EFFECTS OF THE 1993 FLOOD ON WATER LEVELS AND WATER QUALITY IN THE SHEYENNE DELTA AQUIFER, SOUTHEASTERN NORTH DAKOTA, 1993-94

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Abstract

A study was conducted to evaluate the effects of precipitation and flooding on water levels in the Sheyenne Delta aquifer and to evaluate the variations in water quality that are related to the precipitation and flooding. Water-level, streamflow, and water-quality data collected before July 1993 were assumed to be representative of pre-flood conditions, and data collected from July 1993 through May 1994 were used to evaluate the ground-water response.

Water levels in 49 wells were measured every 3 weeks, when possible, between November 1993 and May 1994. Water samples were collected from 16 of the wells during November 1993 and March, April, and May 1994 and analyzed for major ions, nutrients, selected trace elements, and pesticides. The water-level and water-quality data collected during the study, along with similar data collected during previous investigations and during the National Water-Quality Assessment study, provided the basis for describing the general characteristics of the hydrology and water quality of the Sheyenne Delta aquifer.

Generally, precipitation and flooding affect water levels in the aquifer. The largest water-level rise occurs in low-relief areas, and water subsequently moves downgradient toward the river. Topography strongly affects the focus of recharge in the aquifer. During high stage in the river, ground-water flow gradients near the river can reverse, and water flows from the river into the aquifer. Water in the Sheyenne Delta aquifer before and after the 1993 flood generally was a calcium bicarbonate type. Little variation exists between pre-flood and post-flood water-quality conditions in the aquifer. Water quality in the aquifer is affected mainly by precipitation, evapotranspiration, inflow from adjacent ground water, and inflow from the Sheyenne River.

INTRODUCTION

Excessive precipitation produced severe flooding in the upper Midwest (fig. 1) during the summer of 1993 and caused substantial effects on water budgets and flow regimes in surficial aquifers adjacent to flooding streams. A wet-weather pattern that persisted over the upper Midwest for several months in mid-1993 culminated in intense, persistent precipitation in late June and July. Flood-peak discharges exceeded the previous maximum known discharges at 42 streamflow-gaging stations in the upper Mississippi River Basin and the 100-year recurrence intervals at 46 streamflow-gaging stations (Parrett and others, 1993). According to Wahl and others (1993), monthly rainfall in the upper Mississippi River Basin was greater than normal (1961-90) for January through June 1993. Of 10 selected weather stations in the basin, 8 received more than 200 percent of the normal rainfall for July, and 3 received more than 400 percent of the normal rainfall for July.

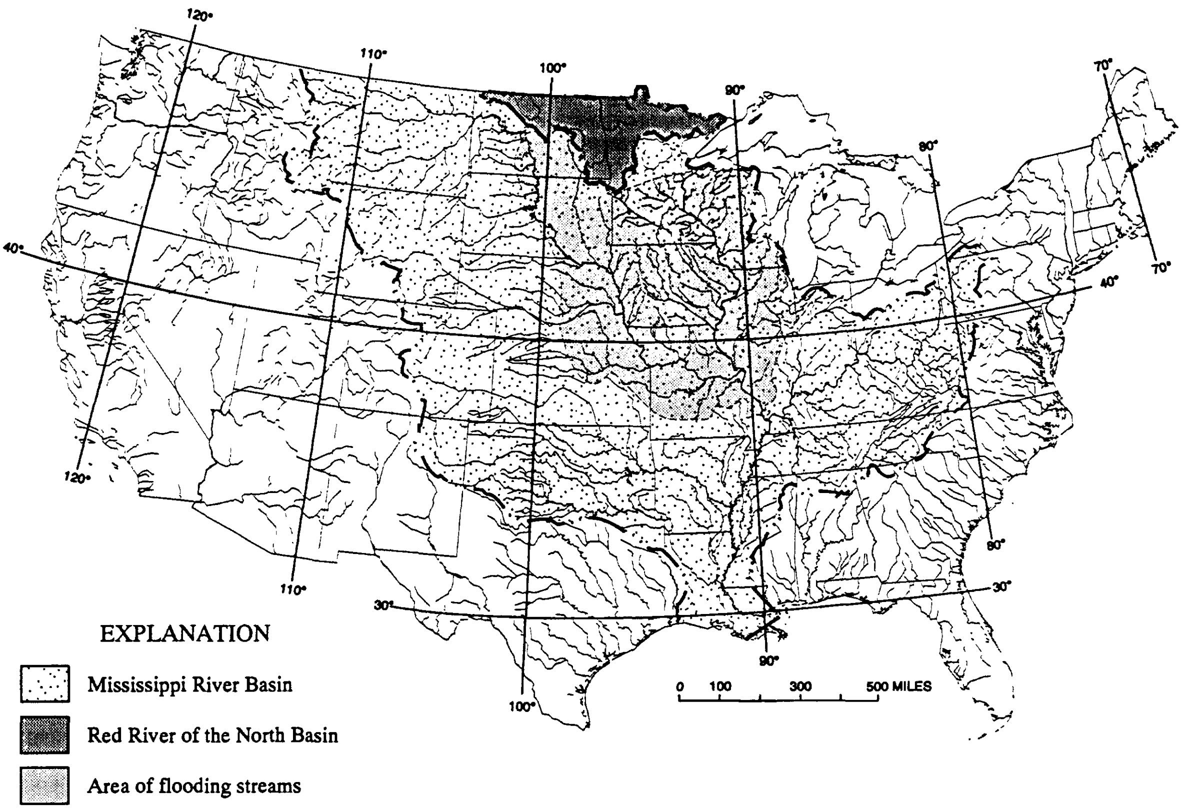


Figure 1. Location of Mississippi River Basin, Red River of the North Basin, and general area of flooding streams, June through August 1993. (From Parrett and others, 1993.)

In North Dakota, the most severe flooding occurred in the Devils Lake, Red River of the North, and upper James River Basins. A total of 39 counties in the State were declared disaster areas. The city of Fargo received about 185 percent of the normal rainfall for July (National Oceanic and Atmospheric Administration, 1993), and water levels in surficial aquifers across the State generally increased during June and July. Direct precipitation, flooding from rivers and tributaries, reduced evapotranspiration because of cooler temperatures and increased cloud cover, and reduced ground-water withdrawals for irrigation all contributed to a major deviation from the typical summer ground-water budget. Intense, localized precipitation and reversed ground-water flow gradients adjacent to flooding streams had a major effect on flow regimes in surficial aquifers.

The unusually large recharge combined with reduced evapotranspiration and water use caused substantial increases in ground-water storage that previously was diminished by drought and pumpage. Water levels in aquifers rose in response to the increased storage. High ground-water levels, depending on the location, may prolong problems caused by flooding streams because the stored water is released slowly to surface drainages. Other problems, such as seepage into buildings, may be caused by rising water levels in parts of the aquifer not directly affected by the flooding streams. Ground-water contamination may occur because of the mobilization of contaminants, such as agricultural chemicals, in surface soils or in previously unsaturated zones and because of large changes or reversals in ground-water flow gradients. These changes or reversals could mobilize or redistribute contaminants previously isolated in the ground-water flow system.

Effects of the widespread flooding that occurred in the upper Mississippi River Basin during the summer of 1993 were documented by Parrett and others (1993), Wahl and others (1993), Perry (1994), Taylor and others (1994), and Visocky (1994). However, the geographic scope of their studies did not include the Red River of the North Basin (fig. 1) or the Sheyenne River Basin (fig. 2), which are adjacent to the upper Mississippi River Basin and which also experienced intense rainfall and flooding during 1993 (mainly in July and August).

A study was conducted to evaluate the effects of precipitation and flooding in 1993 on water levels in the Sheyenne Delta aquifer and to evaluate the variations in water quality that are related to the precipitation and flooding. Specific objectives of the study were to determine pre-flood conditions and to interpret and evaluate the ground-water response to precipitation and flooding. Water-level, streamflow, and water-quality data collected before July 1993 were assumed to be representative of pre-flood conditions, and data collected from July 1993 through May 1994 were used to evaluate the ground-water response. This report describes results of the study, which was conducted by the U.S. Geological Survey in cooperation with the North Dakota Department of Health. Results will help provide improved understanding of the effects of flooding on surficial aquifers.

Description of Study Area

The Sheyenne Delta is a deltaic deposit formed along the margins of glacial Lake Agassiz during the Pleistocene Epoch. The study area consists of most of the Sheyenne Delta aquifer, which drains to the Sheyenne River in southeastern North Dakota (fig. 2). The aquifer underlies parts of Cass, Ransom, and Richland Counties and part of the Sheyenne River Valley and adjacent areas between the cities of Lisbon and Kindred. Land overlying the aquifer consists of about 440 square miles of relatively flat lake plain and gently rolling hills, referred to as low-relief areas (fig. 3), and steep banks and hills adjacent to the river, referred to as high-relief areas (fig. 3). The steep banks and hills were produced by surface erosion and eolian dune formation. The land overlying the aquifer is nearly flat lake plain on the east and rolling glacial-drift prairie on the west and is used mainly for cattle grazing and corn and soybean production.

Land overlying the Sheyenne Delta aquifer drains to the Sheyenne River. Other surface drainage on the delta is poorly developed because of permeable soils and deltaic deposits. Ground-water flow gradients indicate that ground water flows generally toward the river or to the east.

Previous Investigations

The Sheyenne Delta first was designated and described by Upham (1895) but also was discussed by Bennett and others (1909). The geology and ground-water resources of the area were discussed by Dennis and others (1949, 1950); Powell (1956); Paulson (1964); Baker (1966, 1967a, 1967b); Baker and Paulson (1967); and Brophy (1967). Downey and Paulson (1974) completed a detailed investigation on ground-water flow in the Sheyenne Delta aquifer and used a ground-water flow model to simulate the potential effects of a proposed lake in the area. As part of their study, Downey and Paulson (1974) conducted 3 aquifer tests in the Sheyenne Delta aquifer, measured hydraulic conductivity in 25 core samples, and obtained 2 sets of streamflow measurements at various points along the Sheyenne River between Lisbon and Kindred to determine the baseflow contribution from the Sheyenne Delta aquifer. Sheyenne River baseflow was measured (Paulson, 1964; Harkness and others, 1988) to evaluate baseflow contributions from the aquifer. A supplement to the predictive modeling study of Downey and Paulson (1974) was completed by Armstrong (1981).

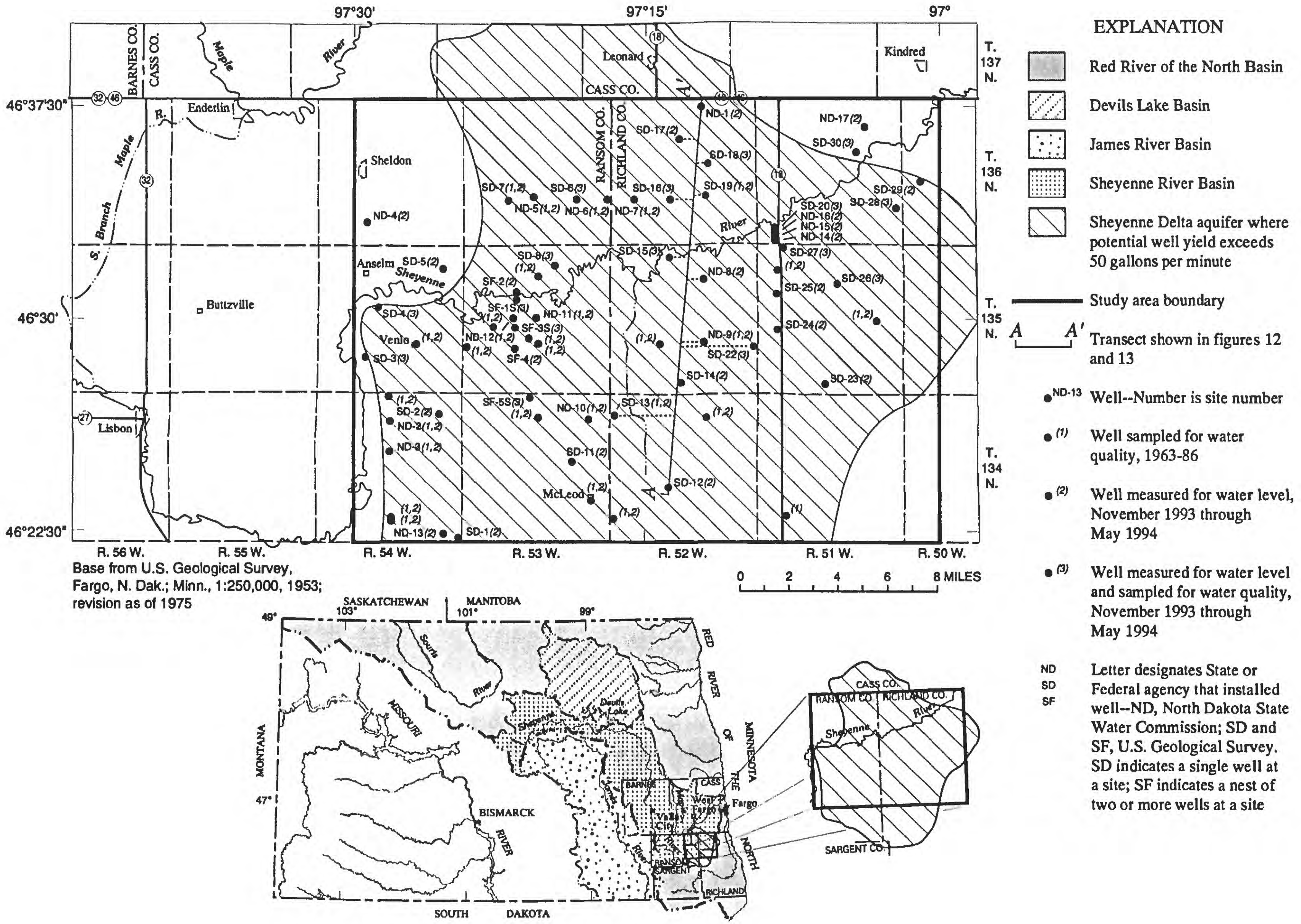


Figure 2. Location of study area and wells used in study.

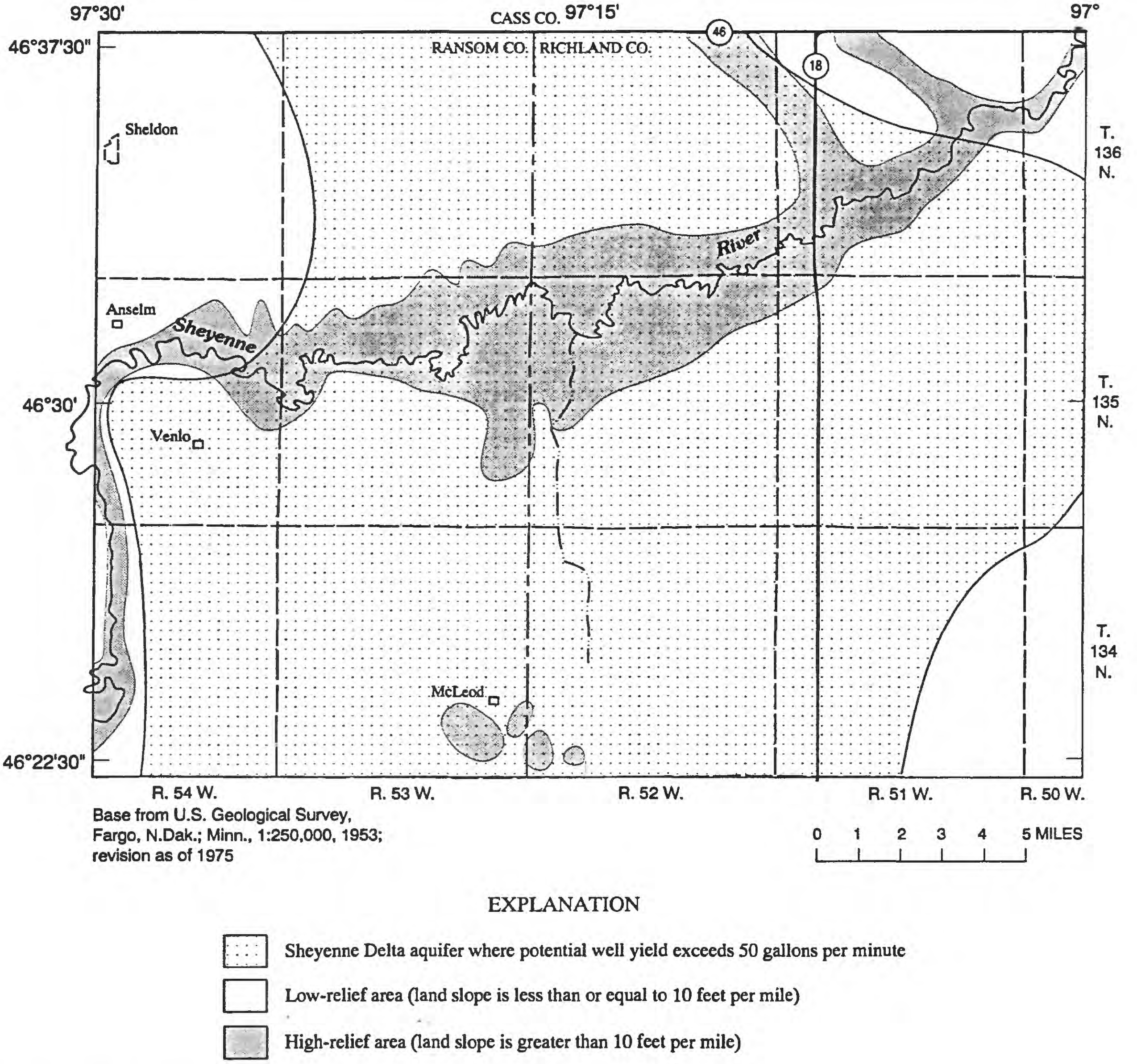


Figure 3. Location of low- and high-relief areas.

Water quality in the Sheyenne Delta aquifer was described by Dennis and others (1949, 1950); Powell (1956); Baker (1966, 1967a); and Armstrong (1979). Roberts and others (1985) conducted an investigation of arsenic in ground water in southeastern North Dakota, including the southern part of the Sheyenne Delta aquifer. The U.S. Geological Survey and the North Dakota Department of Health routinely collect and analyze water samples from wells in the Sheyenne Delta aquifer, and the U.S. Geological Survey also is studying water quality in the aquifer as part of its National Water-Quality Assessment (NAWQA) study of the Red River of the North Basin. Cowdery and Goff (1994) presented a summary of the nitrate-nitrogen concentrations in samples collected as part of the NAWQA study.

General Geology

Although Upham (1895) first described the Sheyenne Delta, Leverett (1912, 1932) and Elson (1957) questioned whether the feature was a true delta or ice-contact stratified drift. Later examinations of test-hole data and surface exposures support Upham's original interpretation of deltaic deposition (Paulson, 1964; Baker, 1967a).

The Sheyenne Delta, which generally delineates the Sheyenne Delta aquifer, is a Pleistocene-age near-surface feature that overlies lacustrine sediments of glacial Lake Agassiz (Baker, 1967a). The delta consists mainly of interbedded fine to medium sand and silt that generally is 49 to 140 feet thick (Downey and Paulson, 1974). The delta is bounded by glacial drift on the west and south and grades into lacustrine sediments in the east and north. The deltaic deposits grade from predominantly sand in the southwest to predominantly silt and clay in the northeast (Downey and Paulson, 1974). The northeastern edge of the delta forms an escarpment and is continuous with sandy deposits of the Campbell beach, one of the lower shorelines of glacial Lake Agassiz (Baker, 1967a). Grain size in the deltaic deposits generally increases in both the upward and shoreward (southwest) directions because of progradation of the delta into glacial Lake Agassiz (Cowdery and Goff, 1994). In many places, the deltaic deposits have been modified into sand dunes by wind action (Downey and Paulson, 1974).

The low-relief areas of the Sheyenne Delta consist of Ulen-Hecla association soils and, to a lesser degree, Ulen-Stirum association soils (Omodt and others, 1968). In both types of soils, surface drainage is absent, and precipitation and snowmelt percolate to the water table. Permeability is moderately high, and infiltration is moderately rapid. The high-relief areas of the Sheyenne Delta consist of Valentine-Hecla-Hamar association soils (Omodt and others, 1968). Surface drainage in these soils also is absent, and precipitation and snowmelt percolate rapidly to the water table. Permeability is high, infiltration is rapid, and the water-retention capacity is small (Omodt and others, 1968).

Pleistocene-age lacustrine clays about 100 feet thick underlie the Sheyenne Delta aquifer throughout the study area (Downey and Paulson, 1974). The clays, which are plastic and have low hydraulic conductivity, form a relatively impermeable basal unit to the aquifer. The contact between the aquifer and the lacustrine clays is poorly defined because the prograding delta deposited over its own bottomset beds, which have essentially the same composition as the lacustrine clays (Baker, 1967a).

A thick sequence of Pleistocene-age till and stratified drift underlies the lacustrine clays (Downey and Paulson, 1974). The 81- to 263-foot thick sequence of glacial deposits has low hydraulic conductivity and, along with the lacustrine clays, generally isolates the Sheyenne Delta aquifer from any significant hydrologic interaction with bedrock aquifers. The major water-bearing bedrock unit underlying the Sheyenne Delta aquifer is sandstone in the Cretaceous-age Dakota Group.

Acknowledgments

Landowners and the U.S. Forest Service provided access to land for well installations, water-level measurements, and water-quality sampling. Wells were installed by the North Dakota State Water Commission and by the U.S. Geological Survey as part of the NAWQA study. The North Dakota Department of Health provided water-quality sampling and laboratory analysis for this study.

Water-level and water-quality data were obtained from the NAWQA study. Wells installed by the U.S. Geological Survey as part of the NAWQA study but sampled by the North Dakota Department of Health as part of this study are designated in this report by an SD or SF. SD indicates a single well at a site, and SF

indicates a nest of two or more wells at a site. Although many water samples have been collected and analyzed as part of the NAWQA study, most of the data are not included in this report.

CONDITIONS IN THE SHEYENNE DELTA AQUIFER BEFORE THE 1993 FLOOD

Results of previous studies of the hydrology of the Sheyenne Delta aquifer were used to determine pre-flood conditions in the aquifer. Detailed analyses of conditions just before the flood were unavailable, but studies completed during the past 30 years and analyses of water samples collected from the Sheyenne Delta aquifer during that period were assumed to be representative of pre-flood conditions.

Aquifer Characteristics and Water Levels

Hydraulic conductivity in the Sheyenne Delta aquifer decreases from the southwest to the northeast (Downey and Paulson, 1974). This trend is consistent with the grain-size distribution expected in a delta that was formed from a river discharging into glacial Lake Agassiz from the southwest. Downey and Paulson (1974) conducted aquifer tests at 3 locations on the delta, measured hydraulic conductivity in 25 core samples, and applied the water-table-profile-analysis method (Rorabaugh, 1960) at various locations to produce a map of hydraulic conductivities for the aquifer. Transmissivities range from about 200 feet squared per day in the silt/clay facies to about 1,400 feet squared per day in the sand facies (Downey and Paulson, 1974).

The Sheyenne Delta aquifer is unconfined throughout the study area and is recharged by direct infiltration of snowmelt and rain. Except for the Sheyenne River, surface drainage across the aquifer is minor because of the generally rapid infiltration of snowmelt and rain through the sandy soils into the aquifer. During the study (July 1993 through May 1994), the water level in low-relief areas ranged from above land surface (surface ponding) to 20.5 feet below land surface. The water level in high-relief areas ranged from 3.5 to 24.1 feet below land surface, commonly about twice as deep as in low-relief areas.

Discharge from the aquifer is mainly to the Sheyenne River, to springs along the northeast edge of the delta, and, to a lesser extent, to wells and by evapotranspiration. Streamflow measurements on the Sheyenne River between Valley City and West Fargo (Paulson, 1964; Harkness and others,1988) indicate that discharge from the Sheyenne Delta aquifer provides substantial baseflow to the Sheyenne River (fig. 4). Measurements made during September through November 1963 showed an increase in streamflow of about 29 cubic feet per second between Lisbon and Kindred with no tributary inflows, which indicates that about 75 percent of the streamflow at Kindred was from discharge from the Sheyenne Delta aquifer (Paulson, 1964). Measurements made during October 1986 showed an increase of about 52 cubic feet per second between Lisbon and Kindred with no tributary inflows, which indicates that about 68 percent of the streamflow at Kindred was from discharge from the aquifer (Harkness and others, 1988). The separation between the two similar curves shown in figure 4 reflects a greater release from the Baldhill Dam upstream from Valley City and a wetter climate pattern during 1986 than during 1963. During the wetter period, more water was discharged from the Sheyenne Delta aquifer to the Sheyenne River, but the difference in the ratio of ground-water discharge to total streamflow for the two periods was only 7 percent.

Generally, the altitude of the water table in the Sheyenne Delta aquifer is greater than the altitude of the glacial Lake Agassiz lake plain to the north and east of the Sheyenne Delta and also is greater than the altitude of the Sheyenne River Valley, which has eroded to as much as 120 feet below the surface of the deltaic deposits (Baker and Paulson, 1967). Therefore, the water table slopes toward the margins of the

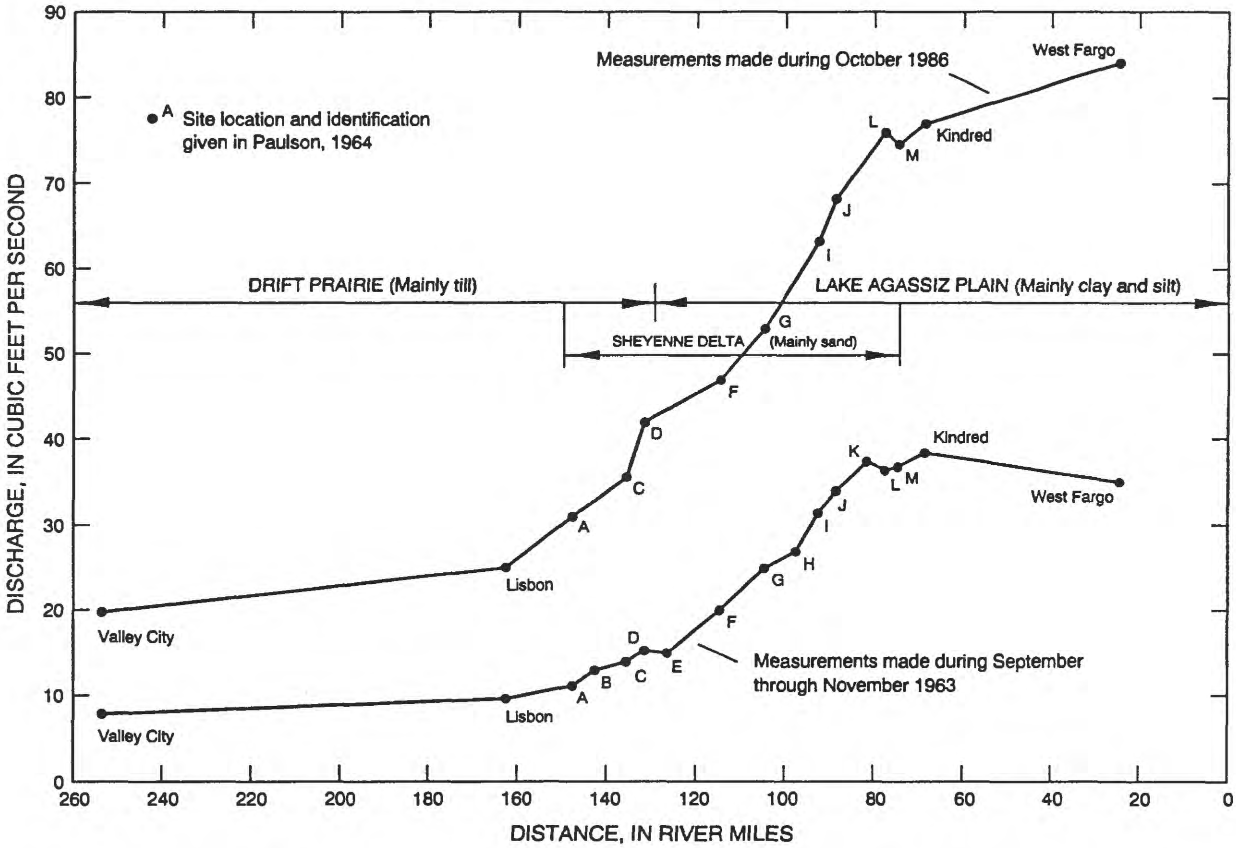


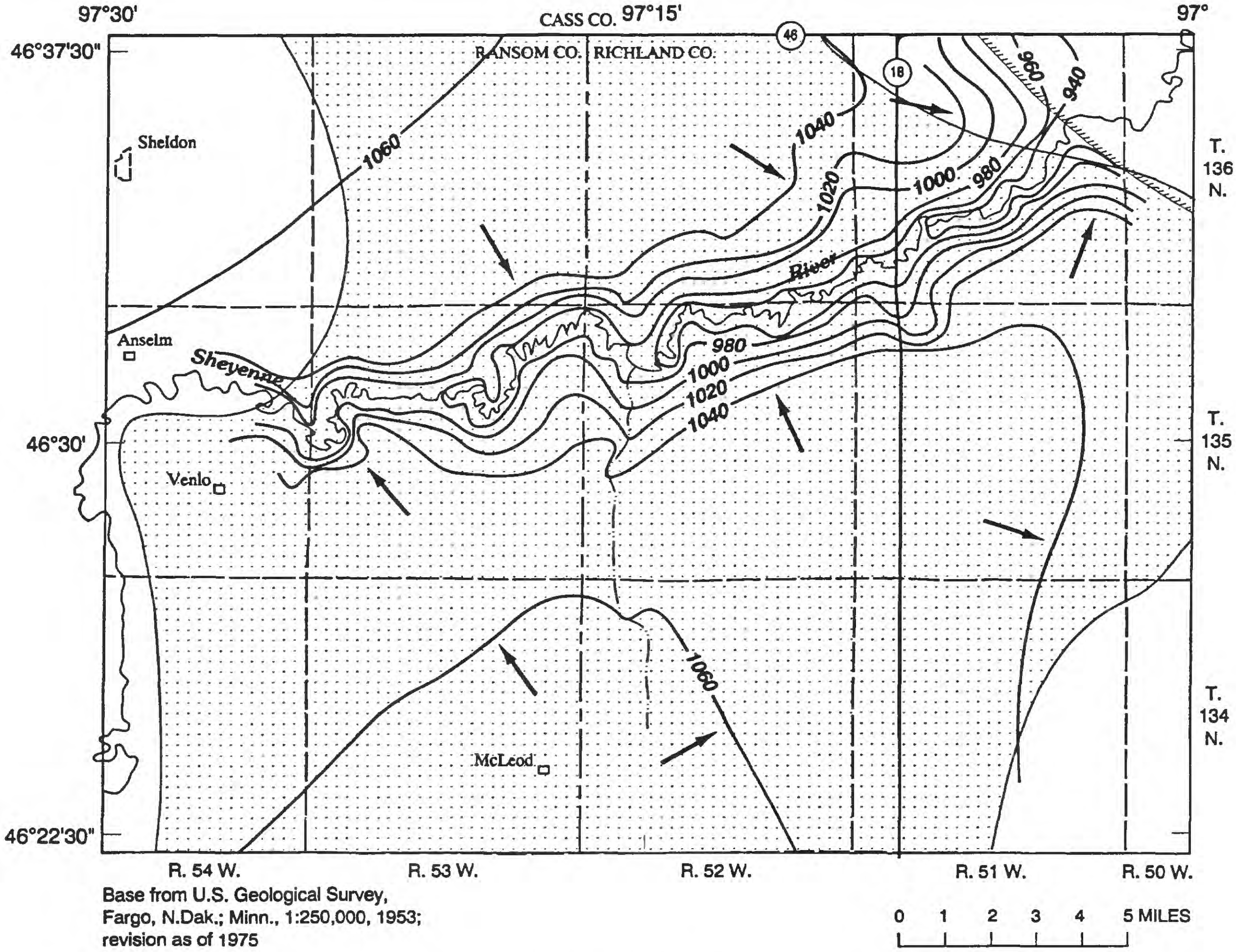
Figure 4. Streamflow in the Sheyenne River between Valley City and West Fargo, North Dakota, during September through November 1963 and October 1986. (Modified from Paulson, 1964. Data from Paulson, 1964, and Harkness and others, 1988.)

delta (to the north and east) or toward the Sheyenne River. Ground water in the study area generally flows toward the Sheyenne River (fig. 5, perpendicular to contours). Water-table gradients are relatively flat in the southern and northern parts of the aquifer and become steep adjacent to the river. The water-table configuration indicates that ground water generally discharges from the aquifer to the river during most of the year. However, data indicate that the river recharges the aquifer during brief periods in the spring and summer when river elevations that are higher than local ground-water altitudes cause water to flow from the river to the aquifer.

Water Quality

Water quality in the Sheyenne Delta aquifer was determined from water samples collected from 29 wells (fig. 2) completed in the aquifer. The samples were collected from 1963 to 1986 and analyzed for selected water-quality properties and constituents. A statistical summary of selected water-quality data for the 29 wells is given in table 1. Some of the wells were sampled more than once, but only the most recent sample was included in the statistical summary. Generally, water quality in the aquifer is good, and, as indicated by the 75th- and 25th-percentile values, little variability exists among locations.

The major-ion composition of water from the 29 wells is shown in figure 6. Water from most of the samples was a calcium bicarbonate to a calcium magnesium bicarbonate type, but water from one well was



EXPLANATION

Sheyenne Delta aquifer where potential well yield exceeds 50 gallons per minute

— 940 — Water-table contour--Shows altitude of water table. Contour interval 20 feet. Datum is sea level

Sheyenne Delta escarpment

Direction of ground-water flow

Figure 5. Altitude of water table in the Sheyenne Delta aquifer determined from mean monthly water levels for September 1972 through August 1973. (Modified from Downey and Paulson, 1974.)

a calcium sodium magnesium sulfate type. Water from that well also had the largest dissolved-solids concentration.

Temporal water-quality trends could not be determined because of the small amount of historic data available. Well SD-13 was sampled in 1981, 1983, and 1986. Chemical constituents in the water changed little during the 5-year period, and the water remained a calcium bicarbonate type.

Table 1. Statistical summary of selected water-quality data for 29 wells completed in the Sheyenne Delta aquifer, 1963-86

[µS/cm, microsiemens per centimeter; °C, degrees Celsius; --, no data; mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter]

Property or constituent	Descriptive statistics				Value at which indicated percent of all sample values is less than or equal to that shown		
	Number of samples	Maximum	Minimum	Mean	75	50 (Median)	25
Specific conductance (µS/cm at 25°C)	29	2,420	400	685	710	590	539
pH (standard units)	24	8.0	6.9	--	7.9	7.8	7.5
Calcium, dissolved (mg/L)	29	280	48	87	95	76	66
Magnesium, dissolved (mg/L)	29	78	16	26	28	23	19
Sodium, dissolved (mg/L)	29	180	3.4	22	16	12	7.2
Potassium, dissolved (mg/L)	29	12	.6	3.7	4.2	3.2	2.2
Bicarbonate, dissolved (mg/L)	26	510	230	364	428	350	308
Sulfate, dissolved (mg/L)	29	930	.4	57	35	14	8.6
Chloride, dissolved (mg/L)	29	140	<.1	10	6.9	3.1	2.4
Dissolved solids, sum (mg/L)	29	1,820	269	416	427	349	315
Nitrate, dissolved (mg/L as N)	26	.90	.05	.26	.23	.23	.23
Iron, dissolved (µg/L)	26	8,800	40	2,770	4,080	2,050	525

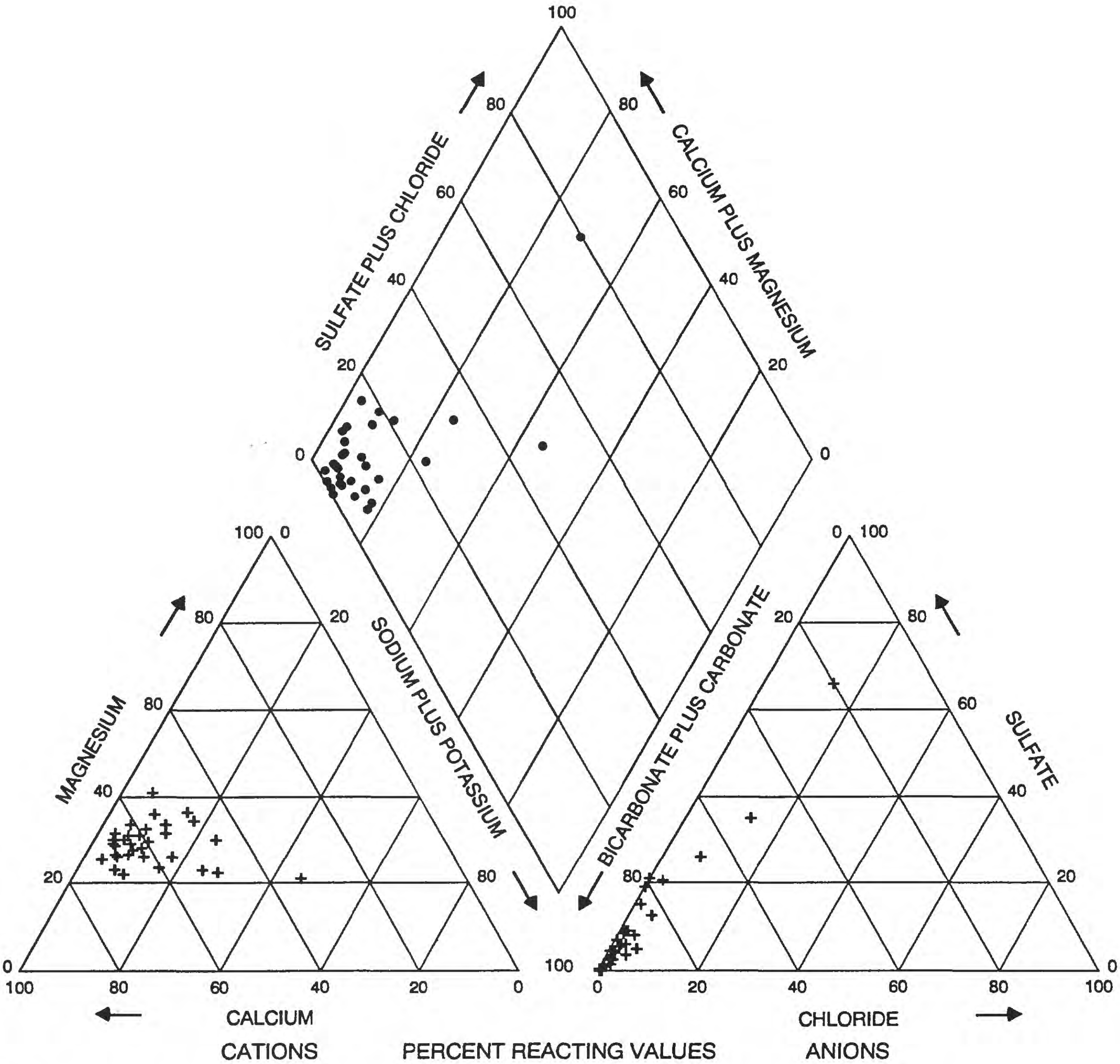


Figure 6. Major-ion composition of water from wells completed in the Sheyenne Delta aquifer, 1963-86.

CONDITIONS IN THE SHEYENNE DELTA AQUIFER AFTER THE 1993 FLOOD

The effects of precipitation on water levels in the Sheyenne Delta aquifer were evaluated by mapping water-level fluctuations that occurred after the 1993 flood. Water levels in 49 wells (fig. 2) were measured every 3 weeks, when possible, between November 1993 and May 1994. All of the wells are screened in the Sheyenne Delta aquifer except for well ND-4, which is screened in glacial till, and wells ND-17, SD-3, SD-5, and SD-30, which are screened in Sheyenne Delta sands along the edge of the aquifer. Chemical analyses of water samples collected during November 1993 and March, April, and May 1994 were used to determine water-quality variations related to the water-level fluctuations and to recharge from both precipitation and inflow from the Sheyenne River.

Water Levels

Water levels in the Sheyenne Delta aquifer began rising in March 1993 in response to recharge from snowmelt (fig. 7). Generally, the water levels also rose in the spring in response to excessive precipitation that was unusually frequent and consistently intense. Discharge in the Sheyenne River increased as a result of overland flow and increased ground-water discharge. However, during high stage in the Sheyenne River, water-table gradients near the river reversed, and water from the river flowed into the aquifer as temporary bank storage. The water level in that part of the aquifer immediately adjacent to the river rose, and, as a result, the gradient toward the river decreased in the rest of the aquifer.

The altitude of the water table in the Sheyenne Delta aquifer during November 16-17, 1993, is shown in figure 8, and the altitude during March 29-30, 1994, is shown in figure 9. Generally, the land surface was snow covered from mid-December through mid-March. Recharge to the aquifer from snowmelt and precipitation began in mid-March. Although water levels in the aquifer rose in March (figs. 8 and 9), the ground-water flow directions and gradients remained relatively constant.

Water levels throughout most of the aquifer generally rose in late November and December 1993. This rise corresponds to precipitation that occurred during a warm period in late November. The Sheyenne River also rose in response to the precipitation (fig. 7), and water levels in wells SF-1S and SF-2, which are located less than 50 feet from the Sheyenne River, rose in response to the rise in river stage. Similar response probably occurred along the banks of the river throughout the study area.

Water levels throughout most of the study area declined slightly between December 1993 and early January 1994. Between January 4 and January 24-25, 1994, water levels continued to decline slightly except in the west-central part of the study area where water levels rose slightly. Generally, the water table changed little during this period, which was the coldest part of the winter. All precipitation was in the form of snow, and air temperatures were never above freezing.

Between January 24-25 and February 17, 1994, water levels throughout most of the aquifer declined substantially. Water levels in some wells in the northern and southern parts of the aquifer were as much as 0.7 foot lower than previously measured. Downgradient from those sites, water levels in some wells rose slightly from the previous measurement. Water levels also rose in wells in the eastern part of the study area and in wells located adjacent to the river (especially in well SF-1S, which usually responded to changes in river stage). Because the water table is much farther below land surface in high-relief areas than in low-relief areas, this slight rise during the winter may be the result of delayed recharge percolating to the water table.

During the first half of March 1994, maximum daily air temperatures generally were above freezing and often were between 40 and 45 degrees Fahrenheit (°F). Some snowmelt occurred, and infiltration into the aquifer caused water levels to rise slightly throughout most of the study area. The river, however, did not begin to respond until March 20 (fig. 7). The water level in the aquifer was higher with distance from the river. Topography, soil permeability, grain-size distribution, snow-cover thickness, and vegetation cover may all affect the rate of recharge to certain parts of the aquifer.

During the second half of March, precipitation and maximum daily air temperatures in the mid-50°F range created conditions that produced substantial recharge over large parts of the aquifer. Water levels rose throughout the entire study area and increased by more than 2 feet in some areas. However, the water-level rise was greater in low-relief areas to the north and south of the river than in high-relief areas closer to the river (fig. 3). The greater water-level rise in low-relief areas probably results from snowmelt lying on the flat surfaces and seeping through pores and cracks into the subsurface. More runoff probably occurs in high-relief areas; thus, less snowmelt percolates through the soils to the water table. Runoff from high-

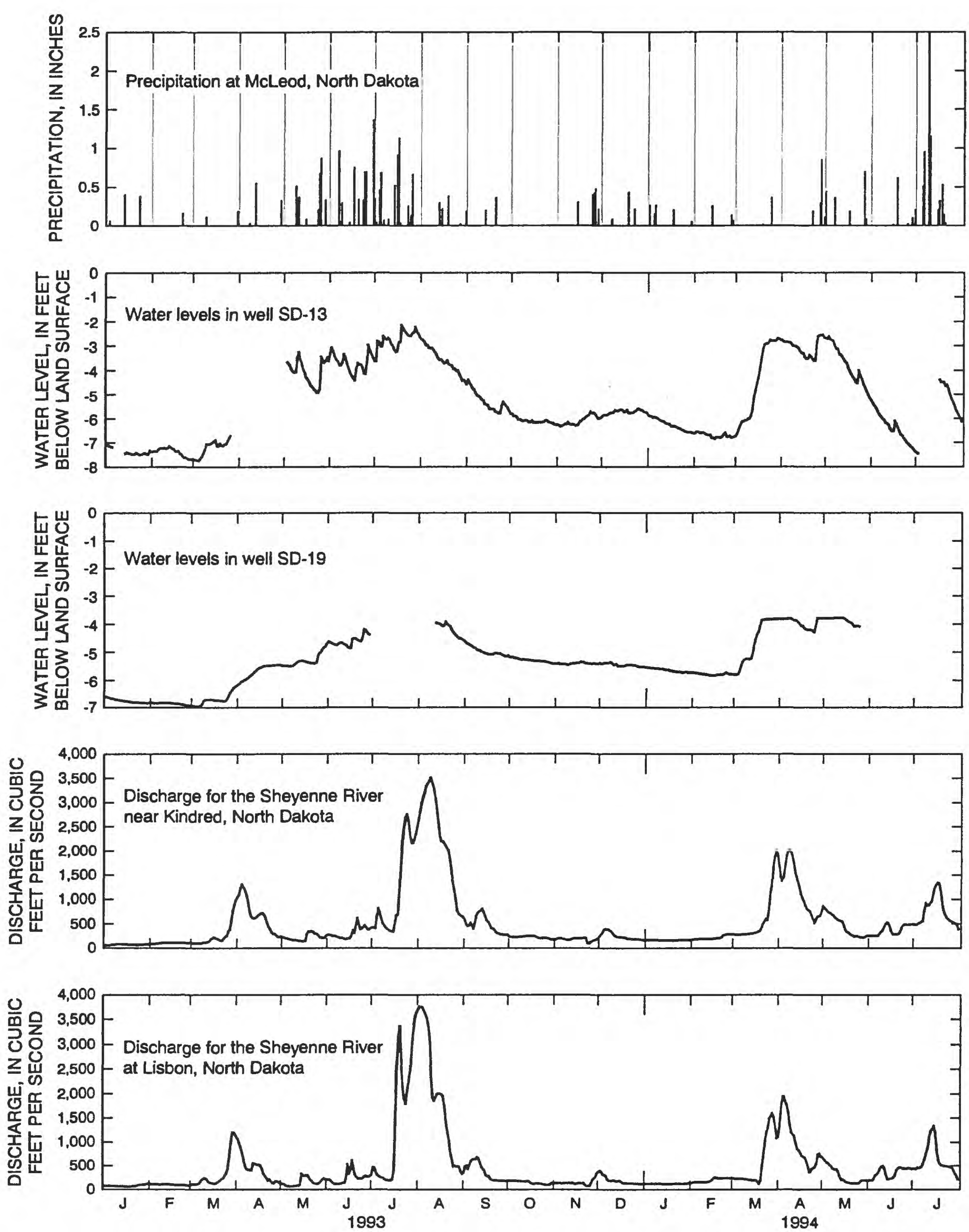


Figure 7. Relation between precipitation at McLeod, North Dakota, water levels in wells SD-13 and SD-19, and stream discharge at Kindred and Lisbon, North Dakota, January 1993 through July 1994.

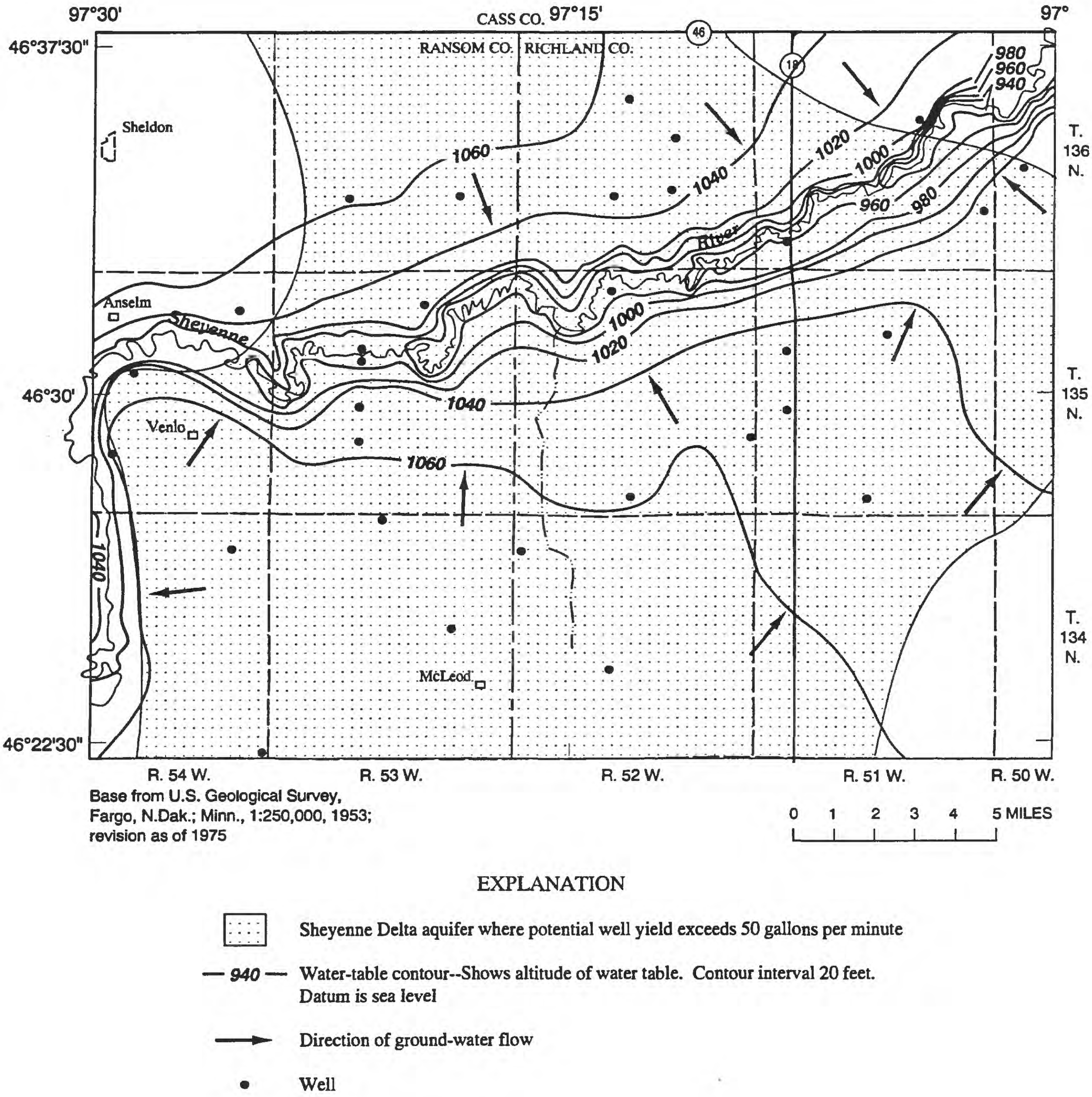
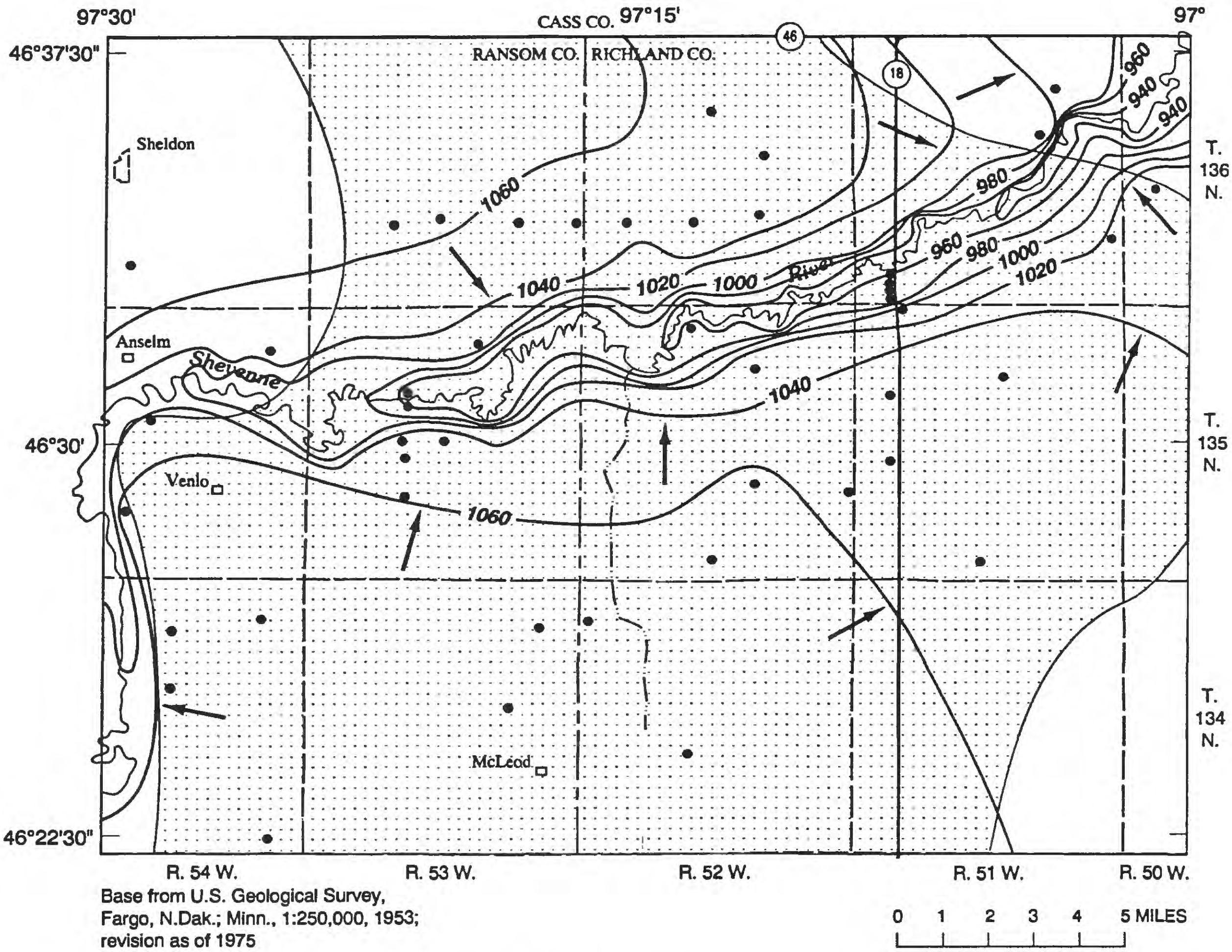


Figure 8. Altitude of water table in the Sheyenne Delta aquifer, November 16-17, 1993.

relief areas probably accounts for the higher water levels in the river and the large increases in river discharge from mid- to late March (fig. 7). The water levels in well SF-1S, which is located adjacent to the river, showed an increase similar to that in the river.

Large increases in water levels in the northern and southern parts of the study area (low-relief areas) during late March caused increased ground-water flow into high-relief areas and produced slight increases in water levels near the river as ground water moved downgradient. Water levels generally declined during the first half of April following the snowmelt period during March.



EXPLANATION

Sheyenne Delta aquifer where potential well yield exceeds 50 gallons per minute

— 940 — Water-table contour--Shows altitude of water table. Contour interval 20 feet. Datum is sea level

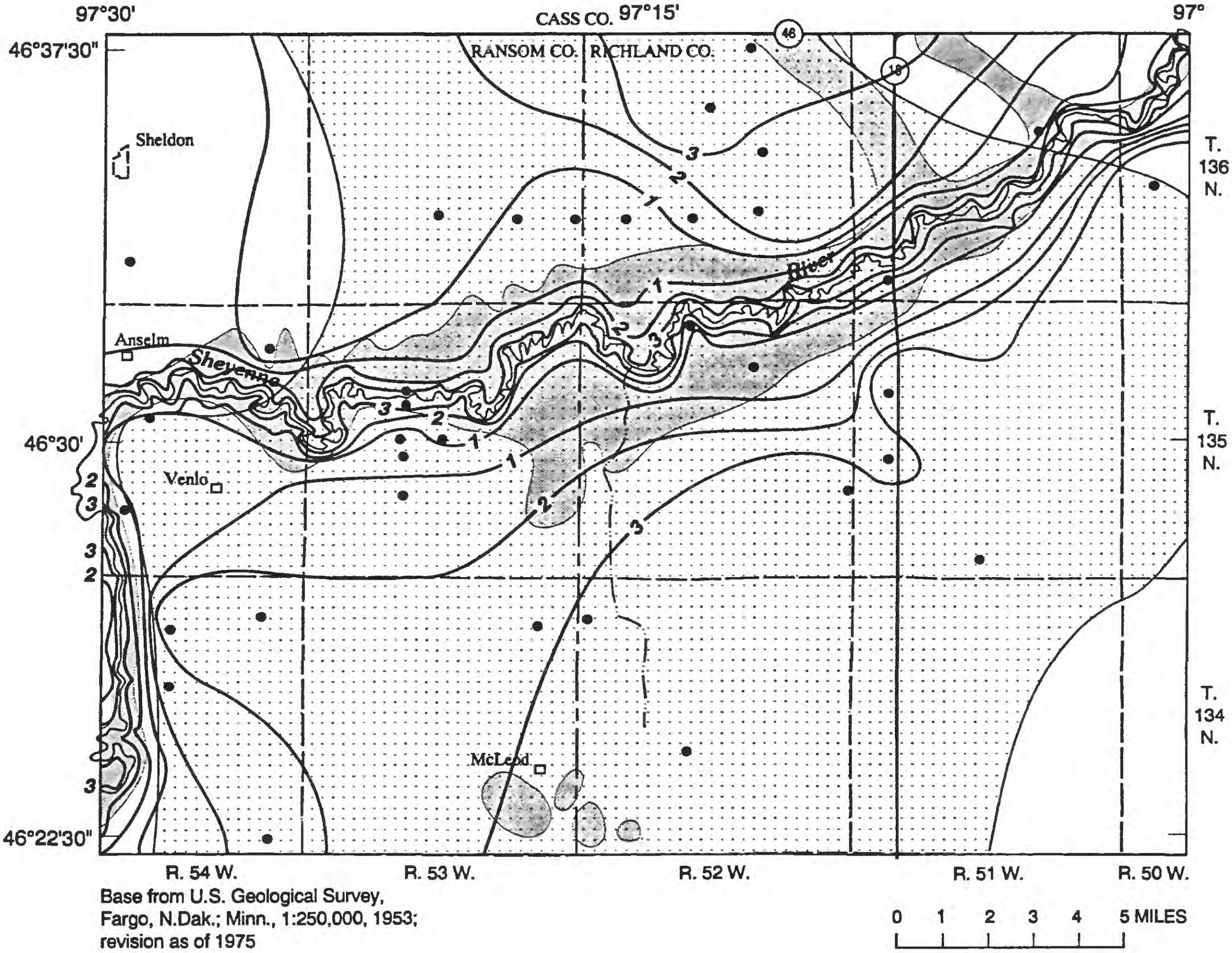
Direction of ground-water flow

• Well

Figure 9. Altitude of water table in the Sheyenne Delta aquifer, March 29-30, 1994.

Excessive precipitation in late April (fig. 7) produced higher water levels throughout most of the aquifer. The river responded slightly to the precipitation (fig. 7). The streamflow peak resulting from the late April rains occurred quickly, then the normal post-snowmelt streamflow recession continued.

The concept of ground-water movement from low-relief areas in the northern and southern parts of the aquifer to the river is shown in figures 10 through 13. Snowmelt and precipitation infiltrate into the aquifer in low-relief areas during early spring and produce a rise in water levels (figs. 10, 12, and 13). Snowmelt and precipitation in high-relief areas, typically in areas near the river, either travel as surface runoff to low-relief areas or to the river or infiltrate to the water table and flow in the direction of the steep hydraulic



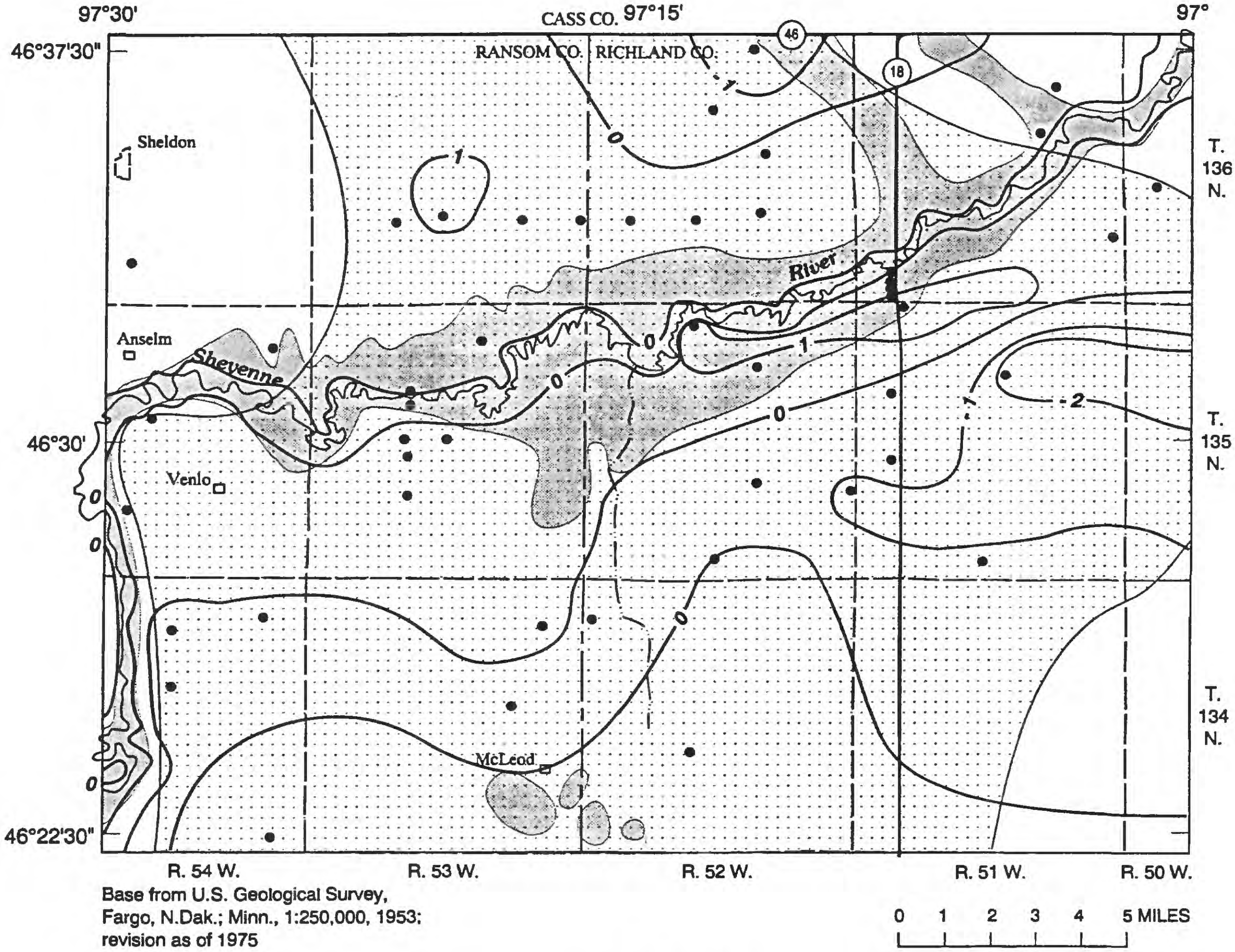
EXPLANATION

Sheyenne Delta aquifer where potential well yield exceeds 50 gallons per minute	High-relief area (land slope is greater than 10 feet per mile)
	—3— Line of equal water-level change--Interval 1 foot
Low-relief area (land slope is less than or equal to 10 feet per mile)	• Well

Figure 10. Change in water levels from January 24-25, 1994, to March 29-30, 1994.

gradient toward the river. This explains the rise in water levels that occurs in wells located in low-relief areas of the aquifer and the rise in stage in the river during spring melt. After spring melt, water levels in low-relief areas begin to decline and levels near the river rise as the aquifer equilibrates toward stable conditions (figs. 11, 12, and 13).

Parts of the aquifer near the Sheyenne River may be affected by inflow from the river during periods of high river stage. Previous studies of streamflow conditions in the Sheyenne River during the fall (when streamflow is comprised mainly of ground-water discharge) showed that flow in the Sheyenne River increased between Lisbon and Kindred (fig. 4), indicating the Sheyenne Delta aquifer contributed water to the river. However, during spring snowmelt periods, much of the increase in streamflow may be from surface runoff over frozen, saturated soils in high-relief areas adjacent to the river. During high stage in



EXPLANATION

Sheyenne Delta aquifer where potential well yield exceeds 50 gallons per minute

Low-relief area (land slope is less than or equal to 10 feet per mile)

High-relief area (land slope is greater than 10 feet per mile)

—— 1 —— Line of equal water-level change--Interval 1 foot

• Well

Figure 11. Change in water levels from March 15-16, 1994, to May 10-11, 1994.

the river, water may enter the aquifer from the river as bank storage. Normally, the water-table gradient in most of the aquifer is toward the river (fig. 12), but this gradient can reverse during periods of high river stage. For example, on February 17, 1994, the gradient between the river and well SD-15, which is located adjacent to the river, was toward the well. The reversal in the gradient was temporary, however, because, as river stage declined, discharge of ground water to the river resumed.

Water Quality

Water samples were collected from the Sheyenne River at Lisbon (upstream from the Sheyenne Delta) and the Sheyenne River at Kindred (downstream from the Sheyenne Delta) as part of the U.S. Geological

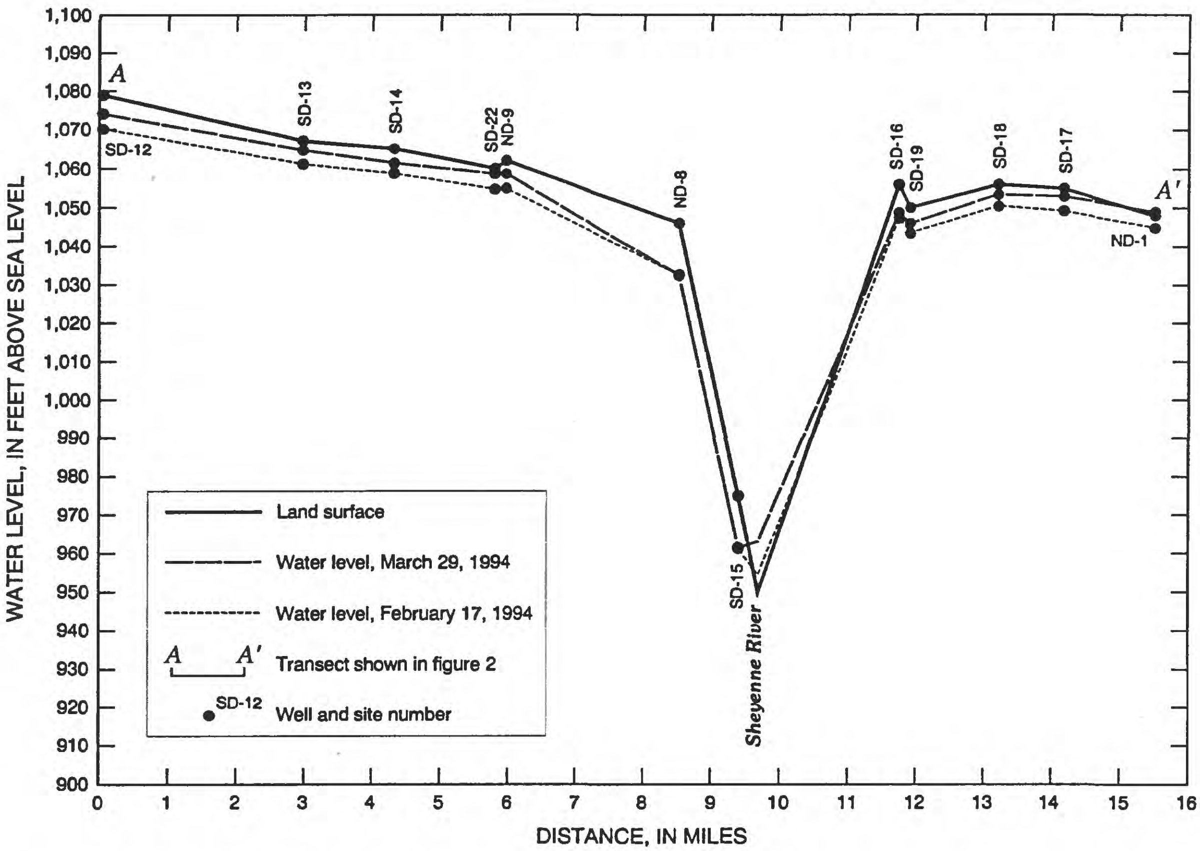


Figure 12. South-north transect across water table in the Sheyenne Delta aquifer.

Survey's routine data-collection program. From December 1993 through April 1994, the water at Lisbon was a mixed calcium magnesium sodium bicarbonate sulfate type, and dissolved-solids concentrations ranged from 503 to 670 milligrams per liter. The water at Kindred also was a mixed calcium magnesium sodium bicarbonate sulfate type, and dissolved-solids concentrations ranged from 515 to 648 milligrams per liter. The similarity between the major-ion water chemistry at the two locations indicates that discharge from the Sheyenne Delta aquifer has little effect on general water quality in the river.

During November 1993 and March, April, and May 1994, water samples were collected from 16 of the 49 wells in which water levels were measured (fig. 2). The samples were collected by the North Dakota Department of Health and analyzed by that agency for major ions, nutrients, selected trace elements, and pesticides (tables 2 and 3). In November 1993, the U.S. Geological Survey concurrently sampled two of the wells and analyzed the samples at the U.S. Geological Survey National Water Quality Laboratory in Arvada, Colo., to evaluate the quality of analytical results. The North Dakota Department of Health samples were collected using Teflon bailers, and the U.S. Geological Survey samples were collected using a submersible pump. Although some discrepancies existed between results from the North Dakota Department of Health laboratory and results from the U.S. Geological Survey laboratory, most of the analyses basically were equivalent.

Samples collected during November 1993 and March, April, and May 1994 generally had a calcium bicarbonate type water (figs. 14, 15, 16, and 17). Except in samples from one well, the water type generally did not change between November 1993 and May 1994, and major-ion concentrations also remained relatively constant.

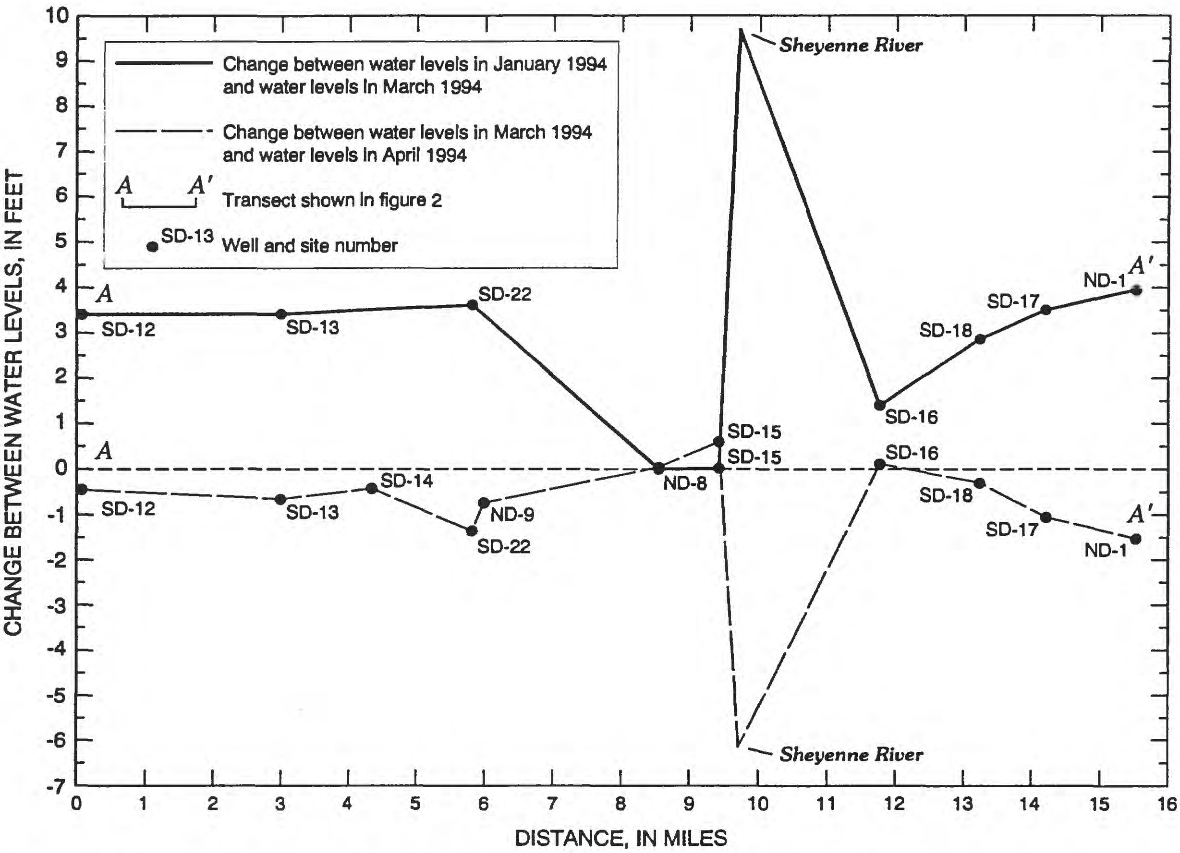


Figure 13. South-north transect of change between water levels in the Sheyenne Delta aquifer.

Water in well SF-1S changed from a calcium bicarbonate type in November 1993 and March 1994 to a sodium calcium bicarbonate type in April and May 1994 (fig. 18). During November, the aquifer probably was discharging ground water to the Sheyenne River. During the spring, water levels in the river were higher than ground-water altitudes, and water flowed from the river to the aquifer. Also, between March and May, snowmelt and precipitation were recharging the aquifer (fig. 7). The change in water type may be caused by a combination of interaction between the aquifer and the river and recharge from snowmelt and precipitation.

The largest dissolved-solids concentrations occurred in samples from well SD-26, which had a magnesium sulfate type water. Water from this well may be affected by upward seepage from the Cretaceous-age Dakota Group. However, clays interbedded with sands in this part of the aquifer also may be a source of magnesium and sulfate to water in this area. Baker (1967a) discussed the presence of interbedded fine sand, silt, and clay in the eastern part of the aquifer, where well SD-26 is located. Well logs based on auger cuttings indicate silt and very fine sand to about 5 feet below land surface and silty clay from 5 to 10 feet below land surface. The well is screened from 4.5 to 9.5 feet below land surface, mainly in the silty clay unit.

Nitrite plus nitrate concentrations in samples collected during November 1993 and March, April, and May 1994 ranged from less than 0.01 to 20 milligrams per liter as N (table 2). Concentrations generally were less than 1.0 milligram per liter as N, and no spatial or temporal pattern was apparent. The largest nitrite plus nitrate concentrations were in samples from well SF-3S and ranged from 7.2 to 20 milligrams

Table 2. Chemical analyses of water samples collected from wells completed in the Sheyenne Delta aquifer, November 1993 and March, April, and May 1994

[Analyses by the North Dakota Department of Health; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; gr/gal, grains per gallon; µg/L, micrograms per liter; --, no data; <, less than]

Well number and sampling period	Specific conductance, laboratory (µS/cm at 25°C)	pH, laboratory (standard units)	Turbidity (NTU)	Hardness, total (mg/L as $CaCO_3$)	Hardness, total (gr/gal)[1]	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)
SD-3 (11/93)	1,060	7.4	--	260	--	71	19
SD-3 (3/94)	476	7.3	65	250	14	69	18
SD-3 (4/94)	450	7.5	45	250	14	69	18
SD-3 (5/94)	505	7.4	65	320	19	90	24
SD-4 (11/93)	455	7.4	--	300	--	85	22
SD-6 (11/93)	425	7.3	--	330	--	89	25
SD-6 (3/94)	618	7.4	180	380	22	100	30
SD-6 (4/94)	608	7.6	95	370	22	100	27
SD-6 (5/94)	603	7.5	70	360	21	100	27
SD-8 (11/93)	396	7.2	--	230	--	67	14
SD-8 (4/94)	468	7.6	45	250	15	74	16
SD-8 (5/94)	475	7.5	15	230	13	69	14
SD-15 (11/93)	637	7.4	--	340	--	85	31
SD-15 (3/94)	653	7.3	45	320	18	76	31
SD-15 (4/94)	658	7.4	35	330	19	82	31
SD-15 (5/94)	650	7.2	40	320	18	76	31
SD-16 (11/93)	616	7.3	--	260	--	78	15
SD-16 (3/94)	462	7.3	95	270	16	83	14
SD-16 (4/94)	469	7.6	60	250	15	73	17
SD-16 (5/94)	445	7.4	30	220	13	67	13
SD-18 (11/93)	632	7.3	--	400	--	110	29
SD-18 (3/94)	837	7.1	65	440	26	130	32
SD-18 (4/94)	787	7.4	80	400	23	110	29
SD-18 (5/94)	908	7.1	70	500	29	130	40
SD-20 (11/93)	462	7.3	--	230	--	66	15
SD-20 (3/94)	455	7.2	85	210	12	60	14
SD-20 (4/94)	468	7.6	25	250	15	71	17
SD-20 (5/94)	468	7.2	35	210	12	59	14
SD-22 (11/93)	672	7.5	--	330	--	84	30
SD-22 (3/94)	701	7.4	70	340	20	94	26

Table 2. Chemical analyses of water samples collected from wells completed in the Sheyenne Delta aquifer, November 1993 and March, April, and May 1994—Continued

[Analyses by the North Dakota Department of Health; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; gr/gal, grains per gallon; µg/L, micrograms per liter; --, no data; <, less than]

Well number and sampling period	Sodium, dissolved (mg/L)	Percent sodium	Sodium adsorption ratio	Potassium, dissolved (mg/L)	Bicarbonate, total (mg/L)	Carbonate, total (mg/L)	Hydroxide (mg/L)
SD-3 (11/93)	2.2	2	0.1	<1.0	250	<1	<1
SD-3 (3/94)	1.2	1	<.1	<1.0	246	<1	<1
SD-3 (4/94)	1.4	1	<.1	<1.0	254	<1	<1
SD-3 (5/94)	1.1	1	<.1	1.1	281	<1	<1
SD-4 (11/93)	3.2	2	<.1	3.0	281	<1	<1
SD-6 (11/93)	5.1	3	.1	<1.0	225	<1	<1
SD-6 (3/94)	5.5	3	.1	<1.0	238	<1	<1
SD-6 (4/94)	4.3	2	.1	1.1	224	<1	<1
SD-6 (5/94)	4.4	3	.1	1.3	227	<1	<1
SD-8 (11/93)	1.6	2	<.1	<1.0	278	<1	<1
SD-8 (4/94)	.9	1	<.1	1.1	284	<1	<1
SD-8 (5/94)	.6	1	<.1	<1.0	293	<1	<1
SD-15 (11/93)	7.4	4	.2	1.8	409	<1	<1
SD-15 (3/94)	7.1	5	.2	1.0	420	<1	<1
SD-15 (4/94)	6.8	4	.2	1.9	413	<1	<1
SD-15 (5/94)	6.9	4	.2	3.3	411	<1	<1
SD-16 (11/93)	4.7	4	.1	<1.0	260	<1	<1
SD-16 (3/94)	3.2	2	<.1	<1.0	264	<1	<1
SD-16 (4/94)	2.9	2	<.1	<1.0	263	<1	<1
SD-16 (5/94)	2.2	2	<.1	<1.0	249	<1	<1
SD-18 (11/93)	12	6	.3	2.2	358	<1	<1
SD-18 (3/94)	17	8	.4	<1.0	438	<1	<1
SD-18 (4/94)	33	15	.7	<1.0	387	<1	<1
SD-18 (5/94)	19	8	.4	3.3	432	<1	<1
SD-20 (11/93)	7.5	7	.2	3.7	282	<1	<1
SD-20 (3/94)	6.9	7	.2	3.5	285	<1	<1
SD-20 (4/94)	8.2	7	.2	3.9	287	<1	<1
SD-20 (5/94)	7.1	7	.2	4.2	285	<1	<1
SD-22 (11/93)	36	19	.9	7.2	420	<1	<1
SD-22 (3/94)	29	16	.7	5.2	387	<1	<1

Table 2. Chemical analyses of water samples collected from wells completed in the Sheyenne Delta aquifer, November 1993 and March, April, and May 1994—Continued

[Analyses by the North Dakota Department of Health; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; gr/gal, grains per gallon; µg/L, micrograms per liter; --, no data; <, less than]

Well number and sampling period	Alkalinity, total, laboratory (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids, sum of constituents (mg/L)	Nitrite plus nitrate, total (mg/L as N)
SD-3 (11/93)	200	23	<3.0	--	--	244	<0.01
SD-3 (3/94)	200	50	3.2	0.2	--	266	<.01
SD-3 (4/94)	210	28	<3.0	.3	28	248	<.01
SD-3 (5/94)	230	44	<3.0	.2	29	304	--
SD-4 (11/93)	230	32	<3.0	--	--	288	<.01
SD-6 (11/93)	180	140	8.3	--	--	376	.06
SD-6 (3/94)	200	140	10	.3	--	403	.36
SD-6 (4/94)	180	150	10	.2	35	405	<.01
SD-6 (5/94)	190	130	9.8	.2	27	384	--
SD-8 (11/93)	230	13	<3.0	--	--	239	<.01
SD-8 (4/94)	230	11	<3.0	.2	32	248	.24
SD-8 (5/94)	240	13	<3.0	.1	26	247	.23
SD-15 (11/93)	340	28	4.8	--	--	362	.01
SD-15 (3/94)	340	24	4.7	.4	--	352	--
SD-15 (4/94)	340	22	5.0	.4	40	354	<.01
SD-15 (5/94)	340	26	4.8	.4	38	352	<.02
SD-16 (11/93)	210	32	<3.0	--	--	264	1.7
SD-16 (3/94)	220	39	<3.0	.2	--	276	.65
SD-16 (4/94)	220	31	<3.0	.2	25	259	.13
SD-16 (5/94)	200	29	<3.0	.2	21	240	--
SD-18 (11/93)	290	78	<3.0	--	--	415	.06
SD-18 (3/94)	360	120	4.2	.3	--	518	.05
SD-18 (4/94)	320	130	3.9	.3	30	501	.04
SD-18 (5/94)	350	140	5.1	.3	30	556	<.02
SD-20 (11/93)	230	16	<3.0	--	--	252	<.01
SD-20 (3/94)	230	18	<3.0	.2	--	247	<.01
SD-20 (4/94)	240	13	<3.0	.2	31	260	<.01
SD-20 (5/94)	230	18	<3.0	.2	30	248	--
SD-22 (11/93)	340	47	<3.0	--	--	416	<.01
SD-22 (3/94)	320	87	<3.0	.2	--	436	.02

Table 2. Chemical analyses of water samples collected from wells completed in the Sheyenne Delta aquifer, November 1993 and March, April, and May 1994—Continued

[Analyses by the North Dakota Department of Health; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; gr/gal, grains per gallon; µg/L, micrograms per liter; --, no data; <, less than]

Well number and sampling period	Ammonia, total (mg/L as N)	Phosphate, total (mg/L as P)	Orthophosphate, total (mg/L as P)	Arsenic, dissolved (µg/L)	Iron, dissolved (µg/L)	Manganese, dissolved (µg/L)	Selenium, dissolved (µg/L)
SD-3 (11/93)	0.08	0.10	0.06	13	<10	<1	<1
SD-3 (3/94)	<.01	.24	.05	3	<10	1	<1
SD-3 (4/94)	<.01	.07	<.01	6	<10	<1	3
SD-3 (5/94)	<.01	.12	.01	9	<10	1	<1
SD-4 (11/93)	.12	.31	.06	6	<10	1	2
SD-6 (11/93)	.06	.05	.06	6	<10	<1	1
SD-6 (3/94)	<.01	.40	.06	5	<10	1	1
SD-6 (4/94)	<.01	.18	<.01	12	<10	<1	2
SD-6 (5/94)	<.01	.13	.02	11	<10	<1	1
SD-8 (11/93)	.04	.04	.05	1	<10	<1	3
SD-8 (4/94)	<.01	.09	<.01	3	<10	<1	6
SD-8 (5/94)	<.01	.03	<.01	1	<10	<1	4
SD-15 (11/93)	.33	.30	.18	9	<10	1	1
SD-15 (3/94)	<.01	.29	.13	<1	<10	<1	<1
SD-15 (4/94)	.19	.30	<.01	8	<10	1	5
SD-15 (5/94)	.19	.24	.01	7	<10	1	1
SD-16 (11/93)	.13	.18	.06	4	<10	<1	4
SD-16 (3/94)	<.01	.27	.04	<1	<10	<1	6
SD-16 (4/94)	<.01	.07	<.01	2	<10	<1	3
SD-16 (5/94)	<.01	.05	.01	2	<10	<1	13
SD-18 (11/93)	.09	.08	.05	7	<10	1	2
SD-18 (3/94)	<.01	.52	.07	<1	<10	1	<1
SD-18 (4/94)	<.01	.14	<.01	2	<10	<1	1
SD-18 (5/94)	<.01	.18	<.01	6	<10	1	2
SD-20 (11/93)	.26	.14	.06	42	10	<1	2
SD-20 (3/94)	<.01	.12	.10	32	10	<1	<1
SD-20 (4/94)	.08	.10	<.01	32	<10	<1	1
SD-20 (5/94)	.06	.10	.05	45	<10	<1	2
SD-22 (11/93)	.23	.81	.10	110	20	4	4
SD-22 (3/94)	.03	.32	.13	31	<10	2	<1

Table 2. Chemical analyses of water samples collected from wells completed in the Sheyenne Delta aquifer, November 1993 and March, April, and May 1994—Continued

[Analyses by the North Dakota Department of Health; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; gr/gal, grains per gallon; µg/L, micrograms per liter; --, no data; <, less than]

Well number and sampling period	Specific conductance, laboratory (µS/cm at 25°C)	pH, laboratory (standard units)	Turbidity (NTU)	Hardness, total (mg/L as $CaCO_3$)	Hardness, total (gr/gal)[1]	Calcium, dissolved (mg/L)	Magnesium, dissolved (mg/L)
SD-22 (4/94)	702	7.8	50	320	19	82	28
SD-22 (5/94)	697	7.4	80	360	21	95	30
SD-26 (11/93)	3,090	7.5	--	1,800	--	100	380
SD-26 (3/94)	3,440	7.5	170	2,200	130	120	450
SD-26 (4/94)	3,470	7.8	60	2,400	140	120	510
SD-26 (5/94)	3,330	7.4	70	2,000	120	120	420
SD-27 (11/93)	645	7.3	--	400	--	110	32
SD-27 (3/94)	645	7.2	90	400	24	110	32
SD-27 (4/94)	659	7.4	30	420	25	110	34
SD-27 (5/94)	655	7.3	85	360	21	91	32
SD-28 (11/93)	998	7.2	--	510	--	120	52
SD-28 (3/94)	1,260	7.1	330	760	45	200	67
SD-28 (4/94)	1,280	7.5	85	650	38	150	66
SD-28 (5/94)	978	7.2	80	540	32	130	55
SD-30 (11/93)	560	7.4	--	330	--	91	25
SD-30 (3/94)	528	7.4	75	290	17	80	23
SD-30 (4/94)	536	7.7	35	300	18	84	22
SD-30 (5/94)	531	7.4	75	340	20	93	25
SF-1S (11/93)	854	7.3	--	610	--	180	40
SF-1S (3/94)	811	7.2	800	490	29	140	35
SF-1S (4/94)	986	7.6	45	220	13	64	16
SF-1S (5/94)	1,030	7.5	80	210	12	61	15
SF-3S (11/93)	1,060	7.3	--	550	--	150	44
SF-3S (3/94)	939	7.2	380	560	33	150	42
SF-3S (4/94)	916	7.5	790	360	21	82	37
SF-3S (5/94)	890	7.1	140	490	29	130	40
SF-5S (11/93)	453	7.4	--	200	--	61	11
SF-5S (3/94)	311	7.4	250	180	10	54	10
SF-5S (4/94)	350	7.7	170	190	11	59	11
SF-5S (5/94)	365	7.6	85	210	12	67	11

Table 2. Chemical analyses of water samples collected from wells completed in the Sheyenne Delta aquifer, November 1993 and March, April, and May 1994—Continued

[Analyses by the North Dakota Department of Health; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; gr/gal, grains per gallon; µg/L, micrograms per liter; --, no data; <, less than]

Well number and sampling period	Sodium, dissolved (mg/L)	Percent sodium	Sodium adsorption ratio	Potassium, dissolved (mg/L)	Bicarbonate, total (mg/L)	Carbonate, total (mg/L)	Hydroxide (mg/L)
SD-22 (4/94)	36	20	0.9	6.0	386	<1	<1
SD-22 (5/94)	30	15	.7	5.9	385	<1	<1
SD-26 (11/93)	94	10	1.0	9.9	482	<1	<1
SD-26 (3/94)	97	9	.9	8.5	487	<1	<1
SD-26 (4/94)	120	10	1.1	9.3	463	<1	<1
SD-26 (5/94)	110	10	1.0	9.8	459	<1	<1
SD-27 (11/93)	3.6	2	<.1	3.5	411	<1	<1
SD-27 (3/94)	3.8	2	<.1	4.0	389	<1	<1
SD-27 (4/94)	3.0	2	<.1	3.2	387	<1	<1
SD-27 (5/94)	3.6	2	<.1	3.5	389	<1	<1
SD-28 (11/93)	40	15	.8	10	474	<1	<1
SD-28 (3/94)	39	10	.6	11	517	<1	<1
SD-28 (4/94)	42	12	.7	10	504	<1	<1
SD-28 (5/94)	38	13	.7	9.2	458	<1	<1
SD-30 (11/93)	4.1	3	.1	2.3	282	<1	<1
SD-30 (3/94)	2.9	2	<.1	1.5	282	<1	<1
SD-30 (4/94)	3.9	3	.1	<1.0	275	<1	<1
SD-30 (5/94)	2.8	2	<.1	2.1	283	<1	<1
SF-1S (11/93)	9.8	3	.2	3.3	599	<1	<1
SF-1S (3/94)	9.8	4	.2	1.2	545	<1	<1
SF-1S (4/94)	130	56	3.8	8.3	453	<1	<1
SF-1S (5/94)	130	58	4.0	8.4	454	<1	<1
SF-3S (11/93)	9.0	3	.2	2.0	469	<1	<1
SF-3S (3/94)	9.0	3	.2	1.9	495	<1	<1
SF-3S (4/94)	7.2	4	.2	2.1	426	<1	<1
SF-3S (5/94)	7.9	3	.2	1.6	442	<1	<1
SF-5S (11/93)	3.5	4	.1	3.8	253	<1	<1
SF-5S (3/94)	2.4	3	<.1	<1.0	175	<1	<1
SF-5S (4/94)	2.3	2	<.1	<1.0	188	<1	<1
SF-5S (5/94)	2.4	2	<.1	<1.0	199	<1	<1

Table 2. Chemical analyses of water samples collected from wells completed in the Sheyenne Delta aquifer, November 1993 and March, April, and May 1994—Continued

[Analyses by the North Dakota Department of Health; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; gr/gal, grains per gallon; µg/L, micrograms per liter; --, no data; <, less than]

Well number and sampling period	Alkalinity, total, laboratory (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Silica, dissolved (mg/L as SiO_2)	Dissolved solids, sum of constituents (mg/L)	Nitrite plus nitrate, total (mg/L as N)
SD-22 (4/94)	320	82	<3.0	0.2	26	429	<0.01
SD-22 (5/94)	320	77	3.3	.2	26	434	--
SD-26 (11/93)	400	1,600	3.3	--	--	2,420	.07
SD-26 (3/94)	400	2,000	4.6	.6	--	2,980	.09
SD-26 (4/94)	380	2,100	5.5	.8	28	3,130	.13
SD-26 (5/94)	380	2,000	4.5	.7	24	2,840	--
SD-27 (11/93)	340	42	<3.0	--	--	396	.01
SD-27 (3/94)	320	43	<3.0	.3	--	389	<.01
SD-27 (4/94)	320	42	3.6	.2	43	392	<.01
SD-27 (5/94)	320	43	3.1	.2	37	369	--
SD-28 (11/93)	390	180	3.2	--	--	640	<.01
SD-28 (3/94)	420	340	6.6	.3	--	919	<.01
SD-28 (4/94)	410	300	8.6	.3	40	832	<.01
SD-28 (5/94)	380	170	5.9	.3	33	634	--
SD-30 (11/93)	230	67	4.8	--	--	335	<.01
SD-30 (3/94)	230	55	3.8	.2	--	307	<.01
SD-30 (4/94)	220	65	4.5	.2	30	318	<.01
SD-30 (5/94)	230	51	3.6	.2	29	319	--
SF-1S (11/93)	490	46	7.0	--	--	582	.07
SF-1S (3/94)	450	37	6.7	.3	--	499	.05
SF-1S (4/94)	370	140	30	.3	39	608	<.01
SF-1S (5/94)	370	120	30	.3	32	590	--
SF-3S (11/93)	380	56	20	--	--	540	20
SF-3S (3/94)	400	58	40	.1	--	551	9.8
SF-3S (4/94)	350	56	41	.1	64	436	7.2
SF-3S (5/94)	360	50	40	.1	41	537	10
SF-5S (11/93)	210	27	<3.0	--	--	236	.01
SF-5S (3/94)	140	27	<3.0	.2	--	186	<.01
SF-5S (4/94)	150	25	<3.0	.1	78	196	<.01
SF-5S (5/94)	160	26	<3.0	.1	36	210	--

Table 2. Chemical analyses of water samples collected from wells completed in the Sheyenne Delta aquifer, November 1993 and March, April, and May 1994—Continued

[Analyses by the North Dakota Department of Health; µS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius; NTU, nephelometric turbidity units; mg/L, milligrams per liter; gr/gal, grains per gallon; µg/L, micrograms per liter; --, no data; <, less than]

Well number and sampling period	Ammonia, total (mg/L as N)	Phosphate, total (mg/L as P)	Orthophosphate, total (mg/L as P)	Arsenic, dissolved (µg/L)	Iron, dissolved (µg/L)	Manganese, dissolved (µg/L)	Selenium, dissolved (µg/L)
SD-22 (4/94)	0.08	0.56	0.04	<1	<10	2	2
SD-22 (5/94)	<.01	.51	.04	45	<10	2	2
SD-26 (11/93)	.07	.10	.05	4	<10	<1	53
SD-26 (3/94)	<.01	.51	.08	<1	<10	<1	38
SD-26 (4/94)	<.01	.15	<.01	4	<10	<1	22
SD-26 (5/94)	<.01	.19	.01	3	<10	<1	29
SD-27 (11/93)	.21	.84	.06	30	20	2	3
SD-27 (3/94)	<.01	1.4	.05	8	<10	1	<1
SD-27 (4/94)	<.01	.76	<.01	20	<10	<1	1
SD-27 (5/94)	<.01	.65	.02	22	<10	1	1
SD-28 (11/93)	.29	.53	.06	28	10	<1	3
SD-28 (3/94)	.08	1.4	.08	12	10	2	<1
SD-28 (4/94)	.07	.50	<.01	26	<10	1	1
SD-28 (5/94)	.03	1.2	.03	25	10	1	3
SD-30 (11/93)	.12	.33	.06	7	<10	1	4
SD-30 (3/94)	<.01	.56	.08	4	<10	1	<1
SD-30 (4/94)	<.01	.21	.02	4	<10	<1	1
SD-30 (5/94)	<.01	.69	.04	7	<10	1	3
SF-1S (11/93)	.22	.76	.11	7	20	3	5
SF-1S (3/94)	<.01	1.9	.32	4	<10	1	<1
SF-1S (4/94)	.59	.24	<.01	43	<10	<1	5
SF-1S (5/94)	.52	.24	.03	28	<10	<1	<1
SF-3S (11/93)	.20	.60	.06	11	20	4	2
SF-3S (3/94)	<.01	1.4	.15	2	10	6	2
SF-3S (4/94)	<.01	.98	<.01	11	30	5	6
SF-3S (5/94)	<.01	.38	.01	17	30	5	3
SF-5S (11/93)	.33	1.2	.24	44	80	10	2
SF-5S (3/94)	<.01	.74	.12	3	10	5	<1
SF-5S (4/94)	<.01	.44	<.01	13	30	5	2
SF-5S (5/94)	<.01	.24	.04	12	20	3	<1

[1]To convert grains per gallon as $CaCO_3$ to milligrams per liter as $CaCO_3$, multiply by 17.11.

Table 3. Detection limits of pesticides for which water samples were analyzed, November 1993 and March, April, and May 1994

[µg/L, micrograms per liter]

Pesticide	Detection limit (µg/L)	Pesticide	Detection limit (µg/L)
Alachlor	0.04	Fenvalerate	0.10
Aldicarb	.50	Heptachlor	.005
Aldicarb-sulfone	.50	Heptachlor epoxide	.005
Aldicarb-sulfoxide	.50	Hoelen	.05
Aldrin	.005	3-Hydroxycarbofuran	.50
Alpha BHC	.005	Lindane	.005
Atrazine	.25	Malathion	.04
Bentazon	.50	MCPA	50
Beta BHC	.005	Methomyl	.50
Bromoxynil	.10	Methoxychlor	.002
Carbaryl	.50	Metolachlor	.05
Carbofuran	.50	Metribuzin	.02
Chlordane	.005	Nonachlor	.005
Cyanazine	.05	Oxamyl	.50
DDD	.005	Parathion, ethyl-	.015
DDE	.005	Parathion, methyl-	.01
DDT	.01	Picloram (Tordon)	.10
Dicamba	.10	Prowl	.01
Dichlorprop	.20	Silvex (2,4,5-TP)	.20
Dieldrin	.005	Simazine	.45
Dinoseb	.20	Triallate (Far-Go)	.01
Endosulfan I	.01	Trifluralin (Treflan)	.005
Endosulfan II	.01	2,4-D	.10
Endosulfan sulfate	.01	2,4,5-T	.10
Endrin	.01		

per liter as N. Well SF-3S is located about 600 feet downgradient from a feedlot, which probably accounts for the large nitrite plus nitrate concentrations.

Phosphate concentrations in samples collected during November 1993 and March, April, and May 1994 ranged from 0.03 to 1.9 milligrams per liter as P, and orthophosphate concentrations ranged from less than 0.01 to 0.32 milligram per liter as P (table 2). The largest concentrations of both constituents were in well SF-1S, which is located adjacent to the Sheyenne River. The large concentrations may be related to the hydraulic connection to the river. Another contributing factor may be that the laboratory analyses for nutrients were conducted on unfiltered "whole water" samples. Small amounts of sediment in a sample can result in large phosphate and orthophosphate concentrations but do not reflect dissolved conditions in the ground water. Filtered samples collected as part of the NAWQA study had much smaller phosphate and orthophosphate concentrations.

Arsenic concentrations ranged from less than 1 microgram per liter (the minimum reporting level) to 110 micrograms per liter. The concentrations were less than 10 micrograms per liter in many samples but exceeded 20 micrograms per liter in samples from wells SD-20, SD-22, SD-27, SD-28, SF-1S, and SF-5S (fig. 19). The concentration in one sample from well SD-22 exceeded 50 micrograms per liter, which is the North Dakota drinking-water standard maximum contaminant level for arsenic (North Dakota Department of Health, 1994).

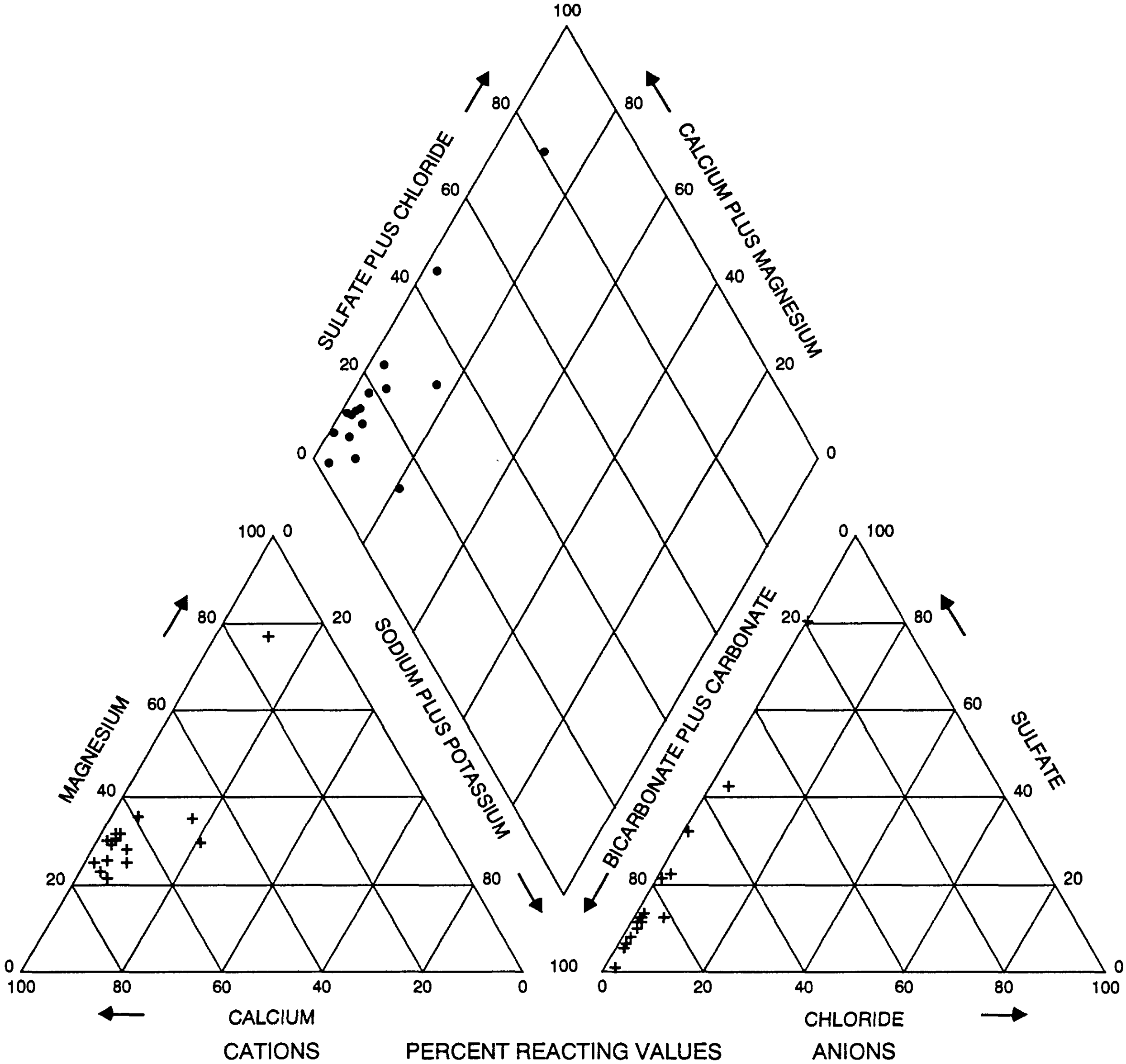


Figure 14. Major-ion composition of water from wells completed in the Sheyenne Delta aquifer, November 1993.

Arsenic concentrations varied spatially across the aquifer and generally were larger in the eastern part of the study area (figs. 2 and 19). The concentrations decreased between November 1993 and March 1994 as a result of dilution from the infiltration of snowmelt and precipitation but generally rose again in April or May. The decrease between November and March was attributed to dilution because the relative distribution of arsenic in the aquifer generally remained the same.

The source, distribution, and transport mechanisms of arsenic in glaciofluvial aquifers are poorly understood. In the early 1980's, large arsenic concentrations in southeastern North Dakota were attributed, in part, to a national grasshopper eradication program during 1934-47. Winter and others (1984) reported arsenic concentrations of about 100 micrograms per liter in a glaciofluvial aquifer in southeastern North Dakota. They attributed the large concentrations to arsenic-bearing pesticides that were used extensively

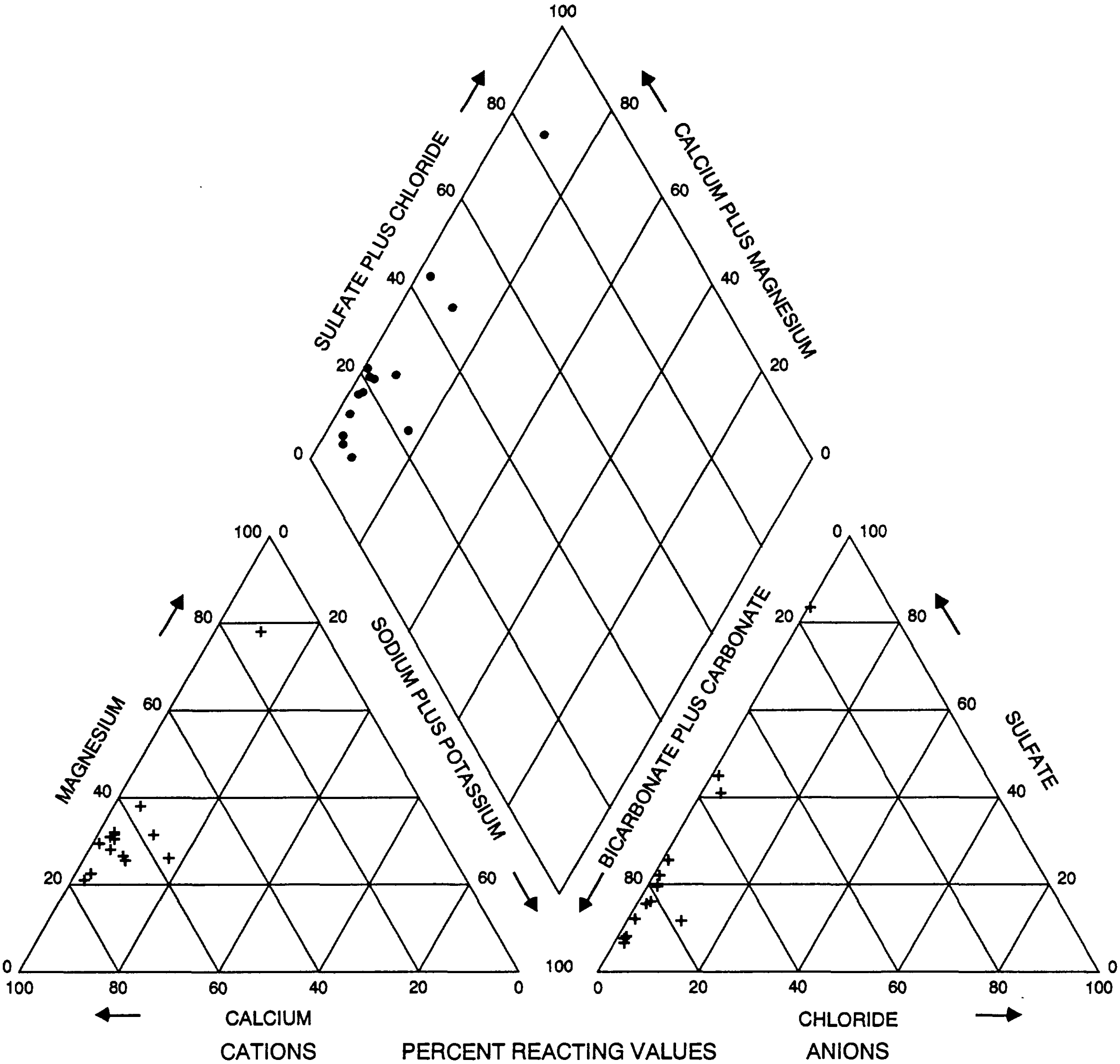


Figure 15. Major-ion composition of water from wells completed in the Sheyenne Delta aquifer, March 1994.

in the 1930's and that were subsequently leached into the ground water. In a study conducted by Roberts and others (1985), arsenic concentrations in about 20 percent of the wells sampled in the southern part of the Sheyenne Delta aquifer were greater than 50 micrograms per liter. However, the arsenic concentrations could not be attributed entirely to grasshopper bait (Roberts and others, 1985). Natural sources in bedrock aquifers and glacial deposits possibly contribute to the arsenic concentrations. Hem (1992) stated that the divalent species $HAsO_4^{2-}$ could be present when pH values are between 7 and 11 (all samples collected during this study had pH values in that range; table 2). The sensitivity of arsenic geochemistry to changes in redox potential may explain the large seasonal variations in arsenic concentrations in some areas of the aquifer.

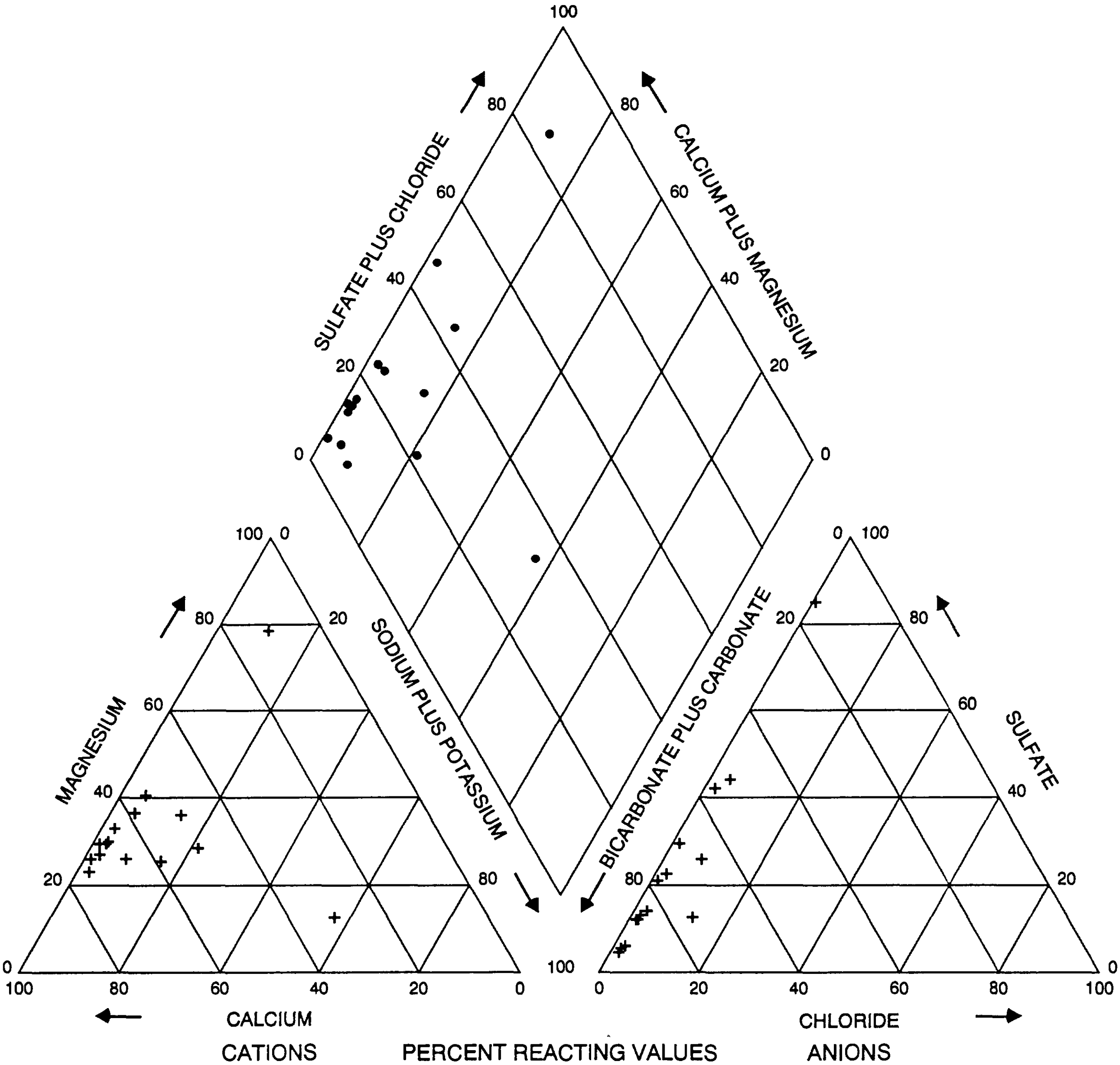


Figure 16. Major-ion composition of water from wells completed in the Sheyenne Delta aquifer, April 1994.

Iron concentrations ranged from less than 10 to 80 micrograms per liter. The average iron concentration for all samples was less than 10 micrograms per liter. The iron in the ground water probably is from direct dissolution of igneous rock minerals in the glaciofluvial deposits and from decomposition of organic materials in the soils.

Selenium concentrations ranged from less than 1 to 53 micrograms per liter. The concentrations were less than 5 micrograms per liter in most of the wells, but the concentration in one sample from well SD-26 was greater than 50 micrograms per liter, which is the North Dakota drinking-water standard maximum contaminant level for selenium (North Dakota Department of Health, 1994).

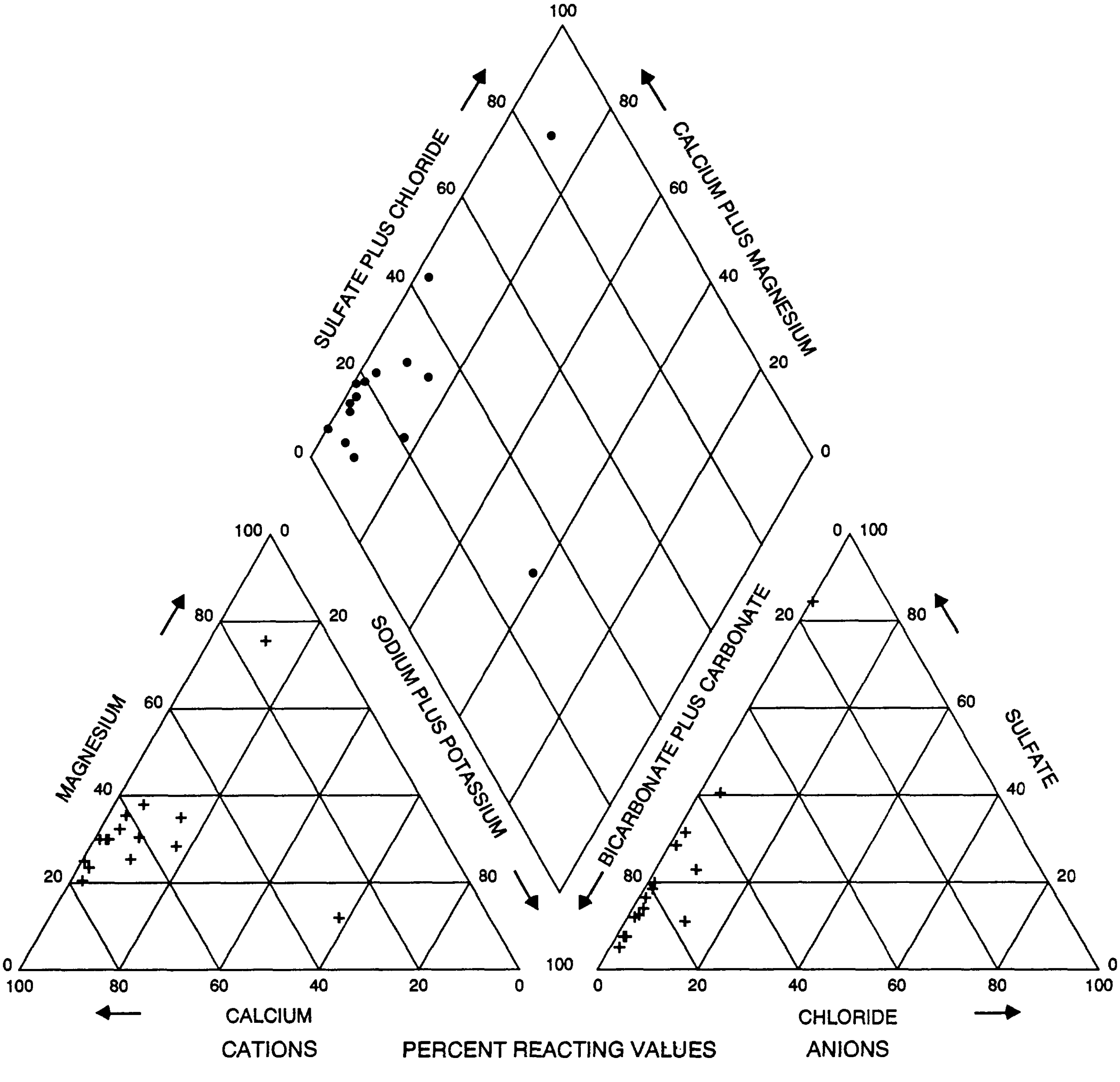


Figure 17. Major-ion composition of water from wells completed in the Sheyenne Delta aquifer, May 1994.

Selenium concentrations in the aquifer generally were small and decreased in March because of dilution (fig. 19). The large concentrations in samples from well SD-26 may have been affected by dissolution of selenium from interbedded clays, silts, and sands that are rich in shale-derived sediments (shale is a source of selenium in eastern North Dakota; Winter and others, 1984) or because the well is screened close to the underlying units of lacustrine clay and glacial till.

Generally, samples that had large arsenic concentrations had small selenium concentrations and samples that had large selenium concentrations had small arsenic concentrations (fig. 19). Arsenic generally is more soluble under reduced conditions (dissolved-oxygen concentrations less than 0.5 milligram per liter), and selenium generally is more soluble under oxidized conditions (dissolved-oxygen concentrations greater than 0.5 milligram per liter).

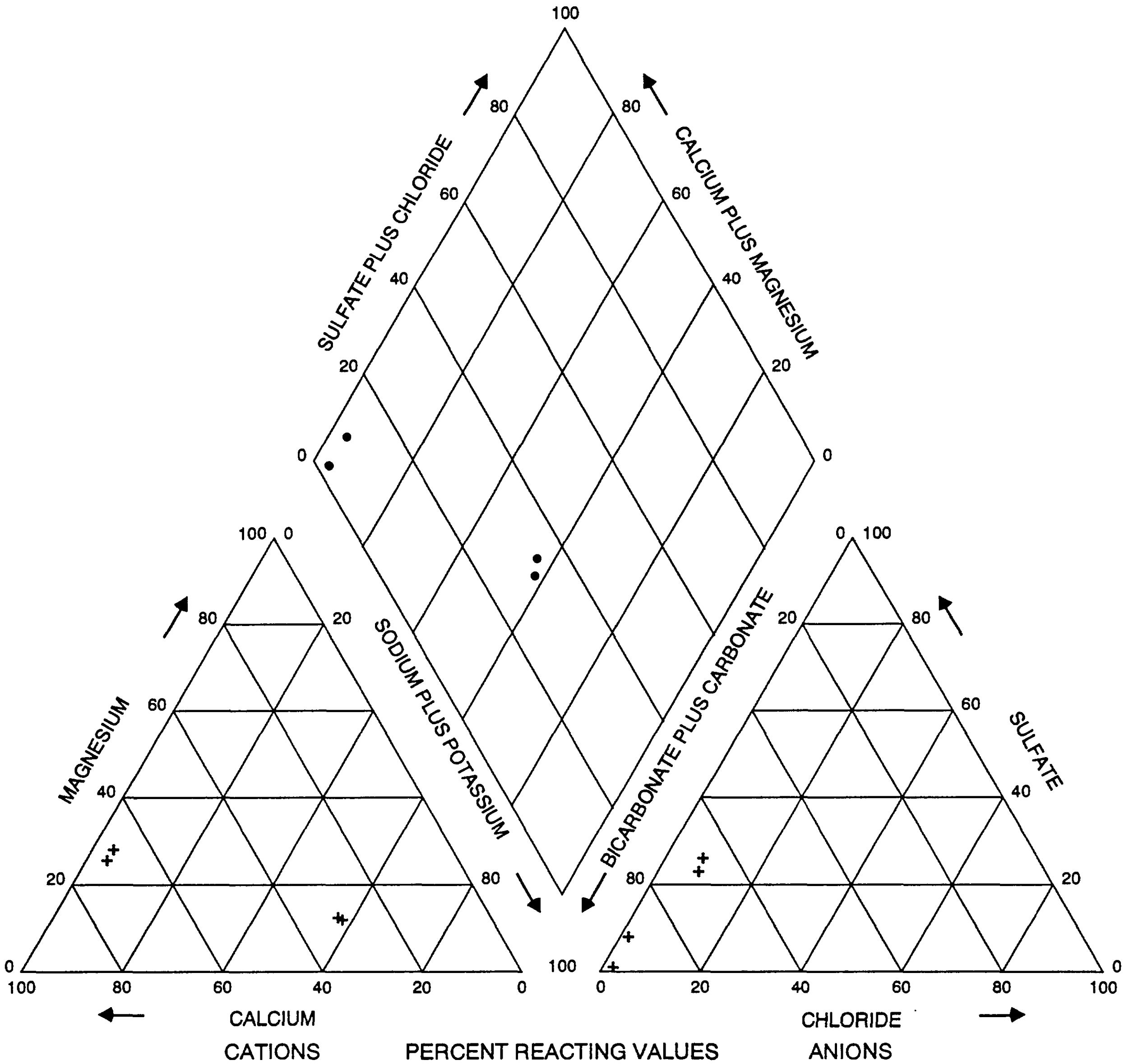


Figure 18. Change in major-ion composition of water in well SF-1S from November 1993 through May 1994.

The pesticides for which water samples were analyzed are given in table 3 along with their detection limits. The only pesticide detected in samples collected as part of this study was picloram (Tordon). Picloram concentrations in samples from wells SD-3, SD-16, SD-22, SD-27, and SD-30 ranged from 0.10 to 8.25 micrograms per liter (table 4).

The distribution of wells at which picloram was detected appears random (table 4; fig. 2), and the concentrations probably reflect local land use. Picloram is used to control noxious weeds, particularly leafy spurge. During the four sampling periods, picloram concentrations in the ground water were inconsistent (table 4), but the largest concentrations occurred in samples from well SD-22. The North Dakota drinking-water standard maximum contaminant level for picloram is 500 micrograms per liter (North Dakota Department of Health, 1994).

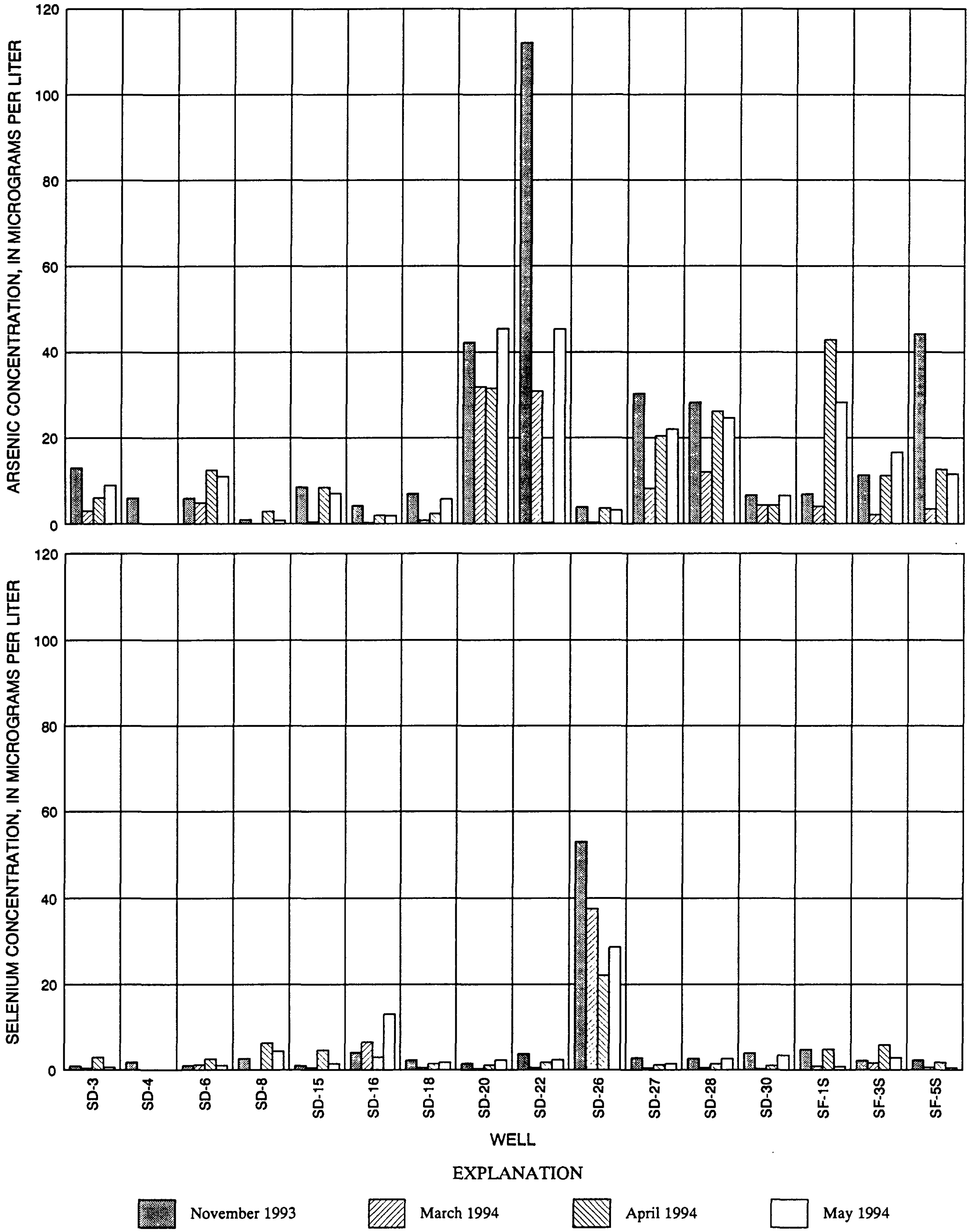


Figure 19. Arsenic and selenium concentrations in the Sheyenne Delta aquifer during November 1993 and March, April, and May 1994.

Table 4. Wells at which picloram was detected

[Concentrations are in micrograms per liter; <, less than]

Well	Sampling date			
	11/16/93	3/15/94	4/19/94	5/24/94
SD-3	[1]0.35, 0.44	0.14	0.18	0.16
SD-16	<0.10	.14	.32	[1]0.37, 0.48
SD-22	8.25	8.20	2.80	3.35
SD-27	<.10	<.10	.10	<.10
SD-30	<.10	.12	<.10	<.10

[1]Duplicate samples collected (detection limit is 0.10 microgram per liter).

EFFECTS OF THE 1993 FLOOD

Water levels in the aquifer began to rise in March 1993 in response to recharge from snowmelt (fig. 7). Generally, the water levels also rose in the spring in response to excessive precipitation that was unusually frequent and consistently intense. Water levels began to decline by the end of July 1993 and generally did not begin to rise again until March 1994. High stage in the Sheyenne River during July and August 1993 probably caused water-table gradients near the river to reverse, and water from the river flowed into the aquifer as temporary bank storage.

Direct effects of the 1993 flood on water levels in the aquifer probably were limited to the area adjacent to the river. These effects dissipated by mid-September 1993 (fig. 7). However, excessive precipitation associated with the flood probably affected water levels throughout the aquifer. Water levels in two observation wells in the aquifer indicate that the water table generally was about 2 feet higher during the fall and winter of 1994 than during the fall and winter of 1993.

Before the 1993 flood, water in the Sheyenne Delta aquifer generally was a calcium bicarbonate or a calcium magnesium bicarbonate type, and dissolved-solids concentrations ranged from 269 to 1,820 milligrams per liter. After the flood, water in the aquifer generally was a calcium bicarbonate type, and dissolved-solids concentrations ranged from 186 to 3,130 milligrams per liter. Dissolved-solids and chloride concentrations in water samples collected from wells completed in the Sheyenne Delta aquifer were examined to determine the effect of flooding on conservative species (figs. 20 and 21). No discernible difference existed between the pre-flood data and the post-flood (November 1993 and March, April, and May 1994) data for both dissolved-solids and chloride concentrations. Nitrite plus nitrate concentrations were examined to determine the effect of flooding on nutrients (fig. 22). Data indicate no clear difference between the pre-flood and the post-flood concentrations. Iron concentrations were examined to determine the effect of flooding on trace-element concentrations (fig. 23). The pre-flood iron concentrations were about two orders of magnitude larger than the post-flood concentrations. The differences between the pre-flood and the post-flood concentrations may be the result of changes in the aquifer but probably are caused by sampling differences. Many wells used for pre-flood data were constructed of metal pipe, and particles of iron oxides may have been collected in the water samples and dissolved in the samples during processing. Wells sampled for post-flood data were constructed of polyvinyl-chloride pipe. The small differences between the pre-flood water chemistry and the post-flood water chemistry indicate that water in the Sheyenne Delta aquifer was not affected substantially by the 1993 flood.

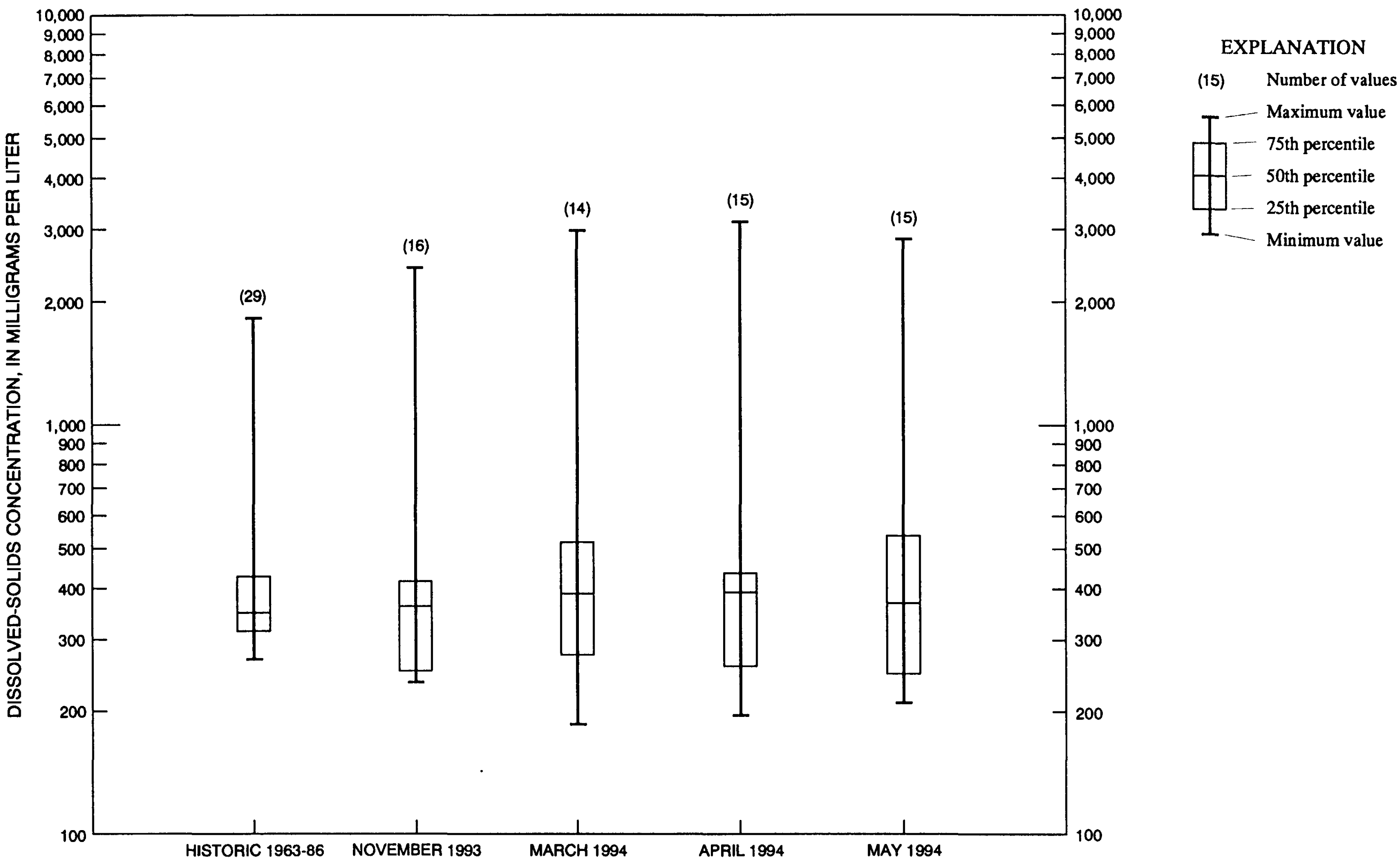


Figure 20. Pre-flood and post-flood dissolved-solids concentrations in the Sheyenne Delta aquifer.

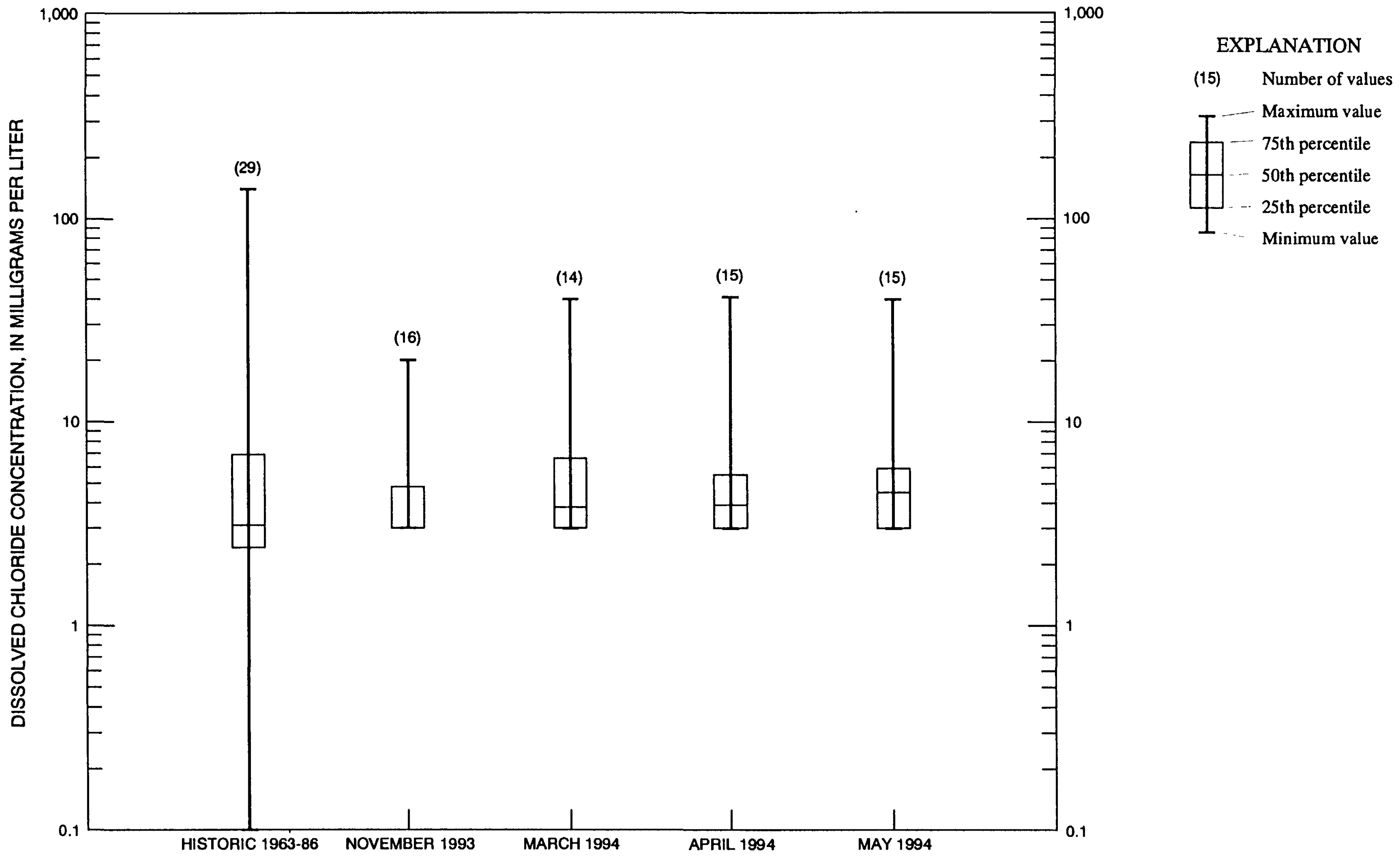


Figure 21. Pre-flood and post-flood dissolved chloride concentrations in the Sheyenne Delta aquifer.

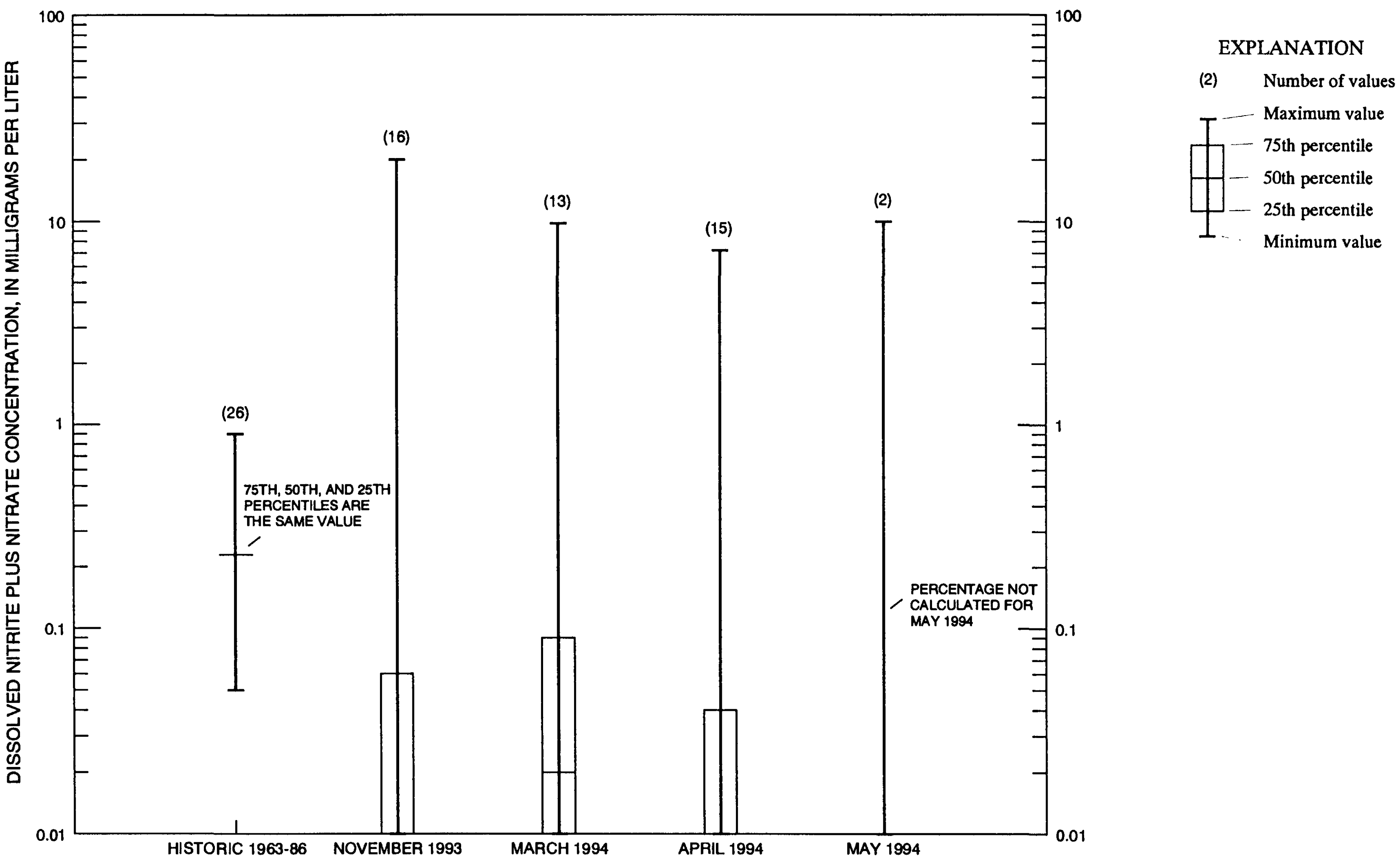


Figure 22. Pre-flood and post-flood dissolved nitrite plus nitrate concentrations in the Sheyenne Delta aquifer.

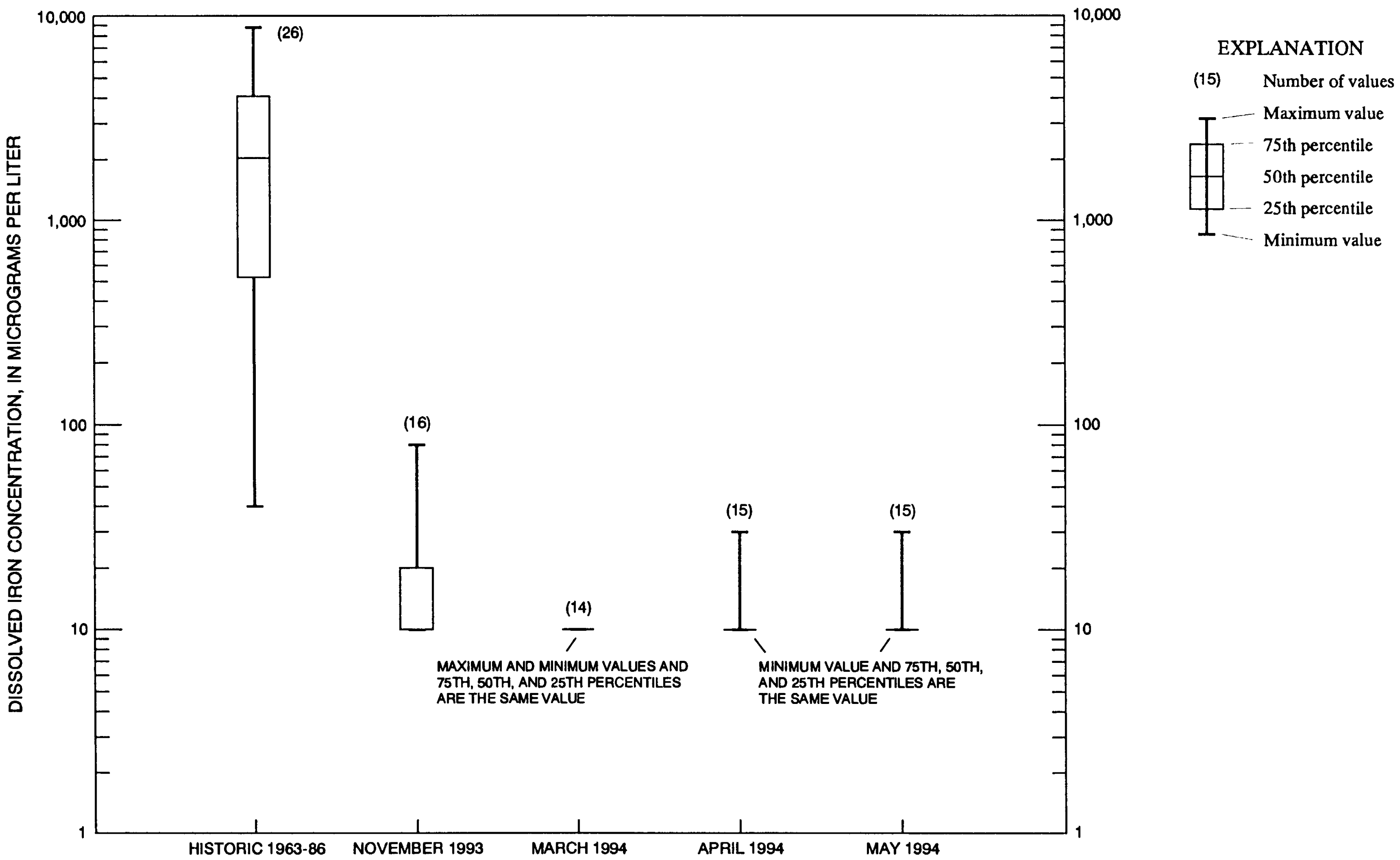


Figure 23. Pre-flood and post-flood dissolved iron concentrations in the Sheyenne Delta aquifer.

SUMMARY AND CONCLUSIONS

This report describes results of a study to evaluate the effects of precipitation and flooding on water levels in the Sheyenne Delta aquifer and to evaluate the variations in water quality that are related to the precipitation and flooding. Specific objectives were to determine pre-flood conditions and to interpret and evaluate the ground-water response to precipitation and flooding. Water-level, streamflow, and water-quality data collected before July 1993 were assumed to be representative of pre-flood conditions, and data collected from July 1993 through May 1994 were used to evaluate the ground-water response.

The Sheyenne Delta aquifer is unconfined throughout the study area and is recharged by direct infiltration of snowmelt and rain. Recharge also occurs from the Sheyenne River when river elevations are higher than local ground-water altitudes. Discharge from the aquifer is mainly to the Sheyenne River, to springs along the northeast edge of the delta, and, to a lesser extent, to wells and by evapotranspiration. Streamflow measurements on the Sheyenne River between Valley City and West Fargo indicate substantial discharge from the Sheyenne Delta aquifer to the river. Ground-water flow gradients are relatively flat in the southern and northern parts of the aquifer and become steep adjacent to the river. Ground water generally discharges from the aquifer to the river during most of the year.

The chemical analyses of water samples collected from the aquifer between 1963 and 1986 indicate the water generally was a calcium bicarbonate or calcium magnesium bicarbonate type. At locations where more than one sample was collected, the data indicate little change through the years.

Water levels in 49 wells were measured every 3 weeks, when possible, between November 1993 and May 1994. Water samples were collected from 16 of the wells during November 1993 and March, April, and May 1994 and analyzed for major ions, nutrients, selected trace elements, and pesticides. The water-level and water-quality data collected during the study, along with similar data collected during previous investigations and during the National Water-Quality Assessment study, provided the basis for describing the general characteristics of the hydrology and water quality of the Sheyenne Delta aquifer.

Water levels in the aquifer generally declined slightly between December 1993 and early January 1994. In March 1994, water levels throughout the entire study area increased by more than 2 feet in some areas. However, the water-level rise was greater in low-relief areas to the north and south of the river than in high-relief areas closer to the river, probably because of snowmelt lying on the flat surfaces above partially thawed soils and seeping through pores and cracks into the subsurface. After spring melt, water levels in low-relief areas began to decline.

Parts of the aquifer near the Sheyenne River may be affected by inflow from the river during periods of high river stage. The reversal in the gradient is temporary, however, because, as the snowmelt or precipitation event dissipates, the river stage declines, ground-water altitudes become higher than river elevations, and the ground water flows to the river.

The precipitation and flooding during 1993 affected ground-water levels differently throughout the Sheyenne Delta aquifer. The largest water-level rise occurred in low-relief areas, and water subsequently moved downgradient toward the river. Topography strongly affected the focus of recharge in the aquifer, causing less recharge to occur in areas of high relief because much of the precipitation and snowmelt runs off to topographic depressions. High stage in the river caused a reversal of ground-water flow gradients near the river and allowed for inflow of river water into the aquifer.

In order to examine the effects of precipitation and flooding on water quality in the Sheyenne Delta aquifer, water-quality data representing pre-flood and post-flood conditions were evaluated. Water quality in the aquifer is affected by precipitation, evapotranspiration, inflow from adjacent ground water, and inflow from the Sheyenne River.

After the 1993 flood, water in the Sheyenne Delta aquifer generally was a calcium bicarbonate type and had dissolved-solids concentrations that ranged from 186 to 3,130 milligrams per liter. Major-ion concentrations remained relatively constant during the four sampling periods. Water in which major-ion concentrations changed probably was affected by a combination of interaction between the aquifer and the Sheyenne River and recharge from snowmelt.

Nitrite plus nitrate concentrations generally were less than 1.0 milligram per liter as N, and no spatial or temporal pattern was apparent. The largest concentrations were in well SF-3S and ranged from 7.2 to 20 milligrams per liter as N.

Phosphate concentrations ranged from 0.03 to 1.9 milligrams per liter as P, and orthophosphate concentrations ranged from less than 0.01 to 0.32 milligram per liter as P. The largest concentrations of both constituents were in well SF-1S, which is located adjacent to the Sheyenne River.

Large arsenic and selenium concentrations were measured in some samples from the Sheyenne Delta aquifer. Arsenic concentrations ranged from less than 1 to 110 micrograms per liter, and the concentration in one sample from well SD-22 exceeded the State drinking-water standard of 50 micrograms per liter. Selenium concentrations ranged from less than 1 to 53 micrograms per liter, and the concentration in one sample from well SD-26 exceeded the State drinking-water standard of 50 micrograms per liter. Generally, wells that had large arsenic concentrations had small selenium concentrations, and wells that had large selenium concentrations had small arsenic concentrations.

The only pesticide detected in samples collected as part of this study was picloram. The distribution of wells at which picloram was detected appears random and probably reflects local land use.

No discernible difference existed between pre-flood and post-flood concentrations for conservative species, such as dissolved solids and chloride. No clear difference existed between pre-flood and post-flood dissolved nitrite plus nitrate concentrations. Pre-flood iron concentrations were about two orders of magnitude larger than post-flood concentrations, probably because of sampling differences. Wells used for pre-flood data were constructed of metal pipe, and wells used for post-flood data were constructed of polyvinyl-chloride pipe.

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