Unit:
 Screen Type: PVC, MFG.
 Casing Type: PVC
 Casing Top Elevation:
 Casing Stick-up: 3.00
 Well Maintenance Date:
 USGS Hydrological Unit Code: 10170203
 Electric Log Information:
 Spontaneous Potential: X
 Natural Gamma: X
 Samples: X

Driller's Log:
 Geologist's Log: X
 Drilling Method: ROTARY

 Test Hole Number: R1-82-158
 SDGS Well Name: R1-82-158

 Aquifer: HOWARD

 Screen Length: 5.0
 Casing Diameter: 2.0

 Total Casing and Screen: 345

Single Point Resistivity: X
 Extra:

0	-	2	Topsoil, black
2	-	7	Clay, yellow-brown, silty
7	-	20	Gravel, coarse, sandy
20	-	33	Clay, yellow-brown, pebbly (till)
33	-	268	Clay, gray, sandy, pebbly; sand lens at 103 to 106 feet (till)
268	-	307	Clay, light-gray, very sandy, silty, pebbly (till)
307	-	338	Gravel, medium to coarse, very sandy
338	-	350	Siltstone, light-gray, clayey; calcareous (Niobrara Formation)

* * * *

County: LAKE
 Legal Location: NE SE SE NE sec. 04, T. 106 N., R. 53 W.
 Latitude: 44.0103
 Land Owner:
 Project: LAKE-MOODY COUNTY STUDY
 Drilling Company: SDGS
 Driller: M. THOMPSON
 Geologist: R. HAMMOND
 Date Drilled: 08-27-1980
 Ground Surface Elevation: 1700.00 T
 Total Drill Hole Depth: 410
 USGS Hydrological Unit Code: 10170203
 Electric Log Information:
 Spontaneous Potential:
 Natural Gamma:
 Samples:

Location: 106N-53W-04ADDA

 Longitude: 97.1120

Driller's Log:
 Geologist's Log: X
 Drilling Method: ROTARY

 Test Hole Number: LM-27C-80

Single Point Resistivity:
 Extra:

0	-	18	Clay, yellow-brown, silty, sandy (till)
18	-	56	Sand, medium to coarse, pebbly
56	-	96	Clay, gray, silty, sandy, pebbly (till)
96	-	114	Gravel, fine to coarse

114 - 155 Clay, gray, silty, sandy
 155 - 325 Clay, gray, silty, sandy, pebbly (till)
 325 - 380 Clay(?), very pebbly (till)
 380 - 410 Chalk, gray, silty; very calcareous (Niobrara Formation)

* * * *

County: LAKE Location: 106N-53W-15CCCD
 Legal Location: SE SW SW SW sec. 15, T. 106 N., R. 53 W.
 Latitude: 43.5845 Longitude: 97.1120
 Land Owner:
 Project: LAKE-MOODY COUNTY STUDY
 Drilling Company: SDGS
 Driller: R. SNYDER/T. CONNER Driller's Log:
 Geologist: R. HAMMOND Geologist's Log: X
 Date Drilled: 08-15-1980 Drilling Method: ROTARY
 Ground Surface Elevation: 1700.00 T
 Total Drill Hole Depth: 335 Test Hole Number: LM-20-80
 USGS Hydrological Unit Code: 10170203
 Electric Log Information:
 Spontaneous Potential: Single Point Resistivity:
 Natural Gamma: Extra:
 Samples:

0 - 6 Sand, brown, bouldery
 6 - 9 Clay, yellow, pebbly (till)
 9 - 33 Clay, gray, silty, sandy, pebbly (till)
 33 - 42 Sand and gravel, medium to coarse
 42 - 121 Silt, gray; calcareous
 121 - 126 Gravel, medium
 126 - 260 Clay, gray, silty, pebbly; calcareous (till)
 260 - 293 Silt, gray, sandy (lacustrine?)
 293 - 302 Gravel, fine to medium, sandy
 302 - 318 Clay, gray, silty, sandy; with several thin gravel stringers
 318 - 335 Chalk, light-gray, silty; very calcareous, lost all water downhole at 335 feet (Niobrara Formation)

* * * *

 THIS LOG CONTAINS UNVERIFIED INFORMATION

County: LAKE Location: 106N-53W-21AAA
 Legal Location: NE NE NE sec. 21, T. 106 N., R. 53 W.
 Latitude: 43.5839 Longitude: 97.1125
 Land Owner: T. NELSON
 Project:
 Drilling Company: TORGRUDE WELL DRILLING
 Driller:
 Geologist: Driller's Log: X
 Date Drilled: 05-23-1983 Geologist's Log:
 Ground Surface Elevation: 1711.00 T Drilling Method: ROTARY
 Total Drill Hole Depth: 226 Test Hole Number:
 Water Rights Well: SDGS Well Name:

Other Well Name: PRIVATE
Basin: BIG SIOUX
Management Unit:
Screen Type: PVC
Casing Type: PVC
Casing Top Elevation:
Casing Stick-up:
Well Maintenance Date:
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential:
Natural Gamma:
Samples:

Aquifer:
Screen Length:
Casing Diameter: 4.0
Total Casing and Screen: 225
Single Point Resistivity:
Extra:

Screen slot size .010. Static water level 200 feet.

0	-	45	Clay, yellow
45	-	210	Clay, blue
210	-	224	Sand
224	-	226	Clay, blue

* * * * *

County: LAKE
Legal Location: SE SE SW SW sec. 34, T. 107 N., R. 52 W.
Latitude: 44.0120
Land Owner:
Project: LAKE-MOODY COUNTY STUDY
Drilling Company: SDGS
Driller: M. THOMPSON/T. CONNER
Geologist: R. HAMMOND
Date Drilled: 08-27-1980
Ground Surface Elevation: 1690.00 T
Total Drill Hole Depth: 323
USGS Hydrological Unit Code: 10170203
Electric Log Information:
Spontaneous Potential: X
Natural Gamma:
Samples:

Location: 107N-52W-34CCDD
Longitude: 97.0410
Driller's Log:
Geologist's Log: X
Drilling Method: ROTARY
Test Hole Number: LM-28-80
Single Point Resistivity: X
Extra:

0	-	32	Clay, yellow-brown, silty, pebbly (till)
32	-	132	Clay, gray, silty, pebbly (till)
132	-	158	Silt, light-gray-brown
158	-	191	Clay, yellow-brown, pebbly (till)
191	-	197	Clay, gray, silty, sandy; very compact, shaley (till)
197	-	211	Silt, dark-brown, sandy
211	-	278	Silt, light-reddish-brown to pink, clayey
278	-	323	Shale, dark-gray; smooth (Pierre Shale)

* * * * *

County: LAKE
Legal Location: SE SE SE SE sec. 36, T. 107 N., R. 52 W.
Latitude: 44.0140
Land Owner:

Location: 107N-52W-36DDDD
Longitude: 97.0034

Project: LAKE-MOODY COUNTY STUDY

Drilling Company: SDGS

Driller: R. GRAVHOLT/D. IVERSON

Geologist: R. HAMMOND

Date Drilled: 07-29-1982

Ground Surface Elevation: 1680.00 T

Total Drill Hole Depth: 440

USGS Hydrological Unit Code: 10170203

Electric Log Information:

Spontaneous Potential: X

Natural Gamma: X

Samples: X

Driller's Log:

Geologist's Log: X

Drilling Method: ROTARY

Test Hole Number: R1-82-125

Single Point Resistivity: X

Extra:

0	-	1	Topsoil, black
1	-	12	Clay, yellow, silty (loess)
12	-	32	Clay, brown, silty, sandy, pebbly (till)
32	-	60	Clay, gray, silty, sandy, pebbly (till)
60	-	73	Sand, red-brown, fine
73	-	185	Clay, gray, sandy, pebbly (till)
185	-	204	Clay, brown, sandy, pebbly (till)
204	-	224	Gravel, medium to coarse, clayey, sandy
224	-	258	Clay, brown, sandy; light-gray from 230 to 245 feet and pink from 245 to 258 feet, intermittently varved (lake clay)
258	-	270	Shale, yellow (Crow Creek Member - Pierre Shale)
270	-	330	Shale, gray-brown; greasy, some thin bentonite beds (Pierre Shale)
330	-	430	Siltstone, gray, very shaley; slightly calcareous
430	-	440	Shale, gray; very hard, drills into hard, long slivers (Carlile Shale?)

* * * *

APPENDIX D

Data from the Howard aquifer test

Drawdown period: March 23 to 26, 1982
Start time: 03:00 p.m. (15:00)
Recovery period: March 26 to April 1, 1982
Start time: 10:05 a.m. (10:05)

Pumping well: Municipal well 11
Discharge: 240.83 gallons per minute

Distance from pumping well (ft)	Well ID	Location (see app. A)	Drill-site number see log in appendix A	Log in appendix C
---	--	106N-52W-08CADB	--	Municipal well 11
52.40	MD-81-14	106N-52W-08CADB 1	3	---
99.10	MD-81-16	106N-52W-08BCDB 2	4	---
600	--	106N-52W-08CAAA	--	Municipal well 10
3200	MD-81-8	106N-52W-08DAAA 2	6	---
9900	MD-81-2	106N-52W-19BBBA	9	---
7200	MD-81-1	106N-52W-07CCCC	2	---

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Drawdown data

Well: City 11

Static water level = 80.00 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/23/82	15:00	80.00
	15:01	124.00
	15:02	126.30
	15:03	129.20
	15:04	129.50
	15:05	130.02
	15:06	130.03
	15:07	130.04
	15:08	130.05
	15:09	130.07
	15:10	130.08
	15:12	131.01
	15:14	131.03
	15:16	131.45
	15:18	131.60
	15:20	131.75
	15:25	133.00
	15:30	133.20
	15:35	133.40
	15:40	133.60
	15:45	134.25
	15:50	134.30
03/24/82	16:00	134.70
	16:10	135.10
	16:30	135.60
	17:00	135.95
	17:54	136.51
	19:30	137.23
	22:26	138.25
	05:23	139.50
	09:06	139.82
	14:32	139.25
03/25/82	17:28	139.56
	09:02	140.87
03/26/82	18:10	141.29
	08:49	142.03

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Recovery data

Well: City 11

Static water level = 80.00 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/26/82	10:05	142.10
	10:06	115.00
	10:07	98.35
	10:08	95.00
	10:09	93.15
	10:10	92.35
	10:11	91.80
	10:12	91.50
	10:13	91.25
	10:14	91.05
	10:15	90.80
	10:16	90.60
	10:18	90.35
	10:20	90.20
	10:22	90.00
	10:24	89.80
	10:30	89.40
	10:35	89.20
	10:40	89.00
	10:45	88.80
	11:00	88.40
11:20	88.00	
11:40	87.70	
12:00	87.50	
12:32	87.18	
13:00	86.82	
13:30	86.50	
14:01	86.36	
14:42	86.04	
15:51	85.73	
03/27/82	08:14	83.58
03/28/82	08:44	82.42
03/29/82	08:35	81.90
03/30/82	08:05	81.40
03/31/82	08:10	81.20
04/01/82	08:10	81.10

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Drawdown data

Well: MD-81-14

Distance from pumping well = 52.4 feet

Static water level = 81.2 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/23/82	15:00	81.20
	15:01	84.13
	15:02	86.40
	15:03	87.37
	15:04	88.32
	15:05	88.40
	15:06	88.50
	15:07	88.54
	15:08	88.74
	15:09	89.00
	15:10	89.25
	15:12	89.45
	15:14	89.62
	15:16	89.78
	15:18	89.80
	15:20	89.90
	15:25	90.20
	15:30	90.38
	15:35	90.55
	15:40	90.82
	15:45	91.00
	15:50	91.22
	16:00	91.50
16:10	91.70	
16:31	92.15	
17:01	92.60	
17:56	93.19	
19:33	94.00	
22:29	95.00	
03/24/82	05:25	96.32
	09:08	96.64
	14:34	97.02
03/25/82	17:30	97.25
	09:05	98.45
03/26/82	18:11	98.94
	08:51	99.50

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Recovery data

Well: MD-81-14

Distance from pumping well = 52.4 feet

Static water level = 81.2 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/26/82	10:05	99.61
	10:06	99.41
	10:07	95.98
	10:08	94.30
	10:09	93.05
	10:10	92.67
	10:11	92.36
	10:12	92.29
	10:13	92.01
	10:14	91.81
	10:15	91.73
	10:17	91.46
	10:19	91.26
	10:21	91.10
	10:23	90.97
	10:25	90.85
	10:30	90.58
	10:35	90.37
	10:40	90.15
	10:45	90.00
	11:00	89.58
11:20	89.18	
11:40	88.85	
12:00	88.61	
12:34	88.19	
13:02	87.93	
13:32	87.71	
14:03	87.55	
14:44	87.16	
15:52	86.73	
03/27/82	08:18	84.60
03/28/82	08:47	83.52
03/29/82	08:30	82.75
03/30/82	08:00	82.55
03/31/82	08:10	82.45
04/01/82	08:10	82.25

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Drawdown data

Well: MD-81-16

Distance from pumping well = 99.1 feet

Static water level = 81.28 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/23/82	15:00	81.28
	15:01	82.56
	15:02	83.69
	15:03	84.44
	15:04	84.86
	15:05	85.23
	15:06	85.55
	15:07	85.73
	15:08	85.91
	15:09	86.07
	15:10	86.18
	15:12	86.43
	15:14	86.65
	15:16	86.82
	15:18	86.96
	15:20	87.12
	15:25	87.44
	15:30	87.63
	15:35	87.82
	15:40	87.98
	15:45	88.14
	15:50	88.38
	16:00	88.63
	16:10	88.83
16:30	89.25	
17:00	89.69	
17:53	90.25	
19:25	91.02	
22:25	91.95	
03/24/82	05:20	93.35
	09:04	93.73
	12:28	94.11
	17:26	94.41
03/25/82	09:00	95.51
	18:07	96.00
03/26/82	08:46	97.09

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Recovery data

Well: MD-81-16

Distance from pumping well = 99.1 feet

Static water level = 81.28 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/26/82	10:05	96.71
	10:06	96.41
	10:07	95.38
	10:08	94.08
	10:09	93.45
	10:10	93.00
	10:11	92.72
	10:12	92.45
	10:13	92.21
	10:14	92.04
	10:15	91.89
	10:16	91.59
	10:18	91.48
	10:20	91.25
	10:22	91.11
	10:24	90.96
	10:30	90.59
	10:35	90.38
	10:40	90.22
	10:45	90.04
	11:00	89.70
11:20	89.20	
11:40	89.00	
12:00	88.68	
12:34	88.35	
12:59	88.03	
13:28	87.85	
13:59	87.64	
14:40	87.35	
15:49	87.02	
03/27/82	08:08	84.91
03/28/82	08:39	83.69
03/29/82	08:40	83.20
03/30/82	08:00	82.65
03/31/82	08:10	82.60
04/01/82	08:20	82.41

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Drawdown data

Well: City 10

Distance from pumping well = 600 feet

Static water level = 83.49 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/23/82	15:00	83.49
	15:05	83.49
	15:10	83.59
	15:15	83.84
	15:20	84.09
	15:34	84.39
	15:42	84.59
	15:52	84.79
	16:03	84.99
	16:12	85.19
	16:23	85.39
	16:33	85.49
	16:45	85.63
	17:10	85.96
	18:05	86.64
	19:42	87.32
03/24/82	22:33	87.47
	05:37	89.51
	09:16	90.09
	14:45	90.63
03/25/82	17:21	90.98
	09:15	92.17
03/25/82	18:24	92.74
	09:10	93.27

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Recovery data

Well: City 10

Distance from pumping well = 600 feet

Static water level = 83.49 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/26/82	10:05	93.37
	10:10	93.27
	10:20	92.98
	10:30	92.68
	10:40	92.47
	10:50	92.28
	11:00	92.08
	11:20	91.93
	11:40	91.57
	12:00	91.28
	12:40	90.94
	13:08	90.39
	13:35	90.15
	14:13	90.01
	14:48	89.76
	16:00	89.34
02/27/82	08:23	87.13
03/28/82	08:52	85.95
03/29/82	08:45	85.39
03/30/82	08:15	84.94
03/31/82	08:10	84.79
04/01/82	08:30	84.61

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Drawdown data

Well: MD-81-8

Distance from pumping well = 3200 feet

Static water level = 80.30 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/23/82	15:00	80.30
03/24/82	09:25	80.33
03/25/82	09:24	80.46
03/25/82	18:26	80.52
03/26/82	08:37	80.62

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Recovery data

Well: MD-81-8

Distance from pumping well = 3200 feet

Static water level = 80.30 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/26/82	10:05	80.62
03/27/82	08:30	80.65
03/28/82	08:57	80.63
03/29/82	09:15	80.61
03/30/82	08:20	80.41
03/31/82	09:00	80.40
04/01/82	09:00	80.42

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Drawdown data

Well: MD-81-2

Distance from pumping well = 9900 feet

Static water level = 135.63 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/23/82	15:00	135.63
03/24/82	09:39	135.70
03/25/82	09:34	136.22
03/25/82	06:40	136.42
03/26/82	08:26	136.74

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Recovery data

Well: MD-81-2

Distance from pumping well = 9900 feet

Static water level = 135.63 feet

Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/26/82	10:05	136.74
03/27/82	08:41	136.79
03/28/82	09:07	136.68
03/29/82	10:00	136.55
03/30/82	08:30	136.35
03/31/82	09:00	136.35
04/01/82	09:00	136.20

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Drawdown data

Well: MD-81-1
 Distance from pumping well = 7200 feet
 Static water level = 106.22 feet
 Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/26/82	10:05	136.74
03/23/82	15:00	106.22
03/24/82	09:45	106.75
03/25/82	09:45	107.43
03/25/82	18:45	108.64
03/26/82	08:18	107.98

**MADISON CITY STUDY AQUIFER TEST USING CITY WELL 11
AS THE PUMPING WELL**

Recovery data

Well: MD-81-1
 Distance from pumping well = 7200 feet
 Static water level = 106.22 feet
 Pumping rate = 240.83 gallons per minute

Date	Time	Water level (ft)
03/26/82	10:05	136.74
03/26/82	10:05	107.98
03/27/82	08:50	107.96
03/28/82	09:14	107.75
03/29/82	09:45	107.60
03/30/82	09:35	107.30
03/31/82	09:00	107.30
04/01/82	09:30	107.20