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EVALUATION OF DATA ON NITRATE CONCENTRATIONS IN THE BIG SIOUX AQUIFER

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INTRODUCTION

The South Dakota Geological Survey (SDGS), a division of the South Dakota Department of Water and Natural Resources (DWNR), has conducted investigations over the past few years for some cities and rural-water systems with high nitrate concentrations in aquifers in the Big Sioux drainage basin. This report summarizes these investigations and some additional available information. It is also intended to compare the results of these investigations with the results of the report entitled *The Big Sioux Aquifer Water Quality Study* (BSAWQS) (South Dakota Department of Water and Natural Resources, undated), which was prepared as a result of investigations conducted to develop baseline data and assess the overall quality of water in the Big Sioux aquifer. The BSAWQS was also designed to determine potential contamination problems and develop a means of protecting the aquifer from contamination. The report recognized the vulnerability of the Big Sioux aquifer to contamination and concluded that the major problem in the aquifer is widespread nitrate and bacteria contamination of domestic wells. The report attributed contamination in the Big Sioux aquifer to point-source pollution and states that there is no documentation of nonpoint-source pollution in the aquifer. The report suggests that better well location and construction practices, along with public education, can minimize many of these problems.

The South Dakota Department of Water and Natural Resources responded to point-source problems by becoming instrumental in formulating above ground and underground storage tank laws, spill-cleanup laws, and revised well construction standards. However, remedies for point source pollution problems will not necessarily solve nonpoint source pollution problems such as those which will be summarized in this report.

Recent ground water investigations conducted by the SDGS indicate that improper well construction is not the cause of nitrate contamination in the city and rural-water system wells that have been investigated. Furthermore, these wells generally are not located downgradient from identifiable point source pollution areas. Thus, it is concluded that nonpoint source areas of contamination are present in the Big Sioux aquifer. These conclusions are based on evaluation and interpretation of several specific areas in the Big Sioux aquifer, which are discussed in the following pages. Final recommendations include a thorough evaluation of nitrate problems and assessment of the role of nonpoint sources of pollution in the Big Sioux aquifer.

The following sections summarize data from some areas in the Big Sioux drainage basin which have high nitrate concentrations in the ground water. Figure 1 shows the locations of the areas discussed in this report.

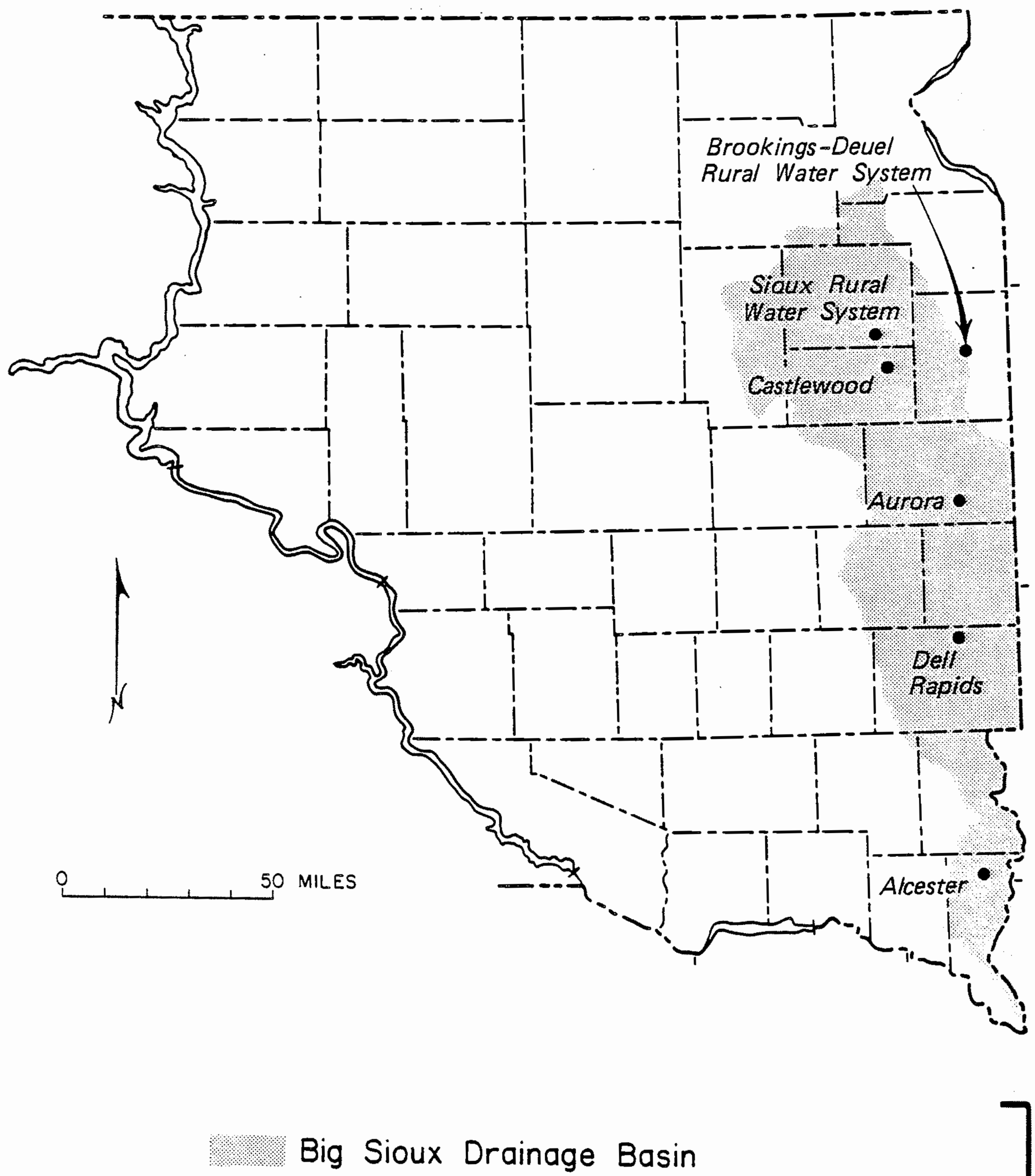

Figure 1. Locations of areas discussed in this report.

Acknowledgements

The investigations conducted by the SDGS were financed by the cities, rural-water systems, East Dakota Water Development District, and the state of South Dakota. The cooperation of Douglas Anderson, Manager of Sioux Rural Water System, for providing data near the well field south of Watertown is greatly appreciated. Several employees of the SDGS, including Patricia Dawson, Louis Frykman, Lynn Hedges, and Sarah Chadima, have made significant contribution to compilation of data or preparation of this report.

SUMMARY OF INVESTIGATIONS

General Comments

The aquifer involved in four of the six investigations discussed below (Aurora city study, Sioux Rural Water System, Castlewood area, and Dell Rapids study) is the Big Sioux aquifer as defined by Hedges and others (1982). This surficial aquifer occurs at or near land surface in these study areas and is composed of outwash (sand and gravel). The other two investigations (Brookings-Deuel Rural Water System and Alcester city water supply) deal with buried aquifers which occur in glacial sediments in or adjacent to the Big Sioux drainage basin but which are not hydraulically connected to the Big Sioux aquifer. Water-table conditions prevail in the Big Sioux aquifer in the areas described in this report and water levels in the aquifer are generally less than 20 feet below land surface. For the most part, the Big Sioux aquifer occurs only in the valleys of the Big Sioux River or its tributaries. The areal extent of the aquifer generally coincides with the margins of the flood plain of the river or creek.

Vertical stratification of nitrate has been reported in shallow aquifers (Thompson and others, 1986; Holm and others, 1986). Data that will be presented in the following sections show some evidence of vertical stratification. This concept is also supported by data from the BSAWQS which show when two wells are completed at different depths at the same site, the shallow well generally has a higher nitrate concentration. Although this concept was recognized as an important factor in evaluating nitrate contamination in the BSAWQS, the statistical analysis and resulting conclusion did not account for vertical stratification. The BSAWQS stated that only about 4 percent of the 95 observation wells sampled had nitrate-nitrogen concentrations greater than 10 parts per million (ppm). If the statistical evaluation had accounted for vertical stratification, there would have been a higher percentage of observation wells with nitrate-nitrogen concentrations greater than 10 ppm.

Some of the water samples collected in the investigated areas have nitrate-nitrogen concentrations that exceed 10 ppm. While 10 ppm is the enforceable nitrate-nitrogen concentration limit for drinking water, work done by Madison and Brunett (1984) concluded that nitrate-nitrogen concentrations greater than 5 ppm may be the result of human activities. Based on this conclusion, we have used the terms high and elevated nitrate concentrations throughout this report to refer to anything greater than 5 ppm nitrate-nitrogen.

Aurora City Study

The City of Aurora (population 507) is located 3 miles east of Brookings, in Brookings County, and pumps water from the Big Sioux aquifer. Because of nitrate concentrations in excess of 10 ppm in private wells within the city limits, a municipal well was drilled on the west edge of town in 1972. High nitrate concentrations have been subsequently measured in this city well (table 1). At the request of the city, the SDGS is presently conducting a ground-water study in the area.

In the Aurora area, the Big Sioux aquifer is an unconfined, surficial ground water system composed of sand and gravel (outwash). The top of the sand and gravel is generally within 3 feet of land surface and lies directly below the soil profile.

Ground-water recharge in the Aurora area is thought to be from downward percolation of precipitation, excess irrigation water, and lateral inflow of water in transient storage. Depth to water is usually less than 10 feet below land surface. Ground water flow direction in the area is generally to the southwest.

The Aurora city well is 66 feet deep, is located on the west side of Aurora, and is completed in the Big Sioux aquifer. At this well site, the top and bottom of the outwash are 2 and 64 feet, respectively, below land surface.

With one exception, (April 23, 1984), water-quality analyses have shown nitrate-nitrogen concentrations of 6.5 ppm or higher in the Aurora city well since 1974 (table 1 and fig. 2). Figure 2 graphically depicts the data in table 1 and shows that nitrate concentrations in the city well fluctuate over time, but generally the concentrations have increased from 1984 to the present.

The SDGS investigation found high nitrate concentrations in the Big Sioux aquifer in the vicinity of Aurora (fig 3). Table 2 shows nitrate concentrations of all water samples collected from 26 wells near Aurora. As shown in figure 3, of the 26 wells sampled, 11 are state observation wells, 14 are private wells, and 1 is the Aurora city well. All but two of the state observation wells were screened greater than 11 feet below the water table, the importance of which will be discussed in the following paragraph. Three of the 11 state observation wells (27 percent) exceed the drinking water standard of 10 ppm, and 5 of the 11 observation wells sampled (45 percent) have nitrate-nitrogen concentrations greater than 5 ppm. Of the 14 private wells sampled, 10 (71 percent) exceed the 10 ppm drinking water standard, and 12 (86 percent) have nitrate-nitrogen concentrations greater than 5 ppm. The Aurora city well has had nitrate-nitrogen concentrations consistently above 10 ppm since June, 1988, and with one exception, consistently above 5 ppm since 1974.

Observed concentrations of nitrate in the state observation wells may have been higher if the wells were screened at the water table.

Table 1. Nitrate-nitrogen data for the Aurora city well

Date	Nitrate-nitrogen (ppm)
11/27/73	0
10/17/74	7.4
10/28/75	8.73
07/21/76	10.6
08/23/76	10.8
02/13/78	7.3
01/16/80	6.5
04/07/81	7.5
01/27/82	7.7
09/13/83	6.7
04/23/84	4.7
10/02/85	8.0
03/30/87	9.3
05/05/87	9.0
07/07/87	8.9
08/10/87	8.4
09/08/87	8.7
10/19/87	9.0
11/09/87	9.3
12/08/87	9.0
01/19/88	9.6
02/08/88	10.4
03/07/88	9.7
04/04/88	9.6
05/09/88	9.8
06/06/88	10.2
07/18/88	10.9
08/08/88	11.5
09/13/88	10.6

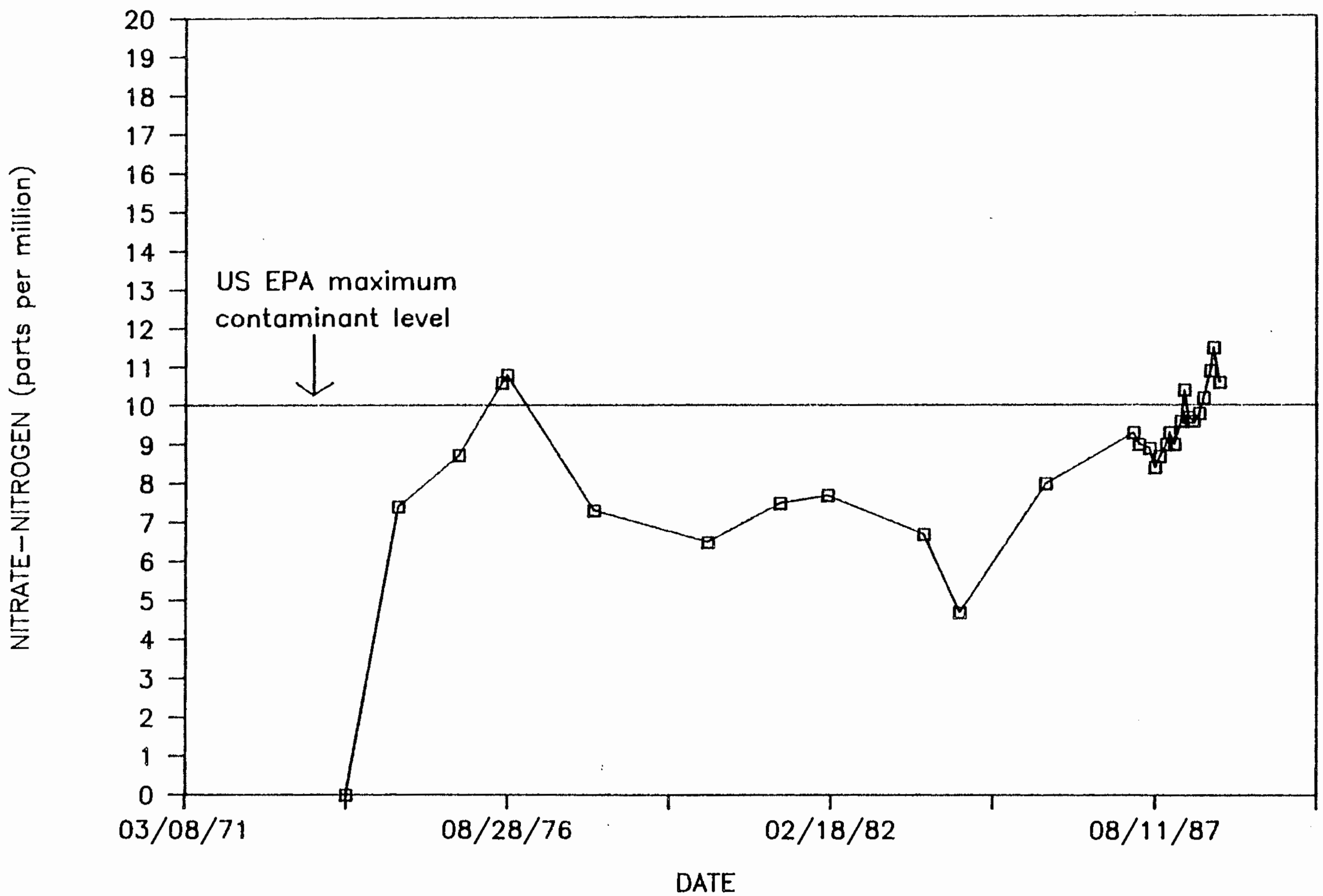

Figure 2. Nitrate—nitrogen concentrations in the Aurora city well.

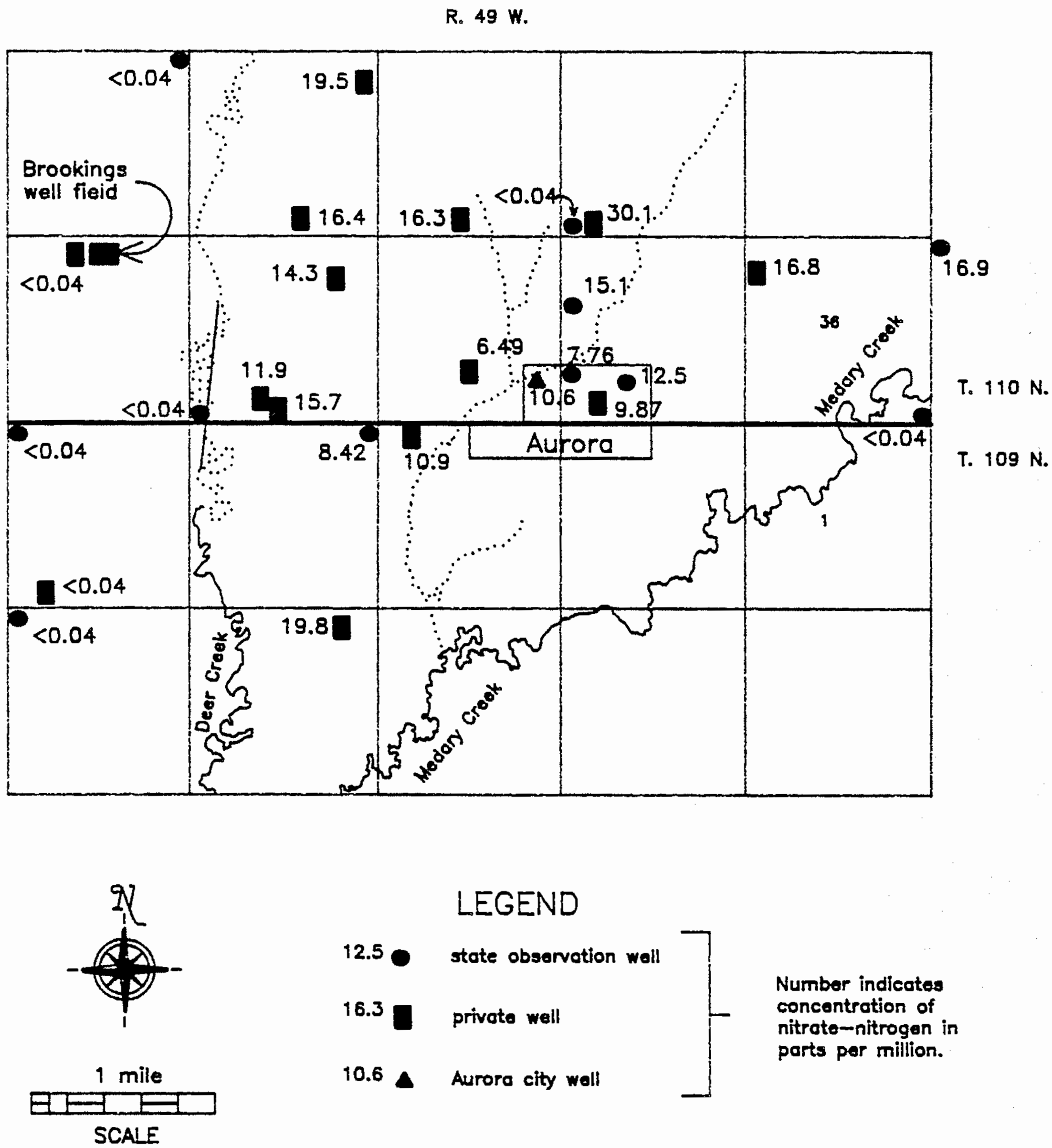

Figure 3. Nitrate-nitrogen concentrations in the Aurora study area.

Table 2. Nitrate-nitrogen concentrations in the Aurora area

Location	Well depth (ft)	Nitrate-nitrogen (ppm)
NW NE NW NW sec. 03, T. 109 N., R. 49 W. *	22	10.9
NE NE NE NE sec. 04, T. 109 N., R. 49 W.	30	8.42
NW NW NW NW sec. 05, T. 109 N., R. 49 W.	23	<0.04
SE SW SW SW sec. 05, T. 109 N., R. 49 W. *	14	<0.04
NW NW NW NW sec. 08, T. 109 N., R. 49 W.	54	<0.04
NE NW NE NE sec. 09, T. 109 N., R. 49 W. *	32	19.8
NW NW NW NW sec. 31, T. 110 N., R. 48 W.	31	16.9
SW SW SW SW sec. 26, T. 110 N., R. 49 W.	49	<0.04
SE SW SW SW sec. 26, T. 110 N., R. 49 W. *	20	30.1
SE SE SE SW sec. 27, T. 110 N., R. 49 W. *	31	16.3
SE NE NE NE sec. 28, T. 110 N., R. 49 W. *	20	19.5
SW SW SW SE sec. 28, T. 110 N., R. 49 W. *	30	16.4
NE NE NE NE sec. 29, T. 110 N., R. 49 W.	33	<0.04
NW NE NE NW sec. 32, T. 110 N., R. 49 W. *	15	<0.04
SE SE NW NE sec. 33, T. 110 N., R. 49 W. *	50	14.3
SW SW SW SW sec. 33, T. 110 N., R. 49 W.	17	<0.04
SE SW SE SW sec. 33, T. 110 N., R. 49 W. *	20	15.7
SE SW SE SW sec. 33, T. 110 N., R. 49 W. *	20	11.9
SE SE NE SW sec. 34, T. 110 N., R. 49 W. *	58	6.49
NW NW SE SE sec. 34, T. 110 N., R. 49 W. **	66	10.6
NW SW SW NW sec. 35, T. 110 N., R. 49 W.	51	15.1
SW SW NW SW sec. 35, T. 110 N., R. 49 W.	37	7.76
NE NE SW SW sec. 35, T. 110 N., R. 49 W.	32	12.5
NW SE SW SW sec. 35, T. 110 N., R. 49 W. *	10	9.87
SW SW NW NW sec. 36, T. 110 N., R. 49 W. *	34	16.8
SE SE SE SE sec. 36, T. 110 N., R. 49 W.	44	<0.04

* Private well
** City well
No markings after the location indicate state observation wells.

Figure 3 shows high nitrate concentrations in the Big Sioux aquifer around the City of Aurora. It is likely that point-source pollution is a factor in the Aurora area (South Dakota Department of Water and Natural Resources, undated, appendix A, Aurora Sewage Lagoon section), but due to the large areal extent of contamination, nonpoint-source pollution must also be addressed and examined.

The land adjacent to the City of Aurora is used for agriculture and nearly all is irrigated. Irrigation is heavily concentrated in a 2-mile radius around the city and is less concentrated farther to the east, west, and south. Nearly all the irrigation wells are completed in the Big Sioux aquifer. The application of nitrogen-based fertilizers in this area is a common farming practice.

Elevated nitrate-nitrogen concentrations were known to exist on the west side of Aurora as early as 1971. The city well, installed in 1972 and located on the west side of town, is downgradient from a feedlot that was discontinued in 1984, and several irrigation wells. Elevated nitrate concentrations have been evident in the city well since at least 1974. However, a recently installed observation well approximately 1/2 mile north of the city has a nitrate-nitrogen content of 15.1 ppm. This observation well is upgradient from any known point source of contamination, including the small discontinued feedlot that was located at the northwest side of the city.

Because the observation and private wells have shown high nitrate concentrations in a relatively large area, it will be necessary to have a better understanding of (1) the extent and severity of the contamination, and (2) the mechanisms of contaminant transport, before a new well site can be recommended.

Sioux Rural Water System

Production wells for the Sioux Rural Water System are located in the Big Sioux River valley just south of Watertown in Codington County. The wells are completed in the Big Sioux aquifer which is a surficial outwash. The top of the outwash (sand and gravel) is either at or very near land surface and has no confining layer (clay) above the aquifer.

The Big Sioux aquifer in this area is under unconfined (water table) conditions. The major portion of ground-water recharge is believed to be from infiltration of precipitation and from lateral inflow from upgradient portions of the aquifer. Also, there appears to be a good connection between the aquifer and the Big Sioux River. Depth to water in the aquifer in this area is generally less than 15 feet below land surface.

Three water supply wells were drilled in the Big Sioux aquifer in 1974 to provide water to a portion of the Sioux Rural Water System service area. Table 3 shows that from the onset, these wells (numbers 1, 2, and 3) exhibited elevated levels of nitrate. The concentrations were, however, below the federal and state drinking water standard of 10 ppm. The first chemistry data to show that the nitrate concentrations had exceeded the standard in all three wells was in December, 1985 (table 3). After this point in time, all three wells remained above or near the drinking-

Table 3. Nitrate-nitrogen concentrations in parts per million for Sioux Rural Water System production wells 1, 2, 3, and 4

Date	Well 1	Well 2	Well 3	Well 4
04/12/77	5.2	4.8		
04/19/78	5.7	4.4	6.3	
04/06/81		8.1		
01/25/82		6.1		
01/17/84	7.9			
11/15/85	13.9	13.8	2.6	
12/06/85	19.6	12.9	11.4	4.0
01/06/86	31.0	13.8	13.5	4.7
02/13/86	42.0	14.3	11.5	4.6
03/10/86	43.0	10.1	6.8	5.2
04/23/86	13.4	13.5	8.2	7.8
05/14/86	30.0	9.4	7.9	4.0
06/17/86	26.8	10.3	8.7	3.4
07/29/86	25.0	11.8	10.2	4.2
08/18/86	21.4	13.1	11.5	4.0
09/29/86	18.2	16.0	12.2	3.6
10/30/86	23.0	16.6	12.9	3.3
11/14/86	27.0	19.6	13.7	3.0
12/08/86	30.5	21.4	13.7	2.8
01/02/87	32.0	21.6	14.5	2.2
02/19/87	35.0	22.6	16.0	2.4
03/30/87	36.0	23.0	17.5	2.4
04/15/87	35.0	22.6	16.9	2.6
05/18/87	39.0	20.8	17.1	2.3
06/11/87	40.0			
07/11/87			19.6	2.3
07/22/87	43.0	19.2	19.6	1.9
09/15/87	31.5	25.5	22.0	2.0

water standard. Figures 4, 5, and 6 graphically depict the data listed in table 3 for production wells 1, 2, and 3.

A temporary production well (number 4, table 3) was drilled near the water-distribution point of the rural-water system with the intent of blending water from this well with water from the other three. The temporary well also draws water from the Big Sioux aquifer, but yields water with a sufficiently low nitrate concentration (table 3) to enable the blended water to meet the drinking-water standard. However, water from the temporary well contains higher concentrations of iron and manganese than the water from the original three production wells.

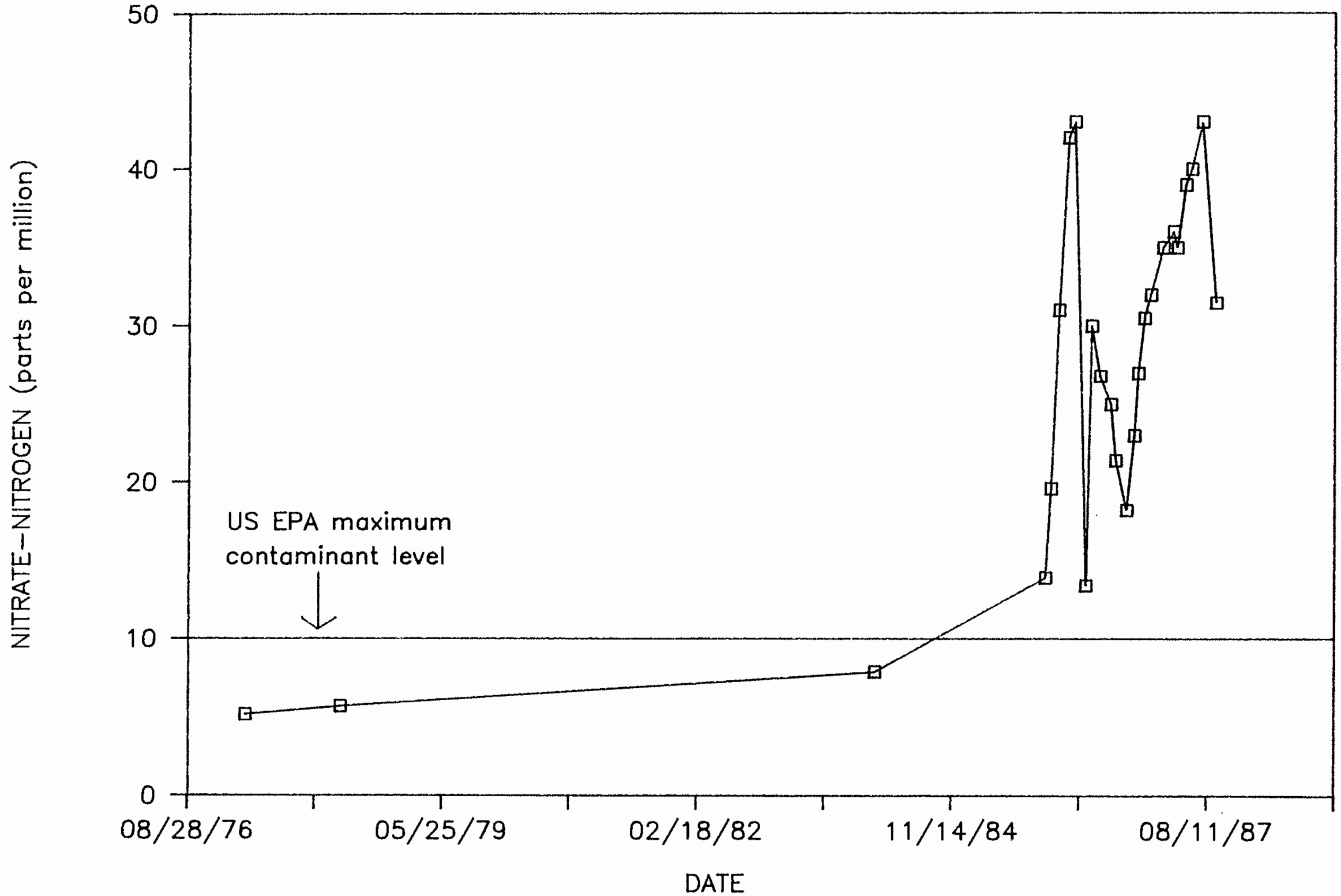

Figure 4. Nitrate-nitrogen concentrations in Sioux Rural Water System well 1.

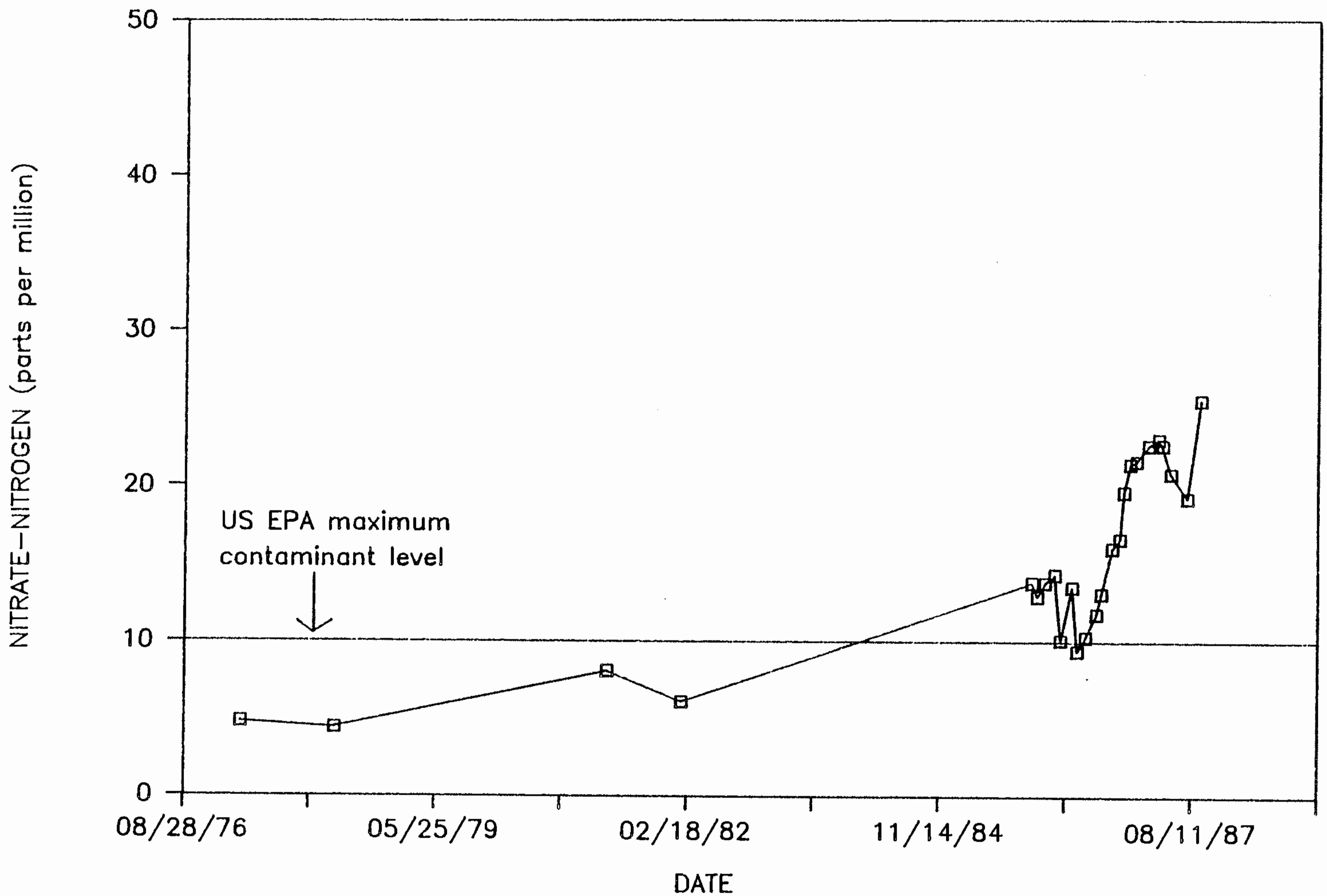

Figure 5. Nitrate–nitrogen concentrations in Sioux Rural Water System well 2.

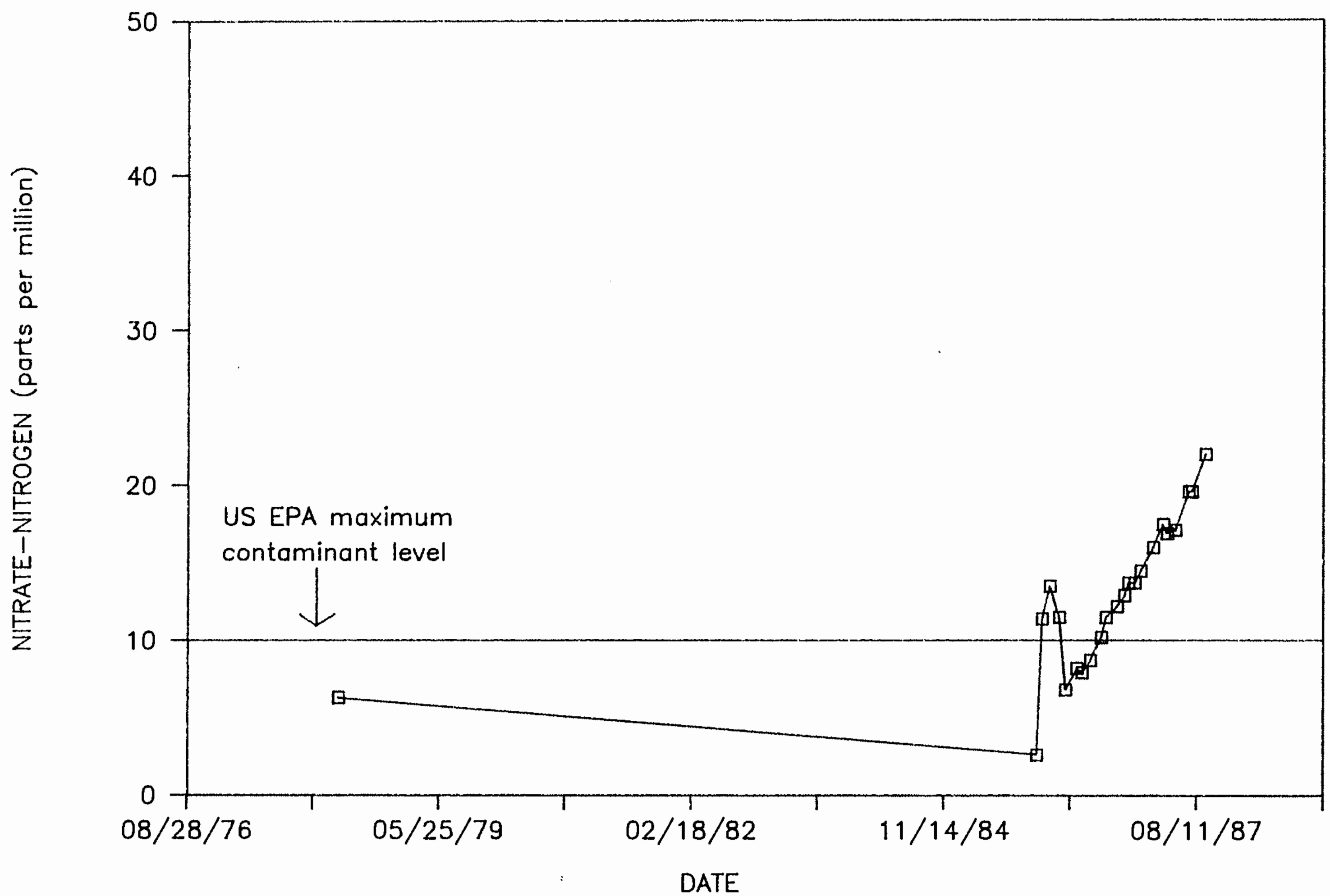

Figure 6. Nitrate–nitrogen concentrations in Sioux Rural Water System well 3.

The Sioux Rural Water System has investigated the possibility of drilling new production wells near the existing distribution system in the same aquifer in hopes of finding good-quality water low in nitrate concentration while at the same time minimizing the costs of laying new water lines to the present water distribution plant. Preliminary results of this investigation show that one or more of the following problems exists in the area investigated:

1. the saturated thickness of the aquifer is not adequate or is only marginal,

2. the concentration of nitrate is too high, or

3. the overall quality of water, especially with respect to hardness, iron, and manganese, is not desirable.

The distribution of nitrate near the rural water system production wells is shown in figure 7. Data in figure 7 were generated by sampling and analyzing water from private wells, observation and production wells, and test holes drilled for the rural-water system by a private drilling company. Nitrate concentrations in table 3 were supplied by the rural-water system. Figure 7 illustrates that there is a relatively large area with elevated levels of nitrate. Not all elevated values are necessarily above the drinking-water standard of 10 ppm, however, 12 of the 39 sampling points (31 percent) shown in figure 7 did exceed the 10 ppm limit. Only 15 of the 39 sampling points (38 percent) had values of nitrate-nitrogen less than 5 ppm and 12 sampling points (31 percent) had values ranging from 5 to 9 ppm. This means that 62 percent of the sampling points had values greater than 5 ppm. The percentages presented are irrespective of the type of sampling point (private well, observation well, production well, or test hole) or depth of well in the aquifer.

There are undoubtedly some point-source problems included in the area (fig. 7), but there are many elevated values of nitrate that cannot entirely be attributed to potential point-source pollution and therefore, nonpoint-source pollution appears to be likely. A probable source of the nitrate contamination is from the primarily agricultural land in this area. The application of nitrogen-based fertilizer would be common to both the irrigated and nonirrigated land.

The problem of elevated concentrations of nitrate in Sioux Rural Water System production wells 1, 2, and 3 is not a new one. Values near or above 5 ppm were recorded in 1977 and 1978 and have generally increased from that time. Unfortunately, background data for the rest of the aquifer are generally lacking, thus not allowing a temporal comparison of nitrate.

Before any other part of the Big Sioux aquifer near the present rural water system well field can be recommended as a future water source, at least the extent and severity of nitrate

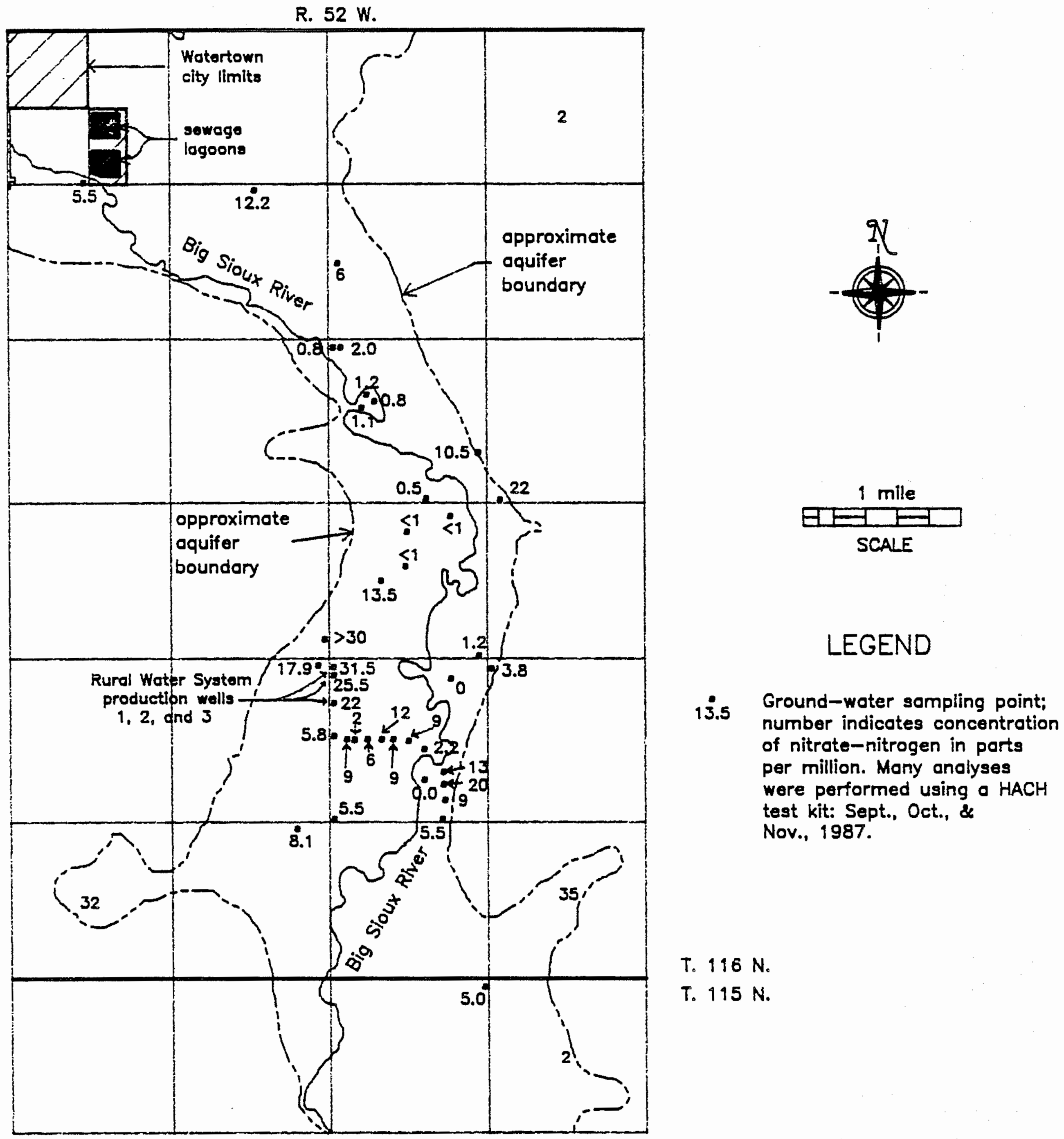

Figure 7. Distribution of nitrate–nitrogen concentrations in the area of the Sioux Rural Water System production wells.

contamination must be examined. Additionally, a better understanding of the mechanism(s) of transport of the contaminant into the aquifer must be gained. Without such knowledge, an area of the aquifer which is presently uncontaminated could be recommended as a water source and become contaminated in the near future.

Castlewood Area

At the request of the Sioux Rural Water System, the SDGS conducted a ground-water study in 1983 to the west and north of Castlewood in Hamlin County (fig. 8). This study was conducted to find a location in this area for the rural-water system to develop a well field. As part of this study, the SDGS installed 19 observation wells in the Big Sioux aquifer (fig. 8) and collected 21 water samples for nitrate analysis. As a result of the water-quality data, it became apparent that nitrate concentrations were noticeably high at many locations in this area.

The study was conducted in the Big Sioux aquifer which in this area is unconfined with the water table about 3 to 10 feet below land surface. Saturated thickness of the aquifer ranges from near zero on the east and west sides of the valley to more than 20 feet in the middle of the valley. There is a good hydraulic connection between the aquifer and the Big Sioux River. Hydraulic gradient is greatest near the sides of the valley and least near the middle of the valley (fig. 8).

Water analyses show that the nitrate concentrations are high at many locations throughout this area. Eight of 19 state observation wells (42 percent) sampled for nitrate had concentrations greater than or equal to 5 ppm nitrate-nitrogen (table 4). Five of 19 state observation wells (26 percent) had concentrations greater than 10 ppm nitrate-nitrogen (table 4). Some of the analyses indicated that nitrate concentrations were extraordinarily high. For example, the well at location NE NE NE NE sec. 33, T. 115 N., R. 52 W. has a nitrate-nitrogen concentration of 60 ppm and the well at location SE SE SE NE sec. 34, T. 115 N., R. 52 W. has a nitrate-nitrogen concentration of 64 ppm. However, the two Castlewood city wells (fig. 8), which are 30 feet deep, have nitrate-nitrogen concentrations of 1.20 and 3.90 ppm.

The important aspect of this study is that nitrate-nitrogen concentrations greater than or equal to 5 ppm are found in many of the observation wells throughout the aquifer. There is no correlation between proximity to point sources of pollution and high nitrate concentrations in the observation wells.

A correlation exists between the depth of the screened zone and nitrate concentration at two specific sites. At locations SE SE SE SW sec. 10, T. 115 N., R. 52 W. and SE SE SE SE sec. 27, T. 115 N., R. 52 W. there are two wells of different depth at each location. In both cases, the well which is screened closest to

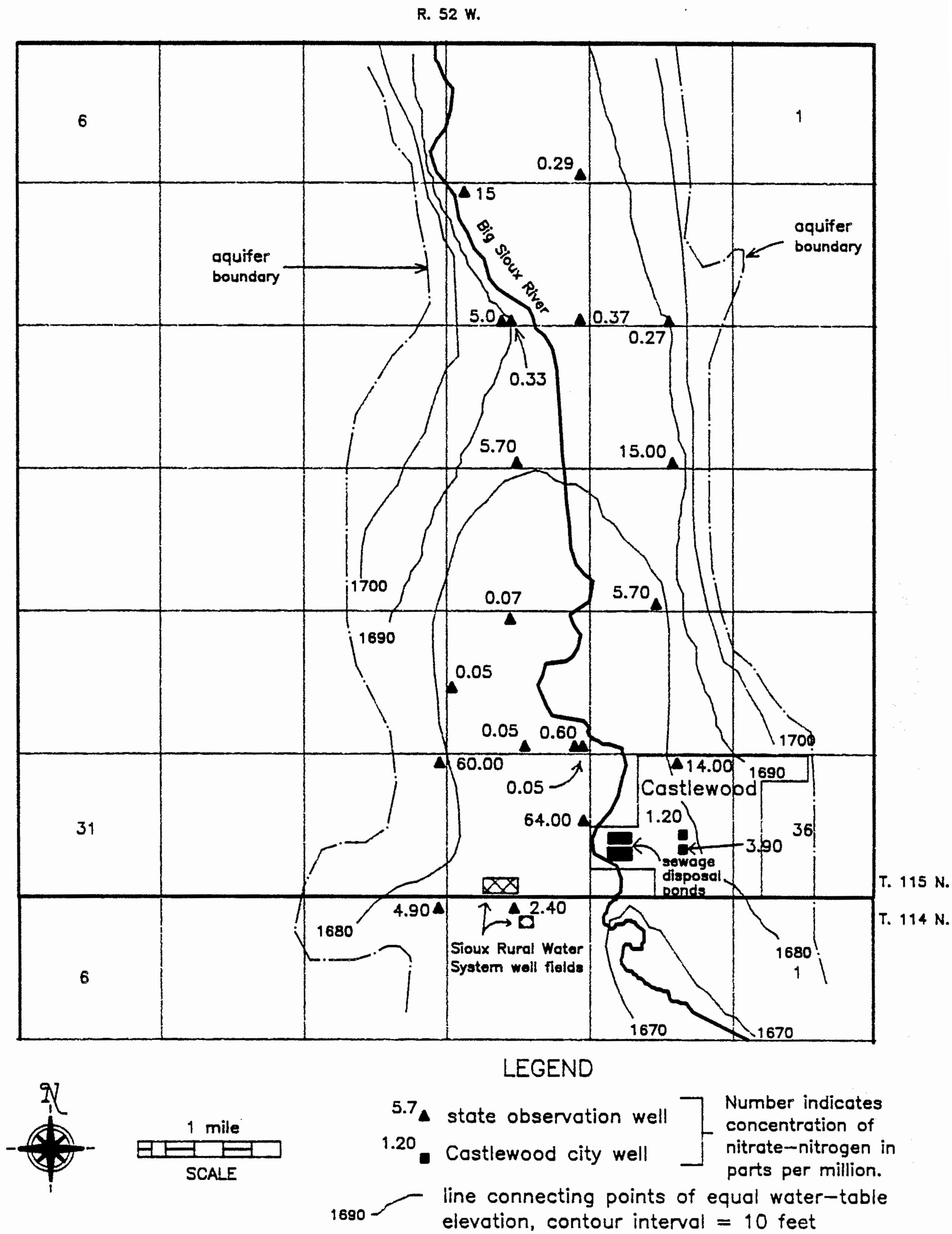

Figure 8. Nitrate–nitrogen concentrations and water–table contours in the Castlewood area.

Table 4. Water-quality data in the Castlewood area

Location	Well Depth (ft)	Nitrate-nitrogen (ppm)
NE NE NE NW sec. 03, T. 114 N., R. 52 W.	41	2.40
NE NE NE NE sec. 04, T. 114 N., R. 52 W.	37	4.90
SE SE SE SE sec. 03, T. 115 N., R. 52 W.	25	0.29
NE NW NW NW sec. 10, T. 115 N., R. 52 W.	27	15.00
SE SE SE SW sec. 10, T. 115 N., R. 52 W.	31	0.33
SE SE SE SW sec. 10, T. 115 N., R. 52 W.	14	5.00
SE SE SE SE sec. 10, T. 115 N., R. 52 W.	23	0.37
SW SW SW SE sec. 11, T. 115 N., R. 52 W.	25	0.27
SW SW SW SE sec. 14, T. 115 N., R. 52 W.	20	15.00
SW SW SW SE sec. 15, T. 115 N., R. 52 W.	22	5.70
SE SE SE SW sec. 23, T. 115 N., R. 52 W.	35	5.70
NE NE NE NW sec. 27, T. 115 N., R. 52 W.	20	0.07
NW NW NW SW sec. 27, T. 115 N., R. 52 W.	36	0.05
SW SW SW SE sec. 27, T. 115 N., R. 52 W.	30	0.05
SE SE SE SE sec. 27, T. 115 N., R. 52 W.	21	0.05
SE SE SE SE sec. 27, T. 115 N., R. 52 W.	14	0.60
NE NE NE NE sec. 33, T. 115 N., R. 52 W.	27	60.00
SE SE SE NE sec. 34, T. 115 N., R. 52 W.	26	64.00
NE NW NW NE sec. 35, T. 115 N., R. 52 W.	22	14.00
NW NE NW SE sec. 35, T. 115 N., R. 52 W. *	30	1.20
SE NE NW SE sec. 35, T. 115 N., R. 52 W. *	30	3.90

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* City of Castlewood well

the top of the aquifer shows a greater nitrate concentration than the well screened lower in the aquifer (table 4). This type of vertical stratification was explained in the General Comments section of this report.

The highest nitrate-nitrogen concentration (64 ppm) is from a well located at SE SE SE NE sec. 34, T. 115 N., R. 52 W. First impressions may suggest that the proximity of the well to the sewage disposal ponds one-fourth of a mile to the southeast may account for the high nitrates (fig. 8). However, further analysis discounts this possibility for two reasons. First, the ground-water gradient at this well is toward the southeast. Thus, water cannot move from the sewage disposal ponds toward the well. Second, the Big Sioux River, which is either a discharge or recharge zone for the aquifer depending on river stage, flows between the sewage disposal ponds and the well in question. Therefore, a hydrologic barrier exists between the ponds and the well and prevents contaminant movement from the ponds to the well.

The lack of identifiable point sources of contamination in the Castlewood study area and the widespread occurrence of contaminants suggests that nitrate contamination in this part of the Big Sioux aquifer is probably a nonpoint-source problem.

Brookings-Deuel Rural Water System

The well field for the Brookings-Deuel Rural Water System near Clear Lake, in Deuel County, is not located in the Big Sioux aquifer, but is adjacent to the Big Sioux River drainage basin. The aquifer presently supplying water to the main well field is an outwash aquifer buried under sandy, silty, weathered till. The overlying confining layer of till may actually be a leaky one which allows downward movement of some shallow ground water and contaminants. It must be noted, however, that the mechanism of contaminant transport into the well field <u>has</u> <u>not</u> been determined.

Water in the main well field of the Brookings-Deuel Rural Water System presently contains nitrate in excess of the federal and state standard for human consumption. Figures 9, 10, and 11 show fluctuating but generally increasing nitrate concentrations, from 1979 to present, in production wells 1, 2, and 3. Recent water analyses for production wells 1, 2, and 3 show nitrate-nitrogen concentrations of 13.3, 10.2, and 11.5 ppm, respectively (table 5 and figs. 9, 10, and 11).

The problem of high nitrate has resulted in the drilling of an emergency production well. This well yields water of generally poorer quality (higher in total dissolved solids, particularly iron and manganese) than those wells in the main well field, but at the same time, yields water low in nitrate concentration. Water from this emergency well is blended with water from the main well field. This effectively dilutes the nitrate to an acceptable level in water which is distributed by the rural-water system. Continued use of water from the emergency well may result in higher maintenance costs for the water-distribution lines and will result in the distribution of water of generally poorer quality to the consumers.

The rural-water system undertook the task of searching for an alternate water source and, as a result, the SDGS conducted a hydrogeologic investigation and recommended an alternate area as a water source. The rural-water system is currently analyzing results of an aquifer test to determine the potential of this recommended area for a well field.

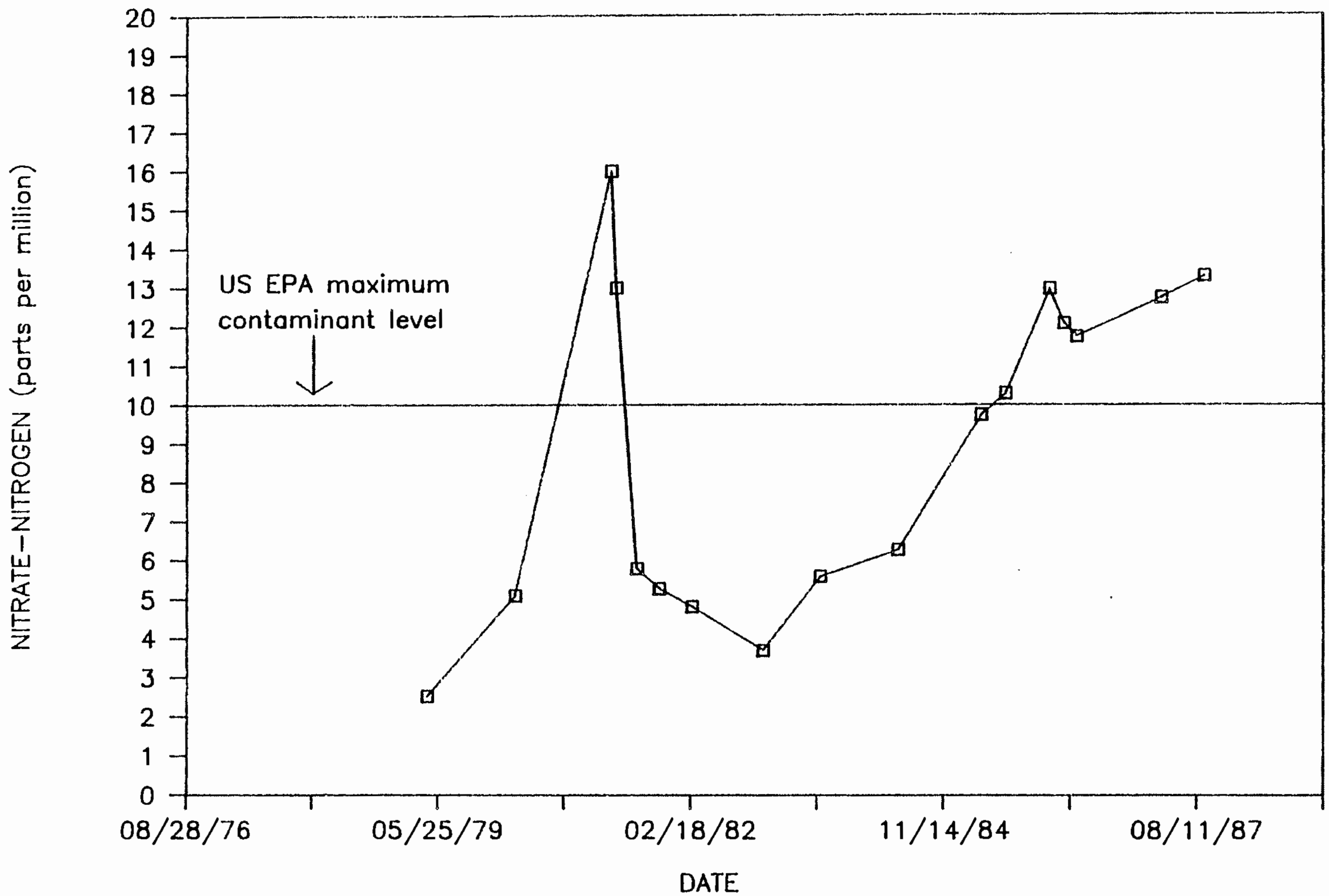

Figure 9. Nitrate–nitrogen concentrations in Brookings–Deuel Rural Water System well 1.

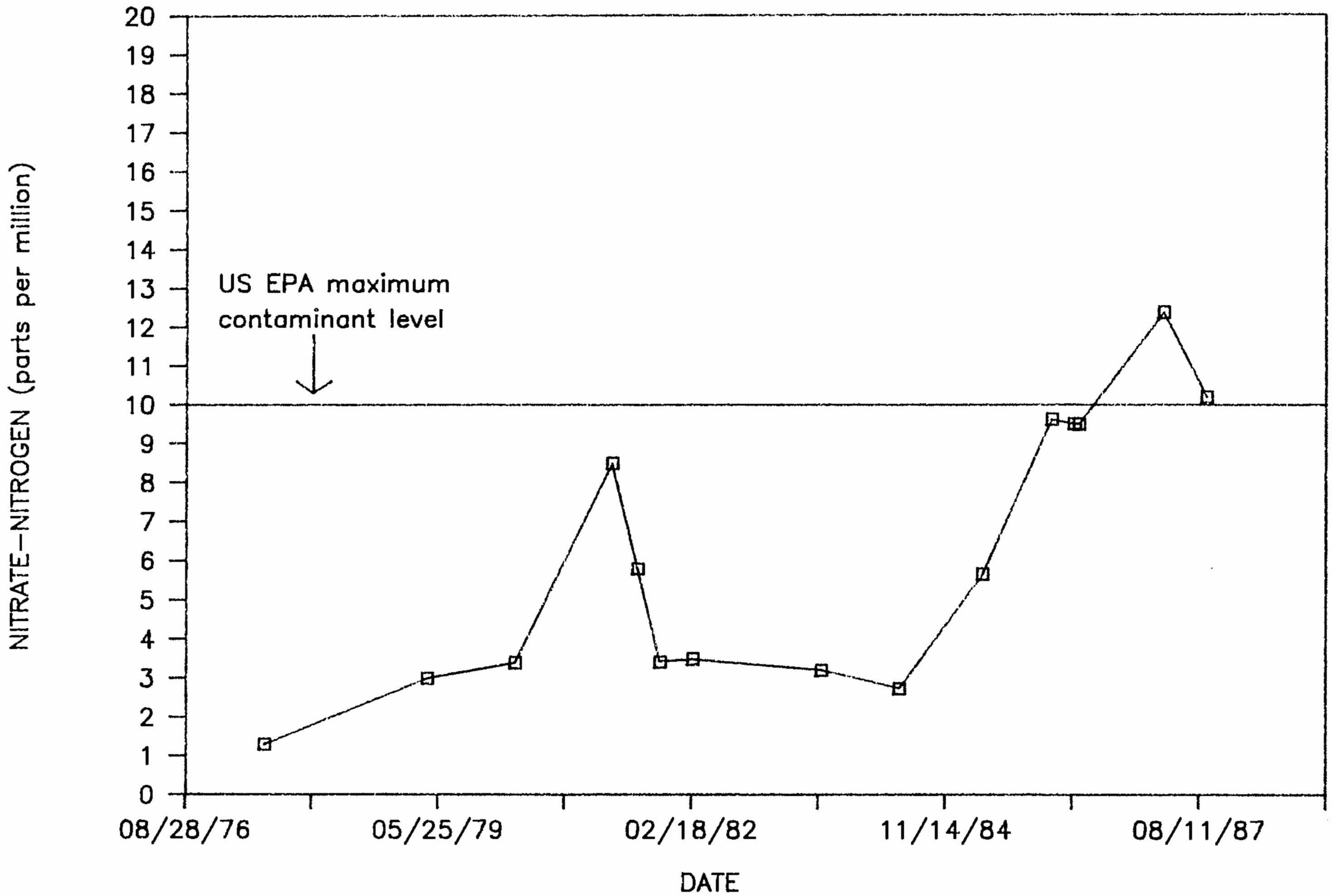

Figure 10. Nitrate–nitrogen concentrations in Brookings–Deuel Rural Water System well 2.

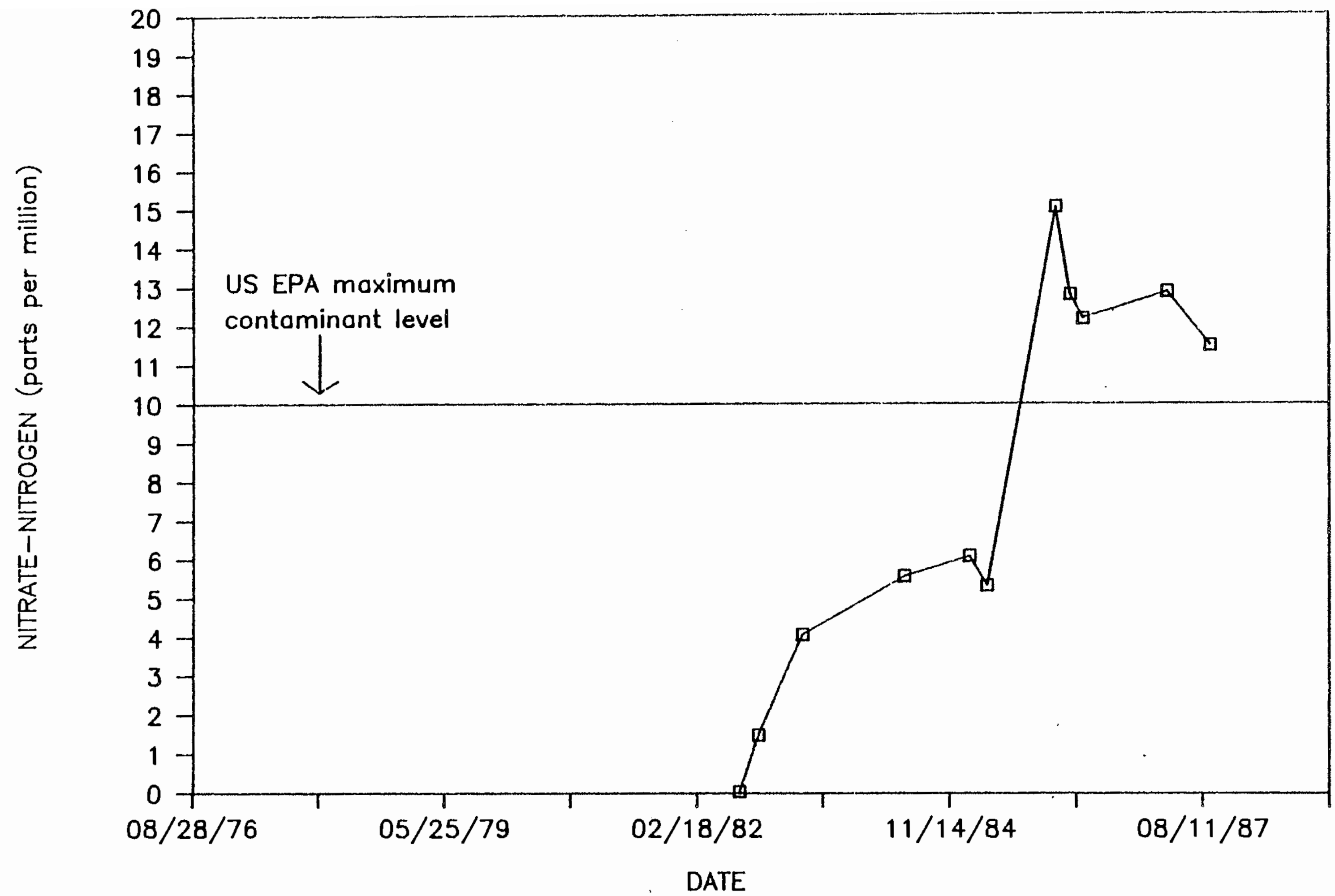

Figure 11. Nitrate–nitrogen concentrations in Brookings–Deuel Rural Water System well 3.

Table 5. Nitrate-nitrogen concentrations in parts per million for Brookings-Deuel Rural Water System production wells 1, 2, and 3

Date	Well 1	Well 2	Well 3
07/08/77		1.3	
04/11/79	2.53	3.00	
03/24/80	5.10	3.40	
04/10/81	16.00	8.50	
04/28/81	13.00		
07/20/81	5.80	5.80	
10/15/81	5.28	3.42	
02/23/82	4.82	3.50	
08/04/82			0.05
10/18/82			1.50
12/01/82	3.7		
04/11/83			4.08
07/15/83	5.60	3.2	
05/17/84	6.28	2.73	5.58
01/30/85			6.1
04/09/85	9.75	5.66	5.34
07/16/85	10.30		
01/06/86	12.98	9.63	15.05
03/04/86	12.09		12.80
04/03/86		9.51	
04/23/86	11.75	9.50	12.18
03/24/87	12.75	12.38	12.88
09/09/87	13.3	10.2	
09/10/87			11.5

If a new source of water is developed in the recommended area, the additional cost of water treatment for iron and manganese removal will be incurred. Except for a low nitrate concentration, the quality of water in the recommended area is not as good, especially regarding iron and manganese, as water in the present main well field area.

Within the study area, there is no obvious point source of pollution to which the contamination can be attributed. However, the area surrounding the well field is agricultural where application of nitrogen-based fertilizers would occur. Again, this suggests a nonpoint source as the primary contaminant source.

This area of contamination is unique because buried aquifers in general are not normally thought to be particularly susceptible to surface sources of contamination. However, the outwash aquifer in this area, buried only by a layer of very sandy and silty weathered till, is contaminated, and has shown a trend of increasing concentrations of nitrate over a 10-year period.

The previous discussion of the problem experienced by the rural-water system is useful in pointing out the need for a better understanding of nitrate as a contaminant in ground water. It also illustrates the point that buried aquifers cannot be categorically dismissed when discussing aquifer susceptibility to nitrate contamination. The composition and weathering of the overlying sediments must be evaluated.

Alcester City Water Supply

The City of Alcester is located in the Big Sioux drainage basin, but the city wells are not completed in the Big Sioux aquifer. The city was experiencing high nitrate concentrations in the municipal supply and, in 1984, requested the SDGS to conduct a ground-water investigation to locate a new water supply. The investigation revealed that a buried aquifer, in which the city wells are completed, is covered locally by loess, alluvium, or till. Although the buried aquifer is confined in some locations and unconfined in others, the majority of the aquifer is under confined conditions. Ground-water movement is generally in a westerly direction in the aquifer (fig. 12).

The city's water supply contained nitrate concentrations greater than the federal and state drinking water standard of 10 ppm (table 6). The high nitrate concentrations in the city wells may be partly attributed to point-source pollution. But, no point source for contamination has been identified for the high nitrate concentrations in the thickest and most promising part of the aquifer for well development south of the city. However, land in the vicinity of Alcester is used primarily for agricultural purposes, which includes the application of nitrogen-based fertilizers. The investigation showed that the city could not be guaranteed a continuous supply of potable water from their present aquifer in the immediate vicinity of the city due to elevated nitrate concentrations (fig. 13). As a result, Alcester joined the South Lincoln Rural Water System.

Dell Rapids Study

The City of Dell Rapids, Minnehaha County, contracted with a private well driller to drill test holes and install an aquifer test well in the Big Sioux aquifer. The area investigated was located 1 mile north and 2.5 miles east of the city in the Big Sioux aquifer (NE sec. 01, T. 104 N., R. 49 W.). On February 11, 1983, 14 test holes were drilled and five of them were completed as observation wells. The saturated sand and gravel ranged from 7 to 20 feet in thickness. The depth to water ranged from 7 to 12

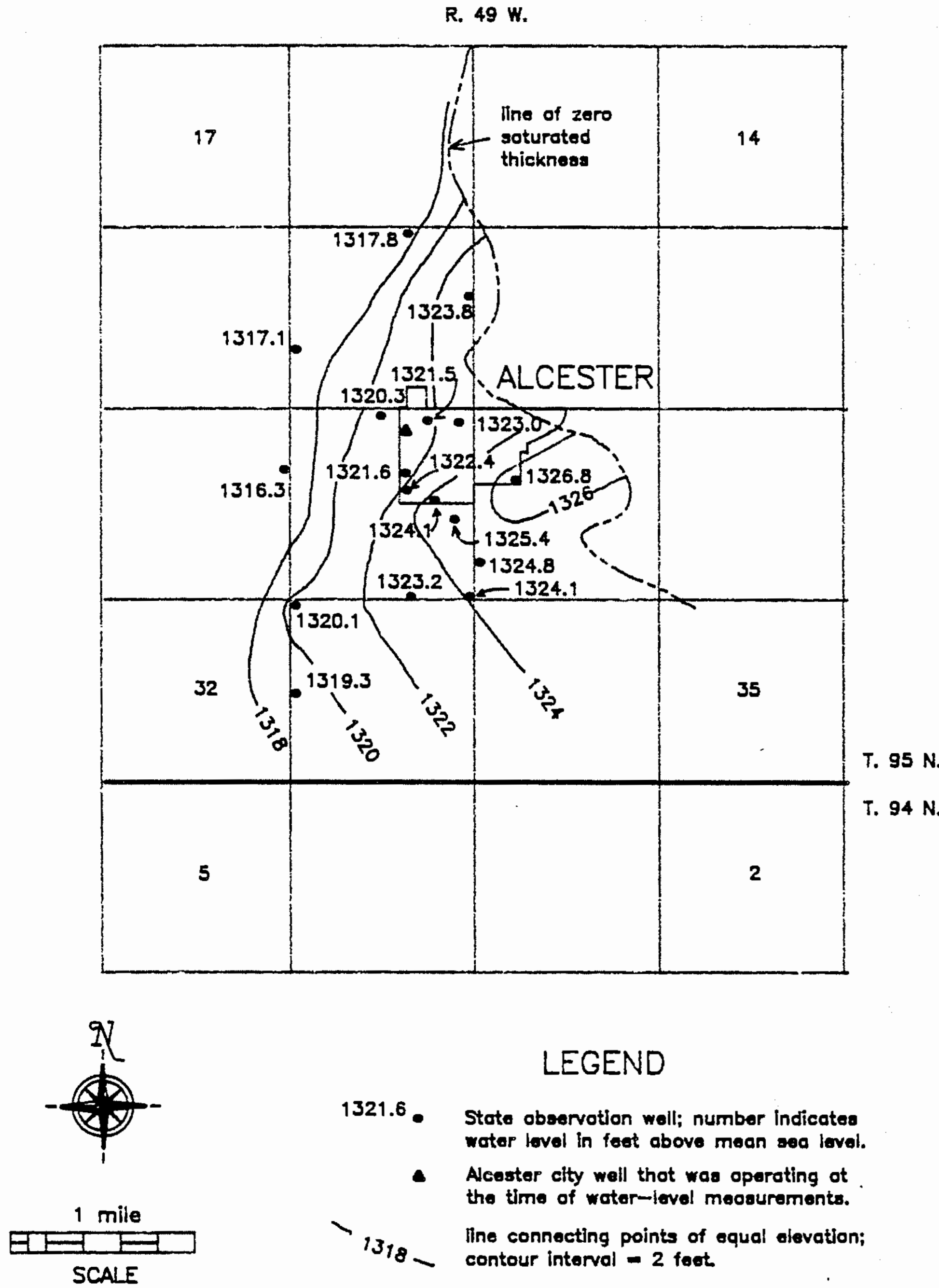

Figure 12. Potentiometric surface of the buried quartz sand aquifer in the Alcester area on January 12, 1987.

Table 6. Nitrate-nitrogen concentrations in the Alcester area

Location	Well Depth (ft)	Nitrate-Nitrogen (ppm)
NW NW NW NW sec. 04, T. 94 N., R. 49 W. **	145	1.0
NW NE NW NE sec. 21, T. 95 N., R. 49 W.	55	4.6
SE NE SE NE sec. 21, T. 95 N., R. 49 W.	53	1.6
NW SW NW SW sec. 21, T. 95 N., R. 49 W.	61	3.8
NE SE SW NW sec. 27, T. 95 N., R. 49 W.	86	9.5
SW SW SE SW sec. 27, T. 95 N., R. 49 W. **	75	20.6
NE NE NW NE sec. 28, T. 95 N., R. 49 W.	82	9.6
NE NW NW NE sec. 28, T. 95 N., R. 49 W.	--	24.1
NW NW NW NE sec. 28, T. 95 N., R. 49 W.	47	9.6
NW NW NW NE sec. 28, T. 95 N., R. 49 W.	26	1.6
NW SW NW NE sec. 28, T. 95 N., R. 49 W. **	65	31.8
NE NW SW NE sec. 28, T. 95 N., R. 49 W.	20	2.5
NE NW SW NE SEC. 28, T. 95 N., R. 49 W.	59	52.8
		88.2 *
NW SE SW NE sec. 28, T. 95 N., R. 49 W. **	--	10.6
NW SE SW NE sec. 28, T. 95 N., R. 49 W.	38	38.7
NW SE SW NE sec. 28, T. 95 N., R. 49 W.	64	112.0
		33.1 *
NW SW SE NE sec. 28, T. 95 N., R. 49 W.	73	8.8
		2.3 *
NW SW SE NE sec. 28, T. 95 N., R. 49 W.	45	140.0
		122.5
		31.5 *
SE NE NE SE sec. 28, T. 95 N., R. 49 W. **	65	6.4
NE NW NE SE sec. 28, T. 95 N., R. 49 W.	68	5.5
		4.8
		3.2 *
NE SW NE SE sec. 28, T. 95 N., R. 49 W. **	40	18.6
SW SE SW SE sec. 28, T. 95 N., R. 49 W.	64	13.0
		9.5 *
SE SE SE SE sec. 28, T. 95 N., R. 49 W.	121	19.8
		29.1 *
SE SE NE NE sec. 29, T. 95 N., R. 49 W.	54	8.0
		6.8 *
SE SE NE NE sec. 29, T. 95 N., R. 49 W.	28	3.4
NW NW NW NW sec. 33, T. 95 N., R. 49 W.	125	6.1
NW NW NW SW sec. 33, T. 95 N., R. 49 W.	150	1.4

* Most recent analysis
** Private well

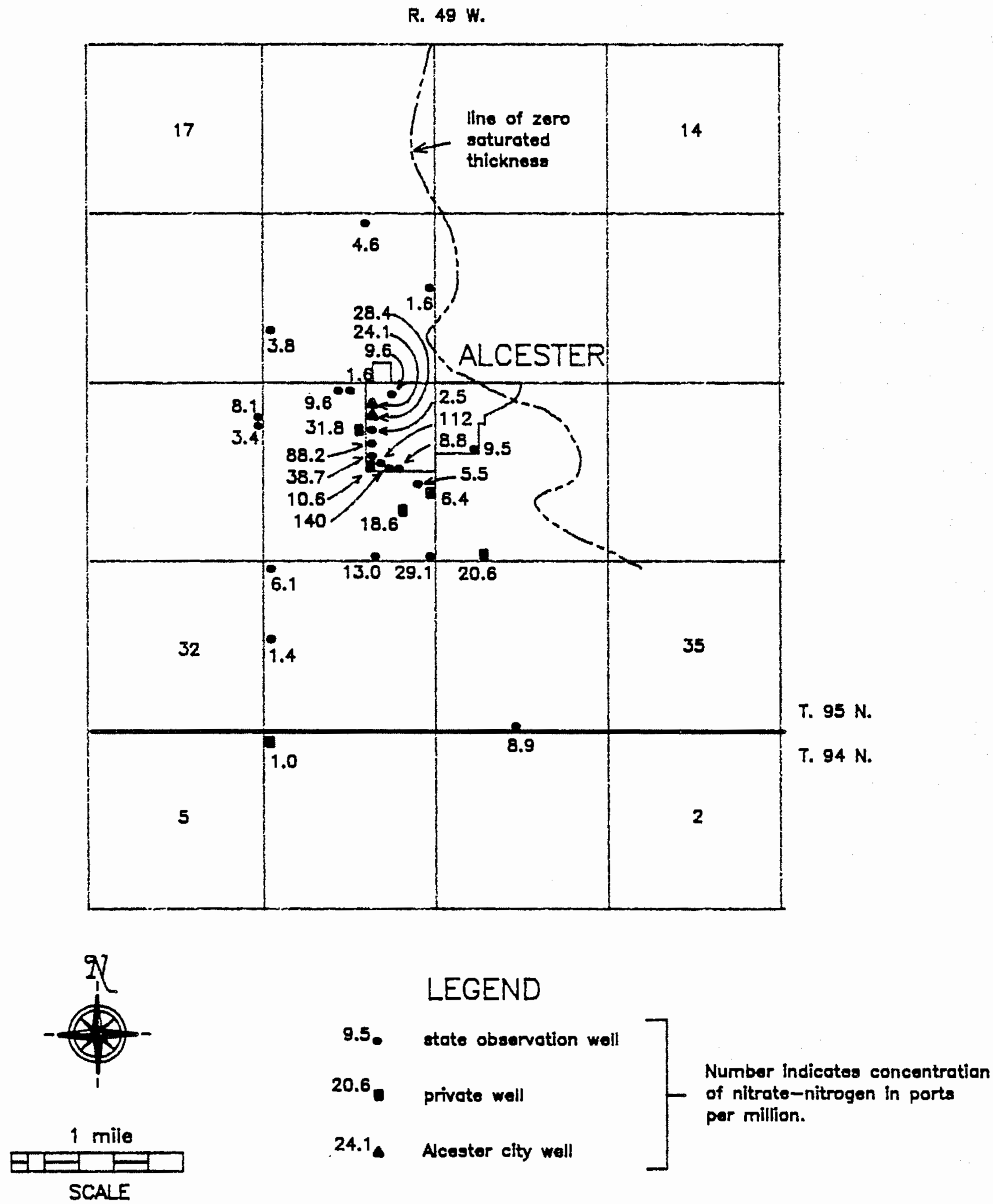

Figure 13. Nitrate–nitrogen concentrations in the buried quartz sand aquifer in the Alcester area.

feet below the land surface. Water samples were collected by the well driller from the five observation wells for chemical analysis and they were analyzed by a private analytical laboratory. The water analyses indicated that the overall water quality was good (total dissolved solids concentrations ranged from 536 ppm to 812 ppm), with the exception of elevated nitrate concentrations. The nitrate-nitrogen concentrations ranged from 4.9 to 7.6 ppm in four of the observation wells, while one well contained 25 ppm.

An aquifer-test well was installed approximately 450 feet north of the well which had a nitrate-nitrogen concentration of 25 ppm. The other four observation wells were all within a 1000-foot radius of the test well. A 48-hour pumping aquifer test was conducted beginning April 25, 1983, under the supervision of the SDGS. The mean pumping rate was 492 gallons per minute. Water samples were collected by the SDGS from the aquifer-test well at the start and conclusion of the test. These samples were analyzed by the SDGS laboratory in Vermillion. An additional sample was collected at the conclusion of the aquifer test for analysis by the State Health Laboratory in Pierre. The results of the analyses from the SDGS laboratory indicated a nitrate-nitrogen concentration of 8.8 ppm at the start of the test and 15.5 ppm at the conclusion of the test. The State Health Laboratory reported a nitrate-nitrogen concentration of 18.4 ppm in the sample taken at the conclusion of the test.

It is known from communications with residents in the area that both livestock manure and commercial fertilizer had been used in the vicinity of the investigation site. In addition, there are no known point sources of pollution near this site. Because of the high nitrate concentrations, it was decided that the aquifer in this area could not be used for a municipal water supply.

DISCUSSION AND CONCLUSIONS

The Big Sioux Aquifer Water Quality Study attributes high nitrate concentrations in private wells completed in the Big Sioux aquifer to improper placement and faulty well construction. Thus, point-source pollution is described as the primary cause of high nitrate concentrations in these wells. The present evaluation does not refute this conclusion, but it does indicate that nonpoint-source pollution could be the primary cause in wells in some areas, and that nonpoint sources are probably contributing factors in other areas. This statement is based on the following conclusions from the current study.

1. Well construction does not appear to be the cause of high nitrate concentrations in the city and rural water system wells. Site investigations show that the wells are either protected from surface contamination by well houses or the

immediate area near the wells is not conducive to surface contamination even if the well construction is poor.

2. In general, the city and rural water system wells are not located downgradient from identifiable point-source pollution in the aquifer, and thus, nonpoint-source pollution is the most probable cause. However, in two of the six cases discussed herein, contamination may be partly attributed to a point source.

3. High nitrate concentrations are found in city and rural water system wells, private wells, and state observation wells in the areas investigated.

4. City and rural water system wells investigated have experienced rising nitrate levels in the last few years.

5. The case studies discussed in this report are recent investigations of parts of the Big Sioux aquifer with known high nitrate levels. Some variation from these findings may be observed in other parts of the aquifer. However, it is apparent that nonpoint-source pollution is a problem in certain areas of the aquifer.

6. Although nonpoint-source pollution does not appear to be a widespread problem in the aquifer now, it may be developing into a serious problem. This conclusion is supported by Hurlburt (1988) who states that nonpoint-source pollution typically increases every year in small increments and by Thompson and others (1986) who have documented a gradual increase in nitrate concentrations in shallow ground water. Because of the similarities in hydrogeology between states such as Iowa [the subject of Thompson and others (1986)] and South Dakota, a similar increase in nitrate concentrations in South Dakota ground water is very likely.

RECOMMENDATIONS

1. Thorough investigations should be conducted on nitrate contamination of the Big Sioux aquifer in areas such as those described in this report. The investigations should include determination of the extent, magnitude, and stratification of nitrates in ground water. In addition, they should assess the source(s) of nitrates and the mechanism(s) of nitrate transport in both the saturated and unsaturated zones.

2. A more intense reconnaissance study should be conducted on nitrate concentrations in the Big Sioux aquifer. This study should focus on collecting water samples from wells with screened intervals at, or near, the water table, and it should also include resampling some of the wells that were used in *The Big Sioux Aquifer Water Quality Study*. Additional observation wells should also be installed to provide a more compre-

hensive representation of the areal distribution of elevated or high nitrate concentrations.

3. Present data indicate nonpoint-source pollution to be a significant factor in nitrate contamination of some areas of the Big Sioux aquifer. Since nonpoint-source contamination is generally associated with the application of agricultural fertilizers and pesticides, concentrations of pesticides in the Big Sioux aquifer should also be examined.

4. The suggested studies mentioned above should be coordinated with other studies in the state on nitrates and pesticides.

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