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INVESTIGATION OF GROUND WATER RESOURCES IN PORTIONS OF ROBERTS COUNTY, SOUTH DAKOTA

by

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INTRODUCTION

Ground water resources are scarce over parts of Roberts County. Where aquifers exist, they are often of limited extent or provide water of generally poor quality. The Lake Traverse-Roberts County Rural Water System has been established to address this problem and to provide good quality water to residents and businesses in the area. In April 1993, the Lake Traverse-Roberts County Rural Water System requested that the South Dakota Geological Survey attempt to delineate the areal extent and define the water quality of aquifers in portions of Roberts, Marshall, and Day Counties which might serve as a water source for this endeavor. Two separate areas became the primary focus of this investigation (fig. 1), an area around the current well field for the city of Sisseton which draws water from the Veblen aquifer (fig. 2), and an area in southwestern Roberts County where occurrences of the Coteau Lakes aquifer were presumed to exist (fig. 3).

Previous water resources investigations in Roberts County were restricted to the areas around Peever (Barari and Buehrer, 1974), Rosholt (Wong, 1960), and Sisseton (Tipton, 1960), and did not provide adequate information for the entire county.

The results of the investigation, conducted by the South Dakota Geological Survey, are presented in this report. The investigation was financed by the Lake Traverse-Roberts County Rural Water System and the South Dakota Geological Survey.

METHODS

Drilling

Forty-one test holes, along with 14 observation wells, were completed for this investigation. Drilling was accomplished by using a forward mud rotary drill rig with a bit diameter of 5 inches. Samples were collected from the drill cuttings at 10-foot intervals and a lithologic log was written. The samples and the lithologic log were used to determine the suitability of the test hole for well construction.

Additional information was obtained from logs of preexisting test holes and observation wells which had been completed for other projects in the area of study. A list of the test hole and observation well logs utilized in the two primary areas of study (figs. 2 and 3) are included in appendix A. Appendix B lists the locations of other test holes and observation wells in Roberts, Marshall, and Day Counties used to determine the areas of focus for this investigation. Copies of the test hole and observation well logs are available from the South Dakota Geological Survey in Vermillion, South Dakota.

Well Construction and Development

Observation wells were constructed using 2-inch diameter, schedule 40, threaded, polyvinyl chloride casing and screen. Filter pack was placed through a tremie line to a depth that covered the entire screen and provided a factor for settlement around the screen. Bentonite grout was then placed in the remaining annular space from the top of the filter pack to a depth no less than 20 feet below ground

surface. The remaining annular space to the land surface was filled with neat cement grout. In those observation wells where the filter pack depth was above or near 20 feet below land surface, neat cement grout was placed directly on the filter pack with no bentonite grout added. After placement of the cement grout, a locking steel well protector was installed.

Observation wells completed for this study were developed using a variety of methods depending on depth to water and rate of recharge to the well. All wells were pumped until the water temperature and conductivity had stabilized and the well water was clear.

Water Sampling and Analyses

Sampling procedures were consistent with the *South Dakota Geological Survey Water Sampling Manual* (Coker and others, 1988). A minimum of 3 well volumes of water was extracted before sampling occurred and the samples were collected using a laboratory-cleaned teflon bailer.

Water samples were analyzed for major cations and anions (app. C). Water quality analyses were performed by the Basic and Analytical Studies Laboratory at the South Dakota Geological Survey. Appendix C also contains the results of previous water quality analyses from preexisting observation wells. Unless otherwise noted, all comments concerning water quality are in reference to samples collected for this investigation only.

RESULTS OF INVESTIGATION

Geology

In general, the geology of the study area consists of glacial deposits, of varying thickness, overlying older bedrock (Lawrence, 1989). Table 1 shows the geologic unit or formation names, their relative ages, and provides a brief description of each unit known to be present in the study area.

Bedrock

The bedrock in the Roberts County area consists of a series of layered sedimentary rocks deposited during the period of geologic time known as the Cretaceous (65 to 144 million years ago). These sediments include (from oldest to youngest) the Dakota Formation, Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, and the Pierre Shale (table 1).

The bedrock surface underlying the study area slopes toward the northeast (Gilbertson, 1985). Test holes have encountered bedrock at elevations of 1,450 feet above mean sea level along the western edge of Roberts County (Koch, 1975; Leap, 1988). Pierre Shale exposures just west of Sisseton are at an elevation of roughly 1,400 feet above mean sea level (Shurr and others, 1987). East of Sisseton, test holes have encountered bedrock at progressively lower elevations. Exposures of the Niobrara Formation and the Carlile Shale near Lake Traverse are found as low as 970 feet above mean sea level (Shurr and others, 1987). The older units (Graneros Shale and Dakota Formation) are encountered only in test holes or wells that penetrate the younger units.

Glacial Deposits

The glacial sediments, deposited during multiple ice advances during the Pleistocene Epoch (10,000 to 1,600,000 years ago), are younger than the bedrock sediments and consist primarily of till and outwash (Flint, 1955; Gilbertson, 1989). Till is a heterogeneous mixture of sand, gravel, and boulders in a predominantly fine-grained matrix of clay and silt. Outwash consists mainly of sand and gravel, with minor amounts of clay and silt. Scattered, water saturated outwash bodies are found throughout the area. Two of these units are large enough to be formally recognized as aquifers in the study area; the Veblen aquifer (Hedges and others, 1982) and the Coteau Lakes aquifer (Koch, 1975).

The thickness of the glacial sediments varies tremendously over the area of investigation. Thicknesses in excess of 1,000 feet are projected for southwestern Roberts County, based on drilling in adjacent parts of Day and Grant Counties (Gilbertson, 1985). Sediment thickness decreases rapidly to the north and east, being reduced to 25 feet or less in the central part of the county, but then increases to 200 to 300 feet in the northern part. Bedrock exposures are found in areas where post-glacial erosion has removed the thin glacial cover.

VEBLEN AQUIFER

The Veblen aquifer is the name applied to water-bearing sand and gravel (outwash) deposit found in northern and eastern Roberts County, a portion of which is shown in figure 2. Although originally defined as a buried aquifer (Hedges and others, 1982), additional drilling in the area around the Sisseton city well field indicates that portions of the aquifer are at the surface (figs. 4, 5, and 6). The lateral extent of the aquifer is poorly defined, and full delineation of this aquifer is beyond the scope of this investigation. Test holes that fully penetrated the aquifer encountered either till or Pierre Shale.

COTEAU LAKES AQUIFER

The Coteau Lakes aquifer is the name applied to a number of water-bearing sand and gravel (outwash) deposits found in southeastern Marshall, eastern Day, and southwestern Roberts Counties, a portion of which is shown in figure 3. In most instances these are surficial units (figs. 7 and 8), although they are locally covered by thin (less than 50 feet thick) deposits of till. They are most often adjacent to, and hydraulically connected with, one or more of the large lakes in these areas. A maximum thickness of 60 feet was encountered at NW NW NW SW sec. 35, T. 123 N., R. 52 W. (map location 18 - fig. 3 and app. A) in southwestern Roberts County. The outwash was deposited by meltwater during the final stages of the last glaciation. Till was found beneath the aquifer wherever the full thickness was penetrated.

Hydrology

Bedrock Aquifers

The Dakota aquifer underlies all of Roberts County (Hedges and others, 1982) and is the only bedrock unit that has the potential for yielding water in the area. The top of the Dakota aquifer is found

at an elevation of about 600 feet above mean sea level in the area (Shurr and others, 1987), requiring wells ranging from 400 to 1,400 deep, depending on where in the county they are drilled. Water quality is generally inferior to that found in the glacial aquifers in the region (Koch, 1975; Leap, 1988; Lawrence, 1989), and for this reason the Dakota aquifer was not considered during this investigation. Dakota aquifer wells are utilized in the areas when no other water source is available.

Veblen Aquifer

The areal extent of the Veblen aquifer has not been fully determined. Hedges and others (1982) indicate that it underlies approximately 809 square miles of Grant, Marshall, and Roberts Counties, although this interpretation was based on limited information. Drilling for this study, and other work in the vicinity of the Sisseton city well field, has failed to encounter all the limits of the Veblen aquifer (fig. 2). Water levels measured in wells completed in this aquifer indicate that it is under both confined and unconfined conditions. Water elevations in the Veblen aquifer on June 17, 1994, are shown in figure 9. Note that in general, ground water levels are similar throughout the central portion of the study area, but appear to drop off to the north. More detailed surveys of the observation wells will be required to resolve the direction(s) of ground water movement in this area.

Water quality in the Veblen aquifer is generally poorer than that of the Coteau Lakes aquifer (table 2; app. C). The following summary of water quality data pertains to samples collected in 1993 for this investigation. Total dissolved solids concentrations range from 348 to 1120 milligrams per liter (mg/L) with an average of 547 mg/L. Sulfates range from 31 to 504 mg/L with an average of 155 mg/L. Hardness concentrations range from 300 to 830 mg/L with an average of 442 mg/L. Concentrations of iron range from 0.18 to 1.59 mg/L with an average of 0.87 mg/L. The concentrations of manganese range from 0.12 to 0.46 mg/L with an average of 0.33 mg/L. Nitrates were not detected in any samples collected for this investigation.

Coteau Lakes Aquifer

The areal extent of the Coteau Lakes aquifer has not been fully determined, in part because it is consists of a number of similar, but separate units (Koch, 1975). Figure 3 shows the limits of the aquifer in part of southwestern Roberts County, where it covers an area of approximately 20 square miles. The Coteau Lakes aquifer in this area is surficial and is under unconfined conditions (figs. 7 and 8). Water levels, and inferred ground water flow directions, in Coteau Lakes aquifer on June 17, 1994, are shown in figure 10. Note that in general, ground water flow is to the southwest.

Water quality in the Coteau Lakes aquifer is generally better than that of the Veblen aquifer (table 2; app. C). The following summary of water quality data pertains to samples collected in 1993 for this investigation. Total dissolved solids concentrations range from 209 to 396 mg/L with an average of 314 mg/L. Sulfates range from 5 to 37 mg/L with an average of 19 mg/L. Hardness concentrations range from 190 to 340 mg/L with an average of 278 mg/L. Concentrations of iron range from less than 0.05 to 6.69 mg/L with an average of 3.57 mg/L when detected (only 3 of 21 samples). The concentrations of manganese range from less than 0.05 to 0.75 mg/L with an average of 0.65 mg/L when detected (only 3 of 18 samples). The concentration of nitrate range from less than 0.04 to 20.7 mg/L with an average of 4.74 mg/L (15 of 21 samples).

SUMMARY AND RECOMMENDATIONS

As noted above, abundant, good quality water is not readily available in parts of the Roberts County area, and a rural water system would provide a needed service to individuals and businesses. This investigation identified two possible water sources: the Veblen aquifer east of Sisseton, and the Coteau Lakes aquifer in the southwestern part of Roberts County, just north of the town of Ortley.

It is recommended that the Lake Traverse-Roberts County Rural Water System examine the possibility of utilizing the Veblen aquifer as its water source. This recommendation is based on several factors:

A. Quantity of water available: The true potential yield of the aquifer in the vicinity of the Sisseton city well field has not been determined, but it does appear to exceed the current estimated requirements of both the city and the Lake Traverse-Roberts County Rural Water System. Aquifer tests run on the city's no. 5 production well indicate the Veblen aquifer in this area is capable of producing up to 600 gallons per minute. By contrast, the Coteau Lakes aquifer near Ortley has been extensively utilized, and additional use would be subject to impact on current water rights holders.

B. Water quality: While the overall quality of ground water is better in the Coteau Lakes aquifer, the presence of detectable nitrates (up to 20.7 mg/L) is a problem. Nitrates have been detected in this unit for as long as water quality records are available (app. C), and the indication is that this problem is likely to degrade further. By contrast, nitrates have only been detected a few times in the Veblen aquifer (app. C), and then the detected levels were quite low ($\leq$0.30 mg/L). Nitrate contamination of wells is a growing concern, and avoidance of aquifers known to have a nitrate problem is strongly recommended.

   Table 3 is a comparison of water quality changes in the Veblen aquifer over a period of roughly 12 years. The 1981 water samples were collected when the area was first investigated, prior to additional well development and the establishment of a regional landfill in the area. While water quality varies between the individual wells, there has been little change over the 12 years suggesting that the aquifer is capable of supporting substantial development without degradation of water quality.

If the Lake Traverse-Roberts County Rural Water System decides to develop an area in the Veblen or any other aquifer, it is recommended that the following be addressed before the final production well and water distribution system is installed.

1. Site specific hydrogeologic exploration should be performed to better determine aquifer thickness and lithology, water levels, and water quality in the aquifer.

2. An aquifer test (or tests) should be performed to allow predictions of water yield from the aquifer, as well as to determine the potential for impact on the well field operated by the city of Sisseton.

3. The Department of Environment and Natural Resources (Water Rights Program) should be contacted regarding a water right permit.

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Figure 1. Location of study areas.

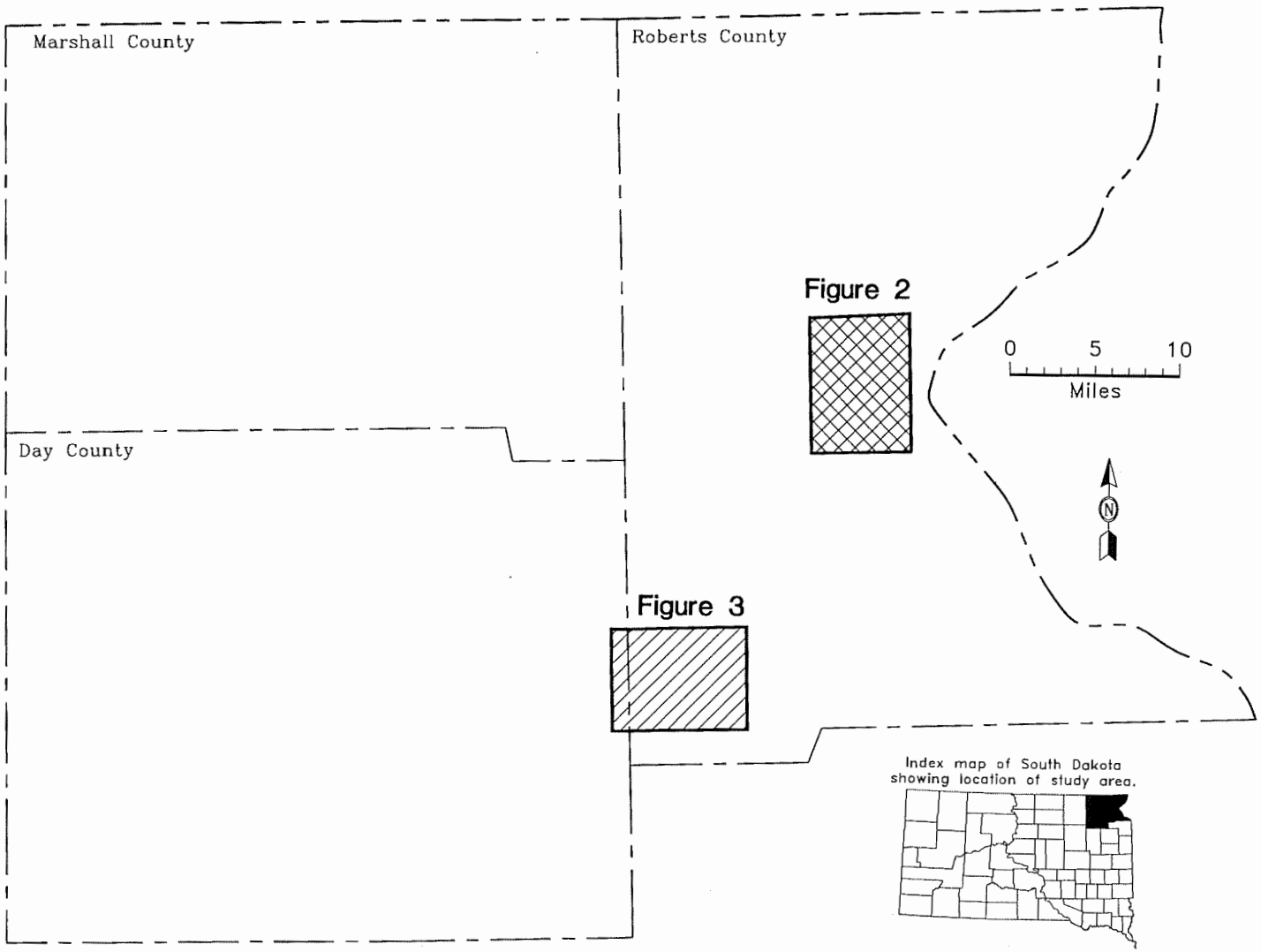

Figure 2. Location of the Veblen aquifer and test holes and observation wells in east-central Roberts County, South Dakota.

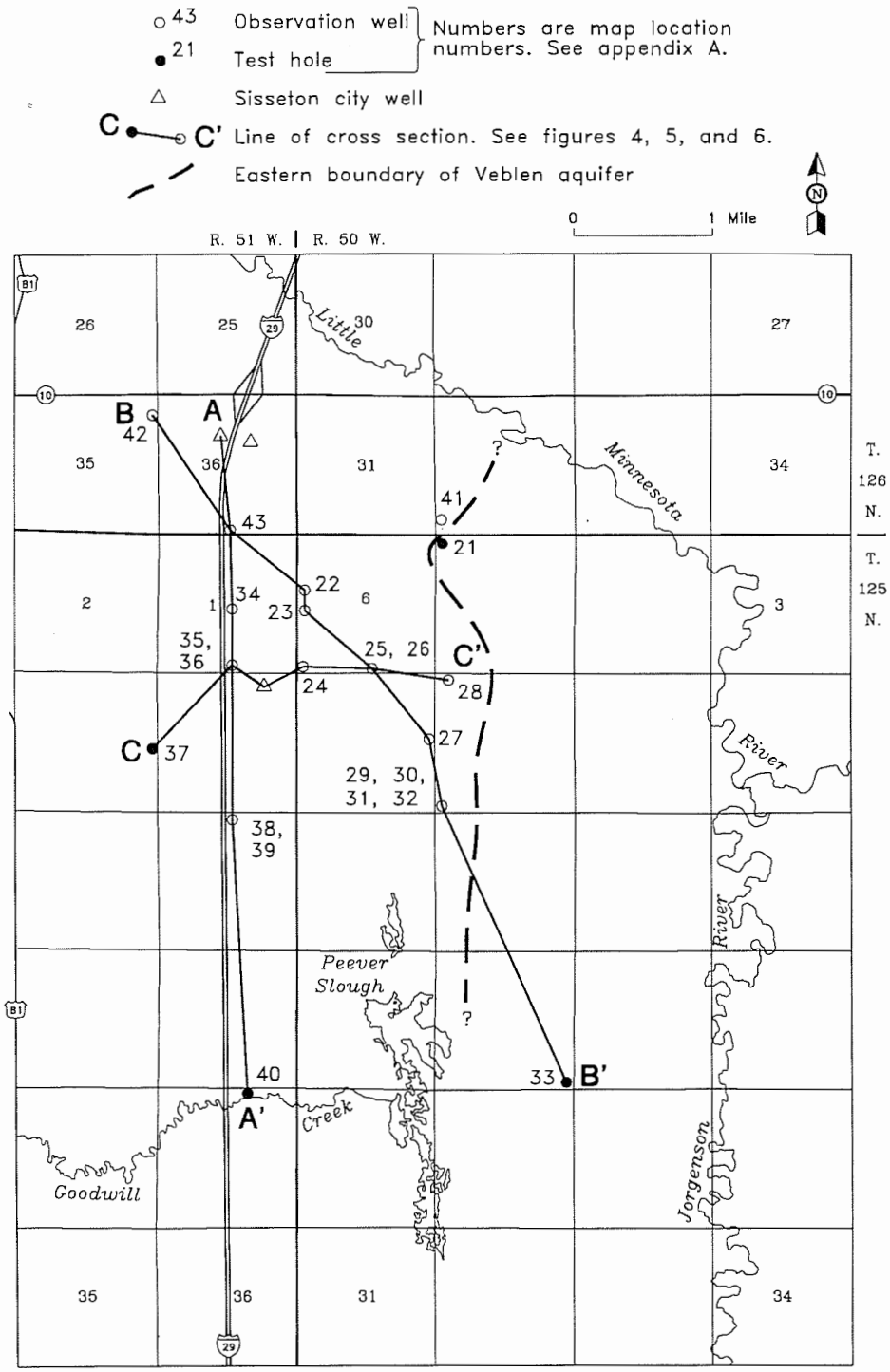

Figure 3. Location of the Coteau Lakes aquifer and test holes and observation wells in southwestern Roberts County, South Dakota.

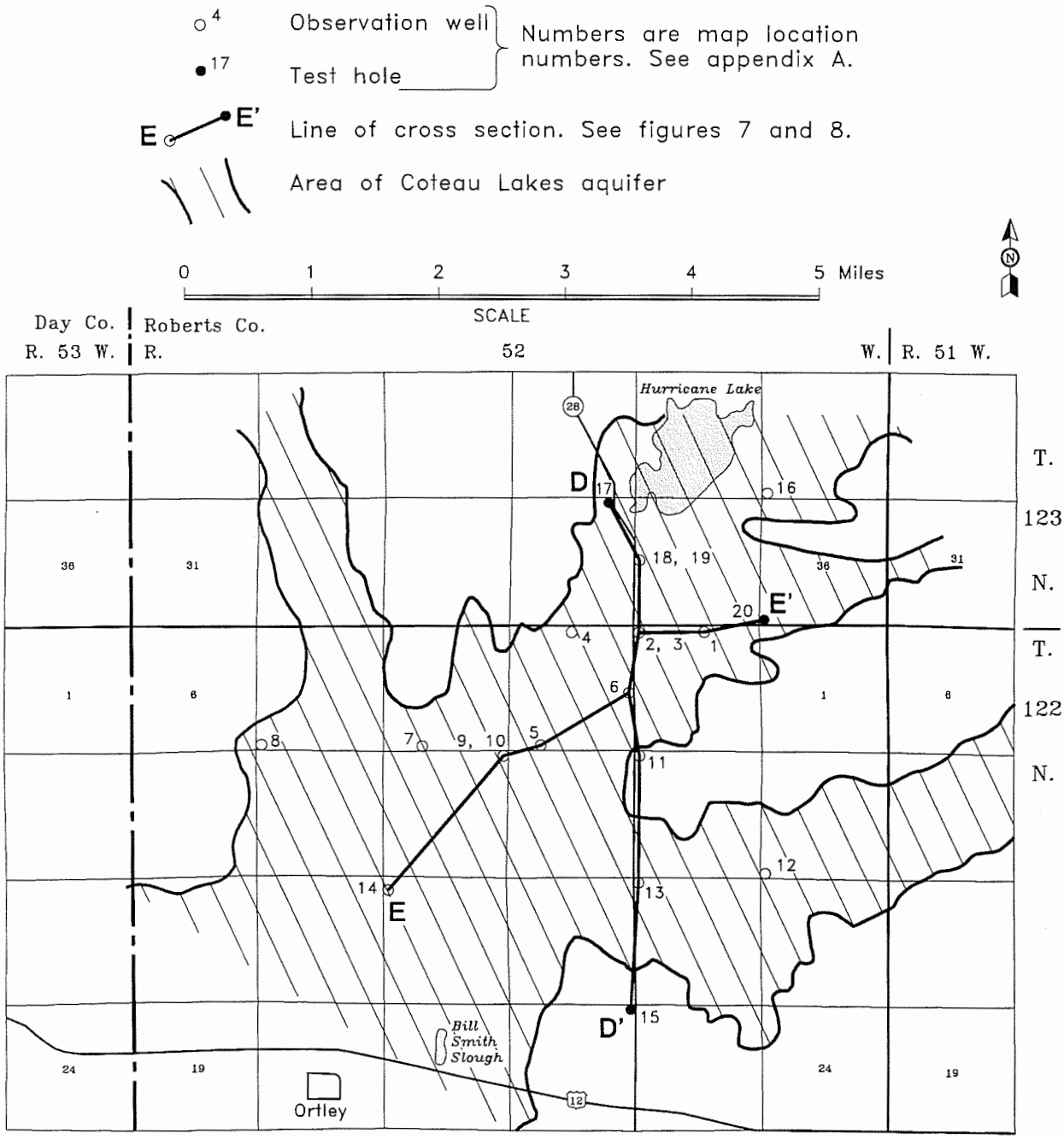

Figure 4. Geologic cross section A-A'.

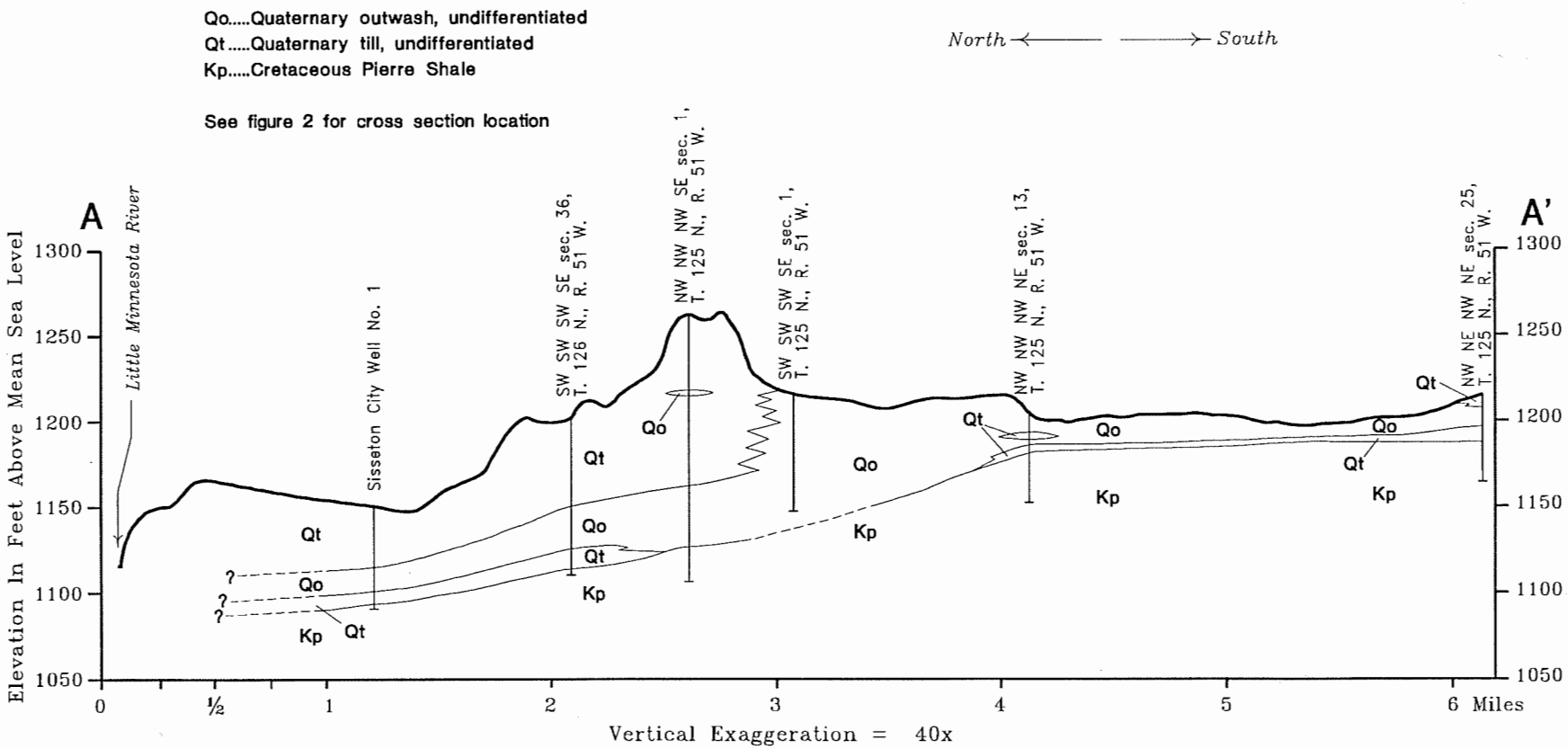

Figure 5. Geologic cross section B-B'.

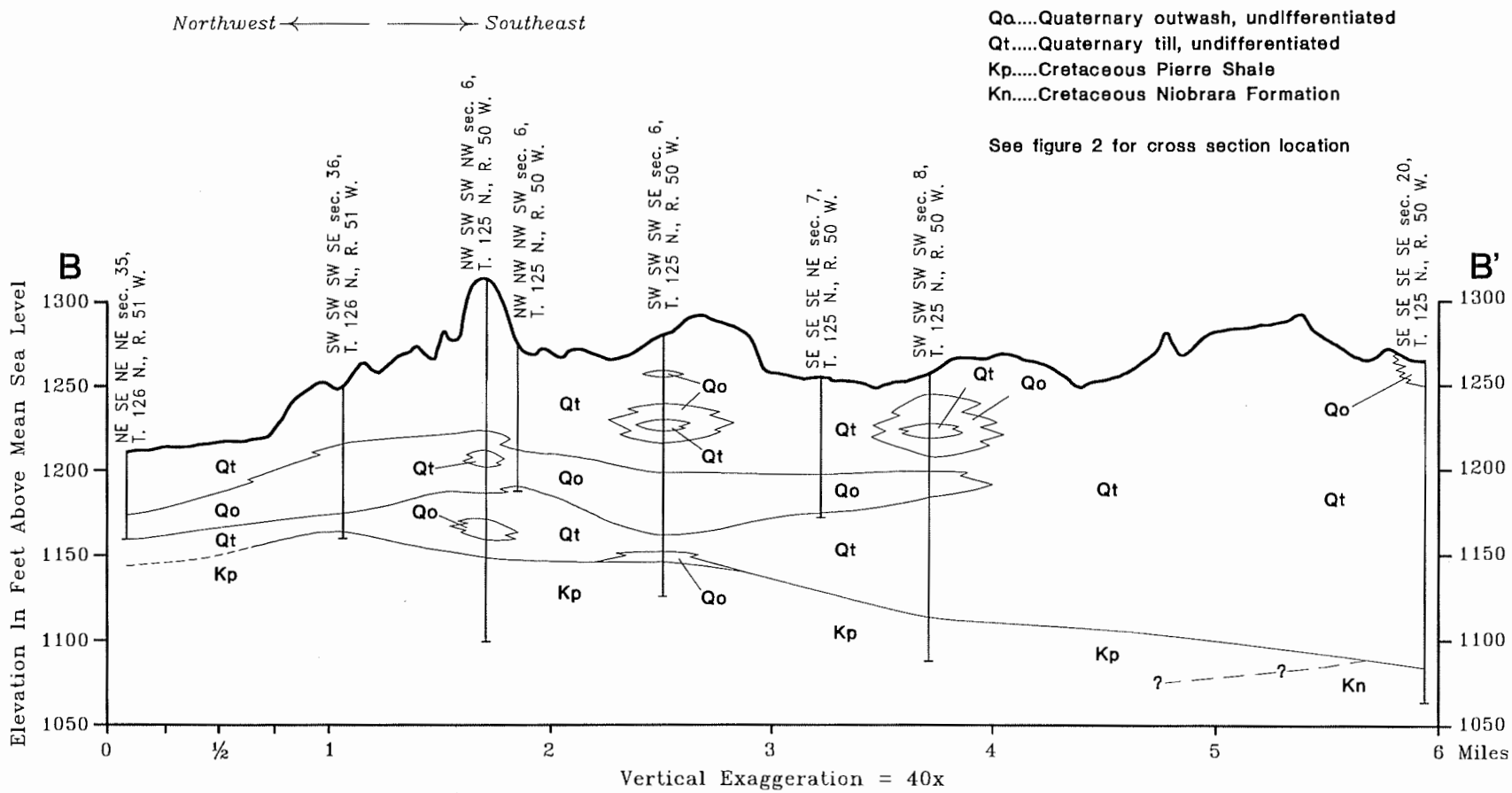

Figure 6. Geologic cross section C-C'.

West ← → *East*

Qo.....Quaternary outwash, undifferentiated
Qt.....Quaternary till, undifferentiated
Kp.....Cretaceous Pierre Shale

See figure 2 for cross section location

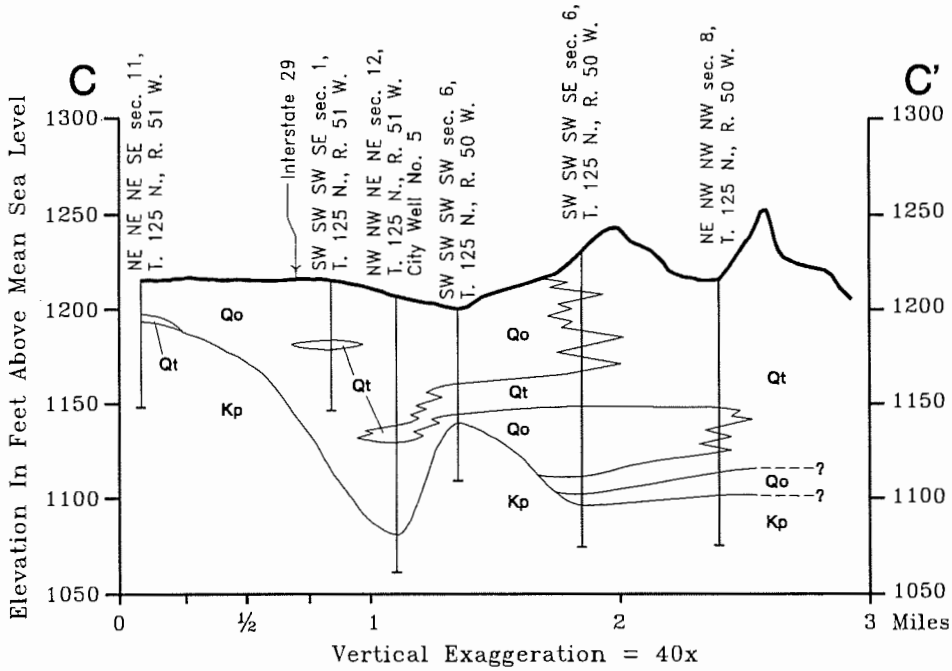

Figure 7. Geologic cross section D-D'.

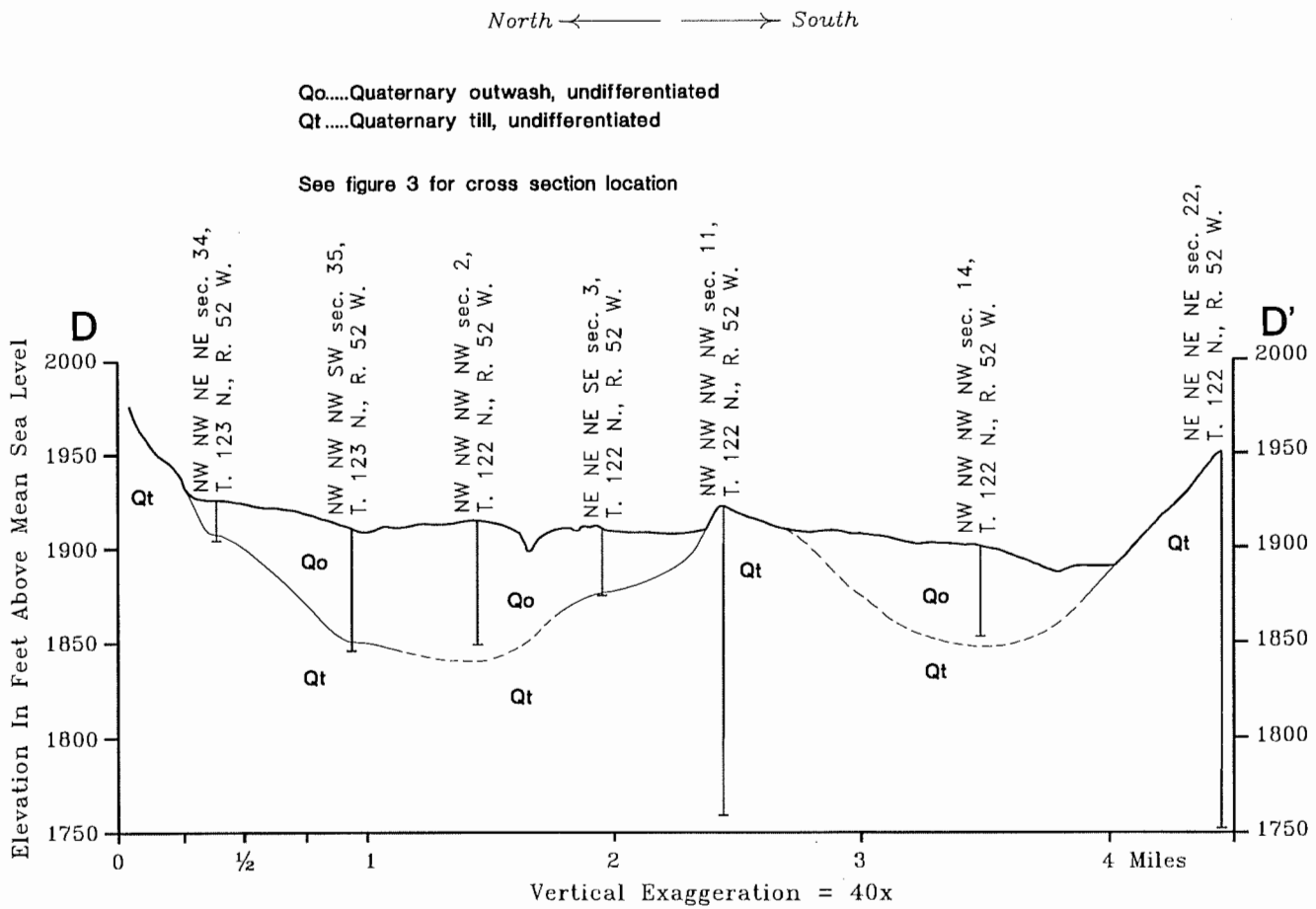

Figure 8. Geologic cross section E-E'.

Southwest ← → *Northeast*

Qo.....Quaternary outwash, undifferentiated
Qt.....Quaternary till, undifferentiated

See figure 3 for cross section location

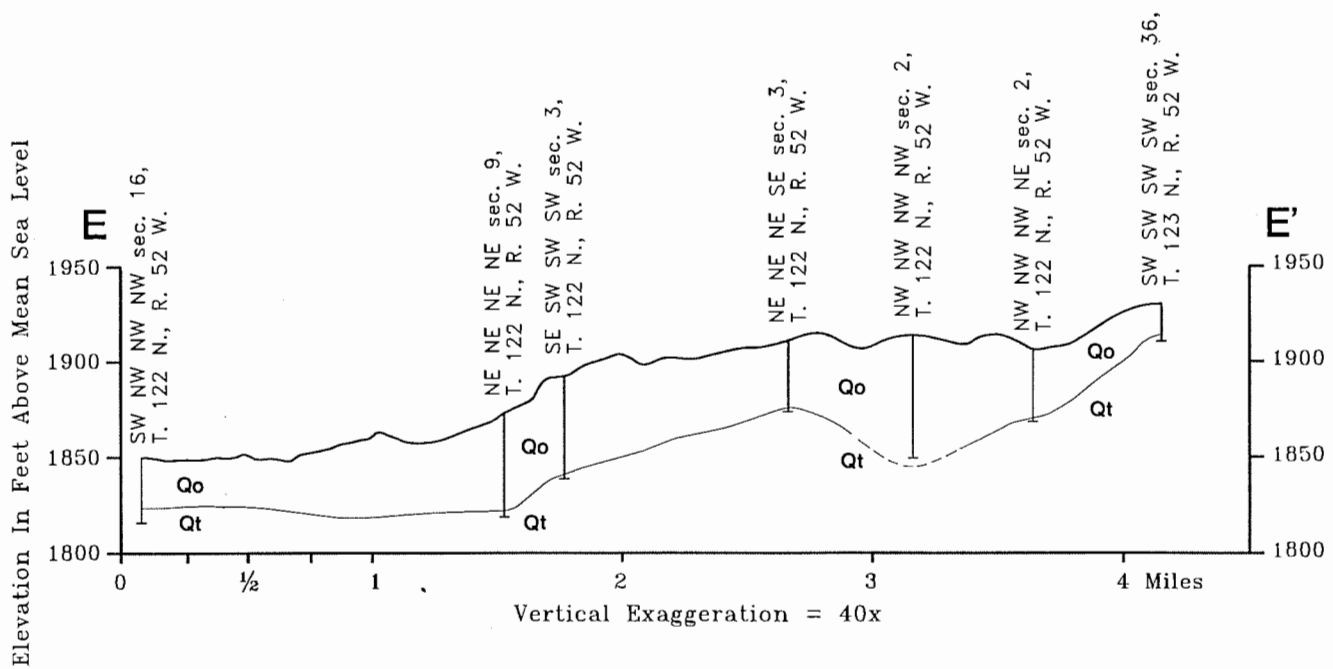

Figure 9. Water levels in the Veblen aquifer, June 17, 1994.

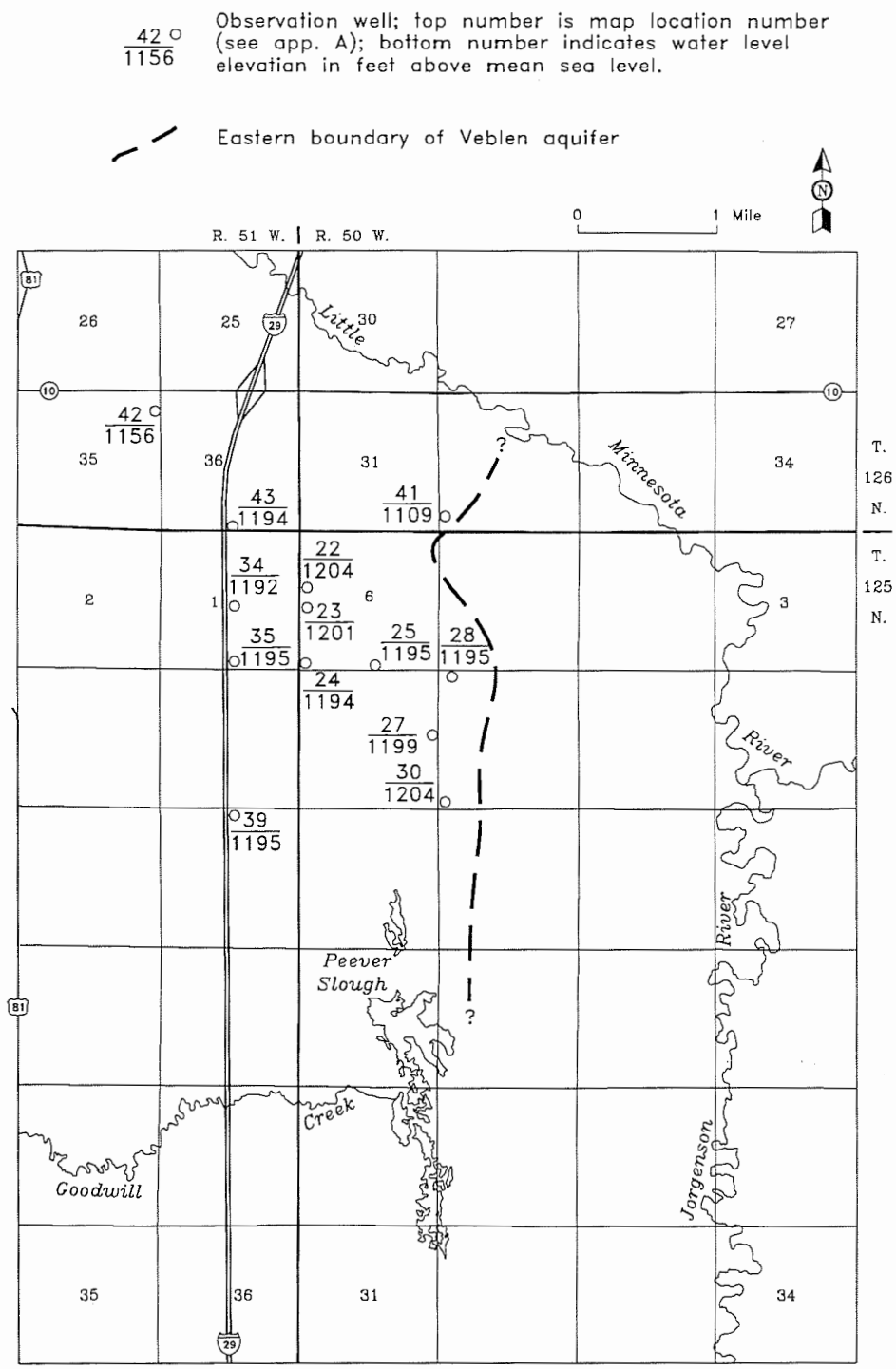

Figure 10. Water levels in the Coteau Lakes aquifer, June 17, 1994.

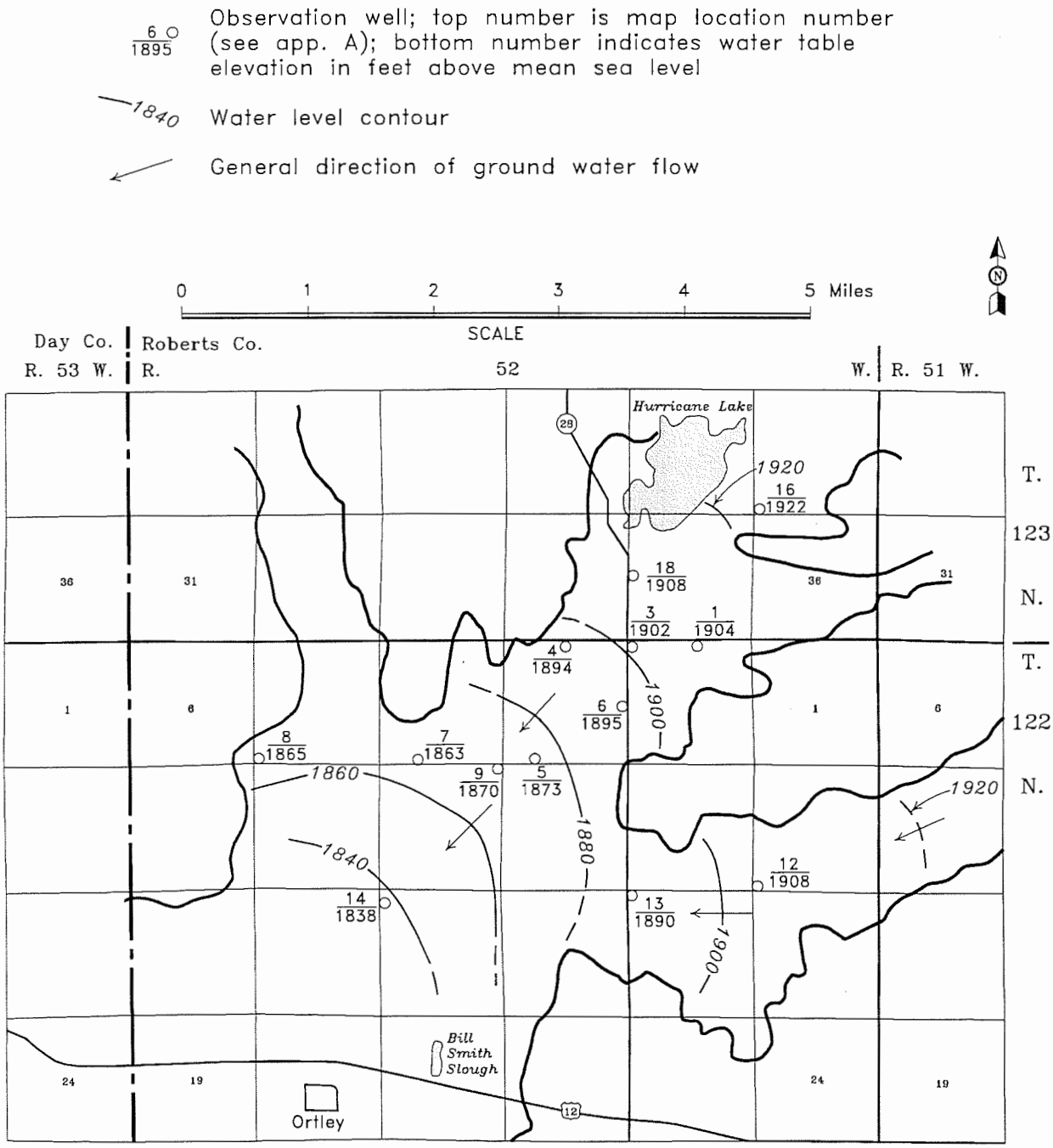

TABLE 1. Description of geologic units

Geologic age from youngest to oldest	Geologic unit or formation name	Descriptions[1]
Quaternary	Till	Heterogeneous mixture of clay, silt, sand, pebbles, and boulders in a predominantly fine grained matrix of clay and silt.
	Outwash	Mixture of sand and gravel with minor amounts of silt and clay. Includes the Coteau Lakes and Veblen aquifers.
Cretaceous	Pierre Shale	Dark-gray, noncalcareous, plastic, fissile shale.
	Niobrara Formation	Medium- to dark-gray calcareous marl.
	Carlile Shale	Medium-gray, noncalcareous, plastic, fissile shale.
	Greenhorn Limestone	Gray, fossiliferous limestone, with interbedded calcareous shales.
	Graneros Shale	Medium- to dark-gray, noncalcareous, silty shale interbedded with thin silt and sand.
	Dakota Formation	Alternating beds of shale, siltstone, and sandstone.

[1] From Koch (1975)

TABLE 2. Comparison of water quality in the Veblen and Coteau Lakes aquifers

Parameter[1]		Veblen aquifer (5 samples)	Coteau Lakes aquifer (Ortley area) (21 samples[2])	
Iron	High	1.59	6.69	
	Average	0.87	3.57	(detected in only 3 samples)
	Low	0.18	<0.05	
Sulfate	High	504	37	
	Average	155	18.8	
	Low	31	5.0	
Nitrate + Nitrite as Nitrogen	High	<0.04	20.7	
	Average	<0.04	4.74	(detected in only 15 samples)
	Low	<0.04	<0.04	
Hardness as Calcium Carbonate	High	830	340	
	Average	442	278	
	Low	300	190	
Total Dissolved Solids	High	1120	396	
	Average	547	314	
	Low	348	209	

[1] Parameter concentrations given in milligrams per liter
[2] Only 18 of the 21 water samples were analyzed for iron and hardness

See appendix C for a complete listing of analytical results.

TABLE 3. Comparison of water quality in the Veblen aquifer between 1981 and 1993

	Well RB-81-12 (Map location 35)		Well RB-81-11 (Map location 28)	
Parameter[1]	1981	1993	1981	1993
Calcium	72[2]	75	197	225
Iron	0.17[2]	0.18	1.28	1.59
Manganese	0.40[2]	0.38	0.33	0.46
Sulfate	127[2]	115	475	504
Fluoride	0.21	0.21	0.31	0.21
Nitrate + Nitrite as Nitrogen	<0.10	<0.04	<0.10	<0.04
Hardness as Calcium Carbonate	310	310	----	830
Total Dissolved Solids	447[2]	413	1125	1120

[1] Parameter concentrations given in milligrams per liter
[2] Average value from two analyses

See appendix C for a complete listing of analytical results.

APPENDIX A

Legal descriptions of test hole and observation well logs utilized in this report

The following list contains the numbers and legal descriptions of the test hole and observation well logs utilized in this report (figs. 2 and 3). These logs are available from the South Dakota Geological Survey in Vermillion, South Dakota. The map location numbers refer only to this report. Any request for logs should contain the legal descriptions.

MAP LOCATION NUMBER	LEGAL DESCRIPTION
1	NW NW NW NE sec. 02, T. 122 N., R. 52 W.
2	NW NW NW NW sec. 02, T. 122 N., R. 52 W.
3	NW NW NW NW sec. 02, T. 122 N., R. 52 W.
4	NW NW NW NE sec. 03, T. 122 N., R. 52 W.
5	SE SE SW SW sec. 03, T. 122 N., R. 52 W.
6	NE NE NE SE sec. 03, T. 122 N., R. 52 W.
7	SW SE SE SW sec. 04, T. 122 N., R. 52 W.
8	SW SW SW SW sec. 05, T. 122 N., R. 52 W.
9	NE NE NE NE sec. 09, T. 122 N., R. 52 W.
10	NE NE NE NE sec. 09, T. 122 N., R. 52 W.
11	NW NW NW NW sec. 11, T. 122 N., R. 52 W.
12	SW SW SW SW sec. 12, T. 122 N., R. 52 W.
13	NW NW NW NW sec. 14, T. 122 N., R. 52 W.
14	SW NW NW NW sec. 16, T. 122 N., R. 52 W.
15	NE NE NE NE sec. 22, T. 122 N., R. 52 W.
16	SW SW SW SW sec. 25, T. 123 N., R. 52 W.
17	NW NW NE NE sec. 34, T. 123 N., R. 52 W.
18	NW NW NW SW sec. 35, T. 123 N., R. 52 W.
19	NW NW NW SW sec. 35, T. 123 N., R. 52 W.
20	SW SW SW SW sec. 36, T. 123 N., R. 52 W.
21	NW NW NW NW sec. 05, T. 125 N., R. 50 W.
22	NW SW SW NW sec. 06, T. 125 N., R. 50 W.
23	NW NW NW SW sec. 06, T. 125 N., R. 50 W.
24	SW SW SW SW sec. 06, T. 125 N., R. 50 W.
25	SW SW SW SE sec. 06, T. 125 N., R. 50 W.
26	SW SW SW SE sec. 06, T. 125 N., R. 50 W.
27	SE SE SE NE sec. 07, T. 125 N., R. 50 W.
28	NE NW NW NW sec. 08, T. 125 N., R. 50 W.
29	SW SW SW SW sec. 08, T. 125 N., R. 50 W.
30	SW SW SW SW sec. 08, T. 125 N., R. 50 W.

Appendix A – continued.

MAP LOCATION NUMBER	LEGAL DESCRIPTION
31	SW SW SW SW sec. 08, T. 125 N., R. 50 W.
32	SW SW SW SW sec. 08, T. 125 N., R. 50 W.
33	SE SE SE SE sec. 20, T. 125 N., R. 50 W.
34	NW NW NW SE sec. 01, T. 125 N., R. 51 W.
35	SW SW SW SE sec. 01, T. 125 N., R. 51 W.
36	SW SW SW SE sec. 01, T. 125 N., R. 51 W.
37	NE NE NE SE sec. 11, T. 125 N., R. 51 W.
38	NW NW NW NE sec. 13, T. 125 N., R. 51 W.
39	NW NW NW NE sec. 13, T. 125 N., R. 51 W.
40	NW NE NW NE sec. 25, T. 125 N., R. 51 W.
41	NW SW SW SW sec. 32, T. 126 N., R. 50 W.
42	NE SE NE NE sec. 35, T. 126 N., R. 51 W.
43	SW SW SW SE sec. 36, T. 126 N., R. 51 W.

APPENDIX B

List of additional test hole and observation well logs

Location	Identifier	Project
NE NE NE NE sec. 30, T. 122 N., R. 52 W.	R1-82-43	Water Rights
NE NE NE NE sec. 32, T. 122 N., R. 52 W.	RB-77S	Water Rights
NW SW SE SW sec. 03, T. 123 N., R. 52 W.	CO-93-25	Roberts County RWS
SE NE SE NE sec. 06, T. 123 N., R. 52 W.	CO-93-29	Roberts County RWS
NE SE SE SE sec. 06, T. 123 N., R. 52 W.	CO-93-28	Roberts County RWS
NE NE NW NE sec. 08, T. 123 N., R. 52 W.	CO-93-41	Roberts County RWS
NE NE NE NW sec. 08, T. 123 N., R. 52 W.	CO-93-26	Roberts County RWS
NE NW NW NW sec. 08, T. 123 N., R. 52 W.	CO-93-40	Roberts County RWS
SW NW NW SW sec. 08, T. 123 N., R. 52 W.	CO-93-30	Roberts County RWS
NW NW NW NW sec. 17, T. 123 N., R. 52 W.	CO-93-24	Roberts County RWS
NE NW NE NW sec. 19, T. 123 N., R. 52 W.	CO-81-02	Big Sioux Aquifer Study
SE NE NE NE sec. 05, T. 124 N., R. 50 W.	RB-81-03	Sisseton DOT
NE NE NW NE sec. 07, T. 124 N., R. 52 W.	CO-93-15	Roberts County RWS
SE SE SE SW sec. 16, T. 124 N., R. 52 W.	CO-93-13	Roberts County RWS
SE SE SE SE sec. 16, T. 124 N., R. 52 W.	CO-93-12	Roberts County RWS
SE SE SW SW sec. 34, T. 124 N., R. 52 W.	CO-93-27	Roberts County RWS
NE NE NE NE sec. 13, T. 124 N., R. 53 W.	CO-93-14	Roberts County RWS
SE SE SE SE sec. 20, T. 125 N., R. 50 W.	RB-81-05	Sisseton DOT
NW NE NW NE sec. 25, T. 125 N., R. 51 W.	RB-81-02	Sisseton DOT
SE SE SE SW sec. 21, T. 125 N., R. 52 W.	CO-93-21	Roberts County RWS
SE SE SE SW sec. 22, T. 125 N., R. 52 W.	CO-93-18	Roberts County RWS
SW SW SW SW sec. 23, T. 125 N., R. 52 W.	CO-93-19	Roberts County RWS
NE NE NE NE sec. 26, T. 125 N., R. 52 W.	CO-93-23	Roberts County RWS
NW NW NW NW sec. 27, T. 125 N., R. 52 W.	CO-93-20	Roberts County RWS
SE SE SE NE sec. 28, T. 125 N., R. 52 W.	CO-93-22	Roberts County RWS
NW NW NW NW sec. 34, T. 125 N., R. 52 W.	CO-93-17	Roberts County RWS
NE NE NE NW sec. 11, T. 125 N., R. 53 W.	R2-93-51	Roberts County RWS
NW NW NE SE sec. 11, T. 125 N., R. 53 W.	R2-93-50	Roberts County RWS
SW SW SW SW sec. 12, T. 125 N., R. 53 W.	CO-93-42	Roberts County RWS
NW SW SW NW sec. 13, T. 125 N., R. 53 W.	R2-93-49	Roberts County RWS
SW NW SE SW sec. 35, T. 126 N., R. 53 W.	R2-93-52	Roberts County RWS

APPENDIX C. Chemical analyses of water samples

Location	ML No.[2]	Well Name	Date Collected	Well Depth[3]	Parameter[1] with concentration in milligrams per liter														Conduc-tivity[4]	Field pH
					Ca	Mg	Na	K	Fe	Mn	HCO_3	SO_4	Cl	F	NO_3-N + NO_2-N	Hardness as $CaCO_3$	Alk T	TDS		
									0.3[5]	0.05[5]		250[5]	250[5]	2.4[6]	10[6]			500[5]		
COTEAU LAKES AQUIFER (Ortley area)																				
NW NW NW NE sec. 02, T. 122 N., R. 52 W.	(1)	CO-93-11	09-15-1993	27.0	72	26	5.2	1.9	<0.05	<0.05	304	29	2.7	0.18	4.58	290	249	333	535	7.40
NW NW NW NW sec. 02, T. 122 N., R. 52 W.	(2)	RB-77T	10-03-1978	59.3	61	27	2	1	0.41	----	239	12	2	----	1.53	---	196	264	464	----
NW NW NW NW sec. 02, T. 122 N., R. 52 W.	(2)	RB-77T	05-05-1993	59.3	61	21	2.5	2.2	<0.05	<0.05	271	14	1.7	0.13	2.42	240	222	262	454	7.63
NW NW NW NW sec. 02, T. 122 N., R. 52 W.	(2)	RB-77T	09-27-1993	59.3	63	20	2.5	2.5	<0.05	<0.05	271	16	1.8	0.11	2.12	240	222	280	452	7.99
NW NW NW NW sec. 02, T. 122 N., R. 52 W.	(3)	RB-93A	07-15-1993	27.5	78.3	28	2.3	2.0	----	----	246	22.4	2.5	----	1.8	---	284	301	535	----
NW NW NW NE sec. 03, T. 122 N., R. 52 W.	(4)	CO-93-36	09-15-1993	28.5	75	26	5.0	2.1	<0.05	<0.05	238	27	9.1	0.09	20.7	290	195	396	584	7.44
SE SE SW SW sec. 03, T. 122 N., R. 52 W.	(5)	CO-93-37	09-15-1993	50.0	67	22	4.5	2.8	3.32	0.63	310	9.5	2.6	0.10	<0.04	260	254	298	480	7.40
NE NE NE SE sec. 03, T. 122 N., R. 52 W.	(6)	CO-93-35	09-15-1993	35.0	57	17	1.9	1.8	<0.05	<0.05	202	20	3.4	0.08	6.76	210	166	251	405	7.49
SW SW SW SW sec. 05, T. 122 N., R. 52 W.	(8)	RB-77R	10-03-1978	31.8	88	33	6	1	0.41	----	293	42	20	----	8.2	---	240	364	661	----
NE NE NE NE sec. 09 T. 122 N., R. 52 W.	(9)	RB-93B	07-14-1993	28.5	82.9	26.4	3.8	2.7	----	----	349	11.7	5.2	----	<0.1	---	286	328	535	----
NE NE NE NE sec. 09, T. 122 N., R. 52 W.	(10)	CO-93-31	09-15-1993	44.0	74	24	3.7	2.8	6.69	0.71	349	5.0	3.2	0.10	<0.04	280	286	324	524	7.19
NW NW NW NW sec. 11, T. 122 N., R. 52 W.	(11)	RB-93C	07-14-1993	158.5	74.2	21.9	4.6	1.8	----	----	312	15.6	1.4	----	<0.1	---	256	269	432	----
NW NW NW NW sec. 11, T. 122 N., R. 52 W.	(11)	RB-93C	09-15-1993	158.5	69	21	4.6	1.7	<0.05	0.75	310	14	0.9	0.20	<0.04	260	254	291	478	7.59
SW SW SW SW sec. 12, T. 122 N., R. 52 W.	(12)	RB-76B	08-02-1977	33.7	78	28	4	1	0.26	----	343	32	4	----	2.30	---	281	304	604	----
SW SW SW SW sec. 12, T. 122 N., R. 52 W.	(12)	RB-76B	05-04-1993	33.7	82	28	4.0	1.8	<0.05	<0.05	350	37	3.1	0.12	1.55	320	287	354	596	7.46
SW SW SW SW sec. 12, T. 122 N., R. 52 W.	(12)	RB-76B	09-28-1993	33.7	83	28	3.8	1.7	<0.05	<0.05	334	33	5.0	0.18	4.36	320	274	364	594	7.35
NW NW NW NW sec. 14, T. 122 N., R. 52 W.	(13)	RB-76A	08-02-1977	36.1	68	26	7	1	1.30	----	298	24	2	----	3.50	---	244	316	539	----
NW NW NW NW sec. 14, T. 122 N., R. 52 W.	(13)	RB-76A	05-05-1993	36.1	76	26	3.2	1.9	<0.05	<0.05	277	24	7.0	0.14	12.9	300	227	335	576	7.69

APPENDIX C. Chemical analyses of water samples (continued)

Location	ML No.[2]	Well Name	Date Collected	Well Depth[3]	Parameter[1] with concentration in milligrams per liter														Conduc-tivity[4]	Field pH
					Ca	Mg	Na	K	Fe	Mn	HCO_3	SO_4	Cl	F	NO_3-N + NO_2-N	Hardness as $CaCO_3$	Alk T	TDS		
									0.3[5]	0.05[5]		250[5]	250[5]	2.4[6]	10[6]			500[5]		
NW NW NW NW sec. 14, T. 122 N., R. 52 W.	(13)	RB-76A	09-28-1993	36.1	73	25	3.1	1.8	<0.05	<0.05	280	24	5.6	0.14	9.14	290	230	326	542	7.55
SW NW NW NW sec. 16, T. 122 N., R. 52 W.	(14)	RB-82B	05-05-1993	24.6	75	26	4.9	1.5	<0.05	<0.05	321	26	3.2	0.16	1.68	290	263	323	537	7.79
SW NW NW NW sec. 16, T. 122 N., R. 52 W.	(14)	RB-82B	09-27-1993	24.6	75	26	4.6	2.3	<0.05	<0.05	318	29	3.7	0.17	1.80	290	261	337	541	7.65
SW SW SW SW sec. 25, T. 123 N., R. 52 W.	(16)	CO-81-01	02-12-1982	29.5	68	28	9	3.0	0.01	0.08	426	5	2	0.12	0.60	---	---	348	531	----
SW SW SW SW sec. 25, T. 123 N., R. 52 W.	(16)	CO-81-01	05-04-1993	29.5	47	17	2.8	2.4	<0.05	<0.05	216	14	1.5	0.11	0.67	190	177	209	360	7.85
SW SW SW SW sec. 25, T. 123 N., R. 52 W.	(16)	CO-81-01	09-28-1993	29.5	73	26	4.1	3.6	<0.05	<0.05	354	9.3	1.6	0.11	0.28	290	290	311	539	7.39
NW NW NW SW sec. 35, T. 123 N., R. 52 W.	(18)	CO-93-33	09-15-1993	53.5	88	29	5.2	3.7	0.71	0.62	421	6.5	5.0	0.17	<0.04	340	345	381	621	7.11
NW NW NW SW sec. 35, T. 123 N., R. 52 W.	(19)	CO-93-34	09-14-1993	20.0	77	27	4.4	4.5	<0.05	<0.05	362	7.1	3.9	0.12	0.38	300	297	323	551	7.33
VEBLEN AQUIFER																				
NW NW NW SW sec. 06, T. 125 N., R. 50 W.	(23)	R2-93-53	11-18-1993	82.0	116	39	8.3	5.1	1.12	0.26	455	92	1.7	0.21	<0.04	450	373	502	782	7.06
SW SW SW SW sec. 06, T. 125 N., R. 50 W.	(24)	RB-81-15	11-19-1993	43.0	78	30	6.3	2.6	0.42	0.42	361	34	1.9	0.34	<0.04	320	296	351	575	7.34
SE SE SE NE sec. 07, T. 125 N., R. 50 W.	(27)	R2-93-54	11-18-1993	82.0	86	21	9.6	6.8	1.04	0.12	364	31	1.7	0.24	<0.04	300	299	348	577	7.10
NE NW NW NW sec. 08, T. 125 N., R. 50 W.	(28)	RB-81-11	04-22-1981	112.9	197	--	70	---	1.28	0.33	---	475	<1	0.31	<0.10	---	---	1125	1490	----
NE NW NW NW sec. 08, T. 125 N., R. 50 W.	(28)	RB-81-11	11-19-1993	112.9	225	66	32	11	1.59	0.46	461	504	2.1	0.21	<0.04	830	378	1120	1410	7.58
SW SW SW SW sec. 08, T. 125 N., R. 50 W.	(30)	RB-81-07	04-24-1981	72.9	125	70	56	---	<0.05	0.17	---	380	8	0.30	0.20	---	---	900	1180	----
NW NW NW SE sec. 01, T. 125 N., R. 51 W.	(34)	RB-81-19	09-09-1981	126.7	89	37	25	---	0.55	0.48	---	163	4	----	<0.10	375	---	903	795	----
SW SW SW SE sec. 01, T. 125 N., R. 51 W.	(35)	RB-81-12	04-23-1981	66.4	70	32	30	---	0.27	0.31	---	132	<1	0.21	<0.10	---	---	438	710	----
SW SW SW SE sec. 01, T. 125 N., R. 51 W.	(35)	RB-81-12	09-09-1981	66.4	74	30	25	---	0.06	0.49	---	122	2	----	0.30	310	---	457	689	----
SW SW SW SE sec. 01, T. 125 N., R. 51 W.	(35)	RB-81-12	11-19-1993	66.4	75	29	19	5.0	0.18	0.38	288	115	2.6	0.21	<0.04	310	236	413	630	7.65

APPENDIX C. Chemical analyses of water samples (continued)

Location	ML No.[2]	Well Name	Date Collected	Well Depth[3]	Parameter[1] with concentration in milligrams per liter														Conduc-tivity[4]	Field pH
					Ca	Mg	Na	K	Fe	Mn	HCO_3	SO_4	Cl	F	NO_3-N + NO_2-N	Hardness as $CaCO_3$	Alk T	TDS		
									0.3[5]	0.05[5]		250[5]	250[5]	2.4[6]	10[6]			500[5]		
NW NW NW NE sec. 13, T. 125 N., R. 51 W.	(39)	RB-81-10	04-23-1981	18.3	50	29	46	---	<0.01	0.27	---	180	12	0.42	<0.10	---	---	460	730	----
NW NW NW NE sec. 13, T. 125 N., R. 51 W.	(39)	RB-81-10	09-09-1981	18.3	61	21	8	---	13	1.26	---	95	4	----	<0.10	241	---	885	514	----
NW SW SW SW sec. 32, T. 126 N., R. 50 W.	(41)	RB-79D	04-24-1981	114.4	307	110	222	---	2.23	0.63	---	1250	6	0.26	<0.10	---	---	2212	2550	----
NE SE NE NE sec. 35, T. 126 N., R. 51 W.	(42)	RB-79C	04-24-1981	52.9	323	155	550	---	3.71	0.48	---	2500	50	0.23	<0.10	---	---	3596	4080	----
NE SE NE NE sec. 35, T. 126 N., R. 51 W.	(42)	RB-79C	09-09-1981	52.9	316	137	491	---	2.56	0.79	---	1840	44	----	<0.10	1353	---	3600	3922	----
SW SW NE NE sec. 36, T. 126 N., R. 51 W.		S OB #5	12-18-1980	45	167	55	63	---	2.03	0.34	---	365	<=2	0.24	<0.10	642	---	942	1042	----
NE SE SW NE sec. 36, T. 126 N., R. 51 W.		S OB #8	12-18-1980	60	154	55	43	---	2.11	0.37	---	285	<=2	0.25	<0.10	610	---	818	895	----
SW SW SW SE sec. 36, T. 126 N., R. 51 W.	(43)	RB-81-20	04-24-1981	66.8	131	58	44	---	1.58	0.30	---	305	<1	0.25	<0.10	---	---	778	1090	----
SW SW SW SE sec. 36, T. 126 N., R. 51 W.	(43)	RB-81-20	09-09-1981	66.8	132	53	28	---	0.64	0.37	---	281	3	----	<0.10	548	---	793	1060	----

[1] **Ca** - calcium; **Mg** - magnesium; **Na** - sodium; **K** - potassium; **Fe** - iron; **Mn** - manganese; **HCO_3** - bicarbonate; **SO_4** - sulfate; **Cl** - chloride; **F** - fluoride; **NO_3-N + NO_2-N** - nitrate + nitrite as nitrogen; **Hardness as $CaCO_3$** - hardness as calcium carbonate; **Alk T** - total alkalinity; **TDS** - total dissolved solids.
[2] ML No. is the map location number shown on figures 2 and 3 and listed in appendix A.
[3] Well depth is presented in feet below top of casing.
[4] Numbers are presented as micromhos.
[5] U.S. Environmental Protection Agency (1994). (Secondary maximum contaminant levels. Recommended limit.
[6] U.S. Environmental Protection Agency (1994). (Maximum contaminant levels. Enforceable limit.