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## Age and Quality of Ground Water and Sources of Nitrogen in the Surficial Aquifers in Pumpkin Creek Valley, Western Nebraska, 2000

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Prepared in cooperation with the  
North Platte Natural Resources District

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Scientific Investigations Report 2005-5157

**U.S. Department of the Interior  
U.S. Geological Survey**

Cover photograph: Overlook of Pumpkin Creek Valley at Redington Gap, Nebraska.

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**U.S. Department of the Interior  
U.S. Geological Survey**



**U.S. Department of the Interior**  
Gale A. Norton, Secretary

**U.S. Geological Survey**  
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## Conversion Factors and Datums

Multiply	By	To obtain
<b>Length</b>		
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
<b>Area</b>		
acre	0.4047	hectare
square foot (ft <sup>2</sup> )	0.09290	square meter
square inch (in <sup>2</sup> )	6.452	square centimeter
square mile (mi <sup>2</sup> )	2.590	square kilometer
<b>Volume</b>		
gallon (gal)	3.785	liter
cubic foot (ft <sup>3</sup> )	0.02832	cubic meter
acre-foot (acre-ft)	1,233	cubic meter
acre-foot (acre-ft)	0.001233	cubic hectometer
<b>Flow rate</b>		
foot per second (ft/s)	0.3048	meter per second
foot per minute (ft/min)	0.3048	meter per minute
foot per hour (ft/hr)	0.3048	meter per hour
foot per day (ft/d)	0.3048	meter per day
foot per year (ft/yr)	0.3048	meter per year
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second
cubic foot per day (ft <sup>3</sup> /d)	0.02832	cubic meter per day
gallon per minute (gal/min)	0.06309	liter per second
gallon per day (gal/d)	0.003785	cubic meter per day
inch per hour (in/h)	0.0254	meter per hour
<b>Mass</b>		
pound, avoirdupois (lb)	0.4536	kilogram
ton per year (ton/yr)	0.9072	metric ton per year
<b>Hydraulic conductivity</b>		
foot per day (ft/d)	0.3048	meter per day
<b>Hydraulic gradient</b>		
foot per mile (ft/mi)	0.1894	meter per kilometer
<b>Transmissivity*</b>		
foot squared per day (ft <sup>2</sup> /d)	0.09290	meter squared per day

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F} = (1.8 \times ^{\circ}\text{C}) + 32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32) / 1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Altitude, as used in this report, refers to distance above the vertical datum.

\*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft<sup>3</sup>/d)/ft<sup>2</sup>]ft. In this report, the mathematically reduced form, foot squared per day (ft<sup>2</sup>/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

Concentrations of isotopic units are given either in parts per thousand (per mil), tritium units (TU), or decays per minute (dpm).

# Age and Quality of Ground Water and Sources of Nitrogen in the Surficial Aquifers in Pumpkin Creek Valley, Western Nebraska, 2000

By G.V. Steele, J.C. Cannia, S.S. Sibray, and V.L. McGuire

## Abstract

Ground water is the source of drinking water for the residents of Pumpkin Creek Valley, western Nebraska. In this largely agricultural area, shallow aquifers potentially are susceptible to nitrate contamination. During the last 10 years, ground-water levels in the North Platte Natural Resources District have declined and contamination has become a major problem for the district. In 2000, the U.S. Geological Survey and the North Platte Natural Resources District began a cooperative study to determine the age and quality of the ground water and the sources of nitrogen in the aquifers in Pumpkin Creek Valley.

Water samples were collected from 8 surface-water sites, 2 springs, and 88 ground-water sites during May, July, and August, 2000. These samples were analyzed for physical properties, nutrients or nitrate, and hydrogen and oxygen isotopes. In addition, a subset of samples was analyzed for any combination of chlorofluorocarbons, tritium, tritium/helium, sulfur-hexafluoride, carbon-14, and nitrogen-15.

The apparent age of ground water in the alluvial aquifer typically varied from about 1980 to modern, whereas ground water in the fractured Brule Formation had a median value in the 1970s. The Brule Formation typically contained ground water that ranged from the 1940s to the 1990s, but low-yield wells had apparent ages of 5,000 to 10,000 years before present. Data for oxygen-18 and deuterium indicated that lake-water samples showed the greatest effects from evaporation. Ground-water data showed no substantial evaporative effects and some ground water became isotopically heavier as the water moved downgradient. In addition, the physical and chemical ground-water data indicate that Pumpkin Creek is a gaining stream because little, if any, of its water is lost to the ground-water system.

The water-quality type changed from a sodium calcium bicarbonate type near Pumpkin Creek's headwaters to a calcium sodium bicarbonate type near its mouth. Nitrate concentrations were largest in the alluvial system (median = 5 mg/L) and smallest in the surface-water system (median = 1 mg/L). Most nitrate concentrations exceeding the U.S. Environmental Protection Agency maximum contaminant level

for drinking water of 10 mg/L as nitrogen were adjacent to irrigated fields and in areas where alluvial sediments are less than 50 ft thick.

Sources of nitrogen in the ground water of the study area included naturally occurring nitrogen, commercial fertilizer, and animal waste. Based on nitrate concentration and delta nitrogen-15, the nitrogen in 65 percent of the water samples appears to have originated from a mixture of commercial fertilizers and animal waste. Some of the smallest nitrate concentrations in the ground-water samples contained some of the largest delta nitrogen-15 values (greater than 10 per mil), which suggests animal waste as the likely source. Commercial fertilizers were the likely source of most of the nitrogen in water samples with nitrate concentrations that exceeded 10 mg/L. The source of the nitrogen in water samples with nitrate concentrations exceeding 10 mg/L, but with delta nitrogen-15 values close to 10 per mil, could not be determined.

## Introduction

Ground water is the source of drinking water for the residents of Pumpkin Creek Valley in western Nebraska (fig. 1). The water tables for the principal aquifers used for drinking-water supply are close to the land surface and can be affected by infiltration of irrigation water containing or mobilizing contaminants. Once in the aquifer, contaminants can move with the ground water and adversely affect water supplies. During the last 10 years, ground-water levels in the North Platte Natural Resources District (NPNRD) have declined severely and contamination of this resource has become a major problem for the district. Background information is needed to determine the human and natural hydrologic processes affecting the drinking-water supplies. This information will help identify ground-water flow paths that can ultimately determine how long it will take for changes in land-use activity to affect the quality of water withdrawn for human consumption. In 2000, the U.S. Geological Survey (USGS), in cooperation with the NPNRD, began a study to determine the age and quality of the ground water and the sources of nitrogen in the surficial aquifers in Pumpkin Creek Valley.

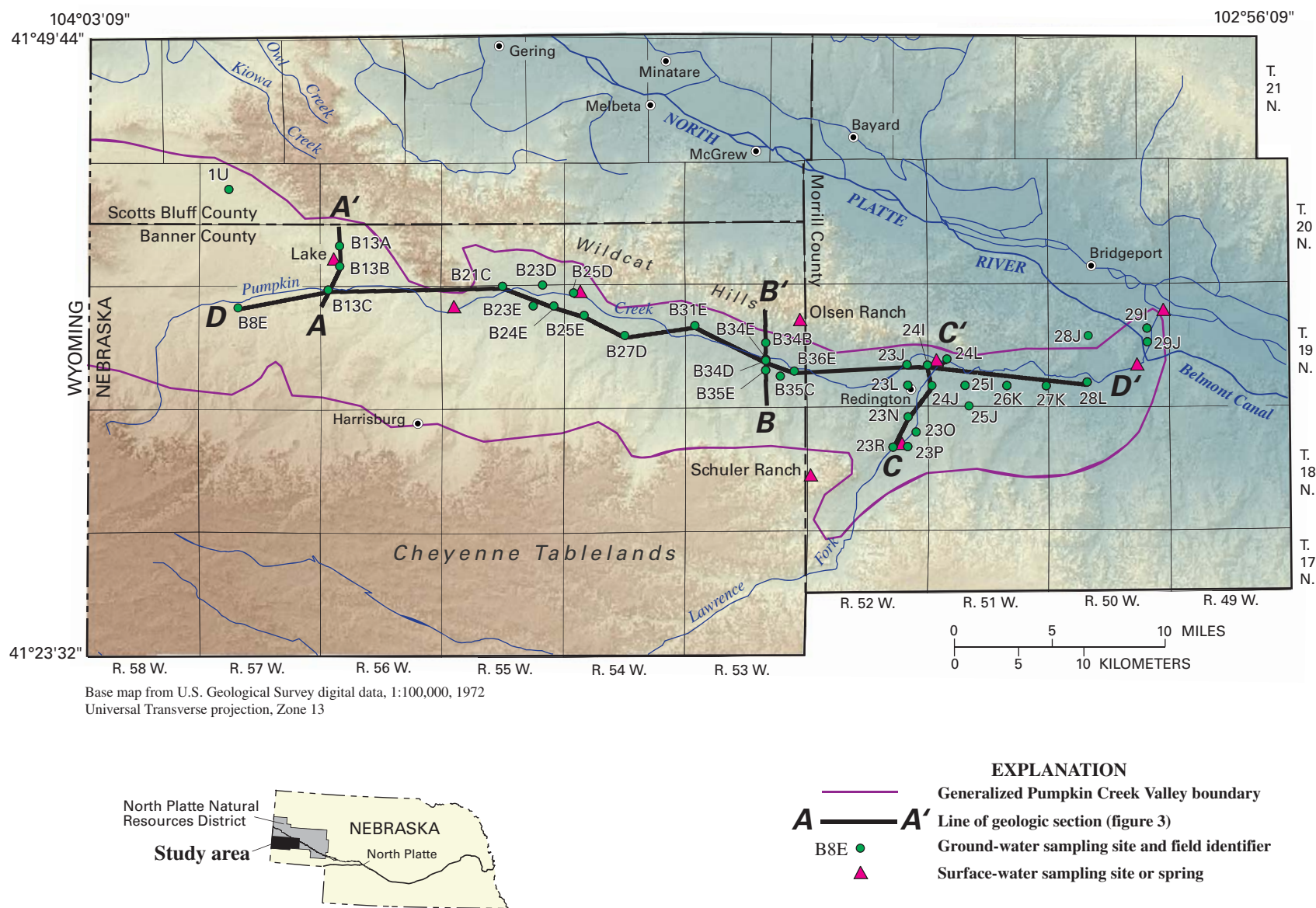


Figure 1. Location of study area, Pumpkin Creek Valley, western Nebraska.

Streamflows and ground-water levels in Pumpkin Creek Basin have dropped severely, and ground-water contamination by nitrates is occurring locally (Ostdiek, 2001). Moreover, historical data and previous studies suggest that nitrates are the primary contaminant of ground water (Verstraeten and others, 1995) and in some areas of the NPNRD nitrate concentrations in ground water are increasing (Exner, 1990; Steele and others, 1998). Drinking water with concentrations of nitrate (as N) greater than the U.S. Environmental Protection Agency's (USEPA) (U.S. Environmental Protection Agency, 2001) Maximum Contaminant Level (MCL) of 10 mg/L has been shown to cause "blue-baby" syndrome (methemoglobinemia) and may be linked to increased rates of stomach cancer, birth defects, miscarriage, leukemia, and other human afflictions (Andrews, Osborn, and Luckey, 2000). In many locales increases in nitrates in ground water are attributed to the application of commercial nitrogen to fields (Exner, 1990; Steele and others, 1998). However, very little recent work has been done in Pumpkin Creek Valley and high nitrate concentrations should not automatically be attributed to the application of commercial or synthetic fertilizers (herein referred to as commercial fertilizer). Additional potential sources of nitrogen found in ground water from Pumpkin Creek Valley include, among others, confined animal feeding operations (CAFOs) and wastewater from septic and lagoon systems. Therefore, it would be useful to the NPNRD to know the principal source of the nitrogen in water from wells in Pumpkin Creek Valley.

## Purpose and Scope

The purpose of this report is to describe the results of analysis of water samples collected to determine (1) the age of ground water through analyses of chlorofluorocarbons (CFCs), tritium ( $^3\text{H}$ ), ratios of tritium/helium ( $^3\text{H}/^3\text{He}$ ), sulfur-hexafluoride ( $\text{SF}_6$ ), and carbon-14 ( $^{14}\text{C}$ ); (2) the source of water through analysis of hydrogen ( $^2\text{H}$ ) and oxygen ( $^{18}\text{O}$ ) isotopes; (3) the source of nitrates and nitrogen through analysis of nitrogen-15 and nitrogen-14 ( $^{15}\text{N}/^{14}\text{N}$ ) isotope ratios; and (4) the general water chemistry of the surface-water and ground-water systems. The report describes the methods used to select and install the monitoring wells and the collection and analysis of water samples. The report presents generalized ground-water flow paths and the likely source of nitrogen in surface-water and ground-water samples at selected locations in Pumpkin Creek Valley. The report also includes results of aquifer test analyses used to determine generalized ground-water flow characteristics of the study area.

## Previous Investigations

Previous investigations that describe regional geology and include Pumpkin Creek Valley include Darton (1903), Meinzer (1923), Babcock and Visser (1952), Smith and Souders (1975), Diffendal (1982, 1983, 1984), Corner and Diffendal (1983), Diffendal and Corner (1983), Swinehart and others (1985), and Goodwin and Diffendal (1987). Regional water quality that

includes at least some part of Pumpkin Creek Valley was discussed by Babcock and Visser (1952), Engberg and Spalding (1979), Engberg (1984), Engberg and Druliner (1988), Verstraeten and others (1995), and Steele and Cannia (1997). Babcock and Visser (1952) and Smith and Souders (1975) are the only reports that specifically include Pumpkin Creek Valley. Babcock and Visser (1952, p. 24) described the quality of ground water in Pumpkin Creek Valley as "moderately mineralized, hard [high calcium and magnesium] water in the alluvium to more highly mineralized, soft [high sodium, lower calcium and magnesium] water in the deeper Lance Formation." Smith and Souders (1975) reported the water quality of the Brule Formation was a calcium sodium bicarbonate type. Steele and Cannia (1997) reported that water samples from Pumpkin Creek showed substantial variations of calcium, sodium, bicarbonate, and sulfate concentrations throughout the summer of 1993. The other water-quality reports used a regional (NPNRD) or statewide scope—Engberg and Spalding (1979), Engberg (1984), Engberg and Druliner (1988), and Verstraeten and others (1995).

## Description of Study Area

This section describes the general aspects of the study area. Specifically the location, physiography, land use, and the geological/hydrological characteristics of the study area are discussed.

## Location and Physiography

The study area lies in the High Plains Section of the Great Plains Province (Fenneman, 1946). The study area encompasses all of Pumpkin Creek Valley from the Nebraska-Wyoming border east to the confluence of Pumpkin Creek with the North Platte River near Bridgeport (fig. 1). The westernmost border of the Pumpkin Creek Valley is located at the approximate elevation of 4,700 ft above North American Vertical Datum of 1988 (NAVD 88) on the surface-water divide between Horse Creek (not shown on any maps) and Pumpkin Creek Valleys about 3.5 mi west of the Nebraska-Wyoming State line. Trending eastward from this point, Pumpkin Creek Valley lies between the Wildcat Hills on the north and the south table escarpment, which forms the Cheyenne Tablelands on the south.

Pumpkin Creek is about a 50-mi long under-fit stream that begins at an altitude of 4,400 ft about 8 mi east of the Wyoming-Nebraska State line. Ancestral Pumpkin Creek Valley originally extended much further west into Wyoming and discharged much more water than recent flows (Swinehart and others, 1985). Through the process of stream capture, Horse Creek re-routed the flows that originally went to Pumpkin Creek. This deepened Horse Creek's drainage below the present day Pumpkin Creek Valley. As a result, a surface-water and ground-water divide now exists between Horse Creek and Pumpkin Creek Valleys. Ephemeral Pumpkin Creek rarely



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flows along much of its length; Pumpkin Creek ends at the confluence with the North Platte River, elevation 3,637 ft above NAVD 88. The stream has an average gradient of 13.9 ft/mi or 0.0026 ft/ft.

### Land Use

Agriculture is the primary land use in the study area with small rural communities (Harrisburg and Redington, fig. 1) being the subdominant land uses (classified as urban for land use purposes) (fig. 2). Agricultural land cover varies from rangeland and irrigated cropland in the valley to forests in the upland areas overlooking the valley. The primary land cover of Pumpkin Creek Valley is rangeland, with a combination of dry and irrigated cropland making up the balance. The percentage of irrigated lands in the valley tends to increase from west to east. Where steep slopes have been cut into the upland areas (Wildcat Hills to the north and Cheyenne Tablelands to the south), woodland vegetation in the form of long pine and cedar trees exists (fig. 2). The primary land uses in dryland areas include wheat, millet, corn, sunflowers, and fallow. Corn, alfalfa, edible beans, wheat, and sugar beets are the primary crops grown in irrigated areas.

Fertilizer use in Pumpkin Creek Valley cannot be quantified confidently because most of the commercial fertilizers used in Banner County were purchased in neighboring counties (Morrill and Scotts Bluff). To estimate a general fertilizer use per acre the assumptions were made that: (1) all fertilizers purchased in Morrill and Scotts Bluff Counties were used in Banner, Morrill, and Scotts Bluff Counties, (2) fertilizer applications per acre were identical in all three counties, (3) no other nitrogen fertilizers were used other than those reported, and (4) all fertilizer used was applied only to irrigated crops, none was applied to dryland fields. Kreitler (1975, p. 15) reported that "fertilizers are used sparingly in dryland farming because of their tendency to burn the crops with insufficient rainfall." Estimates of the tonnage of commercial nitrogen fertilizers sold in Morrill and Scotts Bluff Counties in 2000 and 2001 total about 37,000 tons (Nebraska Agricultural Statistics Service, 2001 and 2002, p. 98) or about 18,600 tons/yr. Reported irrigated cropland in Banner, Morrill, and Scotts Bluff Counties averaged about 232,000 acres. Therefore, the average application of nitrogen fertilizer was inferred to have been about 0.08 tons/acre or about 160 lbs/acre, in 2000-01.

The U.S. Department of Agriculture (2001) reported the amount of nitrogen fertilizer applied in Nebraska for 2000 was  $1.26 \times 10^9$  lbs for corn,  $7.65 \times 10^7$  lbs for winter wheat,  $1.98 \times 10^7$  lbs for soybeans, and  $9.50 \times 10^6$  lbs for sugar beets. Major crops planted in Pumpkin Creek Valley along with recommended fertilizer rates, in lbs/acre, include; (1) alfalfa (irrigated) 40 lbs  $P_2O_5$ ; (2) corn (irrigated) 125 to 175 lbs N, 20 to 30 lbs  $P_2O_5$ ; (3) edible beans (irrigated) 25 to 50 lbs N, 20 to 30 lbs  $P_2O_5$ ; (4) forages (irrigated) 120 lbs N; (5) sugar beets (irrigated) 140 to 180 lbs N, 30 to 50 lbs  $P_2O_5$ ; (6) sunflowers (dryland) no fertilizers; (7) sunflowers (irrigated) 60 to

75 lbs N, 0 to 25 lbs  $P_2O_5$ ; (8) wheat (dryland) 0 to 60 lbs N, 0 to 20 lbs  $P_2O_5$ ; and (9) wheat (irrigated) 100 to 140 lbs N, 20 to 30 lbs  $P_2O_5$  (James Schild, Scotts Bluff County Extension Educator, written commun., 2003).

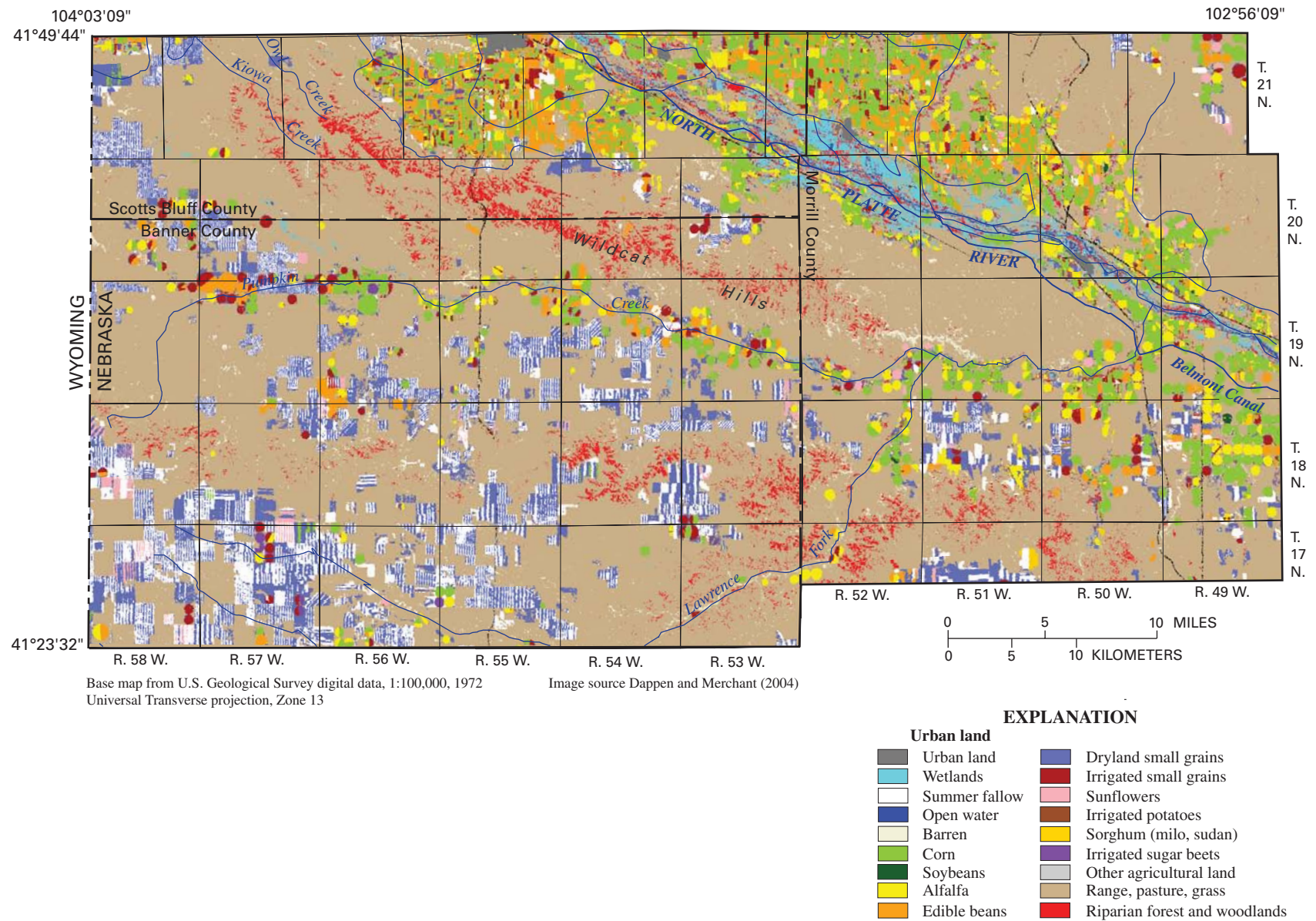
### Hydrogeology

Pumpkin Creek typically has larger flows in the spring months and smaller flows during the summer months. For the study period the daily mean discharge for Pumpkin Creek near Bridgeport for Water Year 2000 (October 1999 through September 2000) was 7.71 ft<sup>3</sup>/s (Nebraska Department of Natural Resources, 2000). Prior to this period, Chen and others (1999) reported that the median discharge for Pumpkin Creek near Bridgeport from 1931 through 1985 had been 26.8 ft<sup>3</sup>/s. Furthermore, they reported that during the same period (1931-1985), Pumpkin Creek's streambed had not significantly (99-percent confidence level, p-value = 0.381) aggradated nor degraded.

The primary surficial ground-water resources in the study area are contained in two geologic units; the Quaternary-age alluvium and eolian sand found along Pumpkin Creek and its tributaries, and the Tertiary-age (Oligocene) Brule Formation of the White River Group (fig. 3, table 1). Swinehart and Diffendal (1997) described the geology and stratigraphic sequence of the surficial geologic units.

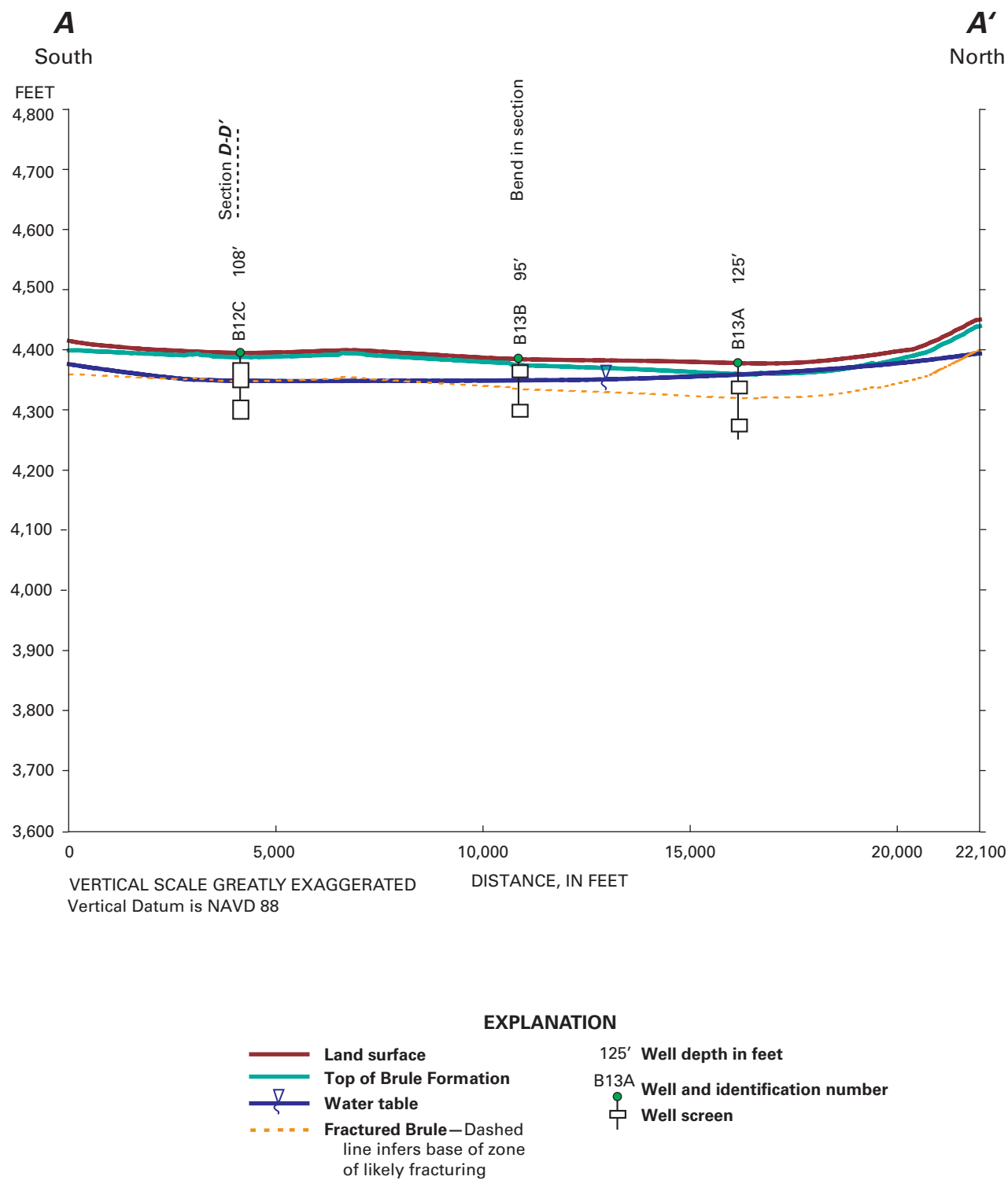
The Brule Formation underlies the Quaternary-age deposits in Pumpkin Creek Valley and the Arikaree Group of Miocene to Oligocene age in the upland areas to the north and south. The Brule Formation largely consists of beds of siltstone that in the study area range from 400 to 600 ft in thickness and does not yield significant quantities of water unless fractured. In areas where the Brule Formation is unfractured siltstone, it is considered to be the base of the shallow aquifer system in the Pumpkin Creek Valley as well as a regional confining unit. Rapp and others (1957) determined a hydraulic conductivity value for the unfractured White River Group of less than 0.027 ft/d.

Lowry (1966) reported that the secondary permeability of the White River Group likely resulted from the formation of pipes that existed prior to the deposition of the overlying Ogallala Group of Tertiary age. Sibray and Zhang (1994) reported that the thickness of the secondary permeability zone of the Brule Formation in the Sidney Draw area near Sidney, Nebraska, (not shown on map) about 32 mi south of the study area, averaged 7.5 ft. Where the Brule Formation is fractured (herein referred to as fractured Brule) hydraulic conductivity values can range from 32 to 119 ft/d. Wenzel and others (1946) report wells can yield large quantities of water (over 1,000 gal/min) with little drawdown. In the Pumpkin Creek study area secondary permeability zones likely are similar to those reported by Lowry (1966) and Sibray and Zhang (1994). Fractured Brule wells generally are located near shallow Quaternary-age alluvial deposits along Pumpkin Creek and its tributaries. In addition, local lenses of sand and gravel present in the Brule Formation provide ground water to a few locations.

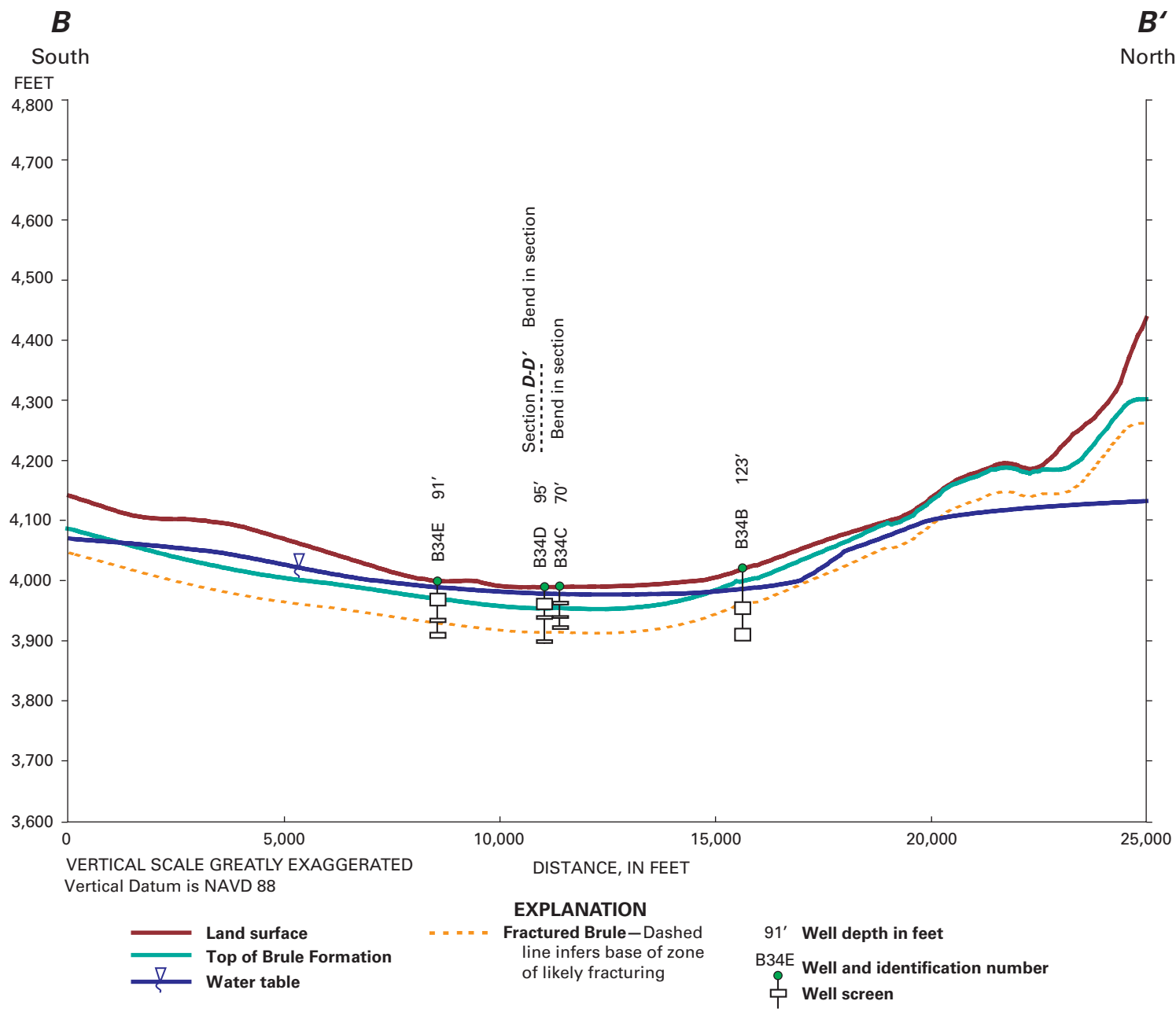


**Figure 2.** Land use in the study area.

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**Figure 3a.** Geologic cross section A-A' of the study area.



**Figure 3b.** Geologic cross section *B-B'* of the study area.

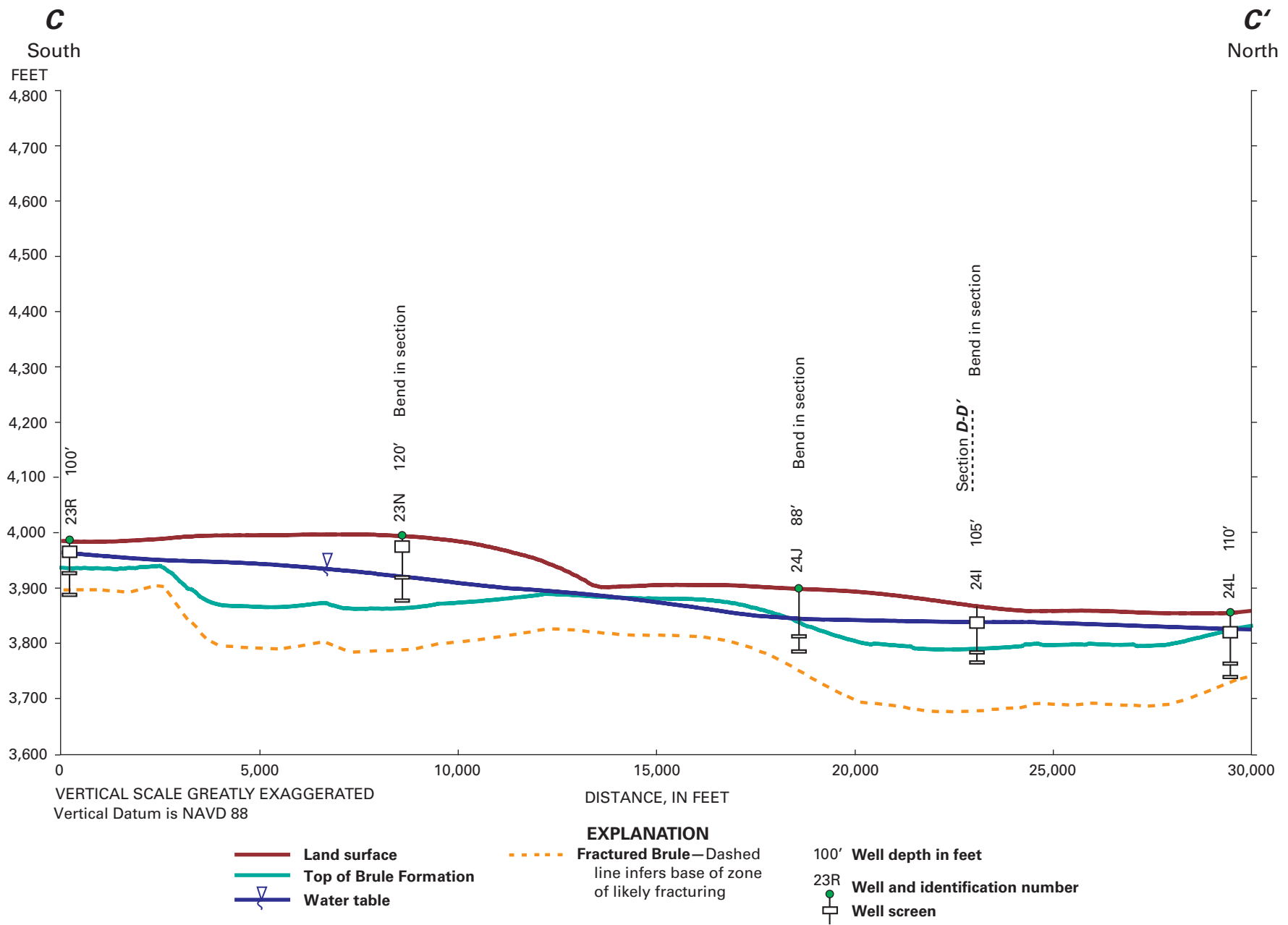


Figure 3c. Geologic cross section C-C' of the study area.



**Table 1.** Hydrogeology of Pumpkin Creek Valley, western Nebraska.

[Geologic characteristics and descriptions modified from Swinehart and Diffendal, 1997]

System	Series	Geologic unit	Geologic characteristics and descriptions	Hydrogeologic unit	Hydrogeologic characteristics
Quaternary	Holocene to Pleistocene	Eolian sand	Eolian sand—well sorted and fine grained, generally less than 50 feet thick.	Aquifer in eolian sand	Unconfined, low yielding water-bearing unit used for stock and domestic wells. Generally shallow depth to water and limited saturated thickness.
		Alluvium <sup>1</sup>	Alluvial deposits of sand and gravel found along Pumpkin Creek and tributaries. Generally less than 0.5-mile wide. General thickness of a trace in the western areas to over 90 feet in the east.	Aquifer in alluvium	Unconfined high yielding water-bearing unit. Some wells capable of yielding over 1,000 gallons per minute. Shallow depth to water. In Pumpkin Creek Valley maximum saturated thickness of alluvium is about 50 feet in Morrill County. Serves as the principal aquifer in Pumpkin Creek Valley.
Tertiary	Miocene	Ogallala Group	Fine- to coarse-grained sand, gravel, and calcareous cemented sandstone and conglomerate; beds of siltstone, caliche, and volcanic ash are common. Generally up to 150 feet in thickness.	Aquifer in Ogallala Group	Unconfined high-yielding water-bearing unit found in Cheyenne Tableland south of Pumpkin Creek. Discharges water to Pumpkin Creek tributaries.
	Lower Miocene to Upper Oligocene	Arikaree Group	Gray, very fine- to medium-grained sandstone with lenses of carbonate cementation. Ash beds and siltstone layers are present. Generally up to 150 feet in thickness.	Aquifer in Arikaree Group	Unconfined water-bearing unit found in Cheyenne Tablelands south of Pumpkin Creek and in the Wildcat Hills north of Pumpkin Creek. Can yield moderate amounts of water. Discharges some water to Pumpkin Creek.
	Lower Oligocene	Brule Formation White River Group	Brown siltstone and mudstone—rich in volcanic glass shards. Regionally correlative ash beds are present. Local lenses of sandstone, sand, and gravel are present. Brule Formation is up to 600 feet thick.	Aquifer in fractured Brule Formation	Shallow unconfined water-bearing unit may yield large volume of water with little draw-down—generally localized near Pumpkin Creek and tributaries. Provides water only where in hydraulic communication with saturated alluvial deposits.
				Aquifer in Brule Formation sand unit	Can be unconfined or confined, very localized, mostly yields small quantities of water for domestic and livestock purposes. Primary aquifer for local irrigation wells in western areas.
				Brule Formation confining unit	Not a source of water, separates unconfined Pumpkin Creek aquifers from confined deeper aquifers. Serves as bedrock in Pumpkin Creek Valley.

<sup>1</sup>Does not include North Platte River alluvial deposits that can be found in the extreme eastern part of the study area.

The Arikaree Group is present both in the Cheyenne Tablelands to the south of Pumpkin Creek and in the Wildcat Hills north of Pumpkin Creek. The aquifer of the Arikaree Group has limited saturated thickness; however, locally some ground water can flow into Pumpkin Creek Valley. In the Wildcat Hills the contact between the Arikaree Group and the underlying Brule Formation creates local springs that discharge into small tributaries of Pumpkin Creek. The Miocene-age Ogallala Group is an important aquifer south of Pumpkin Creek in the Cheyenne Tablelands area. The Ogallala aquifer is an important aquifer in the study area, because it discharges some water to the Pumpkin Creek tributaries in the southern part of the study area.

The youngest Quaternary-age material, coarse sand and gravel deposited along Pumpkin Creek and its tributaries, is the most important aquifer in the study area. These deposits are generally continuous, but usually are less than one-half mile in width and are relatively thin. Some areas in the upper reaches of Pumpkin Creek Valley where ground water is used for irrigation do not contain enough saturated thickness in the aquifer for sufficient yields to individual irrigation wells. In these areas yields from multiple irrigation wells are linked together for the irrigation of crops. In the eastern part of the study area, the maximum saturated thickness of these deposits is approximately 50 ft and wells screened in these deposits are capable of sustaining yields of over 1,000 gal/min (table 1).

The younger sand and gravel deposits of Quaternary age locally overlie older and largely unsaturated sand and gravel of Quaternary age found in widespread terrace deposits. In addition, Quaternary-age eolian sand and loess deposits also are present in the study area, but yield relatively small quantities of water when saturated.

The generalized ground-water-flow direction is from recharge areas in the south and west toward the confluence of Pumpkin Creek with the North Platte River in the eastern part of the study area (fig. 4). Ground-water flow moves in a southwesterly to northeasterly direction before it turns and parallels Pumpkin Creek near the north side of the valley. Locally, ground water may discharge to Pumpkin Creek. A ground-water divide approximates the drainage basin boundary between the Pumpkin Creek and North Platte River Valleys from the extreme northwestern part of the study area to the eastern end of the Wildcat Hills. Another ground-water divide approximates the drainage-basin boundary between Pumpkin Creek and Lawrence Fork Valley (fig. 4).

## Acknowledgments

This study was made possible by support provided by the Nebraska Environmental Trust. Acknowledgment is extended to the landowners who provided access for the installation of monitoring wells and the collection of the water-quality data, and to Thomas Hayden (Nebraska Department of Natural Resources) and his staff for assistance in stream gaging of Pumpkin Creek. Special appreciation and acknowledgment is

extended to Jackie Rick of the North Platte NRD and Kim Scripser (formerly of the North Platte NRD) for maintaining much of the North Platte NRD's database, and for compiling the required field forms and labels during this study.

## Methods

This section describes the methods used to collect the surface-water and ground-water data and the methods used to analyze these data. Measurement of streamflow and ground-water levels and the collection, preparation, and shipment of surface-water and ground-water samples were completed using standard USGS protocols as described by Wells and others (1990), Kolpin and Burkart (1991), Wilde and Radtke (1999), and Wilde and others (1999).

## Well Installation

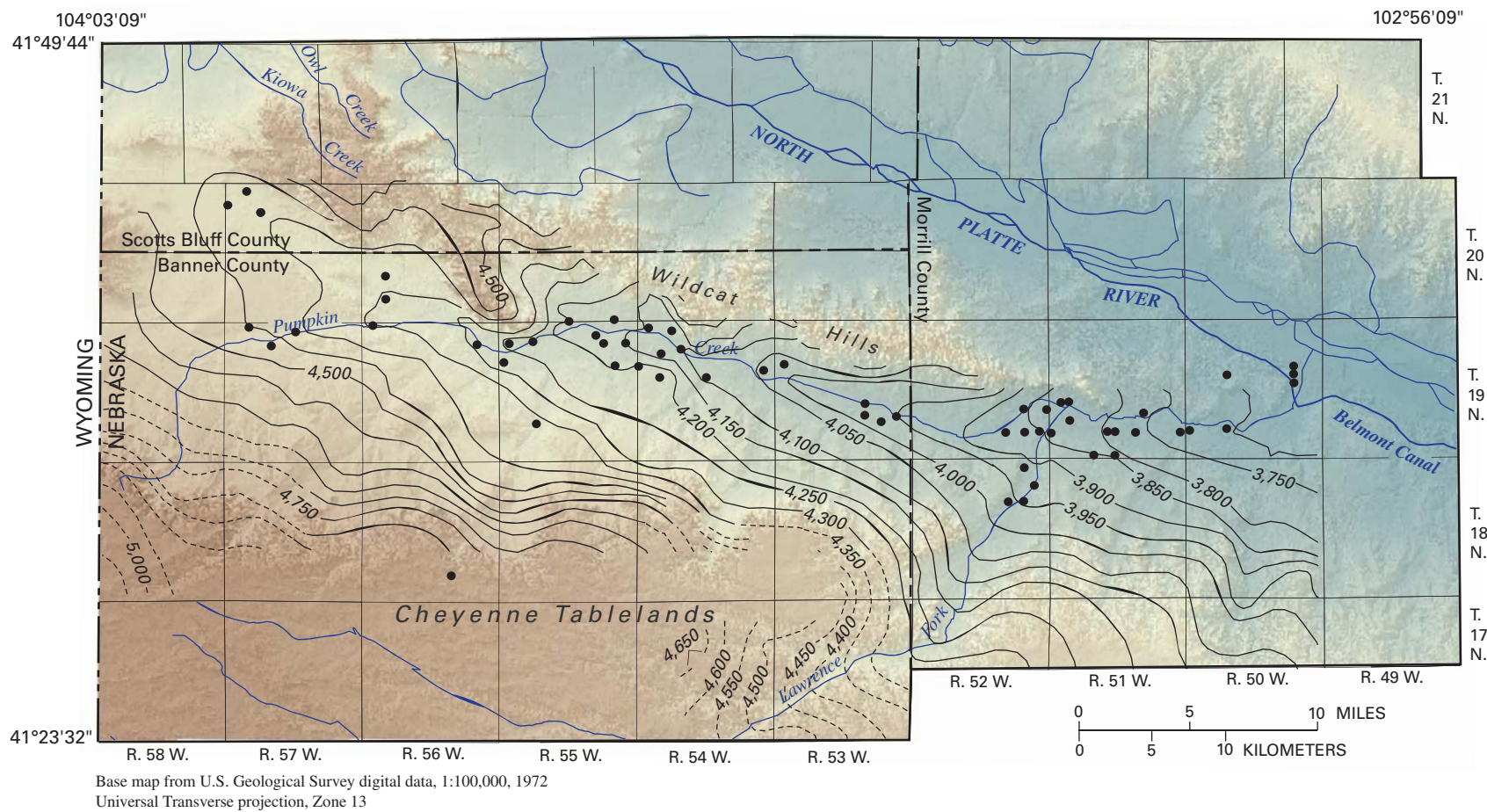
Ground-water samples from the study area were collected only from monitoring wells. Monitoring-well installation was completed by NPNRD and the University of Nebraska-Lincoln, Conservation and Survey Division (CSD) personnel using methods similar to those described by Lapham and others (1997). Development of the monitoring wells was completed using air sparging. Air sparging uses compressed air to lift water up and out of the monitoring well. This, in turn, discharges sediment-laden water from the well and samples representative of ground water in the aquifer can be collected.

The specific classification of each monitoring well was determined by the predominant formation in which it was completed—alluvial, fractured Brule, or Brule Formation. The nomenclature used for wells completed in the Brule Formation was distinguishable by whether or not fracturing was apparent. If fractures were detected during drilling, the monitoring well was designated as “fractured Brule.” If fractures were undetectable during drilling, the monitoring wells were designated as “Brule Formation.” If fractures could not be identified during the installation of the monitoring well, no attempt was subsequently made to reclassify the monitoring well from Brule Formation to fractured Brule. For this report, the classification “fractured Brule” refers to an aquifer, whereas “Brule Formation” refers to a confining unit—the predominant distinguishable hydrogeologic feature between the two classifications.

## Site Identification

This report uses three different methods of site identification. The first method uses the USGS station identification number. USGS assigns a unique number to each type of sampling site (8-digit numbers, such as 06685000, for surface-water sites, and 15-digit numbers, such as 413344103161601, for ground-water sites).





**Figure 4.** Generalized configuration of the water table in the study area, May 2000.

The second method, field identifier, is associated with the transect designation for the NPNRD monitoring-well network. This network, first established in the northwest part of the NPNRD, uses a numeric-alphabetic-alphabetic designation for the monitoring wells (such as 23N-D). Monitoring wells in Banner County were assigned a preceding alphabetic character “B” to identify that well as lying in Banner County (such as B34C-D). Typically, the first number in the field identifier is smallest in the most western section of the NPNRD and increases in an easterly direction. The second alphabetic character (excluding the ‘B’ explained previously) is used to identify the location of the monitoring-well cluster in each transect. This alphabetic character typically proceeds to the south starting with A in the northernmost part of the NPNRD. The terminal alphabetic character is used to identify the depth of the monitoring well in the well cluster; most of the deep monitoring wells were assigned a “D” and ranged in depth from 47 to 194 ft below land surface, the intermediate-depth wells (if present) were assigned an “M” and ranged in depth from 25 to 94 ft below land surface. The shallow monitoring wells were assigned an “S” and ranged in depth from 10 to 125 ft below land surface. A fourth and deepest monitoring well was installed when additional fractures were found during drilling. Well clusters containing four monitoring wells had a “T” assigned as the terminal character (total depth) for the deepest monitoring well. Wells with the “T” assigned ranged in depth from 65 to 96 ft below land surface.

The third method, local identifier, which is not used for identifying surface-water sites, is based on the land subdivisions in the U.S. Bureau of Land Management’s (BLM) survey of Nebraska (fig. 5). The number preceding N (north) indicates the township or tier, the numeral preceding W (west) indicates the range, and the numbers preceding the terminal letters indicate the section in which the well is located. The terminal letters designated A, B, C, and D, denote the quarter section, the quarter-quarter section, the quarter-quarter-quarter section, and the quarter-quarter-quarter-quarter section. The designation is given in a counterclockwise direction beginning with “A” in the northeast corner of each subdivision. Each well also is assigned a terminal number designating the inventory, beginning with “1.” Two or more wells in a cluster are further distinguished by sequentially incrementing the terminal digit of the well number, assigned by order of inventory.

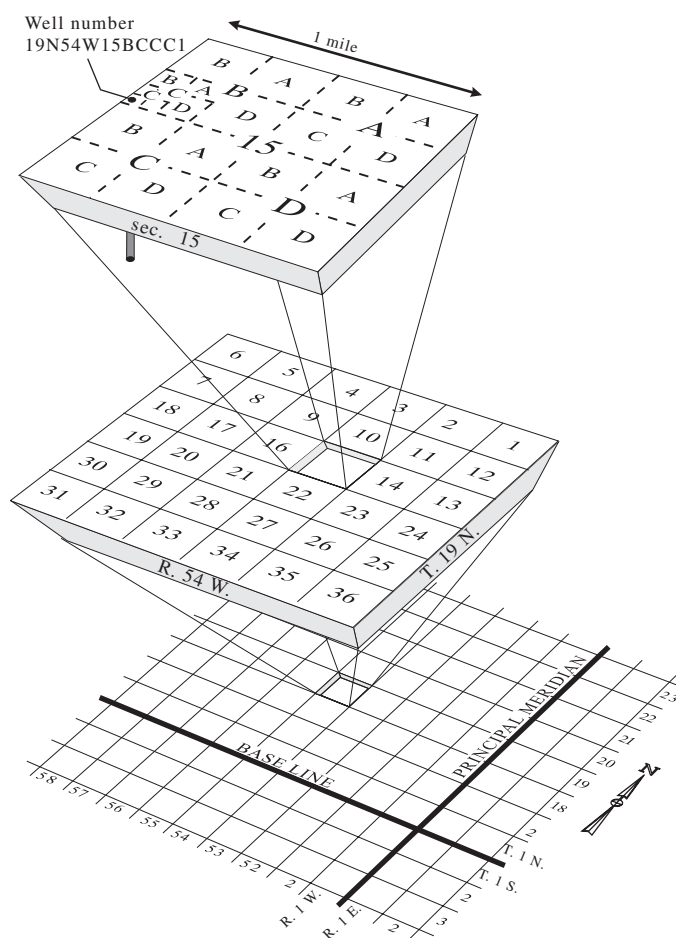
## Sample Collection

Surface-water and ground-water samples were collected from 8 surface-water sites, 88 ground-water sites, and 2 springs in May, July, and August 2000. At all sites, excluding the dry or stagnant surface-water sites (10 samples at 6 sites during July or August), water-level data as well as water-quality samples were collected. All surface-water samples collected from Pumpkin Creek were collected using equal-width increment (EWI) sampling procedures or centroid-of-flow (COF) sampling procedures as described by Wells and others (1990). Water

samples collected from the lake were taken by submerging the sampling container beneath the lake surface to about mid-depth and allowing it to fill with water.

The discharges for all Pumpkin Creek sites (except for Pumpkin Creek near Bridgeport, 06685000), Lawrence Fork, and the two springs were measured by velocity-area method using a standard pygmy current meter at the time of the water-quality collection. The discharge for Pumpkin Creek near Bridgeport was taken from the Nebraska Department of Natural Resources stage-streamflow rating curve (rating number 15) (Tom Haden, Nebraska Department of Natural Resources, written commun., 2004).

Ground-water samples were collected using a stainless steel submersible pump connected to a flow-through chamber. The flow-through chamber facilitates the monitoring of the physical properties of the water to ensure that enough water was



**Figure 5.** Schematic diagram of legal-description numbering system.

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removed from the well casing prior to the collection of a representative sample. Specific conductance, pH, water temperature, and dissolved oxygen were measured in the field at 3-minute intervals. Representative samples were collected after sequential readings stabilized within limits described by Wilde and Radtke (1999) and after three well volumes had been pumped from the well or the well had been nearly pumped dry and allowed to recharge.

About 10 replicate and blank samples, or about 10 percent of the total samples, were collected during each sampling trip for quality control (QC) purposes. All environmental and QC samples were collected and processed on site. Samples requiring filtration (major ions, nutrients,  $\delta^{15}\text{N}$ , and  $^{14}\text{C}$ ) were filtered during sample collection using a clean disposable 45- $\mu\text{m}$  filter. The field equipment was cleaned and decontaminated immediately following the collection of every sample. Samples were sent to various laboratories within 2 days of the collection of water-quality samples. Samples that required cooling (nutrient and  $\delta^{15}\text{N}$ ) were packed on ice in coolers to maintain a maximum of 4° Celsius while enroute to the analytical laboratory (explained in next section). The remaining samples were packed in coolers without ice and were sent to their respective laboratories.

Sampling for CFC and  $^3\text{H}/^3\text{He}$  analyses required special sampling techniques and apparatus to ensure that the ground-water samples do not come in contact with the atmosphere. Samples for CFC analysis were kept from contact with the atmosphere by a special apparatus described by Busenberg and Plummer (1992) and Wilde and others (1999). This special apparatus facilitates sealing water samples into borosilicate-glass ampoules as they are collected. Accuracy of CFC-based dating is improved with the sequential collection of dissolved-gases samples in serum bottles. Analyses of these dissolved-gases samples (argon, carbon dioxide, methane, nitrogen, and oxygen) help define a recharge temperature that is used in calculating the ground-water age (Busenberg and Plummer, 1992). Samples for  $^3\text{H}/^3\text{He}$  analysis were collected and sealed in copper tubing to keep them isolated from the atmosphere (<http://water.usgs.gov/lab/3h3he/sampling>, accessed July 18, 2005).

### Water-Sample Analysis

Water samples from all sites were analyzed for physical properties (specific conductance, pH, temperature), dissolved oxygen, nutrients or nitrate, and the stable isotopes of water— $^2\text{H}$  and  $^{18}\text{O}$ . In May, water samples were collected from all sites and were analyzed for major ions (such as calcium, magnesium, sodium, potassium, sulfates, and chlorides). In addition, a subset of the sites was chosen and samples were analyzed for any combination of these constituents—nitrogen isotope ratios ( $^{15}\text{N}/^{14}\text{N}$ ); CFCs (CFC-12, dichlorodifluoromethane,  $\text{CF}_2\text{Cl}_2$ ; CFC-11, trichlorofluoromethane,  $\text{CFCl}_3$ ; and CFC-113, trichlorotrifluoroethane,  $\text{C}_2\text{F}_3\text{Cl}_3$ ); dissolved gases;  $^3\text{H}$ ;  $^3\text{H}/^3\text{He}$ ; and  $\text{SF}_6$ . During the final collection period in

August, some sites previously sampled for  $^{15}\text{N}/^{14}\text{N}$  isotopes in May were resampled. In addition, six Brule Formation monitoring-well sites—1U-D, 23O-D, 28J-S, B1E-D, B21C-D, and B25B-D—were sampled for carbon isotopes carbon-13/carbon-12 ( $^{13}\text{C}/^{12}\text{C}$ ) and  $^{14}\text{C}$ .

For this report conventional nomenclature was used to describe analyses of water samples for stable isotopes. The composition of stable isotopes of low-mass (light) elements such as oxygen, hydrogen, carbon, and nitrogen commonly are reported as “ $\delta$ ” (delta) values, which indicate parts per thousand or per mil. The general expression for the  $\delta$  value is calculated by the equation (Kendall and Caldwell, 1998):

$$\delta \text{ (in per mil)} = \left[ \frac{R_x}{R_s} - 1 \right] \cdot 1,000 \quad (1)$$

where

$R_x$  is the ratio of the heavy to light isotope of the sample; and

$R_s$  is the ratio of the heavy to light isotope of the standard (for example  $^2\text{H}/^1\text{H}$ ).

A negative  $\delta$  value indicates that the sample is depleted of the heavy isotope relative to the standard or the sample is isotopically “light” (Coplen and others, 2000).

Understanding of stable isotopic composition is aided by identifying related processes. Isotopic fractionation occurs where isotopic compounds are altered by chemical, biological, or physical processes that may result in the preferential enrichment or depletion of one isotope over another. This fractionation process partitions isotopes as a function of the differences in the masses of the isotopes. In general, isotopic fractionation occurs as a result of equilibrium or kinetic isotope reactions by physical or chemical processes (Coplen and others, 2000).

Because the heavier isotope has a stronger molecular bond ( $^2\text{H}$  has a stronger molecular bond than  $^1\text{H}$ , and  $^{18}\text{O}$  has a stronger molecular bond than  $^{16}\text{O}$ ), the liquid phase of water generally is “heavier” than the gaseous phase (Kendall and Caldwell, 1998). Coplen (1993) reported that the lighter isotope is more reactive than the heavier isotope. As a result, evaporation is a major fractionation process in which the lighter isotope is concentrated in the product (water vapor), whereas the heavier isotope enriches the reactant (the aqueous phase).

Water samples were analyzed for major ions, nutrients, nitrates, and  $^{14}\text{C}$  by the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. Methods for analytical procedures used by the NWQL can be found on the World Wide Web at URL [http://nwql.usgs.gov/Public/ref\\_list.html/](http://nwql.usgs.gov/Public/ref_list.html/) (accessed Dec. 4, 2003). Water samples were analyzed for CFC, dissolved gases, and  $\text{SF}_6$  by the USGS Reston Chlorofluorocarbon Laboratory in Reston, Virginia (<http://water.usgs.gov/lab/cfc>, accessed July 18, 2005). Water samples were analyzed for  $^2\text{H}$  and  $^{18}\text{O}$  by the USGS Stable Isotope Laboratory in Reston, Virginia (<http://isotopes.usgs.gov/>, accessed July 18, 2005). Water samples were analyzed for  $^3\text{H}$  by the USGS Isotope Tracers Project laboratory in Menlo Park, California

(Thatcher and others, 1977). Water samples were analyzed for  $^3\text{H}/^3\text{He}$  by the Lamont-Doherty Earth Observatory (LDEO) of Columbia University in Palisades, New York. Methods for analytical procedures used by LDEO can be found on the World Wide Web at URL [http://www.ldeo.columbia.edu/~etg/ms\\_ms/Ludin\\_et\\_al\\_MS\\_Paper.html](http://www.ldeo.columbia.edu/~etg/ms_ms/Ludin_et_al_MS_Paper.html) (accessed Dec. 4, 2003).

## Data-Analysis Procedures

Data-analysis procedures included general statistical analysis and the generation of boxplots, trilinear diagrams, scatter plots, and time-series plots. This report contains only selected plots necessary to support the discussion. Some data were analyzed and described in terms of statistical quartiles (percentiles): data values less than 25, 50 (median), or 75 percent of the sample observations. Percentiles are more descriptive than the minimum and maximum because they more accurately represent the distribution of the data (Helsel and Hirsch, 1992).

Two nonparametric tests were used for comparisons of the data: the Mann-Whitney rank-sum test (Helsel and Hirsch, 1992) and the Wilcoxon signed-rank test for large sample sets (more than 15 samples) (Dowdy and Wearden, 1991; Helsel and Hirsch, 1992). The Mann-Whitney rank-sum test was used to determine if median chemical concentrations were significantly different for independent populations, such as nitrate concentrations in samples from the alluvial aquifer compared with nitrate concentrations in samples from the Brule Formation. The Wilcoxon signed-rank test was used to determine if paired chemical concentrations are significantly different; such as data collected from the same site, but on separate days. All statistical analyses used a confidence level of 95 percent ( $\alpha = 0.05$ ). A confidence level is the probability that the test statistic generated for that test accurately defines the populations being tested. The p-value associated with this particular test result is the probability of getting a value of the test statistic equal to, or more extreme than, the value computed from the data when the null hypothesis (difference in the medians of the two populations is zero) is true. Simpler put, p-values that are 0.05 or smaller indicate that a significant difference between the medians of the two populations can be inferred with 95-percent confidence. That is, the smaller the p-value, the greater is the confidence in the difference between the two populations. For this study, if the p-value was less than or equal to 0.05, the null hypothesis was rejected, and a significant difference between the medians of the two populations was concluded. If the p-value was greater than 0.05, the null hypothesis was accepted.

Nonparametric statistical analysis of the data was performed to accept or reject the hypothesis tests. Nonparametric statistical methods rely on the conversion of data to ranked values and do not require that the data be distributed normally (Dowdy and Wearden, 1991). For the nonparametric statistical analysis, data were grouped into appropriate subgroups and each "censored datum" was assigned a value equal to one-half the reporting limit. Censored data have values less than the reporting limit of the analytical procedure. A value

of one-half the reporting limit assures that the censored data are smaller than the smallest number above the reporting limit. Because the tests performed are nonparametric and compare two independent populations by ranking the data, assigning a minimum value to the censored data does not affect the hypothesis-test results (Helsel and Hirsch, 1992).

## Age Dating

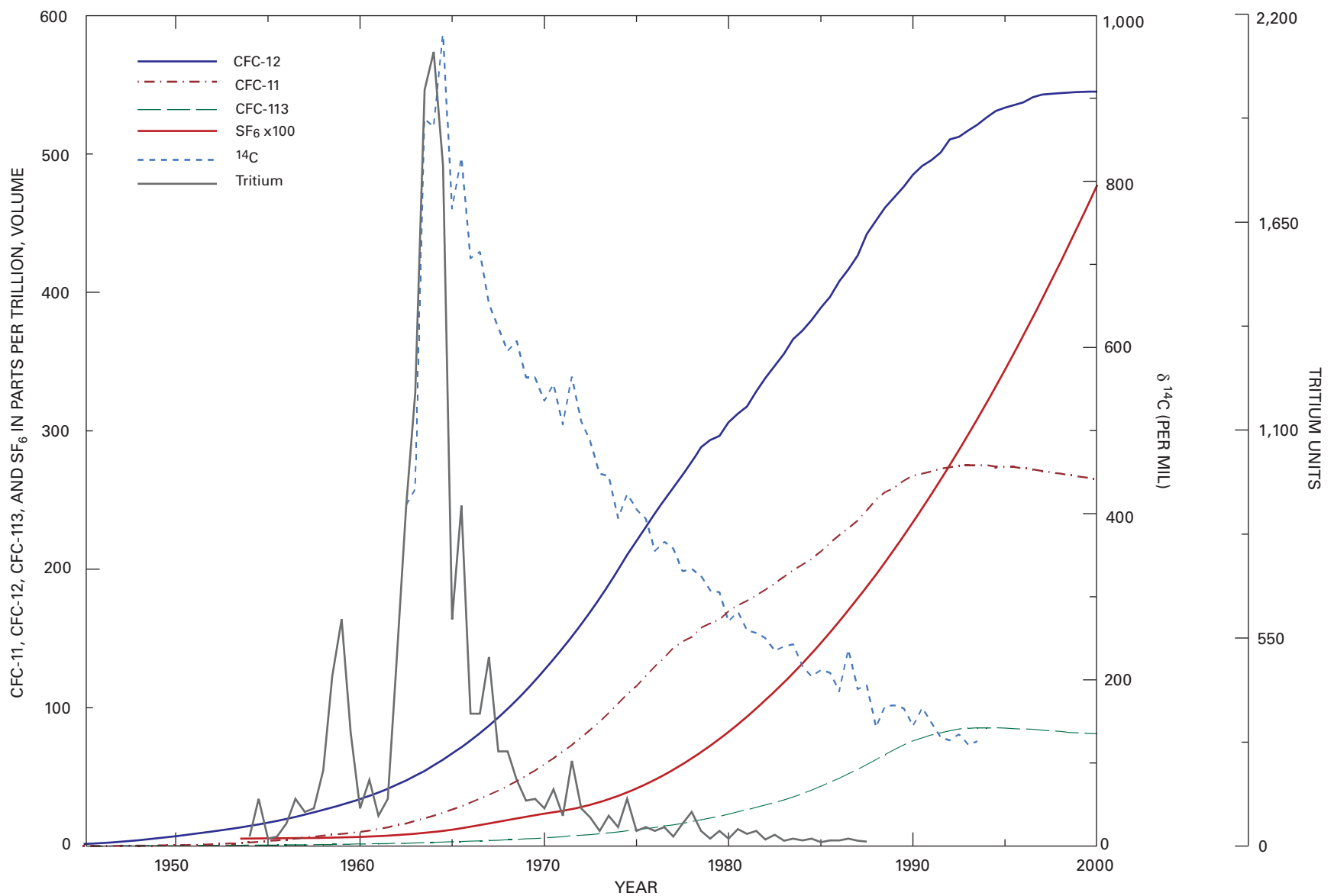
Recharge dates of ground water as long ago as the 1940s can be determined with relatively accurate methods of age dating. These methods, some of which are discussed next, have helped scientists and water managers determine a relation between the history of land-use and ground-water contamination.

### Chlorofluorocarbons

CFCs are stable, synthetic, halogenated alkanes that now can be used for age dating of ground water (Plummer and Busenberg, 2000). CFCs, used as aerosol propellants, cleaning agents, solvents, and blowing agents in the production of foam rubber and plastics, eventually get released into the atmosphere and are subsequently transported into the hydrosphere (Plummer and Busenberg, 2000). Until the early to mid-1990s, CFC concentrations in the atmosphere increased at a nearly linear rate (fig. 6) since they were first produced in the 1930s as safe refrigerants. Consequently, precipitation that fell to the earth since the mid-1940s has a unique CFC signature. The age of relatively young ground water, less than 50 years old, can be determined by analyzing water samples for CFC concentrations.

CFC concentrations in the water samples were compared to calculated and measured values in the air (fig. 6). The CFC age-dating technique is more precise and analytical costs are less than other techniques, such as  $^3\text{H}$ , for dating recent ground water. Previous studies using the CFC technique have determined the age of recently recharged ground water with an accuracy of plus-or-minus 1-to-3 years (Busenberg and Plummer, 1992). CFC ground-water ages also agree favorably with ages determined using other dating techniques, such as  $^3\text{H}$ ,  $^3\text{H}/^3\text{He}$ , and krypton-85 (Ekwurzel and others, 1994). However, over time CFCs can and do degrade under certain conditions (such as anoxic conditions). Therefore, the overall accuracy of CFC-based ground-water age dating also can diminish and must be evaluated using independent dissolved-gases data.

When CFC concentrations in water samples are used to determine the age of ground water, the age is based on the assumption of piston flow and the minimum estimate of time that has elapsed since the newly recharged water came into contact with the saturated zone and, thus became isolated from the soil atmosphere (Szabo and others, 1996; Plummer and Busenberg, 2000). The assumption of piston flow does not account for mixing scenarios that can occur in wells with large open intervals or multiple producing fracture zones, or for



**Figure 6.** Atmospheric concentrations of chlorofluorocarbons (CFC) and sulfur-hexafluoride (SF<sub>6</sub>) in North American air (Plummer and Busenberg, 2000), tritium concentrations in precipitation from Ottawa, Ontario, Canada, and carbon-14 ( $^{14}\text{C}$ ) concentrations in Northern Hemisphere air (N.L. Plummer, U.S. Geological Survey, written commun., 2000).



diffusion or dispersion resulting from ground-water flow and transport. Therefore, the CFC results in this report are referred to as “apparent” ages. Water that is characterized as being of “modern” age refers to water that contains CFC concentrations that are within the possible range of modern air for the CFC concentration, that is, having an apparent age of less than 10 years.

Within the study area, the assumption of piston flow is reasonable considering that in most cases the screened intervals of the wells are much shorter than the thickness of the aquifer. Szabo and others (1996) reported that the difference between the minimum travel time at the top of the screen and the maximum travel time at the bottom of the screen is most significant at depth where ground-water flow lines are closely spaced. Near the water table the ground-water flow lines are not as closely spaced and the small-screened intervals of the wells intersect fewer flow lines. Although the assumption of piston flow was reasonable for this study, other flow regimes, including exponential, linear, and various combinations of all three, also were investigated.

Uncertainties in CFC ages can arise from factors such as: (1) thickness of the unsaturated zone, (2) mixture of young and old water, (3) errors in estimating recharge temperature, (4) degradation of CFCs (oxidation/reduction (redox) conditions from anaerobic, sulfate-reducing, or methanogenic environments), (5) dispersion of ground-water flow, and (6) CFC contamination (Plummer and Busenberg, 2000). Unsaturated-zone thicknesses that exceed 30 ft can cause lag-time errors. Cook and Solomon (1995) presented calculated lag times for CFC concentrations. They suggest that lag times from unsaturated-zone thicknesses less than 30 ft will be less than 2 years and, thus, can be ignored. Mixtures of young and old water or errors in estimating recharge temperature can make the apparent age of the water either too young or too old.

Recharge altitude estimates are needed to help estimate the amount of gas present when recharge occurs. Errors in recharge altitude estimates can cause the apparent age to appear too young or too old because CFC is less soluble at higher altitudes than at lower altitudes. However, recharge altitude estimates that are off more or less than 300 ft are not important because there is not a significant change in solubility between this range of altitude (Plummer and Busenberg, 2000). Degradation of CFCs can cause the apparent age of the water to appear too old. Dispersion of ground-water flow can cause younger water (1975 to 1993) to appear too old or older water (older than 1975) to appear too young. Contamination of CFCs generally produces impossibly young water (water that has recharged in the future) or water that appears too young.

The processes mentioned in the preceding paragraph can affect CFC concentrations in water samples. Therefore, concentrations of CFCs from water samples collected in the study area were evaluated for their sensitivity to these factors. The thickness of the unsaturated zone was initially discarded as a factor because none of the sites where CFC data were collected had water tables (where recharge occurred) greater than 30 ft below

the land surface. However, potential sources of water for some wells could be areas where depths to water are greater than 30 ft. Dispersion of ground-water flow is not expected to have a significant effect on CFC concentrations (Plummer and Busenberg, 2000). The remaining processes that can affect CFC concentrations were considered by reviewing binary mixing scenarios (old water mixed with young water), and testing CFC concentrations for piston, binary, or exponential flow characteristics. Degradation of CFCs was evaluated through analysis of redox, sulfate reducing, and methanogenic conditions from field measurements, water chemistry, and dissolved-gases data collected during the study. CFC contamination was evaluated by comparing CFC air mixture concentrations with the concentrations in water samples.

Sensitivity analysis included testing CFC sample results for sensitivity to changes in altitude or recharge temperature. Samples collected for CFCs also were tested for piston, binary, or exponential flow characteristics. Both sensitivity and flow-characteristic analyses were facilitated using a spreadsheet (Gerald Casale, U.S. Geological Survey, written commun., 2002) containing the original CFC data (in parts per trillion, volume) and worksheets (including sensitivity, binary, and exponential) needed to analyze the CFC data. Each respective worksheet was used to plot the individual CFC data point on a graph to test specific input variables—such as recharge temperature, recharge elevation, age of youngest fraction in water sample, and date of sample collection. Once the data were plotted on the graph, the uncertainties of the CFC data were tested by adjusting the input variables.

### Tritium, Tritium/Helium, Carbon-14

Tritium is a naturally occurring radioactive isotope of hydrogen with a half-life of 4,500 days (12.3 years) (Lucas and Unterwieser, 2000). Most of the  $^3\text{H}$  that was present in the atmosphere prior to thermonuclear testing in the 1950s and 1960s was the result of natural production in the upper atmosphere—bombardment of nitrogen by neutrons in cosmic radiation (Solomon and Cook, 2000).

Tritium's half-life allows it to be used as a dating tool for relatively young water, that is, water recharged less than 50 years ago (Mann and others, 1982). The natural background activity of  $^3\text{H}$  in precipitation prior to 1952 was about 1 to 10 TU (Davis and De Wiest, 1966) with each TU equal to one  $^3\text{H}$  atom in  $10^{18}$  atoms of hydrogen. Beginning in 1952, large amounts of  $^3\text{H}$  were added to this natural background value from above-ground testing of thermonuclear devices. Tritium combines with oxygen to form tritiated water ( $^3\text{HHO}$ ), which is dispersed throughout the hydrosphere. After the onset of thermonuclear testing, large increases of  $^3\text{H}$  concentrations in precipitation were noticed. Concentrations of  $^3\text{H}$  in precipitation continued to rise until an international treaty banned atmospheric thermonuclear testing in 1963 (Solomon and Cook, 2000).

Concentrations of  $^3\text{H}$  in precipitation have been monitored at numerous locations throughout North America since the early 1950s. Ottawa, Ontario, Canada (not shown in figures) has a fairly complete record of  $^3\text{H}$  concentrations in North American precipitation from 1953 to the present (fig. 6). At the 1963 peak, the production of human-generated  $^3\text{H}$  was 100 to 1,000 times greater than that of natural  $^3\text{H}$  (Fontes, 1980). Since that time,  $^3\text{H}$  concentrations in Ottawa precipitation have decreased gradually to about 20 TU (International Atomic Energy Agency, 1992).

Because of its half-life,  $^3\text{H}$  can be used as a natural tracer. However, because the  $^3\text{H}$  input signature varied seasonally and from year-to-year, and the peak input was in the early 1960s, age dating with  $^3\text{H}$  is not as precise as the other methods used in this study. Assuming pre-1950s  $^3\text{H}$  concentrations in ground water were no greater than 6 to 7 TU, water samples with  $^3\text{H}$  concentrations greater than 0.5 TU (in 2000) generally represent water that has recharged after the bomb peak of 1963 (Solomon and Cook, 2000). Water samples with  $^3\text{H}$  concentrations less than 0.5 TU (in 2000) generally represent water that had recharged prior to 1963. Moreover, water samples with  $^3\text{H}$  concentrations that were not measurable (in 2000) likely recharged prior to the 1950s. One of the primary problems with using  $^3\text{H}$  for age dating is that for water that recharged after the 1963 peak, the graph of measured concentrations in North American precipitation (fig. 6) shows that concentrations are too variable to accurately determine an apparent age. In other words,  $^3\text{H}$  concentrations are not a linear function of time—there are too many points on the time line that could correspond to the same concentration of  $^3\text{H}$  and thus to the age that a sample represents.

Another method of age dating with  $^3\text{H}$  is to associate its decay relative to production of  $^3\text{He}$ . Once  $^3\text{H}$  becomes isolated from the atmosphere it can decay to  $^3\text{He}$ . Because the decay rate is constant,  $^3\text{H}/^3\text{He}$  can be measured to determine the age of the water. The  $^3\text{H}/^3\text{He}$  age of ground water is defined (Solomon and others, 1998; Solomon and Cook, 2000) as:

$$t = \lambda^{-1} \ln \left( \frac{^3\text{He}^*}{^3\text{H}} + 1 \right) \quad (2)$$

where

- $t$  is the estimated age of the ground water, in years;
- $\lambda$  is the  $^3\text{H}$  decay constant, in years; and
- $^3\text{He}^*$  is the tritogenic  $^3\text{He}$  concentration, in tritium units.

Most  $^3\text{He}$  in ground water is a product of atomic bomb tests in the mid- to late 1950s. However, terrigenous-derived  $^3\text{He}$  also occurs in ground water. Therefore, concentrations need to be adjusted to account for the terrigenous  $^3\text{He}$ . The symbolic convention for tritogenic  $^3\text{He}^*$  is used to differentiate  $^3\text{He}$  produced from the decay of  $^3\text{H}$ . Details on the uses and limitations of  $^3\text{H}/^3\text{He}$  ratio can be found elsewhere, such as Solomon and Cook (2000) and Solomon and others (1998).

Measurements of  $^{14}\text{C}$  concentrations in ground water are useful for dating ground water with long residence times (greater than 50 years). Age dating with  $^{14}\text{C}$  techniques cannot be done on the water molecule itself, but on the dissolved organic or inorganic carbon in water (Clark and Fritz, 1997). Wang and others (1998) reported the natural production of  $^{14}\text{C}$  in the atmosphere by the interaction of cosmic-ray produced neutrons with nitrogen ( $^{14}\text{N} (n,p) \Rightarrow ^{14}\text{C}$ ; Kalin, 2000), oxygen, or carbon. Once produced,  $^{14}\text{C}$  mixes with carbon dioxide ( $\text{CO}_2$ ) and gets assimilated into the hydrosphere. Consequently, the half-life of  $^{14}\text{C}$  (5,730 years) and the ubiquity of carbon make it an ideal tracer to date ground water that can be 1,000s to 10,000s of years old (Kalin, 2000).

Kalin (2000) reported that the modern activity of  $^{14}\text{C}$  was set by convention to 13.56 dpm per gram of carbon with a 'zero year' (for this activity) of 1950. Therefore, all samples that have an activity less than 13.56 dpm are inferred to be older than 1950, whereas samples with activities greater than 13.56 dpm are inferred to be younger. Typically, the value of 13.56 dpm is reported as 100 percent modern carbon (pmC) and, for this report, is the value used to report  $^{14}\text{C}$  measurements.

The  $^{14}\text{C}$  isotope fractionates during the organic or inorganic phase transformation. To maintain universality for dating purposes,  $^{14}\text{C}$  activity was normalized to the international standard for contemporary carbon (NIST Oxalic Acid SRM 4990-C) (Kalin, 2000). A common  $\delta^{13}\text{C}$  value of -25 per mil was used to normalize for isotope fractionation effects (Clark and Fritz, 1997). Therefore, water samples also were analyzed for  $^{13}\text{C}/^{12}\text{C}$  to determine the  $\delta^{13}\text{C}_x$  value using a variant of equation 1:

$$\delta^{13}\text{C} \text{ (in per mil PDB)} = \left[ \frac{^{13}\text{C}/^{12}\text{C}_x}{^{13}\text{C}/^{12}\text{C}_s} - 1 \right] \bullet 1,000 \quad (3)$$

where

PDB equals the  $\delta^{13}\text{C}$  content of the Vienna Pee Dee belemnite or the standard for computation of  $^{13}\text{C}$  (Bullen and Kendall, 1998);

$^{13}\text{C}/^{12}\text{C}_x$  is the ratio of the sample; and  
 $^{13}\text{C}/^{12}\text{C}_s$  is the ratio of the standard.

The  $^{14}\text{C}$  activity then was normalized to the common  $\delta^{13}\text{C}$  value of -25 per mil using (Clark and Fritz, 1997):

$$\text{Normalization factor (per mil)} = 2.3(\delta^{13}\text{C}_{\text{sample}} + 25) \text{ per mil} \quad (4)$$

where

$\delta^{13}\text{C}_{\text{sample}}$  is the per mil value measured in the water sample.

The normalization factor was used to multiply the measured  $^{14}\text{C}$  activity to obtain a corrected  $^{14}\text{C}$  activity.

Prior to the thermonuclear device tests mentioned previously, atmospheric composition of  $^{14}\text{C}$  was relatively constant ( $A_0$ ) and referred to as 100 pmC (Parkhurst and Plummer, 1993). For this study, an assumption was made that decay was the only process decreasing the amount of  $^{14}\text{C}$  in the ground water. The age of the water was determined by the following equation (modified from Parkhurst and Plummer, 1993):

$$t = \frac{5,730}{\ln(2)} \ln\left(\frac{A_0}{A}\right) \quad (5)$$

where

- $t$  is the estimated age of the ground water, in years;
- 5,730 is the half-life of  $^{14}\text{C}$ , in years;
- $A_0$  is the starting concentration of  $^{14}\text{C}$  in the water, in percent modern carbon; and
- $A$  is the concentration of  $^{14}\text{C}$  in the sample, in percent modern carbon.

Ages derived from  $^{14}\text{C}$  age-dating analyses generally are on the order of 100s to 10,000s of years. Therefore, results are reported in years before present (ybp).

Like  $^3\text{H}/^3\text{He}$  age dating, age dating with  $^{14}\text{C}$  is complicated and many details are not described in this report. However, details on the use and limitations of  $^{14}\text{C}$  in dating of ground water can be found elsewhere, such as Bullen and Kendall (1998), Kalin (2000), and Wang and others (1998).

## Hydrogen and Oxygen Isotopes

Hydrogen (H) and oxygen (O), respectively, are the third and first most abundant elements on the surface of the Earth (Coplen and others, 2002) and are isotopically covariant. In general, the ratio of the two most common isotopes of H and O in terrestrial waters varies within the environment by a factor of 2 and 5 percent, respectively (Coplen and Kendall, 2000). Coplen and others (2000) reported that these large variations are seasonally and climatically induced, which allows hydrologists to identify and quantify the source of water. Relative to precipitation during warm seasons, precipitation during cold seasons is depleted in  $^2\text{H}$  and  $^{18}\text{O}$  (Coplen and others, 2002). Furthermore, chemical analysis of the H and O isotopes provides information about the water molecules directly instead of using physical inferences, such as water-level data and hydraulic conductivity of the aquifer.

Water samples collected for analyses for  $^2\text{H}/^1\text{H}$  and  $^{18}\text{O}/^{16}\text{O}$  are compared relative to the Vienna Standard Mean Oceanic Water (VSMOW). Using this standard, Craig (1961) found that for fresh water, isotopic composition of precipitation worldwide could be expressed using the global meteoric water line (GMWL), which is  $\delta^2\text{H} = 8 \delta^{18}\text{O} + 10$ . Together with the GMWL, this report uses a local meteoric water line (LMWL) established by Harvey and Welker (2000) from analysis of precipitation samples collected at North Platte, Nebraska

(fig. 1). Harvey and Welker (2000) reported the LMWL at  $\delta^2\text{H} = 7.66 \delta^{18}\text{O} + 4.96$ . Although this LMWL is from samples collected about 150 mi to the east-southeast, the LMWL is thought to represent the study area adequately.

## Nitrogen and Nitrogen Isotopes

Nitrogen is essential for plant and animal growth. Nitrogen is one of the most abundant elements on Earth; the most prevalent forms found in ground water are nitrate ( $\text{NO}_3^-$ ), nitrite ( $\text{NO}_2^-$ ), and ammonia ( $\text{NH}_4^+$ ) ions. In ground water,  $\text{NO}_2^-$  generally occurs in substantially smaller concentrations than  $\text{NO}_3^-$ . The major sources of nitrogen derived from natural processes in ground water include precipitation, wildlife wastes, and the oxidation of soil organic matter. Those derived from man-made processes include fertilizer, livestock manure, and sewage effluent. For this report concentrations of  $\text{NO}_2^-$  are combined with concentrations of  $\text{NO}_3^-$  and are presented as  $\text{NO}_3^-$  as nitrogen (herein referred to as  $\text{NO}_3$ ).

For the biosphere, excluding some atmospheric reactions, nitrification is the sole natural source of nitrate (Hallberg and Keeney, 1993). Natural or background concentrations of  $\text{NO}_3$  and  $\text{NH}_4^+$  in the Nation's ground water commonly were less than 2.0 and 0.1 mg/L, respectively (Mueller and Helsel, 1996). Background concentrations of  $\text{NO}_3$  have  $\delta^{15}\text{N}$  values between 2 and 5 per mil (Kendall, 1998; Kendall and Aravena, 2000) with cultivated soils generally having slightly lower  $\delta^{15}\text{N}$  values ( $0.65 \pm 2.6$  per mil) than uncultivated soils ( $2.73 \pm 3.4$  per mil) (Kendall and Aravena, 2000). Nitrogen in water having  $\text{NO}_3$  and  $\delta^{15}\text{N}$  values that lie outside this range probably was caused by applications of commercial fertilizer or animal waste. Moreover, Coplen and others (2002) reported that  $\delta^{15}\text{N}$  values less than 8 per mil generally are typical of areas where synthetic fertilizers are used and  $\delta^{15}\text{N}$  values greater than 8 per mil commonly result from nitrification of animal waste. Background concentrations of  $\text{NO}_3$  in the study area are unknown. However, they likely were similar to that reported by Mueller and Helsel (1996).

With respect to  $\text{NH}_4^+$ , Nolan and Stoner (2000) reported that concentrations of  $\text{NO}_3$  generally were 13 times greater than concentrations of  $\text{NH}_4^+$ . Furthermore, concentrations of  $\text{NH}_4^+$  in ground-water samples in aquifers of the United States rarely exceeded 0.1 mg/L, which indicates the chemical instability of  $\text{NH}_4^+$ . Mueller and Helsel (1996, p. 2) reported that  $\text{NH}_4^+$  "is one of the primary forms of dissolved nitrogen in natural water ... is easily transformed to  $\text{NO}_3$  in waters that contain oxygen and can be transformed to nitrogen gas and released to the atmosphere in waters that are low in oxygen. So it is not surprising that natural concentrations of ammonia are low."

The most prevalent sources of nitrogen found in agricultural areas are derived from commercial fertilizer (anhydrous ammonia ( $\text{NH}_3$ )), urea ( $\text{CO}(\text{NH}_2)_2$ ), and animal waste (although human waste is included in this category, in the study area, animal waste is substantially more prevalent than human waste, so this report only associates animal waste as one of the



prevalent sources). Urea, which is isotopically indistinguishable from commercial fertilizer, can become hydrolyzed to  $\text{NH}_3^+$  and later to  $\text{NH}_4^+$  through protonation of the ammonia molecule, and then to  $\text{NO}_3^-$  (Kendall, 1998). Moreover, urea is irreversibly hydrolyzed to  $\text{NH}_3^+$ , and  $\text{NH}_4^+$  is irreversibly oxidized to  $\text{NO}_3^-$  (Kreitler, 1975; Heaton, 1986; Kendall, 1998). Because  $\text{NH}_4^+$  is a positively charged ion it does not get leached as readily as  $\text{NO}_3^-$  and is attracted to and held by negatively charged soil clay (Barbarick, 1999). As a result,  $\text{NO}_3^-$  is much more prevalent in ground water than  $\text{NH}_4^+$ .

Although fertilizer and livestock waste (in the form of manure) are both applied to agricultural fields, both have distinct isotopic signatures of  $\delta^{15}\text{N}$ . These signatures generally contain a mean  $\delta^{15}\text{N}$  value of  $-0.91 \pm 1.88$  per mil for ammonium ( $\text{NH}_4^+$ );  $+2.75 \pm 0.76$  per mil for nitrogen in commercial fertilizers (Hübler, 1986); and  $+14.0 \pm 8.8$  per mil for nitrogen in animal waste (Kendall, 1998). Coplen and others (2002) reported that with few exceptions, nitrates in commercial fertilizers have  $\delta^{15}\text{N}$  values ranging between -6 and 6 per mil, and averaging between 0 and 4 per mil. Nitrogen uptake by plants in soil causes only a small fractionation. Hence, only slight changes occur to the isotopic signature of the residual fertilizer or organic matter in the soil (Kendall, 1998; Kendall and Aravena, 2000). However, denitrification of nitrogen in fertilizer can yield residual  $\text{NO}_3^-$  that has much higher  $\delta^{15}\text{N}$  values and that is isotopically indistinguishable from animal waste (Kendall, 1998). Therefore, water samples with nitrogen isotope values that first suggested origination from animal waste ( $\delta^{15}\text{N}$  value greater than +10 per mil) and with small dissolved oxygen concentrations (less than 0.5 mg/L) were investigated further to determine if the source of the nitrogen isotope was commercial fertilizer or animal waste. For this report, nitrogen isotopes with a  $\delta^{15}\text{N}$  value greater than +10 per mil are considered to have originated from livestock waste. Nitrogen isotopes with a  $\delta^{15}\text{N}$  value less than +2 per mil are considered to have originated from commercial fertilizer.

## Aquifer Properties

In aquifers, water moves from areas of recharge to areas of discharge. The amount of time that it takes for water to move from one area to another is dependent upon many factors such as the amount of water present, and the porosity, permeability, and general character of the aquifer. Aquifer properties such as hydraulic conductivity (K), transmissivity (T), specific yield ( $S_y$ ), and hydraulic gradient ( $\delta h/\delta l$ ) were used to determine the direction and velocity of ground-water movement. These properties aid in the understanding of the nature of ground-water movement in the study area and the results of water-quality analyses. Although K varies in the horizontal and vertical directions ( $K_h$  and  $K_v$ ),  $K_h$  is used exclusively throughout this report and herein is referred to as K.

To determine K, T, and  $S_y$  one constant-discharge aquifer test and 23 slug tests were conducted in the study area. The constant-discharge test was conducted in a well screened in the

alluvial aquifer. The slug tests were conducted in wells screened in the alluvial aquifer and the fractured and unfractured Brule Formation; all but one of the wells tested were near either Pumpkin Creek or Lawrence Fork.

The constant-discharge aquifer test was about 48 hours long followed by a 72-hour recovery period. Data collected during this test were analyzed using either Neuman's (1975) method of analysis for unconfined aquifers or Moench's (1984) solution for pumping tests in a fractured aquifer using spherical shaped blocks. Procedures along with assumptions used for the Neuman method are available in various textbooks including Kruseman and de Ridder (1990). Data collected during the slug tests were analyzed using Bouwer and Rice's (1976) methods for overdamped responses, and methods developed by Springer and Gelhar (1991) and Butler and others (2003) for critically damped and underdamped responses.

The K computed from the aquifer test was 500 ft/d (table 2), assuming the saturated thickness is the original 36 ft at the pumping well, as opposed to the 16 ft at the observation well. This test was conducted in an area where alluvial sediments were deeper than nearer the edge of Pumpkin Creek Valley. Hydraulic conductivity nearer the edge of Pumpkin Creek Valley, where the alluvial sediments are thinner and likely finer grained than the deeper central part, probably is an order of magnitude less than the central part.

For the combined ground-water system, the range of K from the slug tests was 0.3 to 1,000 ft/d with a median of about 100 ft/d. Five wells were screened in the alluvial aquifer (one well 1U-S also was open to the Brule Formation, but is included as alluvial because of the higher K value); the range of K for these alluvial monitoring wells was 40 to 200 ft/d, and the median K was 200 ft/d. Four wells were screened in the fractured Brule, the range of K for the fractured Brule monitoring wells was 100 to 1,000 ft/d, and the median K was 300 ft/d. Fourteen wells were screened in the Brule Formation, the range of K for the Brule Formation monitoring wells was 0.3 to 200 ft/d, and the median K was 50 ft/d.

Hydraulic gradient for unconfined aquifers is determined from the slope of the water table at its steepest point (Heath, 1983). In the study area,  $\delta h/\delta l$  was determined by using the difference in the elevation of the water levels ( $\delta h$ ) of monitoring wells B12C-S (upgradient) and 28L-S (downgradient) and the distance ( $\delta l$ ) from monitoring well B12C-S to monitoring well 28L-S—the head difference ( $\delta h$ ) was about 620 ft and the length ( $\delta l$ ) was about 200,000 ft. Consequently,  $\delta h/\delta l$  for the study area was about 0.0031 ft/ft, which is close to the surface-water gradient of 0.0026 ft/ft reported previously.

Heath (1983) reported that the ground-water velocity (v) equation is derived from the Darcy equation (Darcy, 1856) and the velocity equation of hydraulics:

$$Q = KA \left( \frac{\delta h}{\delta l} \right) \text{ (Darcy equation),}$$

$$Q = Av, \text{ and } v = K \left( \frac{\delta h}{\delta l} \right)$$

where

- Q is the quantity of water per unit time;
- A is the cross-sectional area;
- $\delta h / \delta l$  is the hydraulic gradient; and
- v is the Darcian velocity component.

However, because water only moves through the openings in the aquifer material, porosity is needed to determine the ground-water velocity.

$$v = \frac{K \delta h}{n \delta l} \quad (6)$$

where n is the porosity term.

Porosity was estimated by using an average n of 0.25 for sand (Heath, 1983), the dominant material in the alluvial aquifer. Using equation 6 with K equal to 500 ft/d, n equal to 0.25, and  $\delta h / \delta l$  equal to 0.0031, results in a representative ground-water velocity in the deeper parts of the alluvial aquifer of about 6 ft/d. Using K as determined from the slug tests (assuming the same ground-water gradient and the alluvial aquifer) gives ground-water velocities ranging from  $3.7 \times 10^{-3}$  ft/d to 12 ft/d (assuming a porosity of 0.25). Likewise, the ground-water velocity in the shallower alluvial sediments nearer the edge of Pumpkin Creek Valley likely is about 1 ft/d. Typical alluvial ground-water velocities in the study area likely average between 1 and 10 ft/d.

## Creation of Water-Table Map and Geologic Sections

The water-table map and the geologic sections were created using historical data and data collected from this study. The water-table map was created using water-level data collected from areally distributed wells during 2000. Where wells were not available for collection of water-level data, data were inferred based on previous studies, historical maps, or historical data.

Geologic sections in this report were generalized from data used for the Cooperative Hydrology Study (COHYST) (Duane Woodward, Central Platte Natural Resources District, written commun., 2004). Digital elevation models created by and for COHYST ([http://cohyst.dnr.state.ne.us/cohyst\\_preliminarydata.html](http://cohyst.dnr.state.ne.us/cohyst_preliminarydata.html), accessed February 14, 2005) were used to create the land surface used for COHYST's western ground-water flow model ([http://cohyst.dnr.state.ne.us/cohyst\\_preliminarydata.html](http://cohyst.dnr.state.ne.us/cohyst_preliminarydata.html), accessed February 14, 2005). To create the geologic layers used for the ground-water model, COHYST used data from test holes drilled by the University of Nebraska-Lincoln. Additional information, such as drillers logs from municipal, irrigation, and domestic wells, were used to refine the geologic contacts and subsequently was incorporated into a geographic information system to create three-dimensional hydrogeologic layers used for COHYST's ground-water flow model. This report generalized those data used by COHYST. For instance, unconsolidated material of Quaternary age was incorporated as a single undifferentiated unit, as opposed to

COHYST's differentiated unconsolidated material. In addition, bedrock formations were generalized as individual single units, differing only by formation.

Placement of the line for zone of likely fracturing in the Brule Formation was based on data obtained during the drilling of the monitoring wells used for the study, but is highly speculative. This line was placed at about 25 ft below the top of the Brule Formation and is shown only as a graphic depiction of the general depth where fractures might be found. Above this line, most of the fractures were found; below this line, fractures were found less frequently. The actual depth of fractures in the Brule Formation is highly variable and could not be delineated with existing data. The fracturing zone as depicted thus does not convey site-specific information for any location in the valley. Wells were not available on the lateral edges of the valley (north and south geologic sections). Therefore, all geologic contacts in these areas were inferred.

## Quality Assurance and Quality Control

Quality assurance (QA) and QC were used to ensure that the collection, processing, and analysis of water samples were of a known and acceptable quality. Prior to the collection of the data, QA objectives for accuracy, precision, completeness, and representativeness were assembled from the USGS Nebraska District QA Plan (A.D. Druliner, U.S. Geological Survey, written commun., 2000) or were developed specifically for this study. The QA objectives included minimum acceptable quality standards for all field and laboratory data. Data for particular analyses that did not meet these standards were still reported in the data tables, but were flagged accordingly and noted in the text. QA objectives also included mandatory participation by USGS field personnel in the National Field Quality Assurance Tests administered annually by the USGS (Erdmann and Thomas, 1985, p. 110-115).

The accuracy of the laboratory analytical data and the field data was determined by analyzing a variety of QC samples. The accuracy of the laboratory analytical data was evaluated by the use of standard methods and blind-reference samples submitted to the NWQL by the Branch of Quality Assurance of the USGS. The accuracy of the field data was evaluated by collection and analysis of replicate and blank field samples. About 10 replicate and blank samples, or about 10 percent of the total samples, were collected during each sampling trip for QC purposes. All QC samples were collected sequentially, processed, and shipped with the regular samples. Field blanks were collected on site, but prior to the collection of the environmental sample. Replicates, using a clean filter, were collected immediately following the collection of the primary environmental sample. Field equipment was cleaned and decontaminated immediately following the collection of every sample including the collection of the replicate sample. Data from the analysis of the replicate were used to assess precision of the overall sampling and analytical process. In addition, samples for major-ion analysis were reanalyzed by the NWQL if their anion and cation concentrations did not balance within about 5 percent of each other.

**Table 2.** Results of aquifer tests, Pumpkin Creek Valley, western Nebraska.

[USGS, U.S. Geological Survey; ID, Identification; fig., figure; A, alluvial; FB, fractured Brule Formation; --, not applicable or not needed for solution; A/B, alluvial and Brule Formation; B, Brule Formation]

USGS station ID	Field ID (fig. 1)	Analysis method [reference or source]	Hydraulic conductivity (K), in feet per day	Depth to water from top of casing, in feet	Measuring point, in feet	Total depth, from top of casing, in feet	Depth to top of screen from land surface, in feet	Depth to bottom of screen from land surface, in feet	Aquifer type
Constant-discharge aquifer test									
413555103150903	24I-S	Neuman, 1975	500	20.69	2.55	42.55	20	40	A
413555103150902	24I-M	Moench, 1984	300	21.31	2.57	88.57	81	86	FB
413555103150901	24I-D	Moench, 1984	400	26.22	2.53	107.53	100	105	FB
--	Composite	Neuman, 1975	500	--	--	--	--	--	--
Slug tests									
413611103242404	B34C-S	Halford and Kuniansky, 2002	40	14.29	2.50	19.45	12	17	A
413611103242403	B34C-M	Butler and others, 2003	200	14.26	2.60	32.85	25	30	A
413541103224602	B36E-S	Butler and others, 2003	200	14.19	2.50	42.65	20	40	A
413510103060104	28L-S	Butler and others, 2003	200	11.27	2.55	29.75	15	25	A
414321103550802	1U-S	Butler and others, 2003	200	11.52	2.50	34.30	10	30	A/B
413611103242402	B34C-D	Butler and others, 2003	1,000	14.22	2.57	54.95	47	52	FB
413228103161802	23P-M	Butler and others, 2003	400	43.34	1.79	95.35	87	92	FB
413510103060103	28L-M	Butler and others, 2003	200	11.29	2.50	49.05	41	46	FB
413510103060102	28L-D	Butler and others, 2003	100	12.10	2.54	68.25	60	65	FB
413916103392603	B21C-S	Butler and others, 2003	50	11.75	2.92	33.15	10	30	B
413916103392602	B21C-M	Butler and others, 2003	100	12.28	2.95	81.55	67	76	B
413919103370902	B23D-S	Butler and others, 2003	200	15.55	2.90	28.05	15	25	B
413826103374102	B23E-S	Butler and others, 2003	40	35.70	2.50	51.80	30	50	B
413900103352302	B25D-S	Butler and others, 2003	50	15.13	3.15	33.75	10	30	B
413611103242401	B34C-T	Halford and Kuniansky, 2002	90	14.45	2.48	72.55	65	70	B
413541103224601	B36E-D	Halford and Kuniansky, 2002	10	14.52	2.94	72.55	66	71	B
413556103161902	23J-M	Halford and Kuniansky, 2002	90	13.50	2.65	58.25	49	54	B
413556103161901	23J-D	Halford and Kuniansky, 2002	6	13.56	2.70	98.75	90	95	B
413344103161601	23N-D	Halford and Kuniansky, 2002	.3	30.38	2.00	120	115	120	B
413228103161803	23P-S	Butler and others, 2003	100	40.64	2.40	57.45	35	55	B
413228103161801	23P-D	Halford and Kuniansky, 2002	.9	41.90	2.08	131.5	124	129	B
413510103060101	28L-T	Butler and others, 2003	100	13.31	2.50	99.75	91	96	B
413653103242402	34B-S	Halford and Kuniansky, 2002	4	54.56	1.75	79.45	58	78	B

## Age and Quality of Ground Water

This section discusses the results of the sampling for age dating and water-quality analysis. The age-dating section discusses the age-dating techniques and the samples analyzed for  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ . The water-quality section is broken down into the overall general chemistry of the water followed by the spatial and temporal distribution of nitrate. Also, although this section is titled age and quality of ground water, discussion in all of the following subsections can contain text on any of the four water systems (surface water, alluvial, fractured Brule, and Brule Formation).

Most of the water-quality data collected during this study is presented in table form in the appendix of this report. However, those data that were not presented in this report (such as nitrite as nitrogen) can be found at the USGS URL <http://waterdata.usgs.gov/ne/nwis/qw>.

### Age of Ground Water

It is important to restate that although this report discusses the “age” of the ground water, reference only is made to an apparent age using the assumption of piston flow. Also, the age of the ground water refers to the date the CFC was introduced into the aquifer and isolated from the atmosphere. It is not the actual age of the water. For brevity, this report herein refers to the apparent recharge age of the water as age of the water. The accuracy of the CFC-based age depends, in part, on how perfectly the CFC was transmitted with the ground water (Plummer and Busenberg, 2000). To help determine the accuracy, the CFC results from the ground-water samples were tested for sensitivity, including differences in recharge temperature and recharge elevation.

Water samples collected from 6 surface-water sites, 59 ground-water sites, and 2 springs (table 3) were analyzed for concentrations of CFC-11, CFC-12, and CFC-113. Analysis of these data indicated that most water samples had CFC concentrations less than those found in modern air, and apparent ages could be assigned. In addition, all water samples to which apparent ages from CFCs could be assigned were further examined using three flow or mixing scenarios—piston flow, binary (old water mixed with young water) mixing, and exponential mixing. These analyses indicated that some samples could have been contaminated or CFC concentrations in water exceeded those concentrations measured in modern air. For these samples, alternate methods of age dating were used where appropriate or apparent ages were not assigned.

Testing the sensitivity (how closely the CFC age is affected by changes in temperature or altitude and different CFC mixing scenarios associated with piston, binary, or exponential flow characteristics) of the CFC data suggested that the assumptions described previously were valid and the age of the

water associated with these assumptions was practical. The results of testing the sensitivity of the CFC data to differing scenarios of binary mixing varied substantially from samples containing only young water, a mixture of young and old water, or old to very old water. In contrast, sensitivity testing for piston, binary, or exponential flow characteristics did not refute the assumption that piston flow dominated the ground-water flow regime in the study area. Although some water samples showed anoxic conditions, such as dissolved-oxygen concentrations less than 0.5 mg/L or the smell of  $\text{H}_2\text{S}$ , sulfate-reducing conditions were not prevalent, and methanogenic conditions, as seen in the water chemistry or dissolved-gases data ( $\text{CH}_4$  values), seemed limited to monitoring well B34C-S (table 8, appendix).

Anoxic conditions were observed in some water samples. As a result, some of the water samples could have had concentrations of CFC-11 and CFC-113 degraded from original concentrations—CFC-11 and CFC-113 typically are not as stable as CFC-12 (Plummer and Busenberg, 2000). However, degradation of CFC-12 probably was negligible and, where appropriate, more weight was placed on the CFC-12 value when age dating the water. As a result, apparent recharge age of the water is reported from CFC-12 data, which appeared not to have degraded, but in some cases was contaminated. If water containing CFC-12 mixed with older water, this apparent age given by the CFC-based sampling represents the maximum age of the young fraction of water.

CFC concentrations from samples from some monitoring wells, such as 1U-D, suggest that because of the extremely low yields (water samples were limited by the amount of water available before the monitoring well pumped dry) the CFC-derived age could have been biased from contamination of the sample during well sparging. Air sparging is often used to develop wells following installation. During this process, air is pumped into the well to help clean and develop the well by lifting the fine particles out with the water. However, in very low-yielding wells, it may be extremely difficult to remove all of the air that was introduced into the aquifer during sparging. This air may become entrapped in the system for several years.

Ground water less than 30 years old was found predominantly in the alluvial and fractured Brule aquifers. In the alluvial aquifer the ground-water age typically varied from about 1980 to modern (table 3). In the fractured Brule the median age of the water was the 1970s. Very few wells developed in the Brule Formation could be sampled for CFCs because the volume of water yielded was too low. Therefore, age dating of the water in the Brule Formation was limited to a few selected wells. The ages of water produced from monitoring wells in the Brule Formation varied widely—from the 1940s to the 1990s. However, most water samples collected from Brule Formation monitoring wells contained the oldest water of all monitoring wells in the study area.

**Table 3.** Apparent age of water samples, Pumpkin Creek Valley, western Nebraska, 2000.

[All dates calculated from month and year of collection; USGS, U.S. Geological Survey; ID, identification; fig., figure; AT, aquifer type, B, Brule Formation, FB, Fractured Brule Formation, A, alluvial; A/B, alluvial and Brule Formation; °C, degrees Celsius; CFC, chlorofluorocarbon; SF<sub>6</sub>, sulfur hexafluoride, C, carbon; ybp, years before present; <sup>3</sup>H, tritium; <sup>3</sup>He, helium-3; --, not analyzed or no result; Mod, water is in equilibrium with modern concentrations in the atmosphere; mix, possible mixture of young and old water; Con, contaminated sample; NP, age determination is not possible]

USGS station ID	Field ID (fig. 1)	Legal ID	AT	Date	Time	Re-charge temper- ature (°C)	CFC- 11	CFC- 12	CFC- 113	CFC ratio						Apparent age			
										11/12	% young CFC- 12	113/ 12	% young CFC- 113	113/ 11	% young CFC- 113	CFC	SF <sub>6</sub>	<sup>14</sup> C, ybp	Corrected <sup>3</sup> H/ <sup>3</sup> He age ±1•
Surface water and springs																			
06684700	Pumpkin Creek at Highway 71			5/3/2000	1245	--	Con	Con	Con	--	--	--	--	--	--	Degraded/ Modern	--	--	--
06684910	Pumpkin Creek at Olsen Ranch			5/3/2000	1610	--	1945	1979	1955	--	--	--	--	--	--	Degraded/ Modern	--	--	--
06684970	Pumpkin Creek at Highway 88			5/4/2000	1130	--	1955	1994	1984	--	--	--	--	--	--	Modern	--	--	--
06685000	Pumpkin Creek near Bridgeport			5/4/2000	1230	--	Mod	Con	Con	--	--	--	--	--	--	Modern	--	--	--
06684950	Lawrence Fork			5/4/2000	0950	--	Con	Con	Con	--	--	--	--	--	--	Degraded/ Modern	--	--	--
06684920	Spring at Schuler Ranch			5/4/2000	0840	--	1988	2000	1990	--	--	--	--	--	--	Modern	--	--	--
06684930	Spring at Olsen Ranch			5/3/2000	1450	--	1968	1974	1977	--	--	--	--	--	--	mid-1970s	--	--	--
06684650	Lake	5/3/2000	1045	--	1945	1955	1955	--	--	--	--	--	--	mid-1940s to mid-1950s	--	--	--		
Wells																			
413820104030001	B1E-D	19N 58W 7ABBB1	B	8/22/2000	1220	--	--	--	--	--	--	--	--	--	--	--	--	Modern	--
413821103543501	B8E-S	19N 57W 8AAAA1	B	5/22/2000	1600	11.1	1980	1982	1985	NP	--	1987	83.2	1988	58.8	early 1980s	--	--	1989
413906103492502	B12C-S	19N 56W 6BADB2	B	5/22/2000	1030	7.8	1983	1988	1988	NP	--	NP	--	Mod	84.6	late 1980s	--	--	--
414006103484602	B13B-S	20N 56W32BBBB2	B	5/22/2000	1210	11.1	1971	1972	1978	NP	--	1985	45.9	1990	72.8	early to mid-1970s	--	--	--
413916103392603	B21C-S	19N 55W 4AABA3	B	5/9/2000	1320	9.7	Con	1990	1988	NP	--	NP	--	NP	--	early 1990s	--	--	1992
413916103392602	B21C-M	19N 55W 4AABA2	B	5/9/2000	1240	10.1	1974	1973	1978	1977	61.0	1984	43.4	1981	24.6	early to mid-1970s	--	--	1970

**Table 3.** Apparent age of water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All dates calculated from month and year of collection; USGS, U.S. Geological Survey; ID, identification; fig., figure; AT, aquifer type, B, Brule Formation, FB, Fractured Brule Formation, A, alluvial; A/B, alluvial and Brule Formation; °C, degrees Celsius; CFC, chlorofluorocarbon; SF<sub>6</sub>, sulfur hexafluoride, C, carbon; ybp, years before present; <sup>3</sup>H, tritium; <sup>3</sup>He, helium-3; --, not analyzed or no result; Mod, water is in equilibrium with modern concentrations in the atmosphere; mix, possible mixture of young and old water; Con, contaminated sample; NP, age determination is not possible]

USGS station ID	Field ID (fig. 1)	Legal ID	AT	Date	Time	Re-charge temper- ature (°C)	CFC- 11	CFC- 12	CFC- 113	CFC ratio						Apparent age			
										11/12	% young CFC- 12	113/ 12	% young CFC- 113	113/ 11	% young CFC- 113	CFC	SF <sub>6</sub>	<sup>14</sup> C, ybp	Corrected <sup>3</sup> H/ <sup>3</sup> He age ±1σ
Wells—Continued																			
413916103392601	B21C-D	19N 55W 4AABA1	B	8/25/2000	1120	--	--	--	--	--	--	--	--	--	--	--	--	16,800	--
413919103370902	B23D-S	20N 55W35DDDD2	B	5/9/2000	1440	11.7	1978	1983	1985	NP	--	1987	88.1	Mod	81.7	early to mid-1980s	--	--	1990
413919103370901	B23D-D	20N 55W35DDDD1	B	5/9/2000	1420	--	--	--	--	--	--	--	--	--	--	--	--	--	--
413826103374102	B23E-S	19N 55W11ABBB2	B	5/10/2000	0905	11.0	Con	1986	1987	NP	--	NP	--	NP	--	mid-1980s	--	--	1993
413826103374101	B23E-D	19N 55W11ABBB1	B	5/10/2000	0820	--	--	--	--	--	--	--	--	--	--	--	--	--	1977
413827103363102	B24E-S	19N 55W12ABBB2	A	5/10/2000	1055	10.9	Con	1987	1987	NP	--	NP	--	NP	--	mid- to late 1980s	--	--	1994
413827103363101	B24E-D	19N 55W12ABBB1	B	5/10/2000	1020	11.0	Con	1986	1986	NP	--	NP	--	NP	--	mid-1980s	--	--	1991
414007103352401	B25B-D	20N 54W 31ABBB1	B	8/25/2000	1340	--	--	--	--	--	--	--	--	--	--	--	--	5,000	--
413900103352302	B25D-S	19N 54W 6ACCC2	B	5/10/2000	1210	11.2	1992	Con	1978	NP	--	NP	--	NP	--	late 1970s	--	--	1978
413803103344602	B25E-S	19N 54W 8BCCC2	A	5/10/2000	1335	--	1985	1989	1987	NP	--	1988	99.9	1989	66.1	late 1980s	--	--	Mod
413653103242402	B34B-S	19N 53W14CCCB2	B	5/10/2000	1530	12.6	1982	1982	1988	NP	--	NP	--	Mod	84.5	late 1980s to early 1990s	--	--	1997
413611103242403	B34C-S	19N 53W23CBCC3	A	5/11/2000	1110	9.2	1974	1980	1980	NP	--	1980	98.5	1985	43.1	early 1980s	1992	--	Mod
413611103242402	B34C-M	19N 53W23CBCC2	A	5/11/2000	1030	10.2	1976	1986	1983	NP	--	NP	--	1985	40.4	early to mid-1980s	1990	--	1989
413611103242401	B34C-D	19N 53W23CBCC1	FB	5/11/2000	1000	11.0	1945	1965	1960	NP	--	NP	--	NP	--	mid-1960s	--	--	1987
413611103242404	B34C-T	19N 53W23CBCC4	B	5/11/2000	0930	8.4	1966	1972	1955	NP	--	NP	--	NP	--	early 1970s	--	--	1984
413608103242403	B34D-S	19N 53W23CCBB3	A	5/11/2000	1200	6.6	1956	1959	1955	NP	--	NP	--	NP	--	late 1950s	--	--	1997
413608103242402	B34D-M	19N 53W23CCBB2	FB	5/11/2000	1300	11.0	1978	1983	1983	NP	--	1985	91.5	1988	62.3	early to mid-1980s	--	--	1990

**Table 3.** Apparent age of water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All dates calculated from month and year of collection; USGS, U.S. Geological Survey; ID, identification; fig., figure; AT, aquifer type, B, Brule Formation, FB, Fractured Brule Formation, A, alluvial; A/B, alluvial and Brule Formation; °C, degrees Celsius; CFC, chlorofluorocarbon; SF<sub>6</sub>, sulfur hexafluoride, C, carbon; ybp, years before present; <sup>3</sup>H, tritium; <sup>3</sup>He, helium-3; --, not analyzed or no result; Mod, water is in equilibrium with modern concentrations in the atmosphere; mix, possible mixture of young and old water; Con, contaminated sample; NP, age determination is not possible]

USGS station ID	Field ID (fig. 1)	Legal ID	AT	Date	Time	Re-charge temper- ature (°C)	CFC- 11	CFC- 12	CFC- 113	CFC ratio						Apparent age			
										11/12	% young CFC- 12	113/ 12	% young CFC- 113	113/ 11	% young CFC- 113	CFC	SF <sub>6</sub>	<sup>14</sup> C, ybp	Corrected <sup>3</sup> H/ <sup>3</sup> He age ±1σ
Wells—Continued																			
413608103242401	B34D-D	19N 53W23CCBB1	B	5/11/2000	1340	--	--	--	--	--	--	--	--	--	--	--	--	--	1935
413543103242403	B34E-S	19N 53W26BBCC3	A	5/12/2000	1020	11.6	1984	1988	1987	NP	--	NP	--	1990	72.8	mid- to late 1980s	--	--	1991
413543103242402	B34E-M	19N 53W26BBCC2	A	5/12/2000	0940	11.2	1980	1985	1985	NP	--	1986	99.7	1989	69.8	mid-1980s	--	--	1989
413543103242401	B34E-D	19N 53W26BBCC1	B	5/12/2000	0900	11.4	1973	1976	1979	NP	--	1981	74.7	1987	55.2	mid-1970s	--	--	1980
413528103233402	B35E-S	19N 53W26DBAA2	A	5/11/2000	1500	11.4	1973	1976	1978	NP	--	1979	89.3	1985	40.4	mid-1970s	--	--	1986
413528103233401	B35E-D	19N 53W26DBAA1	A	5/11/2000	1420	11.5	1977	1983	1984	NP	--	1985	90.2	1989	66.1	early to mid-1980s	--	--	--
413541103224602	B36E-S	19N 53W25BDAB2	A	5/12/2000	1250	11.1	1976	1980	1982	NP	--	1983	92.1	1987	52.1	early 1980s	--	--	1982
413541103224601	B36E-D	19N 53W25BDAB1	B	5/12/2000	1220	10.7	1972	1975	1978	NP	--	1980	73.8	1986	46.0	late 1970s	--	--	1974
414321103550802	1U-S	20N 57W 8BDDA2	A/B	5/22/2000	1510	9.9	1976	1982	1984	NP	--	1985	87.6	1990	72.8	Early 1980s	--	--	--
414321103550801	1U-D	20N 57W 8BDDA1	B	8/22/2000	1100	--	--	--	--	--	--	--	--	--	--	--	--	10,000	--
413556103161903	23J-S	19N 52W25BBBB3	A	5/15/2000	1030	11.7	1966	1970	1972	NP	--	1978	44.5	1987	55.2	late 1960s to early 1970	--	--	1987
413556103161902	23J-M	19N 52W25BBBB2	B	5/15/2000	1000	11.7	1968	1971	1974	NP	--	1979	51.9	1986	48.9	early to mid-1970s	--	--	1978
413556103161901	23J-D	19N 52W25BBBB1	B	5/15/2000	0940	10.3	1956	1955	1955	1961	44.2	NP	--	NP	--	mid-1950s or older	--	--	--
413504103161703	23L-S	19N 52W25CCCC3	A	5/15/2000	1210	10.8	1988	Mod	1990	NP	--	NP	--	1991	80.2	Modern	--	--	Mod
413504103161702	23L-M	19N 50W25CCCC2	A	5/15/2000	1140	9.9	1976	1985	1984	NP	--	1985	92.7	1990	75.9	mid-1980s	--	--	--
413504103161701	23L-D	19N 52W25CCCC1	B	5/15/2000	1120	--	--	--	--	--	--	--	--	--	--	--	--	--	1964
413344103161603	23N-S	18N 52W 1CBBB3	A	5/13/2000	1220	6.2	1986	Con	1988	NP	--	NP	--	1991	78.0	mid- to late 1980s	--	--	Mod

**Table 3.** Apparent age of water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All dates calculated from month and year of collection; USGS, U.S. Geological Survey; ID, identification; fig., figure; AT, aquifer type, B, Brule Formation, FB, Fractured Brule Formation, A, alluvial; A/B, alluvial and Brule Formation; °C, degrees Celsius; CFC, chlorofluorocarbon; SF<sub>6</sub>, sulfur hexafluoride, C, carbon; ybp, years before present; <sup>3</sup>H, tritium; <sup>3</sup>He, helium-3; --, not analyzed or no result; Mod, water is in equilibrium with modern concentrations in the atmosphere; mix, possible mixture of young and old water; Con, contaminated sample; NP, age determination is not possible]

USGS station ID	Field ID (fig. 1)	Legal ID	AT	Date	Time	Re-charge temper- ature (°C)	CFC- 11	CFC- 12	CFC- 113	CFC ratio						Apparent age			
										11/12	% young CFC- 12	113/ 12	% young CFC- 113	113/ 11	% young CFC- 113	CFC	SF <sub>6</sub>	<sup>14</sup> C, ybp	Corrected <sup>3</sup> H/ <sup>3</sup> He age ±1σ
Wells—Continued																			
413344103161602	23N-M	18N 52W 1CBBB2	A	5/13/2000	1400	10.6	1976	1983	1984	NP	--	1985	92.6	1989	69.8	early 1980s	--	--	1986
413344103161601	23N-D	18N 52W 1CBBB1	B	5/13/2000	1310	10.0	1963	1962	1970	1971	32.6	1989	9.9	Mod	84.5	early 1960s; mix	--	--	1964
413305103154901	23O-D	18N 52W12BDAA1	B	8/24/2000	1530	--	--	--	--	--	--	--	--	--	--	--	--	5,600	--
413228103161803	23P-S	18N 52W11DDDD4	FB	5/13/2000	0830	9.6	1980	1986	1986	NP	--	1987	98.2	Mod	84.5	mid-1980s	--	--	1996
413228103161802	23P-M	18N 52W11DDDD3	FB	5/13/2000	1010	11.2	1976	1982	1984	NP	--	1986	84.3	1990	75.9	early 1980s	--	--	1982
413228103161801	23P-D	18N 52W11DDDD2	B	5/13/2000	0940	11.0	1969	1969	1977	1973	55.0	1987	23.6	1989	66.1	late 1960s; mix	--	--	--
413227103170803	23R-S	18N 52W11CDCC3	A	5/12/2000	1410	9.5	1978	1986	1986	NP	--	NP	--	Mod	84.5	mid-1980s	--	--	1992
413227103170802	23R-M	18N 52W11CDCC2	A	5/12/2000	1500	11.4	1976	1981	1983	NP	--	1984	88.1	1989	66.1	early 1980s	--	--	1985
413227103170801	23R-D	18N 52W11CDCC1	B	5/12/2000	1350	--	--	--	--	--	--	--	--	--	--	--	--	--	1972
413555103150903	24I-S	19N 51W19CCCC3	A	5/15/2000	1510	10.8	1976	1980	1983	NP	--	1986	76.5	1990	72.8	late 1970s to early 1980s	--	--	1984
413555103150902	24I-M	19N 51W19CCCC2	FB	5/15/2000	1440	10.5	1966	1970	1970	NP	--	1972	76.8	1982	29.5	late 1960s to early 1970s	--	--	--
413555103150901	24I-D	19N 51W19CCCC1	FB	5/15/2000	1410	10.5	1968	1970	1970	NP	--	1974	62.3	1980	23.0	late 1960s to early 1970s	--	--	1974
413503103145401	24J-S	19N 51W30CCCC1	FB	5/15/2000	1320	10.5	1986	1990	1989	NP	--	NP	--	Mod	84.5	late 1980s to 1990	--	--	1995
413609103140202	24L-S	19N 51W19DADD2	FB	5/16/2000	1050	10.5	1968	1972	1976	NP	--	1980	55.6	1989	66.1	mid-1970s	--	--	--
413503103120003	25I-S	19N 51W29DDDD3	A	5/16/2000	0930	9.4	1982	1987	1986	NP	--	1987	98.2	1990	72.8	mid-1980s	--	--	--
413503103120002	25I-M	19N 51W29DDDD2	A	5/16/2000	0900	9.3	1980	1984	1985	NP	--	1986	94.7	1990	72.8	early to mid-1980s	--	--	--



**Table 3.** Apparent age of water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

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USGS station ID	Field ID (fig. 1)	Legal ID	AT	Date	Time	Re-charge temper- ature (°C)	CFC- 11	CFC- 12	CFC- 113	CFC ratio						Apparent age			
										11/12	% young CFC- 12	113/ 12	% young CFC- 113	113/ 11	% young CFC- 113	CFC	SF <sub>6</sub>	<sup>14</sup> C, ybp	Corrected <sup>3</sup> H/ <sup>3</sup> He age ±1σ
Wells—Continued																			
413503103120001	25I-D	19N 51W29DDDD1	FB	5/16/2000	0840	8.8	1974	1976	1980	NP	--	1984	69.3	1988	58.8	mid-1970s	--	--	--
413411103124703	25J-S	19N 51W33CCCD3	A	5/17/2000	1340	11.2	1972	1975	1979	NP	--	1983	64.6	1989	66.1	mid-1970s	--	--	1985
413502103103703	26K-S	19N 51W27DDDD3	A	5/16/2000	1310	9.3	1978	1984	1986	NP	--	1987	89.0	Mod	84.5	mid-1980s	--	--	--
413502103103702	26K-M	19N 51W27DDDD2	A	5/16/2000	1240	9.6	1973	1976	1981	NP	--	1985	62.9	1989	66.1	mid-1970s; mix	--	--	--
413502103103701	26K-D	19N 51W27DDDD1	FB	5/16/2000	1210	10.1	1974	1977	1980	NP	--	1983	77.0	1988	58.8	mid-1970s	--	--	--
413502103103704	26K-T	19N 51W27DDDD4	FB	5/16/2000	1140	9.4	1976	1980	1982	NP	--	1984	85.7	1987	55.2	early 1980s	--	--	--
413708103055701	28J-S	19N 50W17DADA1	B	8/23/2000	1110	--	--	--	--	--	--	--	--	--	--	--	--	9,300	--
413510103060103	28L-S	19N 50W29DDAA3	A	5/16/2000	1530	9.8	1970	1973	1974	NP	--	1977	70.9	1984	35.4	early 1970s	--	--	--
413510103060102	28L-M	19N 50W29DDAA2	FB	5/16/2000	1500	10.3	1971	1973	1975	NP	--	1977	74.0	1983	31.3	early to mid-1970s	--	--	1973
413510103060101	28L-D	19N 50W29DDAA1	FB	5/16/2000	1430	10.7	1970	1973	1974	NP	--	1976	71.5	1982	27.8	early 1970s	--	--	1973
413510103060104	28L-T	19N 50W29DDAA4	B	5/16/2000	1400	9.3	1950	1944	1955	1970	1.2	NP	--	NP	--	mid-1940s to mid-1950s	--	--	--
413726103023503	29I-S	19N 50W14AAAD3	A	5/17/2000	1550	10.4	1980	1992	1988	NP	--	NP	--	Mod	84.5	late 1980s to early 1990s	--	--	Mod
413726103023502	29I-M	19N 50W14AAAD2	A	5/17/2000	1510	13.5	1975	1977	1981	NP	--	1984	73.6	1987	55.2	mid- to late 1970s; mix	--	--	1981
413726103023501	29I-D	19N 50W14AAAD1	A	5/17/2000	1440	12.5	1971	1972	1974	NP	--	1977	63.7	1979	20.1	early to mid-1970s	--	--	1976

CFC age-dating results indicated that the age of the water in most of the shallowest monitoring wells in the study area was from the early 1980s (fig. 7). This date applies to most of the water samples from monitoring wells along Pumpkin Creek in Banner County. Most of the younger water appears to be nearer the head of Pumpkin Creek Valley and at shallower depths. However, the water sample containing the youngest apparent ground-water age was collected from monitoring well 29I-S, which is close to the mouth of Pumpkin Creek. This monitoring well is close to a surface-water canal. Therefore, the modern apparent age of the ground water likely is a reflection of infiltration of surface water from the canal and not a result of very young ground water. The water sample containing the oldest ground water dated using CFC age-dating techniques was collected from a Brule Formation monitoring well 28L-T with an apparent age of early to mid-1940s. As was seen with most of the CFC-based age dating, the older ground water appeared to be nearer the downgradient end of Pumpkin Creek Valley.

Results of the  $^3\text{H}/^3\text{He}$  sample analyses suggest that much of the ground water in the study area was less than 40 years old and generally supported the results of the CFC data. Although some differences between the CFC date and the  $^3\text{H}/^3\text{He}$  date were greater than 10 years, assuming that the apparent age from the CFC-12 method is correct, the median difference was about 3 years. The  $^3\text{H}/^3\text{He}$  values that were substantially different from the CFC dates could suggest a problem with  $^3\text{He}$  loss because of the domination of diffusive transport in low recharge areas. Solomon and Cook (2000) reported downward advective transport retains the  $^3\text{He}$  concentration in the ground-water system. Therefore, if diffusive instead of advective transport is dominant and assuming a porosity of 30 percent,  $^3\text{He}$  can be transported from the ground water to the interstitial air just above it. Furthermore,  $^3\text{He}$  losses can be less than 20 percent in areas receiving less than 1.2 in/yr recharge if advective transport dominates, but if diffusion dominates,  $^3\text{He}$  losses can be greater than 80 percent in areas receiving less than 0.12 in/yr recharge (Solomon and Cook, 2000). If diffusion dominates and  $^3\text{He}$  is transported to the water table, little information on ground-water age is retained from  $^3\text{He}$  concentrations. Because the NPNRD climate is classified as semiarid, recharge rates would tend to be low and, thus, much of the  $^3\text{He}$  could be lost from diffusion. This would explain some of the discrepancies between the age dates derived from the CFC and  $^3\text{H}/^3\text{He}$  data.

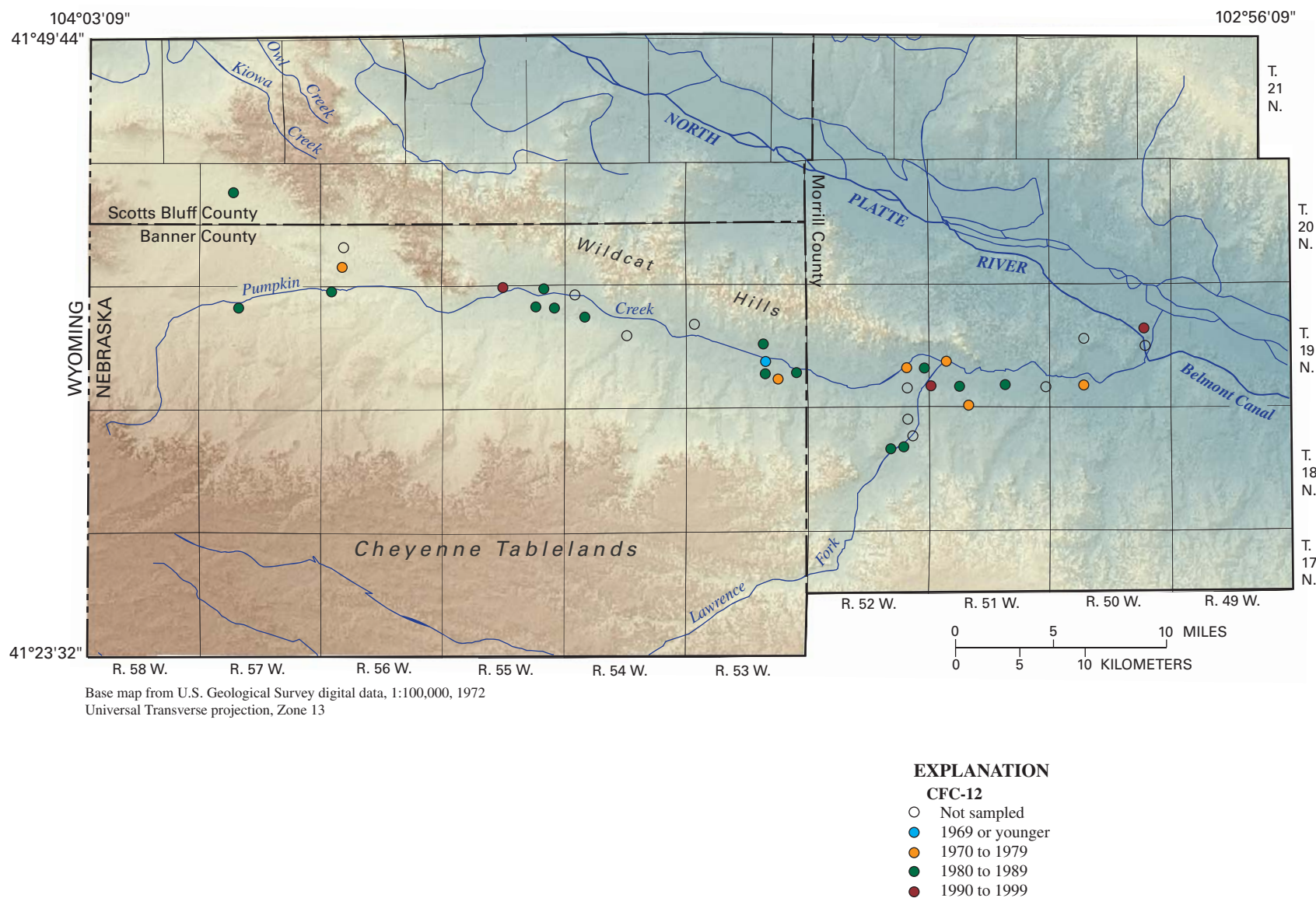
Water samples from the six Brule Formation wells analyzed for  $^{14}\text{C}$  concentrations ranged from 6.1 to 73 pmC and were isotopically light in  $^{13}\text{C}/^{12}\text{C}$  relative to the standard. The  $\delta^{13}\text{C}$  ratios ranged from -10.69 to -7.56 per mil or about 1 percent. Correcting for  $\delta^{13}\text{C}$  gives apparent ages ranging from about 17,000 ybp to present. Except for two samples, the water samples showed apparent ages of either about 5,000 or 10,000 ybp. Therefore, the water in the Brule Formation is substantially older than water in the unconsolidated alluvium or the fractured Brule and probably recharged between 5,000 to 10,000 ybp.

Clark and Fritz (1997) reported that  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  signatures of water are shifted below the LMWL by most meteoric and subsurface processes. In the study area this appeared

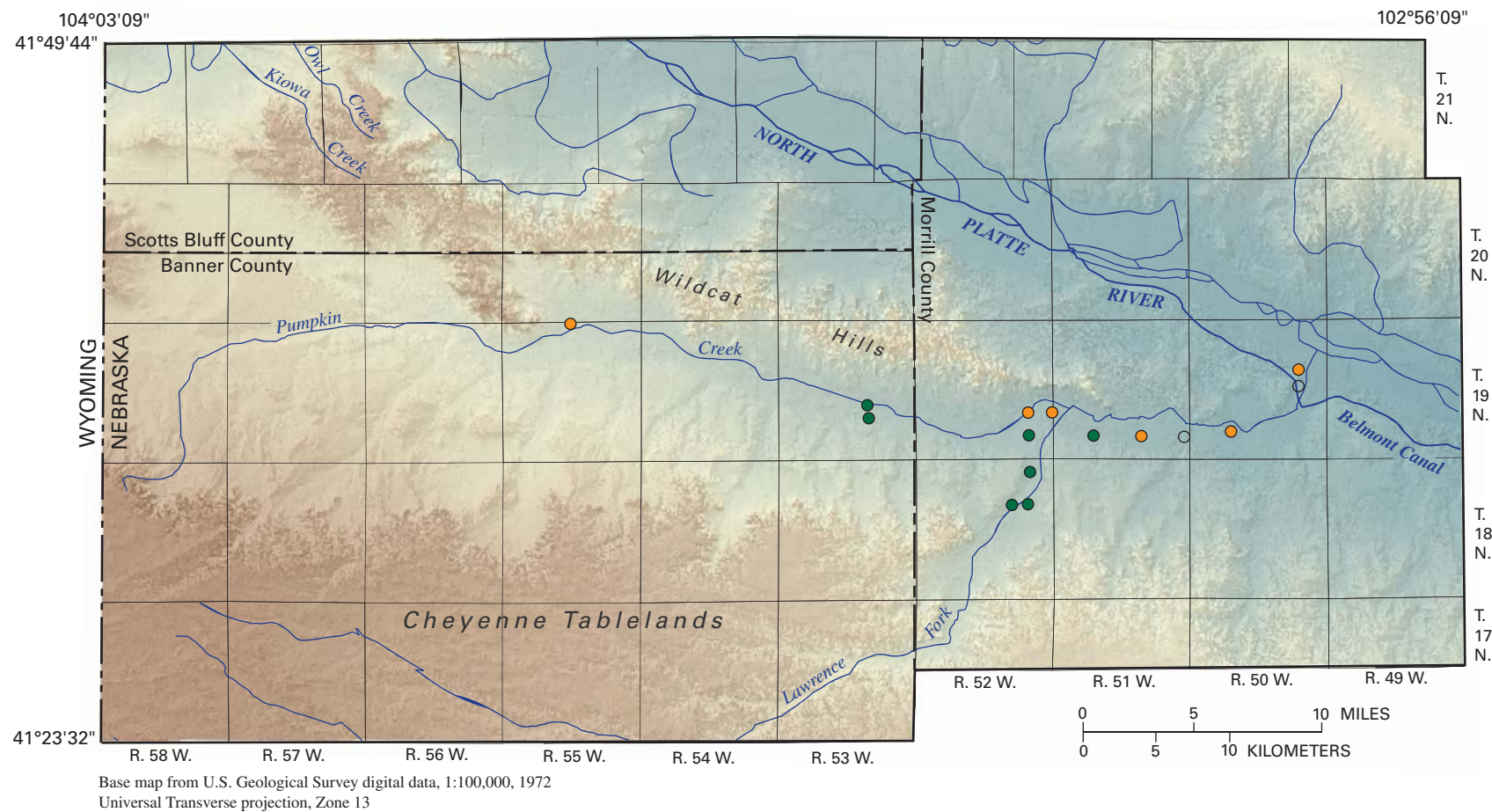
evident in all water samples analyzed for stable isotopes ( $^{18}\text{O}$  and  $^2\text{H}$ ). Results showed that most of these water samples appeared to have undergone secondary refractive processes—such as evaporation—evident from the displacement of the  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  below the LMWL (fig. 8). Most of the ground-water samples collected from monitoring wells in the alluvial and fractured Brule systems were somewhat isotopically heavier than water samples collected from monitoring wells in the Brule Formation. This might suggest warmer overall climatic conditions occurred during the time of recharge to the alluvial and fractured Brule systems compared to the overall climatic conditions during the time of recharge to the Brule Formation.

Evaporative effects on several of the surface-water samples were evident. The largest effect was shown on the sample from the lake whose displacement from the LMWL was 3.78 per mil for  $\delta^{18}\text{O}$  and 28.92 per mil for  $\delta^2\text{H}$  (fig. 8). Other surface-water samples that showed substantial effects of evaporation lie on a line between the ground-water samples and the lake. Generally, these samples were collected in the summer when streamflow was reduced or ponded throughout much of Pumpkin Creek Valley.

Clark and Fritz (1997) reported that there is a strong correlation between temperature and the position  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  data plot on a graph. The lower end of a graph showing  $\delta^2\text{H}$  as a function of  $\delta^{18}\text{O}$  typically is dominated by ground water recharged from precipitation falling during a process that Clark and Fritz (1997) called rainout where the heavier isotope gets distilled from the vapor mass. Data on the lighter end of the graph also is indicative of cooling air masses distant from the oceanic sources. Data values for ground-water samples collected in the study area and analyzed for  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  all are in the isotopically lighter end of the graph (fig. 8). Slight distinctions can be made between water samples collected from monitoring wells in the Brule Formation and water samples collected from monitoring wells in the alluvial and fractured Brule aquifers. Many of the water samples from the Brule Formation were isotopically lighter than those collected from the alluvial and fractured Brule aquifers. This, together with the same apparent ages of most water samples in the Brule Formation, such as 5,000 to 10,000 ybp, suggests that some of the ground water in samples collected from the Brule Formation recharged during a climatic era, such as the early Pliocene, that likely had an isotopic signature different than the modern Holocene signature, which appears in the alluvial and fractured Brule water samples. With respect to evaporation, many of the ground-water-data points fall below the LMWL and are grouped together in a cluster. This clustering effect likely results from some of the ground water undergoing evaporation. Otherwise, most of the data would fall in a more linear pattern paralleling the LMWL. However, unlike the shift from the LMWL that was seen in data from the lake and some of the stream sites, none of the ground-water data showed the same magnitude of evaporation (fig. 8) as these surface-water data. Together, the physical (water-level) and chemical (isotopic) data indicate that ground-water discharges to Pumpkin Creek, creating a gaining stream.



**Figure 7a.** Age distribution of ground water in the study area, by depth—shallow wells.



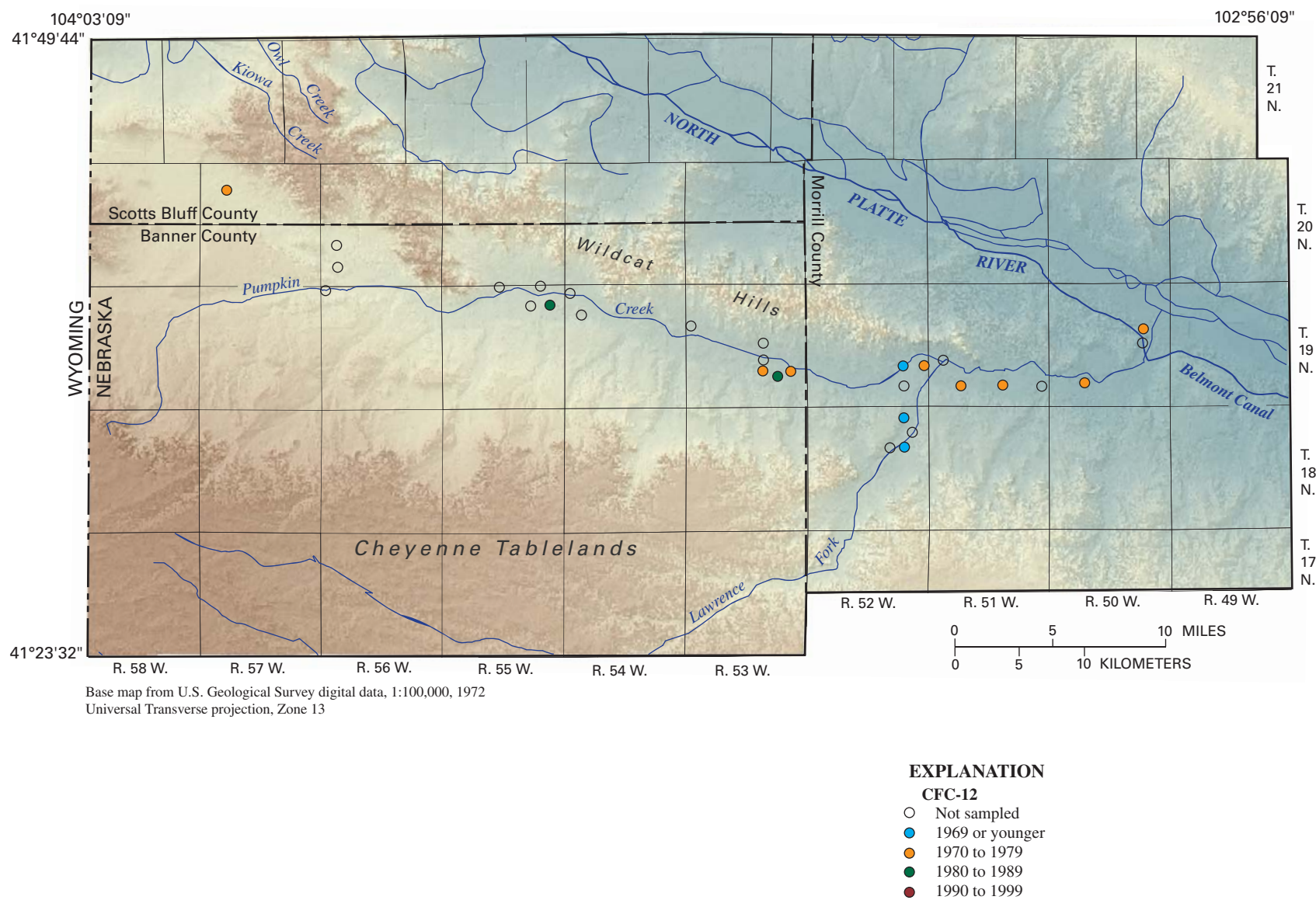
#### EXPLANATION

##### CFC-12

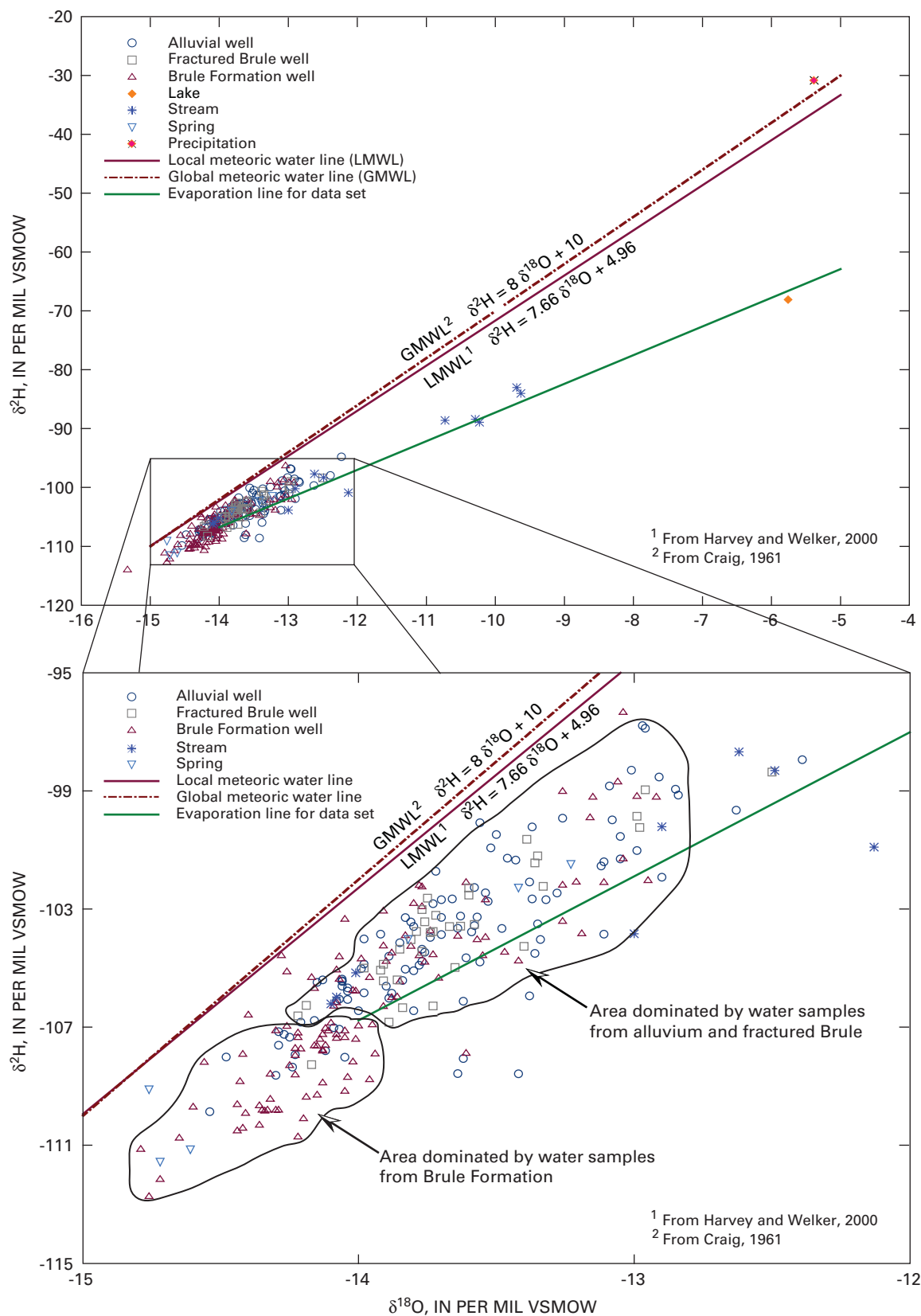
- Not sampled
- 1969 or younger
- 1970 to 1979
- 1980 to 1989
- 1990 to 1999

**Figure 7b.** Age distribution of ground water in the study area, by depth—intermediate-depth wells.





**Figure 7c.** Age distribution of ground water in the study area, by depth—deep wells.



**Figure 8.** Oxygen ( $\delta^{18}\text{O}$ ) and stable hydrogen ( $\delta^2\text{H}$ ) composition of water samples from the study area (VSMOW=Vienna Standard Mean Oceanic Water).

Water that entered the study area as precipitation in the upper reaches of Pumpkin Creek Valley eventually moved downgradient toward the confluence of Pumpkin Creek and the North Platte River. As the water moved down valley, locally some of it was captured by irrigation wells that are prevalent throughout the valley. That water captured by irrigation wells then was re-introduced to the dry air where evaporative processes can fractionate it further. Much of the refractionated water that was not evaporated completely or used by the plants eventually reentered the ground water. After the water reentered the ground-water system, it continued to move downgradient where it could be recaptured by another irrigation well; thus the process of fractionation by evaporation could once again occur. As a result, some of the ground water in the study area that moved downgradient for long distances (such as from the upper reaches of Pumpkin Creek Valley to the North Platte River Valley) became isotopically heavier.

The effect of evaporation and fractionation from irrigation can be seen by comparing of  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  in water samples collected at clustered monitoring wells adjacent to or distant from irrigated fields. At sites where water samples were collected from multiple monitoring wells, water samples from the deepest monitoring wells typically were isotopically lighter than water samples from the shallower monitoring wells (table 8, appendix). In contrast, data from five clustered monitoring well sites (B13A, B13B, B23D, B24E, and B35E), which were not adjacent to irrigated cropland, indicated that the samples from the shallower monitoring wells were isotopically lighter than water samples from the deeper monitoring wells. Results from the two monitoring-well sites that lie in close proximity to center pivot irrigated lands (B24E and B35E) both showed less differentiation in isotopic ratios between the deeper and shallower water samples. This suggests that ground water underlying or adjacent to irrigated fields appears to have been subjected to refractionation as evidenced by the shallowest ground water showing the effects of evaporation, whereas these effects are not present at locations farthest from irrigated fields.

## Water Quality

Analysis of the water-quality data in samples from Pumpkin Creek shows that the water type changes from a sodium calcium bicarbonate type near the headwaters to a calcium sodium bicarbonate type near the mouth of Pumpkin Creek. Data from the lake sample suggest that it was similar to the water found in the upper reaches of Pumpkin Creek—predominantly a sodium calcium bicarbonate chloride type. However, results from Lawrence Fork and the two springs showed that they are a calcium bicarbonate to a calcium magnesium bicarbonate type. The calcium bicarbonate type water found in Lawrence Fork and in the spring at Olsen Ranch was very similar to the water type found in Pumpkin Creek downstream from these locations. This suggests that water in Lawrence Fork, which becomes subterranean before it reaches Pumpkin Creek, likely helps influence the water type of

Pumpkin Creek Valley downstream from the virtual confluence of Lawrence Fork and Pumpkin Creek.

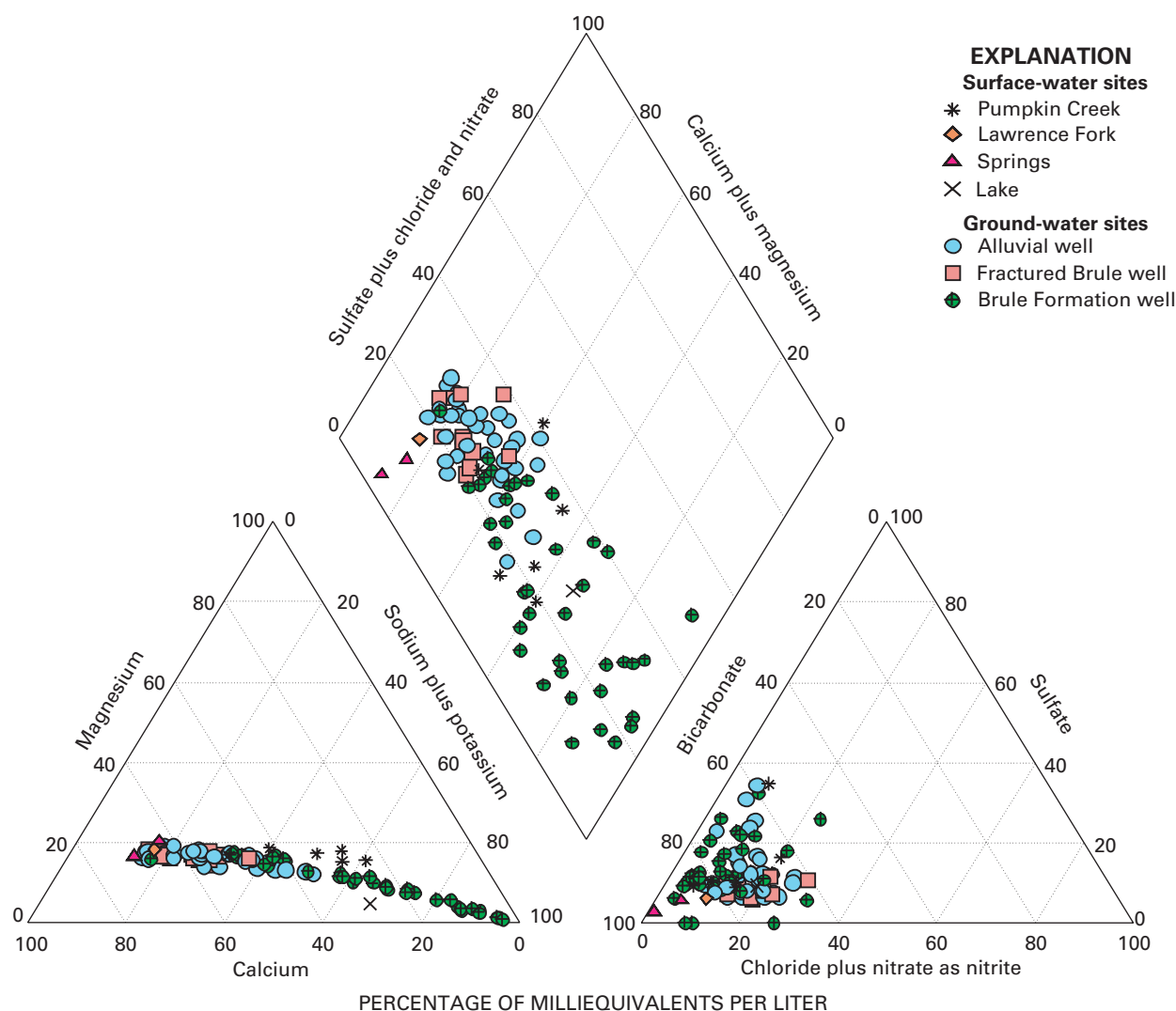
Analysis of ground-water samples collected in Pumpkin Creek Valley suggests that two of the three ground-water systems were similar in water type. The alluvial and the fractured Brule aquifers were predominantly a calcium sodium bicarbonate type, whereas water in the Brule Formation was predominantly a sodium calcium bicarbonate type (fig. 9). In addition, the water type in the alluvial and fractured Brule aquifers are similar to the water type found in the downstream reaches of Pumpkin Creek.

Analysis of water-quality data suggests that concentrations of calcium and sodium in surface-water and ground-water samples were variable (table 7, appendix). Water samples from the surface-water, alluvial, and fractured Brule sites all had larger median calcium concentrations than water samples collected from the Brule Formation (fig. 10). However, water samples collected from sites in the Brule Formation had larger sodium concentrations than water samples collected from the surface water, alluvial, and fractured Brule sites.

The differences in median concentration of calcium in water samples collected from the surface water and three ground-water systems were significant for all comparisons except the alluvial aquifer compared with the fractured Brule ( $p$ -value = 0.5826) (table 4). The differences in median concentration of sodium in water samples were significant only for the Brule Formation compared with the alluvial aquifer, the Brule Formation compared with the surface water, and the Brule Formation compared with the fractured Brule (all  $p$ -values less than 0.0264) (table 4). The higher sodium concentration in the Brule Formation could be related to ion exchange with calcium in clays. Sodium concentrations in water samples collected from the surface water, alluvial, and fractured Brule systems were not significantly different. This suggests that these waters likely interacted or intermixed with one another.

Sodium concentrations that exceeded 100 mg/L, and most that exceeded 60 mg/L, occurred in water samples collected from the Brule Formation (table 7). Also, most of the wells exceeding 100 ft in depth were open to the Brule Formation. Analysis of these samples also indicated that except for one sample at monitoring well 28J-S, all of the samples with sodium concentrations that exceeded 120 mg/L were located in Banner County, which is upstream of the confluence of Pumpkin Creek and Lawrence Fork. The lower end of the Wildcat Hills, where monitoring well 28J-S is located, is predominantly Brule Formation and large sources of calcium are absent.

The oldest ground-water samples and the largest concentrations of sodium were associated with most of the wells that were open to the Brule Formation. This suggests that calcium exchange likely occurred in the Brule Formation and sodium has replaced calcium as the predominant ion in the clays of the Brule Formation. This also suggests that water in the shallowest aquifers of Pumpkin Creek (alluvial and fractured Brule) is not moving downward into the Brule Formation and that there is a relatively poor hydraulic connection between these shallowest aquifers and the Brule Formation.



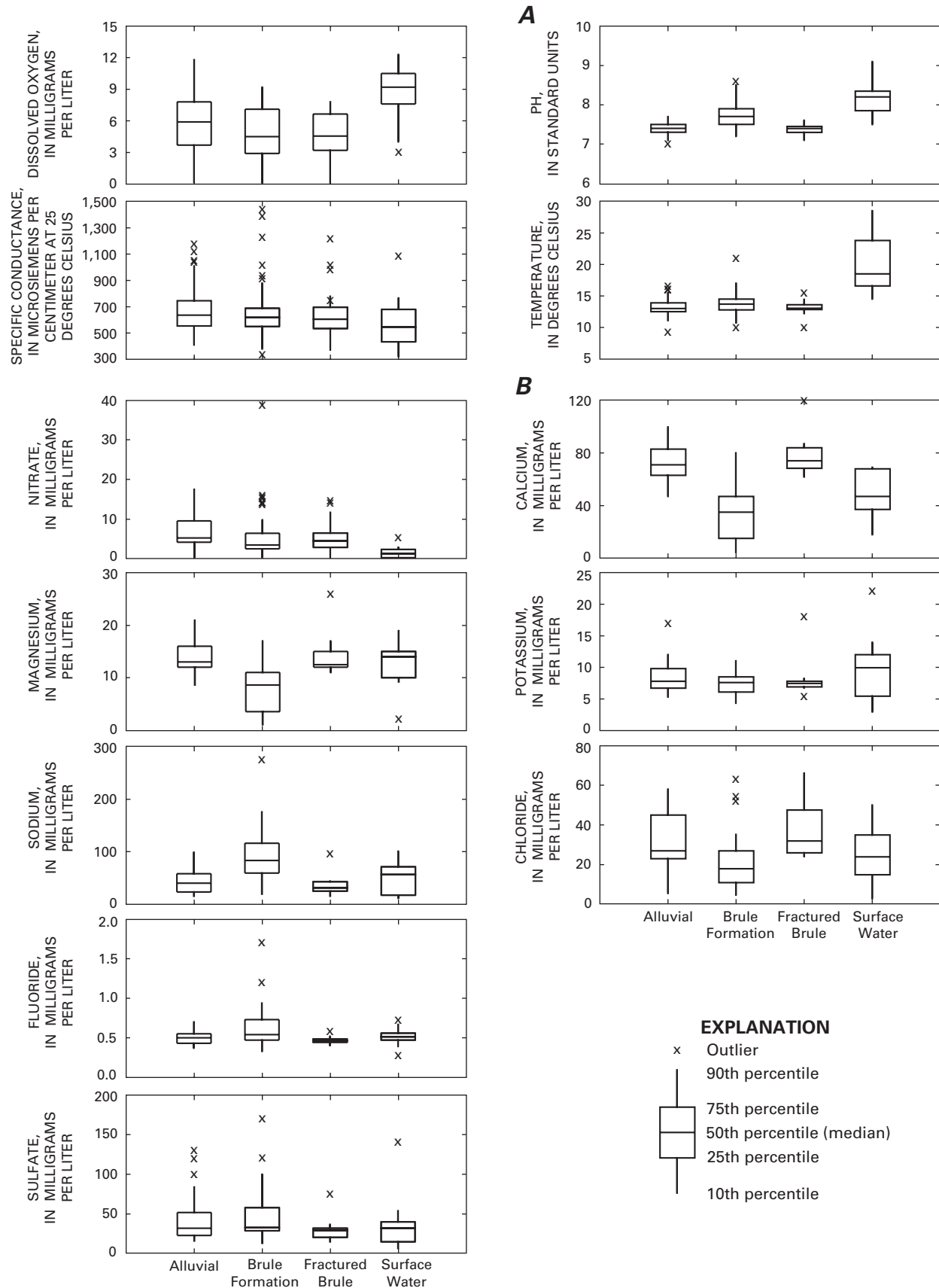
**Figure 9.** Ionic composition of surface water and ground water in the study area.

**Table 4.** Significance of differences in median concentrations in the alluvial and fractured Brule aquifers, Brule Formation, and the surface water in Pumpkin Creek Valley, western Nebraska, 2000.

[ $\alpha$  equals 0.05; vs., versus; colored cells indicate no significant difference can be inferred]

Constituent	p-value					
	Alluvial aquifer vs. surface water	Alluvial aquifer vs. fractured Brule	Fractured Brule vs. surface water	Brule Formation vs. surface water	Brule Formation vs. alluvial aquifer	Brule Formation vs. fractured Brule
Calcium	0.0007	0.5826	0.0021	0.0272	0.0000	0.0000
Sodium	.4445	.4640	.2759	.0264	.0000	.0000
Nitrate as N	.0000	.0270	.0000	.0000	.0000	.2736





**Figure 10.** Boxplots showing distribution of (A) physical properties and (B) water-quality constituents in the study area, by source.

In contrast, monitoring wells whose samples had the largest sodium concentrations generally had the smallest chloride concentrations (table 7). Except for one sample (B13B-D), the largest chloride concentrations typically were found in monitoring wells open to the alluvium and less than 50 ft in depth. Ground-water samples from monitoring well B13B-D were high in both chloride and sodium. The reason for this is could not be determined with existing data. However, B13B-D also contained the largest concentrations of total dissolved solids (table 7).

Samples collected for QC analysis indicated that blank samples were generally clean and ground-water environmental samples typically were similar to the replicate samples (mean of 0 percent). One environmental ground-water sample collected for orthophosphate analysis varied as much as 12 percent (0.07 to 0.08 mg/L) from the replicate sample. However with very small concentrations such as this, the variance was not determined to be significant. Another environmental ground-water sample for potassium varied from the replicate by about 29 percent (18 mg/L to 14 mg/L). No determination could be made as to the reason for this variance. All other environmental ground-water samples were within 5 percent of the replicate samples. Samples collected for QC analysis of ground-water cleaning techniques used in the study indicate that the blank samples were generally clean, although one ground-water sample contained a silica concentration of 2.8 mg/L. No determination could be made as to the reason for this detection, but subsequent analyses indicated silica concentrations less than or near the USGS NWQL reporting limit of 0.1 mg/L.

## Spatial Distribution of Nitrate

In the environment, nitrogen is biologically labile and can be easily assimilated, nitrified, or denitrified. Therefore, "nitrate is perhaps the most widespread contaminant of ground water" (Hallberg and Keeney, 1993, p. 297). Because  $\text{NO}_3$  is ubiquitous in the environment, and easily soluble and mobile,  $\text{NO}_3$  is easily transported through the soil and into the ground water (Hallberg and Keeney, 1993).

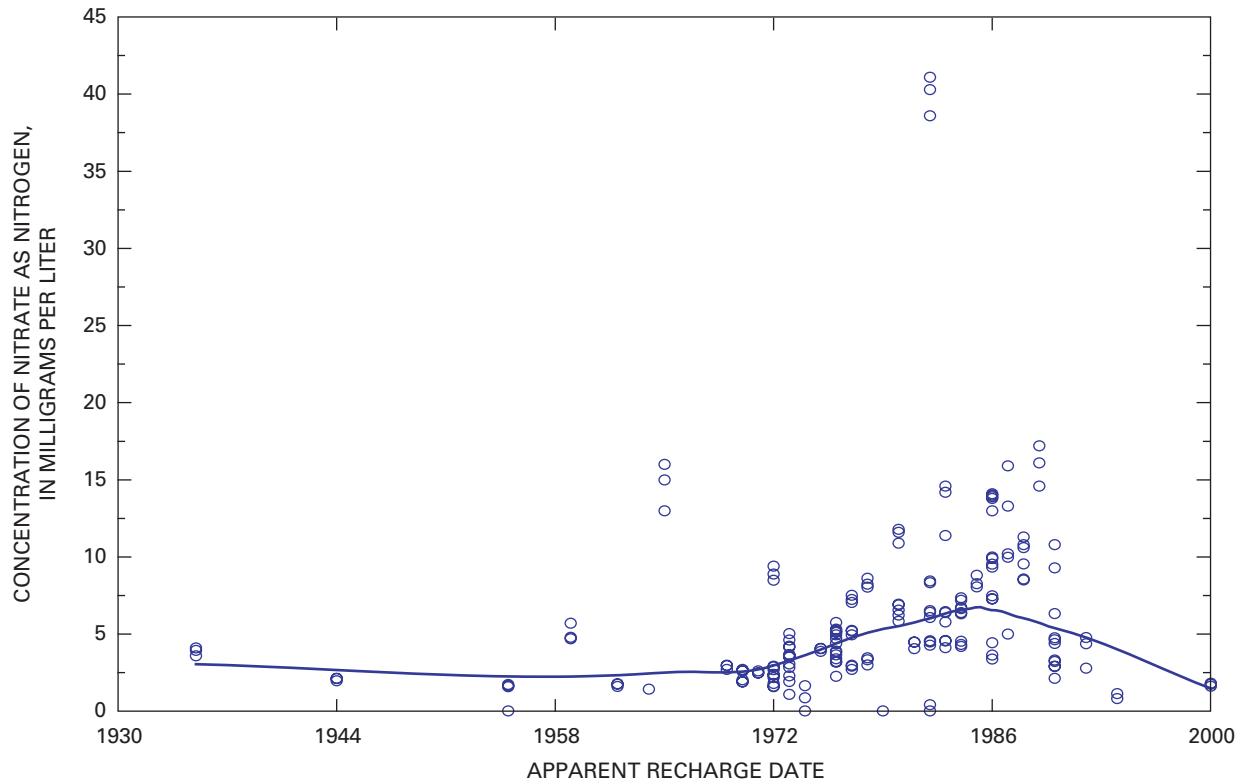
Nitrate forms in the soil and not on the surface. As a result, high  $\text{NO}_3$  fluxes in streams that drain agricultural land primarily are derived from ground-water inflow and not overland runoff. Denitrification may occur in the same soil as  $\text{NO}_3$  formation, but under differing soil-moisture conditions (Hallberg and Keeney, 1993). If the soil becomes saturated, anaerobic conditions can occur. However, when the soil drains, oxygenated conditions can return with nitrification. Denitrification also can occur in young alluvial sediment that contains substantial amounts of organic matter. Addy and others (1999), Gold and

others (1998), and Jacinthe and others (1998) reported that patches or hotspots of organic matter are critical for ground-water denitrification. Moreover, denitrification in patches occurred more readily in poorly drained soil than in moderately well drained soil. Jacinthe and others (1998) reported that for their study biological activity occurred most frequently in patchy areas of decomposing roots. They further suggested that patchy areas provide significantly ( $p$ -value less than 0.05) more stimulation for the removal of  $\text{NO}_3$  than surface-derived dissolved-organic carbon. Older alluvial sediment or sediment that is moderately well drained can contain little organic matter or patchy areas and, consequently, be well oxidized.

Analysis of  $\text{NO}_3$  data as a function of ground-water age shows that  $\text{NO}_3$  concentrations were largest in the younger ground water (fig. 11). Between about 1970 and 1987  $\text{NO}_3$  concentrations increased at a nearly linear rate (fig. 11), which also coincides with the predominant ground-water age in the valley. In samples of ground water age-dated between 1987 and present,  $\text{NO}_3$  concentrations were lower. However, this probably reflects the smaller sample size (not many samples having apparent age between 1987 and present) and not necessarily a decreased use of commercial fertilizer.

With respect to median  $\text{NO}_3$  concentrations in flow systems, the largest was detected in the alluvial system with a median  $\text{NO}_3$  concentration of 5 mg/L and the smallest was detected in the surface-water system with a median  $\text{NO}_3$  concentration of 1 mg/L (table 5). Differences between the median  $\text{NO}_3$  concentrations of all four systems (surface water, alluvial, fractured Brule, and Brule Formation) were analyzed and results are presented in table 4. The results of the Mann-Whitney rank-sum test of the median  $\text{NO}_3$  concentrations showed that the only contrast for which a significant difference could not be inferred was between the Brule Formation and the fractured Brule.

The largest  $\text{NO}_3$  concentration observed (41 mg/L) occurred in a water sample from a monitoring well in the Brule Formation (tables 5 and 8). However, the age of the water sample from this well dated only to the early 1980s. Therefore, the Brule Formation at this site likely contains fractures that were too small to be detected during drilling and that permitted mixing of younger water with typically less contaminated Brule Formation water. Excluding samples from this well, the largest  $\text{NO}_3$  concentration in the study area (17 mg/L) occurred in a water sample from a monitoring well in the alluvial aquifer (table 5).



**Figure 11.** Nitrate concentration as a function of apparent recharge date.

The relation of  $\text{NO}_3$  concentrations to depth of screen was not comprehensively examined because of the variance in thickness of alluvium at the monitoring wells. For example, some of the monitoring wells in the Brule Formation were less than 50 ft deep, but because the Brule Formation is completely different than the alluvium with respect to geologic and geochemical character medium, they would not correlate well with most of the shallower alluvial monitoring wells. Rather, most of the discussion focuses on the relations between  $\text{NO}_3$  concentration and the hydrogeologic deposit. However, with respect to depth of the open interval of the monitoring well and without regard to aquifer type, the largest  $\text{NO}_3$  concentrations occurred in monitoring wells that were open from 25 to 50 ft below land surface.

Nitrate concentrations in the alluvial aquifer had the greatest overall variance between the 25<sup>th</sup> and 75<sup>th</sup> quartiles (table 5). Nitrate concentrations in ground-water samples from the fractured Brule and Brule Formations had similar 25<sup>th</sup> and 75<sup>th</sup> quartiles.

The largest  $\text{NO}_3$  concentrations appear to be associated with monitoring wells that were adjacent to irrigated fields. Most of the  $\text{NO}_3$  concentrations exceeding the USEPA MCL of 10 mg/L were in areas associated with ground-water irrigation, and where the alluvial sediment is less than 50 ft thick. These areas, most of which are in Banner County, lie adjacent to areas that have large tracts of land used for row-crop production. Substantial row-crop production also is associated with areas where  $\text{NO}_3$  concentrations in water samples were lower than the 10 mg/L MCL, but larger than 5 mg/L.

Nitrate concentrations in ground-water samples were detected in areas that were adjacent to land used for the production of row crops or livestock. The largest  $\text{NO}_3$  concentrations were associated with areas where alluvial sediment was less than 50 ft thick and ground water was used extensively for irrigation. This indicates that nitrogen applied to the fields for crop production was mobilized and subsequently transported to the ground water by irrigation water.

**Table 5.** Summary statistics for concentrations of major ions and nitrate in water samples from surface water, the alluvial and fractured Brule aquifers, and the Brule Formation in Pumpkin Creek Valley, western Nebraska, 2000.

[All units in milligrams per liter unless otherwise indicated; CaCO<sub>3</sub>, carbonate; N, nitrogen; µg/L, micrograms per liter; Min, minimum; %, percent; Med, median (50<sup>th</sup> percentile); Max, maximum; <, less than the minimum reporting level]

Hydrologic system	Quartile	Calcium	Magnesium	Sodium	Potassium	Alkalinity as CaCO <sub>3</sub>	Sulfate	Chlorine	Fluoride	Silicate	Total dissolved solids	Nitrate as N	Iron, in µg/L	Manganese, in µg/L
Surface water	Min	18	2	11	2.9	130	6.7	2.9	0.3	2.7	208	<0.05	<10	3
	25%	38	10	23	6.5	220	15	16	.5	16	310	<.05	<10	3
	Med	47	14	56	10	240	32	24	.5	28	381	1	20	7
	75%	68	15	70	12	280	39	33	.6	48	431	2	30	10
	Max	69	19	100	22	320	140	50	.7	55	513	5.4	90	63
Alluvial aquifer	Min	47	8.6	15	5.3	160	16	5.7	.4	44	312	<.05	<10	<2.2
	25%	64	12	24	6.8	200	23	23	.4	55	376	3.9	<10	<2.2
	Med	71	13	40	7.8	230	32	27	.5	56	428	5	<10	<2.2
	75%	82	16	57	9.4	250	50	44	.5	59	493	9.2	<10	<2.2
	Max	100	21	99	17	370	130	58	.7	65	671	17	<10	260
Fractured Brule aquifer	Min	62	11	15	5.4	190	15	24	.4	43	344	<.05	<10	<2.2
	25%	69	12	25	7	210	22	26	.4	55	370	2.6	<10	<2.2
	Med	74	12	31	7.4	220	30	32	.5	57	401	4.2	<10	<2.2
	75%	84	15	42	7.8	240	32	47	.5	58	431	6	<10	<2.2
	Max	120	26	96	18	440	74	94	.6	65	741	15	410	690
Brule Formation	Min	4.5	1	19	4.3	160	13	4.7	.3	54	304	<.05	<10	<2.2
	25%	16	4	60	6.4	200	29	12	.5	60	389	2.3	<10	<2.2
	Med	35	8.6	83	7.6	230	33	18	.5	63	427	3.2	<10	<2.2
	75%	47	11	120	8.4	260	60	26	.7	67	469	6.1	<10	<2.2
	Max	80	17	280	11	340	170	110	1.7	71	851	41	1,100	510

## Temporal Distribution of Nitrate

Temporal series of  $\text{NO}_3$  concentrations were investigated to determine if there were any significant changes in concentrations, those over the course of the summer, and if so, where the changes occurred. Surface-water and ground-water sites that had at least two samples collected during the three sampling periods were investigated using two-sided Wilcoxon signed-rank tests.

The Wilcoxon signed-rank test results indicated that there were significant changes in  $\text{NO}_3$  concentrations for some of the site types sampled. For all samples (surface water and ground water combined) significant changes in  $\text{NO}_3$  concentrations were found between all three sample periods; May to July (p-value = 0.025), May to August (p-value < 0.0001), and July to August (p-value < 0.0001). With respect to just the surface-water system, a significant change in  $\text{NO}_3$  concentrations in water samples collected between May and August (p-values ranged from 0.371 to 1.000) could not be concluded. Nitrate concentrations in water samples collected from the alluvial monitoring wells were significantly different between the May and July sample periods (p-value = 0.021) and the July and August sample periods (p-value = 0.006). Nitrate concentrations in alluvial water samples from May and August were not significantly different. Water samples collected from the fractured Brule monitoring wells had  $\text{NO}_3$  concentrations from May to August that did not change significantly (p-values

ranged from 0.065 to 0.937). Nitrate concentrations in water samples collected from Brule Formation monitoring wells were significantly different between the May and August sample periods (p-value < 0.0001) and the July and August sample periods (p-value < 0.0001). However, a significant change in  $\text{NO}_3$  concentration in water samples collected from the Brule Formation monitoring wells between May and July could not be concluded (p-value = 0.387).

## Sources of Nitrogen

Nitrogen species analyzed for during this study include  $\text{NO}_3$ ,  $\text{NO}_2^-$ ,  $\text{NH}_4^+$ ,  $\text{NH}_3$ ,  $\text{NH}_4^+$ ,  $^{15}\text{N}/^{14}\text{N}$  (herein the ratio is expressed as  $\delta^{15}\text{N}$ ), and nitrogen gas. The most important nutrient in ground-water systems typically is  $\text{NO}_3$  because of its potential effects on human health, as well as its solubility and stability in oxic ground water. Therefore, this report focuses on the occurrence of  $\text{NO}_3$ . The source of the nitrogen was determined by analysis of the nitrogen isotope data.

Sources of nitrogen in the ground water of the study area can be classified as occurring naturally (soil and precipitation) or unnaturally (commercial fertilizer and animal waste) (fig. 12). Most of the  $\delta^{15}\text{N}$  in water samples collected in the study area show  $\text{NO}_3$  likely derived from the use of commercial fertilizers (fig. 12), although some of the  $\delta^{15}\text{N}$  values that are

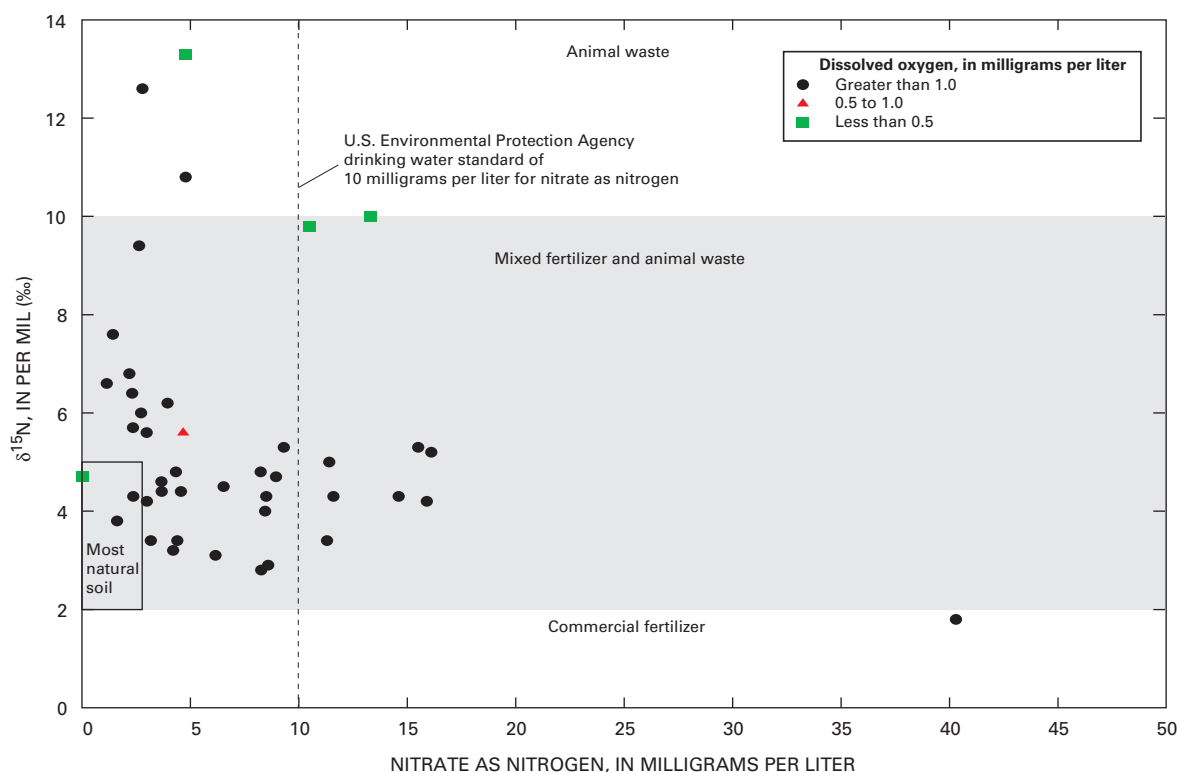


Figure 12.  $\delta^{15}\text{N}$  as a function of nitrate concentration.

less than 5 per mil might also be associated with background sources. For this report a mixture of animal waste and fertilizer as the most likely source of  $\text{NO}_3$  was assumed when the  $\delta^{15}\text{N}$  value was between 2 and 10 per mil and  $\text{NO}_3$  concentration was above 2 mg/L. Nitrogen isotopes with a  $\delta^{15}\text{N}$  value greater than +10 per mil were considered to have originated from livestock waste. Nitrogen isotopes with a  $\delta^{15}\text{N}$  value less than +2 per mil were considered to have originated from commercial fertilizer.

The water sample with the largest  $\text{NO}_3$  concentration also showed one of the smallest (less than 2 per mil)  $\delta^{15}\text{N}$  values. This suggests that the largest  $\text{NO}_3$  concentration likely was derived from commercial fertilizer. In contrast, ground-water samples with some of the smallest  $\text{NO}_3$  concentrations also contained some of the largest (greater than 10 per mil)  $\delta^{15}\text{N}$  values, which suggests animal waste as the likely source.

Very small concentrations of dissolved oxygen (less than 0.5 mg/L) can indicate denitrification processes have occurred. Denitrification can cause a smaller  $\delta^{15}\text{N}$  value (less than 5 per mil) to become larger (greater than 10 per mil). This, in turn, could create an appearance that the smaller  $\delta^{15}\text{N}$  value originated from animal waste when instead defractionation of  $\delta^{15}\text{N}$  caused the increase. Therefore, the source of nitrogen in the water samples that contained the largest  $\delta^{15}\text{N}$  values (9.8 and 10 per mil at monitoring well B34C-M, and 13 per mil at B34D-S) and a very small dissolved-oxygen concentration (0.10 mg/L) might not be animal waste. To test this possibility, the original  $\delta^{15}\text{N}$  values from the three water samples were estimated using the Rayleigh's equation (1896). Using estimates of the original  $\text{NO}_3$  concentration as 10 mg/L and 15 mg/L, and an enrichment factors as -8.1 and -4.1 resulted in estimates shown in table 6. These estimates suggest that if initial  $\text{NO}_3$  concentrations in water samples from monitoring wells B34C-M and B34D-S were large (15 mg/L) and the enrichment factor was -8.1, then the source of  $\text{NO}_3$  in these water samples likely was a mixture of commercial fertilizer and animal waste. However, if the same initial  $\text{NO}_3$  concentrations existed, but the enrichment factor was -4.1, then the source of the nitrogen in these water samples likely was animal waste. This argument is only

valid for the estimates used. Because initial  $\text{NO}_3$  concentrations and  $\delta^{15}\text{N}$  values were not known, the source of the  $\text{NO}_3$  could not be verified using this method with existing data.

As mentioned previously,  $\text{NH}_4^+$  is irreversibly oxidized to  $\text{NO}_3$ . Some water samples collected from monitoring well B34C-S indicated the presence of  $\text{NH}_4^+$  (table 8). Thus denitrification at this site would not have contributed to the large  $\delta^{15}\text{N}$  values. Therefore, the source of the nitrates at monitoring well B34C-S likely was animal waste and not commercial fertilizer.

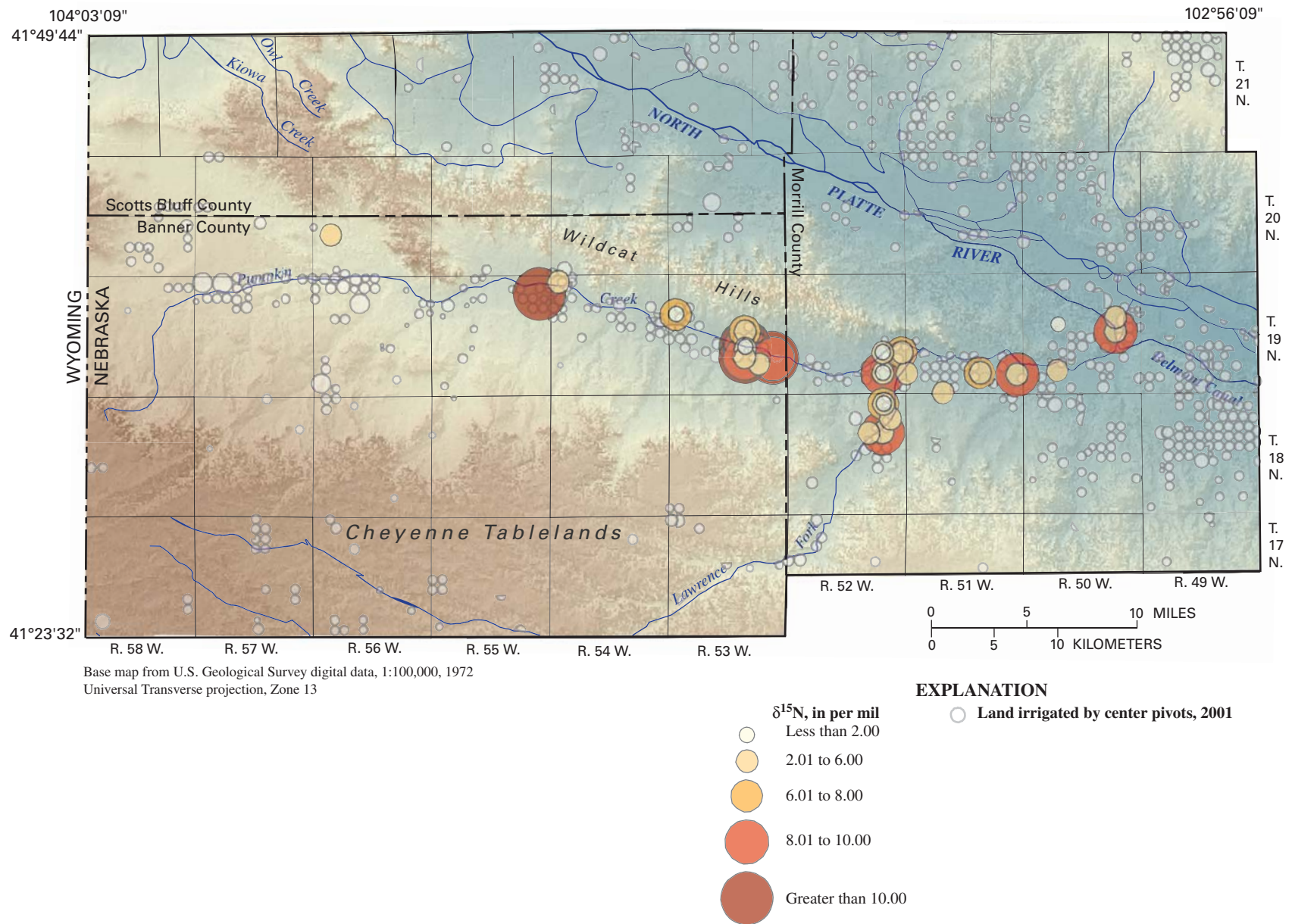
Similar to water samples from monitoring well B34C-M,  $\delta^{15}\text{N}$  values in water samples from monitoring well 29I-S (2 samples) also exceeded 10 per mil. Water samples from monitoring well 29I-S probably originated from animal waste because the  $\delta^{15}\text{N}$  values were large and the dissolved-oxygen concentrations were greater than 2 mg/L, indicating that denitrification was negligible. The  $\delta^{15}\text{N}$  value in the water sample from Pumpkin Creek near Bridgeport also may indicate a source from animal waste because: (1) high  $\delta^{15}\text{N}$  values (9.4 per mil) were coupled with high dissolved-oxygen values, (2) it is directly downstream from monitoring well 29I-S, and (3) Pumpkin Creek has been shown to be a gaining stream.

Analysis of the other  $\delta^{15}\text{N}$  data indicates that the source of most of the nitrogen found in water samples could be classified as a mixture of animal waste and commercial fertilizer. Most of these data (28 of 43 samples or 65 percent) had  $\delta^{15}\text{N}$  values less than 6 per mil (fig. 12), but  $\text{NO}_3$  concentrations greater than 3 mg/L. The specific source of nitrogen could not be confidently identified with the existing data. The source of the  $\text{NO}_3$  in the 10 water samples that had concentrations at or above the 10 mg/L MCL and where nitrogen isotopes were collected and analyzed was probably commercial fertilizers. Nitrate in samples with concentrations above the 10 mg/L MCL, but with  $\delta^{15}\text{N}$  values close to 10 per mil, could not be assumed to have originated from commercial fertilizer. However, it is likely that with a high  $\delta^{15}\text{N}$  value it could have originated from animal waste. The areal distribution of nitrogen isotope values in the study area indicates that possible local sources of animal waste exist (fig. 13).

**Table 6.** Results of denitrification analysis using Rayleigh equation for samples having  $\delta^{15}\text{N}$  values greater than 10 per mil and dissolved-oxygen concentrations less than 0.5 milligrams per liter.

[ID, identification; fig., figure; mg/L, milligrams per liter;  $\delta\text{R}$ , measured nitrogen-15 value of water sample, in per mil;  $\delta\text{R}_0$ , estimated initial nitrogen-15 value, in per mil;  $\delta^{15}\text{N}$ , delta nitrogen-15;  $\epsilon$ , enrichment factor]

Field ID (fig. 1)	Measured nitrate value (mg/L)	$\delta\text{R}$		$\delta\text{R}_0$			
		Measured $\delta^{15}\text{N}$ value (per mil)	nitrate = 10 mg/L		nitrate = 15 mg/L		
			$\epsilon = -8.1$	$\epsilon = -4.1$	$\epsilon = -8.1$	$\epsilon = -4.1$	
B34C-M	14.0	10	12	11	9	9.6	
B34C-M	10	9.8	10	10	6.9	8.3	
B34D-S	4.8	13	7.4	10	4.1	8.6	



**Figure 13.** Nitrogen isotope distribution in the study area.



## Summary

Ground water is the source of drinking water for the residents of Pumpkin Creek Valley. During the last 10 years, ground-water levels in the North Platte Natural Resources District have declined severely and contamination of this resource a major problem for the district. In 2000, the USGS and the North Platte Natural Resources District began a cooperative study to determine the age and quality of the ground water and the sources of nitrogen in the surficial aquifers in Pumpkin Creek Valley, western Nebraska. The study area encompasses all of Pumpkin Creek Valley from the Nebraska-Wyoming border east to the confluence of Pumpkin Creek with the North Platte River near Bridgeport. The Wildcat Hills form the northern border and the south table escarpment of the Cheyenne Tablelands is the southern border of Pumpkin Creek Valley.

Agriculture is the primary land use of the study area, and the land cover varies from rangeland and irrigated cropland in the valley to forests in the upland areas overlooking the valley. In Pumpkin Creek Valley the primary land cover is rangeland, secondary land cover is a combination of dry and irrigated cropland, the percentage of which increases from west to east.

Pumpkin Creek typically has larger flows in the spring months and smaller flows during the summer months. During water year 2000, the daily mean discharge for Pumpkin Creek near Bridgeport was 7.71 ft<sup>3</sup>/s. The surficial ground-water resources in the study area are limited to two geologic units; the Quaternary-age alluvial material found along Pumpkin Creek and its tributaries, and the fractured Tertiary-age Brule Formation of the White River Group. Wells in the fractured Brule aquifer can yield large quantities of water (over 1,000 gal/min) with little drawdown. The most important aquifer in the study area is the alluvial aquifer composed of Quaternary-age coarse sand and gravel deposits along Pumpkin Creek and its tributaries. These deposits are generally continuous and have a maximum saturated thickness of about 50 ft in the eastern part of the study area. Ground-water flow generally moves in a southwesterly to northeasterly direction before it turns and parallels Pumpkin Creek near the north side of the valley.

During the study, temporal surface-water and ground-water data were collected from 8 surface-water sites, 2 springs, and 88 ground-water sites in May, July, and August 2000. Ground-water samples were collected from a series of monitoring wells installed by the North Platte Natural Resources District and the University of Nebraska Conservation and Survey Division and screened in the alluvial or fractured Brule aquifers, or Brule Formation. Water samples from all sites were analyzed for physical properties, nutrients or NO<sub>3</sub> (as N), and  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$ . In addition, a subset of the sites were sampled for any combination of  $\delta^{15}\text{N}$ , CFCs, dissolved gases,  $^3\text{H}$ ,  $^3\text{H}/^3\text{He}$ , and SF<sub>6</sub>. During the final collection period in August, some sites previously sampled for  $\delta^{15}\text{N}$  in May were resampled. In addition, six Brule well sites—1U-D, 23O-D, 28J-S, B1E-D, B21C-D, and B25B-D—were sampled for  $^{13}\text{C}/^{12}\text{C}$  and  $^{14}\text{C}$ .

A representative K was about 500 ft/d, assuming a saturated thickness of 36 ft, as determined from a 48-hour constant-discharge aquifer test, for the deeper parts of the Pumpkin Creek alluvial aquifer, as opposed to nearer the valley walls. Hydraulic conductivity nearer the valley walls where the alluvial sediments are thinner and likely finer grained than the deeper central portion, probably is an order of magnitude less than the central part. Slug tests were conducted in wells screened in the alluvial aquifer and the fractured and unfractured Brule; generally the wells tested were located near either Pumpkin Creek or Lawrence Fork. From the slug test results, the K for the combined ground-water system ranged from 0.3 to 1,000 ft/d with a median value of about 100 ft/d. The median K in the alluvial aquifer was 200 ft/d, the median K in the fractured Brule was 300 ft/d, and the median K in the Brule Formation was 50 ft/d. A value of the ground-water gradient for the study area was determined to be about 0.0031 ft/ft, which is close to the surface-water gradient of 0.0026 ft/ft. A representative ground-water velocity in the deeper parts of the aquifer is about 6 ft/d. Likewise, the ground-water velocity in the shallower alluvial sediments nearer the valley walls likely is about 1 ft/d. Representative ground-water velocities in the study area likely average somewhere between 1 and 10 ft/d.

The results of age-dating of the ground water in the study area suggest that most of the ground water in the alluvial and fractured Brule aquifers is less than 30 years old. The age of ground water in the alluvial aquifer typically varied from about 1980 to modern, whereas the age of ground water in the fractured Brule typically contained a median age of the 1970s. In contrast, the apparent ages of water from a few monitoring wells in the Brule Formation that could be sampled for CFCs ranged from the 1940s to the 1990s, but most Brule Formation wells contained some of the oldest waters sampled. Some Brule Formation wells that yielded low volumes of water were age dated using  $^{14}\text{C}$  age-dating techniques. The apparent age of the water in these wells was substantially older—5,000 to 10,000 years before present—than water from other wells.

Analysis of  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  in ground-water samples indicated values at the isotopically lighter end of the graph that is typically dominated by ground water recharged from precipitation falling during rainout or from cooling air masses distant from the oceanic source. Analysis of stable isotope data showed that slight distinctions can be made between water samples collected from monitoring wells in the Brule Formation and water samples collected from monitoring wells in the alluvial and fractured Brule aquifers. Many of the water samples from the Brule Formation were isotopically lighter than those collected from the other ground-water systems. In addition, the apparent ages of water in the Brule Formation are on the order of 5,000 to 10,000 years before present, suggesting that the ground-water samples collected from the Brule Formation recharged during a different climatic era than water samples collected from the alluvial and fractured Brule aquifers.

Evaporative effects are evident in several of the surface-water samples analyzed for  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ . Water samples from the lake show the greatest displacement from the LMWL



(3.78 per mil for  $\delta^{18}\text{O}$  and 28.92 per mil for  $\delta^2\text{H}$ ). Other surface-water samples that showed effects of substantial evaporation lie on a line between the ground-water samples and the lake. Generally, these samples were collected in the summer when streamflow was reduced or ponded throughout much of Pumpkin Creek Valley. Most of the ground-water samples showed very little, if any, seasonal variation or evaporative effects. The physical and chemical data indicate that Pumpkin Creek is a gaining stream because very little of its water was lost to the ground-water system.

Water that entered the study area as precipitation in the upper reaches of Pumpkin Creek Valley eventually moved downgradient toward the confluence of Pumpkin Creek and the North Platte River. As the ground water moved down valley, locally some of it was captured by irrigation wells that are prevalent throughout the valley. This water was then re-introduced to dry air where it could be refractionated. After the water reentered the ground-water system, it continued to move downgradient where it could be recaptured by another irrigation well; thus the process of fractionation by evaporation could be repeated. As a result, some ground water in the study area that moved downgradient for long distances generally became isotopically heavier.

Water samples from the deepest monitoring wells typically were isotopically lighter than water samples from the shallower monitoring wells at almost all sites with multiple monitoring wells. However, water samples from five clustered monitoring well sites (B13A, B13B, B23D, B24E, and B35E) that were not adjacent to irrigated cropland indicated the opposite effect. Water samples collected at these five sites indicated that the water from the shallower monitoring wells was isotopically lighter than water from the deeper monitoring wells. Data indicate that ground water underlying or adjacent to irrigated fields appears to be subjected to refractionating as evidenced by the shallowest ground water showing the effects of evaporation, whereas these effects are not present at locations farthest from irrigated fields.

Analysis of the water-quality data from Pumpkin Creek shows the water type changes from a sodium calcium bicarbonate type near the headwaters to a calcium sodium bicarbonate type near the mouth. Water samples from the lake suggest that it was similar to the water found in the upper reaches of Pumpkin Creek—predominantly a sodium calcium bicarbonate chloride type. Water samples from Lawrence Fork and the two springs show that they are a calcium bicarbonate to a calcium magnesium bicarbonate type. The calcium bicarbonate type water found in Lawrence Fork and in the spring at Olsen Ranch was very similar to the water type found in Pumpkin Creek downstream from these locations. This suggests that water in Lawrence Fork, which becomes subterranean before it reaches Pumpkin Creek, likely influences the water type of Pumpkin Creek Valley downstream from the virtual confluence of Lawrence Fork and Pumpkin Creek.

Analysis of water samples collected in Pumpkin Creek Valley suggests that two of the three ground-water systems were similar in water type. Water in the alluvial and the

fractured Brule aquifers were predominantly a calcium sodium bicarbonate type, whereas water in the Brule Formation was predominantly a sodium calcium bicarbonate type. The alluvial and fractured Brule aquifers indicate a water type similar to that found in the downstream reaches of Pumpkin Creek.

The median concentration of calcium in water samples collected from the surface water and three ground-water systems was significantly different in all paired contrasts except the alluvial and fractured Brule ( $p$ -value = 0.5826). The median concentration of sodium in water samples was significantly different in the Brule Formation than in samples collected from the surface water, the alluvial aquifer, or the fractured Brule aquifer (all  $p$ -values <0.0001).

The largest  $\text{NO}_3$  concentration in any surface-water or ground-water sample collected was 41 mg/L in a monitoring well in the Brule Formation. Excluding samples from this well, the largest  $\text{NO}_3$  concentration in the study area (17 mg/L) occurred in a water sample from a monitoring well in the alluvial aquifer. Median  $\text{NO}_3$  concentrations were largest in the alluvial ground-water system (5 mg/L) and smallest in the surface-water system (1 mg/L).

The largest  $\text{NO}_3$  concentrations appear to be associated with monitoring wells that were adjacent to irrigated fields. Nitrate was detected in ground-water samples collected in areas that were adjacent to land used for the production of row crops or livestock. Most  $\text{NO}_3$  concentrations exceeding the USEPA MCL of 10 mg/L occurred in areas associated with ground-water irrigation, and where the alluvial sediments are less than 50 ft thick. These areas, most of which are in Banner County, lie adjacent to areas that have large tracts of land used for row crop production. Substantial row crop production also is associated with areas where  $\text{NO}_3$  concentrations in water samples were less than the 10 mg/L MCL, but greater than 5 mg/L.

Sources of nitrogen in the ground water of the study area include background sources (soil and precipitation) or naturally occurring nitrogen, commercial fertilizer, and animal waste. Results for most of the  $\delta^{15}\text{N}$  water samples collected in the study area showed the most likely  $\text{NO}_3$  source was from a mixture of commercial fertilizer and animal waste (28 of 43 samples or 65 percent), with  $\delta^{15}\text{N}$  values less than 6 per mil, but  $\text{NO}_3$  concentrations greater than 3 mg/L. The water sample with the largest  $\text{NO}_3$  concentration (41 mg/L) also had one of the smallest (less than 2 per mil)  $\delta^{15}\text{N}$  values. This suggests that the largest  $\text{NO}_3$  concentrations were derived from commercial fertilizer. In contrast, some of the smallest  $\text{NO}_3$  concentrations in the ground-water samples also contained some of the largest (greater than 10 per mil)  $\delta^{15}\text{N}$  values, which suggests animal waste as the likely source.

The source of nitrogen in the water samples that contained the largest  $\delta^{15}\text{N}$  values (9.8 and 10 per mil at monitoring well B34C-M, and 13 per mil at monitoring well B34D-S) and a very small dissolved-oxygen concentration (0.10 mg/L) might not have been animal waste, because the large  $\delta^{15}\text{N}$  values could have resulted from denitrification. However,  $\text{NH}_4^+$  was present in some water samples collected from monitoring well B34C-S and thus, because  $\text{NH}_4^+$  is irreversibly oxidized to

NO<sub>3</sub>, denitrification probably was not a factor and the large  $\delta^{15}\text{N}$  values likely originated from animal waste and not denitrification of commercial fertilizer.

In water samples from monitoring well 29I-S (2 samples),  $\delta^{15}\text{N}$  values also exceeded 10 per mil. Nitrogen in water samples from this site probably originated from animal waste, as indicated by the high  $\delta^{15}\text{N}$  values and the character of Pumpkin Creek that has been shown to be a gaining stream. In addition, water samples from monitoring well 29I-S also contained large dissolved-oxygen values indicative of non-reducing conditions.

Analysis of the other  $\delta^{15}\text{N}$  data suggests that most of the nitrogen found in water samples had anthropogenic sources. Most of these data had  $\delta^{15}\text{N}$  values less than 6 per mil, but NO<sub>3</sub> concentrations greater than 3 mg/L. Furthermore, the likely source of most of the nitrogen in water samples that had NO<sub>3</sub> concentrations above the 10 mg/L MCL was from commercial fertilizers. The source of nitrogen in samples with NO<sub>3</sub> concentrations above the 10 mg/L MCL, but with  $\delta^{15}\text{N}$  values close to 10 per mil could not be confidently identified.

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# Appendix

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**Table 7.** Results of water-quality analyses for major ions in water samples, Pumpkin Creek Valley, western Nebraska, 2000.

[All values in milligrams per liter unless otherwise noted; ID, Identifier; fig., figure; SI, screened interval of well, in feet below land surface; AT, aquifer type; B, Brule Formation; A, alluvial; FB, Fractured Brule; A/B, alluvial and Brule Formation; CaCO<sub>3</sub>, calcium carbonate; Ca, calcium; Mg, magnesium; Na, sodium; SAR, sodium adsorption ratio; K, potassium; ANC, acid-neutralizing capacity; CO<sub>2</sub>, carbon dioxide; SO<sub>4</sub>, sulfate; Cl, chloride; F, fluoride; Si, silica; TDS, total dissolved solids; Cr, creek; --, not analyzed or no data; <, less than; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1)	Legal ID	Date	Time	SI	AT	CaCO <sub>3</sub>	Ca	Mg	Na	SAR (ratio)	K	ANC	CO <sub>2</sub>	SO <sub>4</sub>	Cl	F	Si	TDS
Surface water																			
06684700	Pumpkin Cr at Highway 71		5/3/2000	1245			170	43	14	69	2.0	9.9	285	2.4	30	15	0.5	24	376
06684750	Pumpkin Cr at Hoehn Farms		5/3/2000	1330			150	37	15	101	4.0	12	321	3.1	40	26	.7	15	440
06684910	Pumpkin Cr at Olsen Ranch		5/3/2000	1610			150	37	15	71	2.0	22	221	.3	54	50	.5	2.7	386
06684940	Pumpkin Cr at Schneider Ranch		5/4/2000	1030			190	48	16	99	3.0	14	317	9.7	35	44	.7	6.8	454
06684970	Pumpkin Cr at Highway 88		5/4/2000	1130			230	68	14	44	1.0	9.8	261	3.5	34	35	.6	38	404
06685000	Pumpkin Cr nr Bridgeport		5/4/2000	1230			250	69	19	69	2.0	10	235	1.8	140	24	.5	31	513
06684950	Lawrence Fork		5/4/2000	0950			220	69	12	17	.5	5.4	216	4.2	15	18	.4	51	327
06684920	Spring at Schuler Ranch		5/4/2000	0840			150	46	9.2	11	.4	4.6	166	4.0	10	6.6	.6	54	249
06684930	Spring at Olsen Ranch		5/3/2000	1450			210	68	10	13	.4	2.9	240	15	6.7	2.9	.5	55	304
06684650	Lake		5/3/2000	1045			54	18	2.0	42	2.0	11	127	1.5	16	24	.3	18	208
Ground water																			
413821103543501	B8E-S	19N 57W 8AAAA1	5/22/2000	1600	58-108	B	230	66	16	69	2.0	8.3	193	12	29	15	0.5	62	560
413906103492502	B12C-S	19N 56W 6BADB2	5/22/2000	1030	17-57	B	170	50	12	58	2.0	8.3	219	13	33	18	.4	60	410
413906103492501	B12C-D	19N 56W 6BADB1	5/22/2000	1010	78-108	B	63	17	5.3	131	7.0	7.3	306	7.4	69	22	.6	59	512
414059103484702	B13A-S	20N 56W29BBBB2	5/24/2000	1430	30-50	B	150	43	11	86	3.0	9.2	288	16	43	13	.5	64	452
414059103484701	B13A-D	20N 56W29BBBB1	5/24/2000	1410	95-125	B	110	33	7.3	73	3.0	8.9	242	10	25	6.1	.3	66	378
414006103484602	B13B-S	20N 56W32BBBB2	5/22/2000	1210	10-30	B	84	24	6.0	96	5.0	9.1	230	8.9	29	9.6	.3	65	390
414006103484601	B13B-D	20N 56W32BBBB1	5/22/2000	1150	75-95	B	43	12	3.1	275	18	9.7	342	4.1	170	110	.9	57	851
413916103392603	B21C-S	19N 55W 4AABA3	5/9/2000	1320	10-30	B	210	64	13	64	2	8.0	291	28	36	23	.4	58	460
413916103392602	B21C-M	19N 55W 4AABA2	5/9/2000	1240	67-76	B	120	35	8.6	81	3	8.1	254	9.8	29	13	.5	62	406
413916103392601	B21C-D	19N 55W 4AABA1	5/9/2000	1210	100-109	B	23	6.4	1.6	164	15	5.5	296	1.4	78	9.1	1.7	60	516

**Table 7.** Results of water-quality analyses for major ions in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All values in milligrams per liter unless otherwise noted; ID, Identifier; fig., figure; SI, screened interval of well, in feet below land surface; AT, aquifer type; B, Brule Formation; A, alluvial; FB, Fractured Brule; A/B, alluvial and Brule Formation; CaCO<sub>3</sub>, calcium carbonate; Ca, calcium; Mg, magnesium; Na, sodium; SAR, sodium adsorption ratio; K, potassium; ANC, acid-neutralizing capacity; CO<sub>2</sub>, carbon dioxide; SO<sub>4</sub>, sulfate; Cl, chloride; F, fluoride; Si, silica; TDS, total dissolved solids; Cr, creek; --, not analyzed or no data; <, less than; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1)	Legal ID	Date	Time	SI	AT	CaCO <sub>3</sub>	Ca	Mg	Na	SAR (ratio)	K	ANC	CO <sub>2</sub>	SO <sub>4</sub>	Cl	F	Si	TDS
Ground water—Continued																			
413919103370902	B23D-S	20N 55W35DDDD2	5/9/2000	1440	15-25	B	160	46	10	67	2	7.6	192	7.4	17	63	0.5	68	414
413919103370901	B23D-D	20N 55W35DDDD1	5/9/2000	1420	70-80	B	57	15	4.4	176	10	8.5	321	4.9	100	29	.7	68	611
413826103374102	B23E-S	19N 55W11ABBB2	5/10/2000	0905	30-50	B	170	47	12	49	2	7.7	197	6.5	33	21	.5	63	385
413826103374101	B23E-D	19N 55W11ABBB1	5/10/2000	0820	55-95	B	160	44	11	50	2	7.5	179	5.6	32	35	.4	61	380
413827103363102	B24E-S	19N 55W12ABBB2	5/10/2000	1055	35-40	A	210	63	13	40	1	7.9	188	8.5	32	30	.4	62	419
413827103363101	B24E-D	19N 55W12ABBB1	5/10/2000	1020	55-65	B	220	63	14	43	1	7.4	189	8.2	31	21	.5	63	419
413900103352302	B25D-S	19N 54W 6ACCC2	5/10/2000	1210	10-30	B	140	42	9.7	83	3	8.6	265	14	28	22	.6	64	432
413900103352301	B25D-D	19N 54W 6ACCC1	5/10/2000	1145	65-95	B	20	5.7	1.4	134	13	5.2	252	1.5	34	12	.8	67	422
413803103344602	B25E-S	19N 54W 8BCCC2	5/10/2000	1335	19-31	A	250	75	16	50	1	7.5	213	16	38	52	.4	62	493
413803103344601	B25E-D	19N 54W 8BCCC1	5/10/2000	1315	93-110	B	260	78	17	60	2	8.2	234	9.2	46	52	.5	62	--
413711103322701	B27D-S	19N 54W15BCCC1	5/24/2000	1300	37-62	A	200	59	12	27	.8	6.0	172	7.8	39	26	.4	59	354
413737103282702	B31E-S	19N 53W18ABBB2	5/24/2000	1230	46-65	B	150	42	9.9	84	3.0	11	226	10	58	22	.6	65	460
413737103282701	B31E-D	19N 53W18ABBB1	5/24/2000	1210	100-140	B	15	4.5	1.0	132	15	5.3	252	1.2	33	29	1.2	66	429
413653103242402	B34B-S	19N 53W14CCCB2	5/10/2000	1530	58-78	B	160	47	10	35	1	4.3	179	7.2	29	12	.4	70	343
413653103242401	B34B-D	19N 53W14CCCB1	5/10/2000	1500	118-123	B	33	9.6	2.2	124	9	6.1	203	4.8	65	24	.5	62	450
413611103242403	B34C-S	19N 53W23CBCC3	5/11/2000	1110	12-17	A	420	120	26	96	2	*18	441	68	74	94	.6	43	741
413611103242402	B34C-M	19N 53W23CBCC2	5/11/2000	1030	25-30	A	340	100	21	85	2	12	371	36	62	51	.5	55	671
413611103242401	B34C-D	19N 53W23CBCC1	5/11/2000	1000	47-52	FB	300	89	18	70	2	11	296	26	52	48	.4	57	582
413611103242404	B34C-T	19N 53W23CBCC4	5/11/2000	0930	65-70	B	210	63	13	60	2	9.0	235	15	41	32	.4	61	460
413608103242403	B34D-S	19N 53W23CCBB3	5/11/2000	1200	20-35	A	280	84	17	99	3	11	366	25	70	43	.7	52	618
413608103242402	B34D-M	19N 53W23CCBB2	5/11/2000	1300	49-54	FB	280	83	17	44	1	7.8	219	14	37	66	.4	65	502
413608103242401	B34D-D	19N 53W23CCBB1	5/11/2000	1340	90-95	B	38	11	2.4	96	7	5.1	189	2.3	30	11	.6	67	--
413543103242403	B34E-S	19N 53W26BBCC3	5/12/2000	1020	20-40	A	230	70	13	28	.8	7.0	196	10	22	34	.5	60	403
413543103242402	B34E-M	19N 53W26BBCC2	5/12/2000	0940	58-63	A	220	66	13	21	.6	5.8	190	9.4	20	27	.5	59	363
413543103242401	B34E-D	19N 53W26BBCC1	5/12/2000	0900	86-91	B	150	45	9.7	30	1	5.6	173	7.3	17	17	.6	61	304



**Table 7.** Results of water-quality analyses for major ions in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All values in milligrams per liter unless otherwise noted; ID, Identifier; fig., figure; SI, screened interval of well, in feet below land surface; AT, aquifer type; B, Brule Formation; A, alluvial; FB, Fractured Brule; A/B, alluvial and Brule Formation; CaCO<sub>3</sub>, calcium carbonate; Ca, calcium; Mg, magnesium; Na, sodium; SAR, sodium adsorption ratio; K, potassium; ANC, acid-neutralizing capacity; CO<sub>2</sub>, carbon dioxide; SO<sub>4</sub>, sulfate; Cl, chloride; F, fluoride; Si, silica; TDS, total dissolved solids; Cr, creek; --, not analyzed or no data; <, less than; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1)	Legal ID	Date	Time	SI	AT	CaCO <sub>3</sub>	Ca	Mg	Na	SAR (ratio)	K	ANC	CO <sub>2</sub>	SO <sub>4</sub>	Cl	F	Si	TDS
Ground water—Continued																			
413528103233402	B35E-S	19N 53W26DBAA2	5/11/2000	1500	30-50	A	170	52	10	22	0.7	5.4	186	7.7	17	16	0.6	60	312
413528103233401	B35E-D	19N 53W26DBAA1	5/11/2000	1420	72-77	A	190	55	11	26	.8	5.3	187	7.9	21	19	.5	61	332
413541103224602	B36E-S	19N 53W25BDAB2	5/12/2000	1250	20-40	A	270	83	16	47	1.0	7.6	229	17	35	58	.5	59	495
413541103224601	B36E-D	19N 53W25BDAB1	5/12/2000	1220	66-71	B	250	80	12	19	.5	7.3	208	13	21	27	.5	55	383
414321103550802	1U-S	20N 57W 8BDDA2	5/22/2000	1510	10-30	A/B	140	40	10	112	4.0	8.8	236	11	67	54	.5	67	523
414321103550801	1U-D	20N 57W 8BDDA1	5/22/2000	1450	70-100	B	42	11	3.3	155	10	7.0	320	3.9	45	10	.8	56	495
413556103161903	23J-S	19N 52W25BBBB3	5/15/2000	1030	10-30	A	170	51	11	72	2.0	8.8	278	17	32	21	.7	60	432
413556103161902	23J-M	19N 52W25BBBB2	5/15/2000	1000	49-54	B	170	51	11	59	2.0	8.0	252	15	29	18	.6	61	399
413556103161901	23J-D	19N 52W25BBBB1	5/15/2000	0940	90-95	B	75	21	5.6	94	5.0	7.6	245	9.5	32	8.3	.9	71	394
413504103161703	23L-S	19N 52W25CCCC3	5/15/2000	1210	25-45	A	330	100	19	23	.6	17	272	32	27	57	.6	55	505
413504103161702	23L-M	19N 50W25CCCC2	5/15/2000	1140	89-94	A	250	81	12	16	.4	7.2	214	17	24	41	.4	55	385
413504103161701	23L-D	19N 52W25CCCC1	5/15/2000	1120	114-119	B	120	35	8.0	115	5.0	7.2	228	11	120	20	.7	66	514
413344103161603	23N-S	18N 52W 1CBBB3	5/13/2000	1220	10-30	A	180	55	11	50	2.0	7.8	242	28	29	33	.5	60	401
413344103161602	23N-M	18N 52W 1CBBB2	5/13/2000	1400	73-78	A	250	79	13	16	.4	6.7	174	13	18	37	.4	55	357
413344103161601	23N-D	18N 52W 1CBBB1	5/13/2000	1310	115-120	B	120	34	8.9	110	4.0	8.8	265	19	52	19	.4	54	455
413305103154902	23O-S	18N 52W12BDAA2	5/23/2000	1400	38-58	B	160	47	9.9	72	2	8	234	14	72	5.7	.6	59	437
413305103154901	23O-D	18N 52W12BDAA1	5/23/2000	1340	95-110	B	50	14	3.4	116	7	7.7	238	5.8	52	5.6	.9	69	425
413228103161803	23P-S	18N 52W11DDDD4	5/13/2000	0830	35-55	FB	220	70	12	18	.5	6.1	202	14	16	27	.4	58	371
413228103161802	23P-M	18N 52W11DDDD3	5/13/2000	1010	87-92	FB	220	69	12	15	.4	5.4	191	11	15	31	.4	57	358
413228103161801	23P-D	18N 52W11DDDD2	5/13/2000	0940	124-129	B	44	12	3.2	73	5	4.9	197	2.5	23	5.2	.9	69	323
413227103170803	23R-S	18N 52W11CDCC3	5/12/2000	1410	10-30	A	250	81	12	19	.5	6	228	18	23	33	.4	55	381
413227103170802	23R-M	18N 52W11CDCC2	5/12/2000	1500	57-62	A	220	71	12	15	.4	5.9	207	12	16	24	.4	56	342
413227103170801	23R-D	18N 52W11CDCC1	5/12/2000	1350	95-100	B	110	30	7.4	98	4	5.1	217	8	70	16	.6	58	435
413555103150903	24I-S	19N 51W19CCCC3	5/15/2000	1510	20-40	A	260	81	13	49	1	8.4	258	22	30	45	.5	55	468
413555103150902	24I-M	19N 51W19CCCC2	5/15/2000	1440	81-86	FB	240	75	13	35	1	7.8	219	19	29	26	.5	57	386

**Table 7. Results of water-quality analyses for major ions in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued**

[All values in milligrams per liter unless otherwise noted; ID, Identifier; fig., figure; SI, screened interval of well, in feet below land surface; AT, aquifer type; B, Brule Formation; A, alluvial; FB, Fractured Brule; A/B, alluvial and Brule Formation; CaCO<sub>3</sub>, calcium carbonate; Ca, calcium; Mg, magnesium; Na, sodium; SAR, sodium adsorption ratio; K, potassium; ANC, acid-neutralizing capacity; CO<sub>2</sub>, carbon dioxide; SO<sub>4</sub>, sulfate; Cl, chloride; F, fluoride; Si, silica; TDS, total dissolved solids; Cr, creek; --, not analyzed or no data; <, less than; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1)	Legal ID	Date	Time	SI	AT	CaCO <sub>3</sub>	Ca	Mg	Na	SAR (ratio)	K	ANC	CO <sub>2</sub>	SO <sub>4</sub>	Cl	F	Si	TDS
Ground water—Continued																			
413555103150901	24I-D	19N 51W19CCCC1	5/15/2000	1410	100-105	FB	230	73	12	41	1	7.8	258	23	30	26	0.5	57	415
413503103145401	24J-S	19N 51W30CCCC1	5/15/2000	1320	83-88	FB	220	68	11	21	.6	7.2	205	11	18	24	.5	55	344
413609103140202	24L-S	19N 51W19DADD2	5/16/2000	1050	20-40	FB	250	76	15	44	1	8.3	281	22	33	34	.5	58	443
413609103140201	24L-D	19N 51W19DADD1	5/16/2000	1020	105-110	B	67	18	5.1	75	4	5.9	164	3.2	<.31	12	.8	69	--
413503103120003	25I-S	19N 51W29DDDD3	5/16/2000	0930	20-40	A	270	85	13	44	1	7.8	245	15	23	57	.5	55	478
413503103120002	25I-M	19N 51W29DDDD2	5/16/2000	0900	81-86	A	260	81	13	26	.7	6.7	221	12	19	43	.4	55	409
413503103120001	25I-D	19N 51W29DDDD1	5/16/2000	0840	98-103	FB	200	62	11	32	1	7.5	200	9.7	17	33	.4	54	360
413411103124703	25J-S	19N 51W33CCCD3	5/17/2000	1340	30-35	A	150	47	8.6	40	1	8.9	162	6.2	39	23	.6	65	347
413502103103703	26K-S	19N 51W27DDDD3	5/16/2000	1310	18-38	A	290	90	16	42	1	7.8	274	27	41	47	.5	55	492
413502103103702	26K-M	19N 51W27DDDD2	5/16/2000	1240	51-56	A	280	87	15	25	.7	7.2	239	18	26	46	.4	55	428
413502103103701	26K-D	19N 51W27DDDD1	5/16/2000	1210	60-65	FB	280	87	15	24	.6	6.8	239	18	26	46	.4	56	427
413502103103704	26K-T	19N 51W27DDDD4	5/16/2000	1140	80-85	FB	270	85	14	25	.7	6.7	225	14	23	49	.4	55	421
413501103082203	27K-S	19N 51W36AAAA3	5/23/2000	1520	18-38	A	270	87	14	29	.8	8.5	236	23	48	23	.5	55	443
413501103082202	27K-M	19N 51W36AAAA2	5/23/2000	1500	89-94	A	220	69	12	23	.7	6.8	207	13	23	21	.5	55	361
413501103082201	27K-D	19N 51W36AAAA1	5/23/2000	1440	115-120	B	180	54	11	38	1	8.3	197	12	21	27	.5	58	361
413708103055701	28J-S	19N 50W17DADA1	5/23/2000	1550	120-125	B	56	17	3.5	149	9	7.2	275	6.7	99	8.9	.4	58	510
413510103060103	28L-S	19N 50W29DDAA3	5/16/2000	1530	15-25	A	220	68	12	32	.9	7.3	228	18	34	27	.5	57	396
413510103060102	28L-M	19N 50W29DDAA2	5/16/2000	1500	41-46	FB	220	69	12	30	.9	7.4	216	17	30	26	.5	59	387
413510103060101	28L-D	19N 50W29DDAA1	5/16/2000	1430	60-65	FB	210	66	12	28	.8	7	212	13	31	26	.5	58	373
413510103060104	28L-T	19N 50W29DDAA4	5/16/2000	1400	91-96	B	78	21	6.2	57	3	6.7	194	4.7	13	4.7	.6	69	304
413726103023503	29I-S	19N 50W14AAAD3	5/17/2000	1550	10-30	A	260	76	16	60	2	10	255	16	100	27	.5	47	507
413726103023502	29I-M	19N 50W14AAAD2	5/17/2000	1510	75-80	A	230	69	15	67	2	11	230	11	130	15	.6	56	517
413726103023501	29I-D	19N 50W14AAAD1	5/17/2000	1440	159-164	A	200	62	12	65	2	10	252	12	120	15	.6	58	507
413651103023403	29J-S	19N 50W14DDDA3	5/24/2000	1050	25-45	A	240	70	16	56	2	9.8	240	12	84	24	.6	47	466
413651103023402	29J-M	19N 50W14DDDA2	5/24/2000	1030	85-90	A	230	67	15	58	2	10	256	15	59	24	.5	44	451
413651103023401	29J-D	19N 50W14DDDA1	5/24/2000	1000	189-194	A	240	73	14	34	1	8.6	244	17	27	12	.4	53	410

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium;  $\delta^{15}\text{N}$ , nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron;  $\mu\text{g/L}$ , micrograms per liter; Mn, manganese;  $\delta^2\text{H}$ , hydrogen-isotope ratios in per mil Vienna standard mean oceanic water;  $\delta^{18}\text{O}$ , oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Surface water																						
06684700	Pumpkin Cr at Highway 71	5/03/2000	1245		8.4	591	10	<0.05	--	--	<0.01	--	12	8.0	-100.90	-12.13	--	--	--	--	--	--
		7/19/2000	0800		7.8	712	6.5	<.05	--	--	--	--			-88.61	-10.73	--	--	--	--	--	--
06684750	Pumpkin Cr at Hoehn Farms	5/03/2000	1330		8.3	717	10	<.05	--	--	<.01	--	18	6.4	-84.01	-9.63	--	--	--	--	--	--
06684910	Pumpkin Cr at Olsen Ranch	5/03/2000	1610		9.1	647	9.2	<.05	0.17	--	.14	0.42	26	11	-88.42	-10.29	--	--	--	--	--	--
06684940	Pumpkin Cr at Schneider Ranch	5/04/2000	1030		7.8	767	3.0	<.05	--	--	<.01	--	30	13	-83.03	-9.69	--	--	--	--	--	--
06684970	Pumpkin Cr at Highway 88	5/04/2000	1130		8.2	637	9.8	1.1	--	6.6	<.01	--	E7.0	4.7	-100.21	-12.90	--	--	--	--	--	--
		7/19/2000	1150		8.2	629	7.6	.82	--	--	--	--	--	--	-97.68	-12.62	--	--	--	--	--	--
06685000	Pumpkin Cr near Bridgeport	5/04/2000	1230		8.4	765	11	2.6	.03	9.4	<.01	--	<10	8.3	-103.84	-13.00	--	--	--	--	--	--
		7/19/2000	1240		8.3	1,080	15	5.4	--	--	--	--	--	--	-88.91	-10.23	--	--	--	--	--	--
		8/24/2000	1250		8.3	602	10	.71	--	--	--	--	--	--	-98.31	-12.49	--	--	--	--	--	--
06684950	Lawrence Fork	5/04/2000	0950		8.0	493	9.8	2.4	.03	4.3	.02	.07	E6.2	2.8	-106.21	-14.10	--	--	--	--	--	--
		7/19/2000	1100		8.4	494	9.6	2.3	--	--	--	--	--	--	-105.98	-14.08	--	--	--	--	--	--
		8/24/2000	1230		8.4	502	12	2.3	--	--	--	--	--	--	-105.16	-14.01	--	--	--	--	--	--
06684920	Spring at Schuler Ranch	5/04/2000	0840		7.9	370	8.1	1.6	--	3.8	<.01	--	<10	2.8	-109.12	-14.76	--	--	--	--	--	--
		7/19/2000	1010		8.0	372	7.6	1.8	--	--	--	--	--	--	-111.57	-14.72	--	--	--	--	--	--
		8/24/2000	0940		8.0	413	8.6	1.8	--	--	--	--	--	--	-111.15	-14.61	--	--	--	--	--	--

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium; δ<sup>15</sup>N, nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron; µg/L, micrograms per liter; Mn, manganese; δ<sup>2</sup>H, hydrogen-isotope ratios in per mil Vienna standard mean oceanic water; <sup>18</sup>O, oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Surface water—Continued																						
06684930	Spring at Olsen Ranch	5/03/2000	1450		7.5	456	6.3	<0.05	--	--	<0.01	--	33	63	-102.29	-13.42	--	--	--	--	--	--
		7/19/2000	0900		7.5	454	4.0	1.6	--	--	--	--	--	--	-101.49	-13.23	--	--	--	--	--	--
		8/24/2000	1720		7.6	321	--	.88	--	--	--	--	--	--	-104.03	-13.82	--	--	--	--	--	--
06684650	Lake	5/03/2000	1045		8.2	338	8.4	<.05	--	--	.49	1.5	88	2.6	-68.08	-5.76	--	--	--	--	--	--
Ground water																						
413821103543501	B8E-S 19N 57W 8AAAA1	5/22/2000	1600	B	7.5	811	7.9	40	--	1.8	<0.01	--	<10	<2.2	-102.19	-13.26	16	0.58	4.0	15	0.0	--
		7/18/2000	1030		7.5	814	8.2	41	--	--	--	--	--	--	-103.84	-13.19	--	--	--	--	--	--
		8/22/2000	1300		7.4	838	7.3	39	--	1.2	--	--	--	--	-103.42	-13.26	--	--	--	--	--	--
413821103543502	B8E-D 19N 57W 8AAAA2	8/22/2000	1220	B	7.8	640	5.4	7.3	--	--	--	--	--	--	--	--	--	--	--	--	--	
413906103492502	B12C-S 19N 56W 6BADB2	5/22/2000	1030	B	7.5	620	8.9	8.6	--	2.9	.02	0.07	<10	<2.2	-109.81	-14.29	19	.65	5.5	14	.0	1.0
		7/18/2000	1120		7.6	621	9.1	9.6	--	--	--	--	--	--	-109.62	-14.44	--	--	--	--	--	--
		8/22/2000	1350		7.5	635	5.7	8.5	--	--	--	--	--	--	-109.44	-14.32	--	--	--	--	--	--
413906103492501	B12C-D 19N 56W 6BADB1	5/22/2000	1010	B	7.9	654	2.4	4.2	--	3.2	.04	.12	<10	<2.2	-108.59	-14.32	--	--	--	--	--	--
		7/18/2000	1100		7.9	661	5.2	3.7	--	--	--	--	--	--	-109.66	-14.36	--	--	--	--	--	--
		8/22/2000	1340		7.9	880	2.9	4.7	--	--	--	--	--	--	-109.81	-14.33	--	--	--	--	--	--
414059103484702	B13A-S 20N 56W 29BBBB2	5/24/2000	1430	B	7.6	682	4.6	*2.1	--	--	.01	*.04	<10	<2.2	-108.84	-14.43	--	--	--	--	--	--
		7/18/2000	1230		7.5	675	4.6	4.8	--	--	--	--	--	--	-109.84	-14.34	--	--	--	--	--	--
		8/22/2000	1450		7.4	695	7.3	2.0	--	--	--	--	--	--	-110.42	-14.42	--	--	--	--	--	--

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium;  $\delta^{15}\text{N}$ , nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron;  $\mu\text{g/L}$ , micrograms per liter; Mn, manganese;  $\delta^2\text{H}$ , hydrogen-isotope ratios in per mil Vienna standard mean oceanic water;  $^{18}\text{O}$ , oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
414059103484701	B13A-D 20N 56W29BBBB1	5/24/2000	1410	B	7.7	546	5.2	2.9	--	--	0.01	0.03	<10	<2.2	-108.62	-14.23	--	--	--	--	--	--
		7/18/2000	1210		7.6	543	5.2	8.5	--	--	--	--	--	--	-108.89	-14.13	--	--	--	--	--	--
		8/22/2000	1440		7.5	556	5.3	2.7	--	--	--	--	--	--	-109.37	-14.19	--	--	--	--	--	--
414006103484602	B13B-S 20N 56W32BBBB2	5/22/2000	1210	B	7.7	616	7.1	2.9	--	--	.02	.05	<10	<2.2	-110.72	-14.22	16	0.59	4.0	11	0.0	--
		7/18/2000	1320		7.7	590	6.9	2.9	--	--	--	--	--	--	-110.10	-14.20	--	--	--	--	--	--
		8/22/2000	1550		7.6	612	6.2	2.7	--	--	--	--	--	--	-107.81	-14.13	--	--	--	--	--	--
414006103484601	B13B-D 20N 56W32BBBB1	5/22/2000	1150	B	8.2	1,360	1.1	2.4	--	--	.10	.31	<10	<2.2	-108.70	-14.04	--	--	--	--	--	--
		7/18/2000	1300		8.2	1,390	3.0	2.2	--	--	--	--	--	--	-107.13	-14.05	--	--	--	--	--	--
		8/22/2000	1520		8.1	1,440	2.9	1.8	--	--	--	--	--	--	-106.86	-14.10	--	--	--	--	--	--
413916103392603	B21C-S 19N 55W 4AABA3	5/09/2000	1320	B	7.3	680	7.4	4.4	--	3.4	.01	.03	<10	E1.5	-106.92	-13.95	17	.62	3.4	26	.0	--
		7/10/2000	1205		7.4	702	6.8	4.8	--	--	--	--	--	--	-105.78	-14.01	--	--	--	--	--	--
		8/25/2000	1220		7.4	703	6.2	4.6	--	--	--	--	--	--	-106.96	-14.00	--	--	--	--	--	--
413916103392602	B21C-M 19N 55W 4AABA2	5/09/2000	1240	B	7.7	601	3.9	3.7	--	4.4	<.01	--	<10	<2.2	-108.78	-13.96	17	.61	.59	15	.0	--
		7/10/2000	1145		7.6	584	4.7	3.6	--	--	--	--	--	--	-107.41	-14.01	--	--	--	--	--	--
		8/25/2000	1200		7.7	594	4.5	3.5	--	--	--	--	--	--	-108.18	-14.02	--	--	--	--	--	--
413916103392601	B21C-D 19N 55W 4AABA1	5/09/2000	1210	B	8.6	753	1.0	2.3	--	6.4	.39	1.2	22	E2.1	-105.32	-13.96	--	--	--	--	--	--
		7/10/2000	1125		8.2	751	.3	2.3	--	--	--	--	--	--	-103.35	-14.05	--	--	--	--	--	--
		8/25/2000	1120		8.5	748	.8	2.1	--	--	--	--	--	--	-107.35	-14.05	--	--	--	--	--	--

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium;  $\delta^{15}\text{N}$ , nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron;  $\mu\text{g/L}$ , micrograms per liter; Mn, manganese;  $\delta^2\text{H}$ , hydrogen-isotope ratios in per mil Vienna standard mean oceanic water;  $\delta^{18}\text{O}$ , oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (μg/L)	Mn (μg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413919103370902	B23D-S 20N 55W35DDDD2	5/09/2000	1440	B	7.7	632	8.1	4.5	--	--	<0.01	--	<10	<2.2	-107.91	-13.94	16	0.57	5.1	12	0.0	--
		7/10/2000	1355		7.6	647	9.2	4.6	--	--	--	--	--	-104.25	-13.91	--	--	--	--	--	--	
		8/28/2000	0910		7.5	686	7.6	4.3	--	--	--	--	--	-106.30	-13.91	--	--	--	--	--	--	
413919103370901	B23D-D 20N 55W35DDDD1	5/09/2000	1420	B	8.1	915	5.7	2.6	--	--	.16	0.48	<10	<2.2	-105.46	-13.85	--	--	--	--	--	--
		7/10/2000	1340		8.0	877	7.5	2.2	--	--	--	--	--	-105.34	-13.71	--	--	--	--	--	--	
		8/28/2000	0900		7.9	935	4.1	1.9	--	--	--	--	--	-104.58	-13.78	--	--	--	--	--	--	
413826103374102	B23E-S 19N 55W11ABBB2	5/10/2000	0905	B	7.8	560	7.8	7.3	--	--	<.01	--	<10	<2.2	-108.19	-14.56	15	.57	5.3	9.6	.0	--
		7/10/2000	1305		7.7	557	8.5	7.5	--	--	--	--	--	-110.76	-14.65	--	--	--	--	--	--	
		8/28/2000	1230		7.6	581	7.3	7.3	--	--	--	--	--	-109.71	-14.60	--	--	--	--	--	--	
413826103374101	B23E-D 19N 55W11ABBB1	5/10/2000	0820	B	7.8	535	5.4	7.2	--	--	<.01	--	<10	E1.7	-112.74	-14.76	--	--	--	--	--	--
		7/10/2000	1245		7.7	533	8.6	7.5	--	--	--	--	--	-112.16	-14.72	--	--	--	--	--	--	
		8/28/2000	1210		7.6	557	6.5	7.0	--	--	--	--	--	-111.14	-14.79	--	--	--	--	--	--	
413827103363102	B24E-S 19N 55W12ABBB2	5/10/2000	1055	A	7.6	619	8.3	13	--	--	<.01	--	<10	<2.2	-109.86	-14.54	16	.59	4.5	13	.0	--
		7/10/2000	1450		7.5	643	9.1	16	--	--	--	--	--	-108.01	-14.48	--	--	--	--	--	--	
413827103363101	B24E-D 19N 55W12ABBB1	5/10/2000	1020	B	7.7	640	7.8	14	--	--	.01	.03	<10	<2.2	-110.51	-14.44	16	.58	4.1	12	.0	--
		7/10/2000	1425		7.6	639	8.9	14	--	--	--	--	--	-109.92	-14.41	--	--	--	--	--	--	
		8/28/2000	0940		7.5	676	7.6	14	--	5.0	--	--	--	-107.92	-14.42	--	--	--	--	--	--	
413900103352302	B25D-S 19N 54W 6ACCC2	5/10/2000	1210	B	7.6	636	3.5	3.3	--	--	.01	.04	<10	<2.2	-107.89	-13.61	17	.60	.60	18	.0	--
		7/10/2000	1540		7.4	652	3.8	3.5	--	--	--	--	--	-104.04	-13.57	--	--	--	--	--	--	
		8/28/2000	1150		7.4	680	2.8	3.0	--	--	--	--	--	-103.96	-13.54	--	--	--	--	--	--	

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium;  $\delta^{15}\text{N}$ , nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron;  $\mu\text{g/L}$ , micrograms per liter; Mn, manganese;  $\delta^2\text{H}$ , hydrogen-isotope ratios in per mil Vienna standard mean oceanic water;  $\delta^{18}\text{O}$ , oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413900103352301	B25D-D 19N 54W 6ACCC1	5/10/2000	1145	B	8.5	594	1.7	2.5	--	--	0.02	0.07	<10	<2.2	-107.38	-14.08	--	--	--	--	--	--
		7/10/2000	1520		8.4	597	1.9	2.6	--	--	--	--	--	--	-107.25	-14.13	--	--	--	--	--	--
		8/28/2000	1130		8.3	627	1.4	2.5	--	--	--	--	--	--	-114.00	-15.33	--	--	--	--	--	--
413803103344602	B25E-S 19N 54W 8BCCC2	5/10/2000	1335	A	7.4	753	8.1	15	--	4.3	<.01	--	<10	<2.2	-106.44	-13.80	18	0.63	4.4	20	0.0	--
		7/10/2000	1630		7.4	785	9.5	17	--	--	--	--	--	--	-103.59	-13.80	--	--	--	--	--	--
		8/28/2000	1030		7.3	799	7.5	16	--	5.2	--	--	--	--	-105.42	-13.84	--	--	--	--	--	--
413803103344601	B25E-D 19N 54W 8BCCC1	5/10/2000	1315	B	7.7	811	7.1	16	--	4.2	.24	--	<10	<2.2	-103.90	-13.83	--	--	--	--	--	--
		7/10/2000	1610		7.6	817	6.8	15	--	--	--	--	--	--	-105.98	-13.86	--	--	--	--	--	--
		8/28/2000	1010		7.9	1,020	3.2	6.2	--	3.1	--	--	--	--	-104.58	-14.28	--	--	--	--	--	--
413711103322701	B27D-S 19N 54W15BCCC1	5/24/2000	1300	A	7.6	533	8.4	4.9	--	--	.02	.05	<10	<2.2	-108.63	-14.30	--	--	--	--	--	--
		7/12/2000	0800		7.5	535	8.6	5.0	--	--	--	--	--	--	-107.15	-14.29	--	--	--	--	--	--
		8/28/2000	1100		7.5	547	7.4	4.9	--	--	--	--	--	--	-107.24	-14.27	--	--	--	--	--	--
413737103282702	B31E-S 19N 53W18ABBB2	5/24/2000	1230	B	7.6	684	7.7	7.0	--	--	.01	.03	E5.3	E1.2	-102.09	-13.21	--	--	--	--	--	--
		7/12/2000	0850		7.5	683	8.3	7.4	--	--	--	--	--	--	-99.02	-13.26	--	--	--	--	--	--
413737103282701	B31E-D 19N 53W18ABBB1	5/24/2000	1210	B	8.6	593	1.2	1.4	0.07	--	.11	.35	E5.6	<2.2	-104.69	-13.99	--	--	--	--	--	--
		7/12/2000	0840		8.5	610	1.5	1.4	--	--	--	--	--	--	-104.49	-13.88	--	--	--	--	--	--
413653103242402	B34B-S 19N 53W14CCCB2	5/10/2000	1530	B	7.7	466	7.7	6.5	--	4.5	<.01	--	<10	<2.2	-102.04	-12.95	15	.55	4.4	9.8	.0	--
		7/12/2000	0950		7.6	465	8.3	6.4	--	--	--	--	--	--	-99.21	-12.92	--	--	--	--	--	--
		8/25/2000	1540		7.5	471	6.9	6.1	--	--	--	--	--	--	-99.19	-12.99	--	--	--	--	--	--

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium; δ<sup>15</sup>N, nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron; µg/L, micrograms per liter; Mn, manganese; δ<sup>2</sup>H, hydrogen-isotope ratios in per mil Vienna standard mean oceanic water; <sup>18</sup>O, oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413653103242401	B34B-D 19N 53W14CCCB1	5/10/2000	1500	B	7.9	638	0.6	4.7	--	5.6	4.8	15	25	E1.1	-102.10	-13.11	--	--	--	--	--	--
		7/12/2000	0920		7.9	609	.5	3.6	--	--	--	--	--	-99.91	-13.16	--	--	--	--	--	--	
		8/25/2000	1520		7.9	610	.2	3.0	--	--	--	--	--	-101.30	-13.04	--	--	--	--	--	--	
413611103242403	B34C-S 19N 53W23CBCC3	5/11/2000	1110	A	7.1	1,220	.1	<0.05	0.44	--	.10	.31	410	687	-94.80	-12.23	22	0.66	--	73	1.0	3.0
		7/11/2000	0930		7.1	1,120	.2	<.05	--	--	--	--	--	-97.94	-12.39	--	--	--	--	--	--	
		8/25/2000	1450		7.0	1,180	.1	.42	.65	--	.18	.55	--	--	-100.54	-13.05	--	--	--	--	--	--
413611103242402	B34C-M 19N 53W23CBCC2	5/11/2000	1030	A	7.3	1,040	.1	14	--	10	.06	.17	<10	7.2	-101.30	-13.05	21	.62	0.07	39	.0	5.0
		7/11/2000	0910		7.3	1,040	.1	13	--	--	--	--	--	-99.98	-13.08	--	--	--	--	--	--	
		8/25/2000	1430		7.2	1,050	.1	10	--	9.8	--	--	--	--	-104.79	-13.56	--	--	--	--	--	--
413611103242401	B34C-D 19N 53W23CBCC1	5/11/2000	1000	FB	7.3	897	2.5	13	--	4.7	.03	.08	<10	<2.2	-104.76	-13.42	18	.61	.34	30	.0	1.0
		7/11/2000	0850		7.3	864	4.0	15	--	--	--	--	--	-102.10	-13.61	--	--	--	--	--	--	
		8/25/2000	1420		7.2	781	5.3	16	--	5.3	--	--	--	--	-106.00	-13.88	--	--	--	--	--	--
413611103242404	B34C-T 19N 53W23CBCC4	5/11/2000	0930	B	7.5	690	4.5	8.9	--	4.7	.01	.04	<10	<2.2	-106.83	-13.89	17	.61	.80	19	.0	--
		7/11/2000	0830		7.4	694	5.0	9.4	--	--	--	--	--	-105.43	-13.91	--	--	--	--	--	--	
		8/25/2000	1400		7.2	713	4.7	8.5	--	4.3	--	--	--	--	-98.36	-12.50	--	--	--	--	--	--
413608103242403	B34D-S 19N 53W23CCBB3	5/11/2000	1200	A	7.5	959	.1	4.8	--	13	.09	.27	<10	255	-99.14	-12.84	24	.69	.07	26	.0	4.0
		7/11/2000	1045		7.4	962	.2	4.7	--	--	--	--	--	-98.53	-12.91	--	--	--	--	--	--	
		8/25/2000	1340		7.3	1,010	.1	5.7	--	--	--	--	--	--	-98.94	-12.85	--	--	--	--	--	--



**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium;  $\delta^{15}\text{N}$ , nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron;  $\mu\text{g/L}$ , micrograms per liter; Mn, manganese;  $\delta^2\text{H}$ , hydrogen-isotope ratios in per mil Vienna standard mean oceanic water;  $\delta^{18}\text{O}$ , oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413608103242402	B34D-M 19N 53W23CCBB2	5/11/2000	1300	FB	7.5	780	6.7	11	--	5.0	0.02	0.05	<10	E1.3	-103.59	-13.67	17	0.60	2.4	18	0.0	--
		7/11/2000	1025		7.4	984	7.3	15	--	--	--	--	--	-104.26	-13.40	--	--	--	--	--	--	
		8/25/2000	1330		7.3	1,020	7.2	14	--	--	--	--	--	-102.23	-13.33	--	--	--	--	--	--	
413608103242401	B34D-D 19N 53W23CCBB1	5/11/2000	1340	B	8.2	493	1.3	4.0	--	6.2	.14	.43	120	E1.1	-106.97	-14.26	--	--	--	--	--	--
		7/11/2000	1005		8.1	504	1.1	4.1	--	--	--	--	--	-107.96	-14.23	--	--	--	--	--	--	
		8/25/2000	1310		8.0	521	1.0	3.6	--	--	--	--	--	-107.20	-14.22	--	--	--	--	--	--	
413543103242403	B34E-S 19N 53W26BBCC3	5/12/2000	1020	A	7.6	599	8.0	11	--	3.4	.02	.08	<10	<2.2	-105.78	-14.04	16	.58	2.9	14	.0	--
		7/11/2000	1150		7.5	599	8.7	11	--	--	--	--	--	-105.48	-14.15	--	--	--	--	--	--	
		8/25/2000	1240		7.4	617	7.1	11	--	--	--	--	--	-107.07	-14.07	--	--	--	--	--	--	
413543103242402	B34E-M 19N 53W26BBCC2	5/12/2000	0940	A	7.6	541	8.0	8.3	--	2.8	.02	.05	<10	<2.2	-106.44	-14.00	16	.58	4.8	12	.0	--
		7/11/2000	1130		7.5	547	8.8	8.8	--	--	--	--	--	-104.86	-13.98	--	--	--	--	--	--	
		8/25/2000	1230		7.4	555	7.1	8.1	--	--	--	--	--	-108.02	-14.05	--	--	--	--	--	--	
413543103242401	B34E-D 19N 53W26BBCC1	5/12/2000	0900	B	7.7	434	8.1	3.2	--	3.4	<.01	--	E7.5	<2.2	-108.30	-14.25	16	.57	5.6	90	.0	--
		7/11/2000	1115		7.6	441	8.8	3.4	--	--	--	--	--	-107.74	-14.21	--	--	--	--	--	--	
		8/25/2000	1220		7.5	453	7.2	3.2	--	--	--	--	--	-107.35	-14.22	--	--	--	--	--	--	
413528103233402	B35E-S 19N 53W26DBAA2	5/11/2000	1500	A	7.7	445	7.8	3.7	--	4.6	.02	.05	<10	<2.2	-108.35	-14.24	16	.58	4.2	10	.0	--
		7/11/2000	1240		7.5	445	8.5	3.9	--	--	--	--	--	-106.83	-14.21	--	--	--	--	--	--	
		8/25/2000	1150		7.5	460	7.2	3.8	--	--	--	--	--	-107.61	-14.29	--	--	--	--	--	--	
413528103233401	B35E-D 19N 53W26DBAA1	5/11/2000	1420	A	7.7	487	7.8	4.6	--	4.4	.01	.03	<10	<2.2	-107.80	-14.12	16	.58	5.0	11	.0	--
		7/11/2000	1220		7.5	480	8.5	4.6	--	--	--	--	--	-105.40	-14.13	--	--	--	--	--	--	
		8/25/2000	1130		7.5	486	6.9	4.1	--	--	--	--	--	-107.02	-14.09	--	--	--	--	--	--	

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium; δ<sup>15</sup>N, nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron; µg/L, micrograms per liter; Mn, manganese; δ<sup>2</sup>H, hydrogen-isotope ratios in per mil Vienna standard mean oceanic water; <sup>18</sup>O, oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Exces N <sub>2</sub>
Ground water—Continued																						
413541103224602	B36E-S 19N 53W25BDAB2	5/12/2000	1250	A	7.4	763	4.9	12	--	4.3	0.01	0.03	<10	<2.2	-106.02	-13.89	18	0.61	1.0	21	0.0	--
		7/11/2000	1335		7.3	779	5.4	12	--	--	--	--	--	-105.85	-13.88	--	--	--	--	--	--	
		8/25/2000	1110		7.3	803	4.3	11	--	4.5	--	--	--	--	-104.90	-13.78	--	--	--	--	--	--
413541103224601	B36E-D 19N 53W25BDAB1	5/12/2000	1220	B	7.5	614	5.1	8.2	--	4.8	<.01	--	<10	<2.2	-109.30	-14.15	17	.61	2.5	14	.0	--
		7/11/2000	1315		7.4	630	5.5	8.6	--	--	--	--	--	-107.78	-14.13	--	--	--	--	--	--	
		8/25/2000	1050		7.4	645	4.4	8.0	--	4.6	--	--	--	--	-107.72	-14.23	--	--	--	--	--	--
414321103550802	1U-S 20N 57W 8BDDA2	5/22/2000	1510	A/B	7.6	792	4.4	4.7	--	--	.05	.15	<10	<2.2	-107.64	-14.15	17	.61	1.4	15	.0	--
		7/18/2000	0850		7.5	798	4.2	2.3	--	--	--	--	--	-107.25	-14.08	--	--	--	--	--	--	
		8/22/2000	1130		7.5	821	3.2	4.4	--	--	--	--	--	--	-109.17	-14.05	--	--	--	--	--	--
414321103550801	1U-D 20N 57W 8BDDA1	5/22/2000	1450	B	8.2	757	2.5	3.1	--	--	.08	.24	12	<2.2	-109.81	-14.35	24	.69	.41	60	.0	--
		7/18/2000	0830		8.1	747	7.6	2.3	--	--	--	--	--	-109.81	-14.30	--	--	--	--	--	--	
		8/22/2000	1100		8.0	793	4.3	1.9	--	--	--	--	--	--	-110.32	-14.36	--	--	--	--	--	--
413556103161903	23J-S 19N 52W25BBBB3	5/15/2000	1030	A	7.5	655	2.0	1.9	--	--	.01	.04	<10	<2.2	-104.03	-13.34	18	.61	.07	20	.0	--
		7/13/2000	0900		7.5	655	2.2	2.0	--	--	--	--	--	--	-102.66	-13.37	--	--	--	--	--	--
		8/24/2000	1600		7.3	671	2.4	1.9	--	--	--	--	--	--	-102.68	-13.32	--	--	--	--	--	--
413556103161902	23J-M 19N 52W25BBBB2	5/15/2000	1000	B	7.5	597	3.9	2.5	--	--	.01	.03	<10	<2.2	-104.46	-13.47	17	.60	.17	19	.0	--
		7/13/2000	0840		7.5	597	4.2	2.6	--	--	--	--	--	--	-102.69	-13.54	--	--	--	--	--	--
		8/24/2000	1550		7.4	609	4.9	2.5	--	--	--	--	--	--	-104.58	-13.55	--	--	--	--	--	--

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium;  $\delta^{15}\text{N}$ , nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron;  $\mu\text{g/L}$ , micrograms per liter; Mn, manganese;  $\delta^2\text{H}$ , hydrogen-isotope ratios in per mil Vienna standard mean oceanic water;  $\delta^{18}\text{O}$ , oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413556103161901	23J-D 19N 52W25BBBB1	5/15/2000	0940	B	7.7	563	4.1	1.6	--	--	0.02	0.07	<10	<2.2	-107.41	-14.14	17	0.61	0.74	11	0.0	--
		7/13/2000	0820		7.3	529	5.7	1.7	--	--	--	--	-107.13	-14.11	--	--	--	--	--	--		
		8/24/2000	1540		7.6	590	4.5	1.6	--	--	--	--	-105.38	-14.07	--	--	--	--	--	--		
413504103161703	23L-S 19N 52W25CCCC3	5/15/2000	1210	A	7.2	799	7.9	9.3	--	5.3	.03	.09	<10	<2.2	-101.34	-13.43	16	.58	3.8	30	.0	--
		7/13/2000	1020		7.3	848	8.1	11	--	--	--	--	-99.92	-13.26	--	--	--	--	--	--		
		8/24/2000	0910		7.2	754	8.8	6.3	--	--	--	--	-98.83	-13.09	--	--	--	--	--	--		
413504103161702	23L-M 19N 50W25CCCC2	5/15/2000	1140	A	7.4	606	5.9	4.3	--	4.8	.02	.06	<10	<2.2	-105.61	-14.06	17	.61	1.6	20	.0	--
		7/13/2000	0950		7.4	615	6.1	4.5	--	--	--	--	-106.10	-14.08	--	--	--	--	--	--		
		8/24/2000	0900		7.3	632	6.7	4.2	--	--	--	--	-105.67	-14.04	--	--	--	--	--	--		
413504103161701	23L-D 19N 52W25CCCC1	5/15/2000	1120	B	7.6	743	1.3	1.4	--	7.6	.51	1.6	<10	E1.3	-103.92	-13.64	--	--	--	--	--	--
		7/13/2000	0930		7.7	615	1.3	1.4	--	--	--	--	-102.81	-13.80	--	--	--	--	--	--		
		8/23/2000	0840		7.6	607	2.6	1.3	--	--	--	--	-102.20	-13.78	--	--	--	--	--	--		
413344103161603	23N-S 18N 52W 1CBBB3	5/13/2000	1220	A	7.2	580	8.2	2.1	--	--	.05	.15	<10	<2.2	-105.43	-14.06	18	.66	.12	31	.0	--
		7/13/2000	1140		7.3	622	7.5	2.9	--	--	--	--	-105.02	-13.99	--	--	--	--	--	--		
413344103161602	23N-M 18N 52W 1CBBB2	5/13/2000	1400	A	7.4	603	6.2	6.5	--	--	.02	.05	<10	<2.2	-105.37	-14.06	17	.61	1.0	19	.0	--
		7/13/2000	1120		7.4	605	6.4	6.4	--	--	--	--	-106.05	-14.07	--	--	--	--	--	--		
		8/24/2000	1300		7.3	621	6.9	5.8	--	--	--	--	-106.06	-14.04	--	--	--	--	--	--		
413344103161601	23N-D 18N 52W 1CBBB1	5/13/2000	1310	B	7.4	674	3.2	1.8	--	--	.01	.04	14	2.8	-106.29	-14.09	18	.59	.06	21	.0	3.0
		7/13/2000	1050		7.6	745	3.5	1.8	--	--	--	--	-104.62	-14.07	--	--	--	--	--	--		
		8/24/2000	1250		7.4	778	2.9	1.6	--	--	--	--	-106.17	-14.08	--	--	--	--	--	--		

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium; δ<sup>15</sup>N, nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron; µg/L, micrograms per liter; Mn, manganese; δ<sup>2</sup>H, hydrogen-isotope ratios in per mil Vienna standard mean oceanic water; <sup>18</sup>O, oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413305103154902	23O-S 18N 52W12BDAA2	5/23/2000	1400	B	7.5	632	4.0	4.8	--	--	0.03	0.09	<10	<2.2	-100.08	-13.56	--	--	--	--	--	--
		7/13/2000	1220		7.5	595	3.4	4.0	--	--	--	--	--	--	-100.48	-13.50	--	--	--	--	--	--
		8/24/2000	1600		7.5	570	2.7	3.0	--	--	--	--	--	--	-100.22	-13.37	--	--	--	--	--	--
413305103154901	23O-D 18N 52W12BDAA1	5/23/2000	1340	B	7.9	610	3.7	2.8	--	--	.03	.09	35	<2.2	-107.62	-14.12	--	--	--	--	--	--
		7/13/2000	1210		7.9	619	3.6	2.6	--	--	--	--	--	--	-107.04	-14.12	--	--	--	--	--	--
		8/24/2000	1530		7.9	628	4.2	2.4	--	--	--	--	--	--	-105.06	-14.08	--	--	--	--	--	--
413228103161803	23P-S 18N 52W11DDDD4	5/13/2000	0830	B	7.5	513	9.0	9.3	--	--	<.01	.01	<10	<2.2	-104.01	-13.98	18	0.63	3.2	18	0.0	--
		7/12/2000	1320		7.3	574	9.3	10	--	--	--	--	--	--	-105.61	-13.90	--	--	--	--	--	--
		8/24/2000	1010		7.3	613	9.4	*10	--	--	--	--	--	--	-103.29	-13.83	--	--	--	--	--	--
413228103161802	23P-M 18N 52W11DDDD3	5/13/2000	1010	FB	7.5	549	7.3	8.4	--	4	.01	.04	<10	<2.2	-106.26	-14.19	17	.59	2.6	15	.0	--
		7/12/2000	1300		7.4	552	7.6	8.3	--	--	--	--	--	--	-106.62	-14.22	--	--	--	--	--	--
		8/24/2000	0950		7.4	566	6.3	8.5	--	--	--	--	--	--	-108.27	-14.17	--	--	--	--	--	--
413228103161801	23P-D 18N 52W11DDDD2	5/13/2000	0940	B	8.2	446	5.5	3.0	--	4.2	<.01	--	12	2.3	-105.69	-14.16	--	--	--	--	--	--
		7/12/2000	1240		7.9	452	3.3	3.0	--	--	--	--	--	--	-107.63	-14.16	16	.59	.35	4.8	.0	1.0
		8/24/2000	0950		7.9	500	2.5	2.7	--	--	--	--	--	--	-105.32	-14.17	--	--	--	--	--	--
413227103170803	23R-S 18N 52W11CDCC3	5/12/2000	1410	A	7.4	595	5.4	3.4	--	--	.02	.07	<10	<2.2	-105.84	-13.98	18	.63	2.2	22	.0	--
		7/12/2000	1210		7.3	608	5.8	3.6	--	--	--	--	--	--	-105.45	-14.06	--	--	--	--	--	--
		8/24/2000	1210		7.2	636	6.4	4.4	--	--	--	--	--	--	-103.85	-13.92	--	--	--	--	--	--

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium;  $\delta^{15}\text{N}$ , nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron;  $\mu\text{g/L}$ , micrograms per liter; Mn, manganese;  $\delta^2\text{H}$ , hydrogen-isotope ratios in per mil Vienna standard mean oceanic water;  $\delta^{18}\text{O}$ , oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413227103170802	23R-M 18N 52W11CDCC2	5/12/2000	1500	A	7.5	524	5.8	4.5	--	--	0.02	0.05	<10	<2.2	-107.93	-14.23	16	0.59	1.6	16	0.0	--
		7/12/2000	1150		7.4	533	5.9	4.5	--	--	--	--	--	-107.34	-14.25	--	--	--	--	--	--	
		8/24/2000	1150		7.3	556	6.2	4.1	--	--	--	--	--	-106.77	-14.16	--	--	--	--	--	--	
413227103170801	23R-D 18N 52W11CDCC1	5/12/2000	1350	B	7.7	618	1.9	2.8	0.37	--	1.5	4.7	1,100	163	-106.59	-14.40	--	--	--	--	--	--
		7/12/2000	1140		7.6	612	2.4	2.2	--	--	--	--	--	-105.13	-14.26	--	--	--	--	--	--	
		8/24/2000	1130		7.6	669	1.7	2.2	--	--	--	--	--	-107.12	-14.30	--	--	--	--	--	--	
413555103150903	24I-S 19N 51W19CCCC3	5/15/2000	1510	A	7.3	732	5.2	6.9	--	--	.02	.06	<10	<2.2	-104.77	-13.77	17	.60	1.1	22	.0	--
		7/13/2000	1410		7.4	725	5.6	6.6	--	--	--	--	--	-103.44	-13.81	--	--	--	--	--	--	
		8/25/2000	0910		7.4	765	5.2	6.9	--	--	--	--	--	-104.14	-13.85	--	--	--	--	--	--	
413555103150902	24I-M 19N 51W19CCCC2	5/15/2000	1440	FB	7.3	575	3.3	2.7	--	--	.02	.06	<10	<2.2	-105.07	-13.92	17	.61	.88	21	.0	--
		7/13/2000	1350		7.3	629	3.5	2.6	--	--	--	--	--	-105.00	-13.98	--	--	--	--	--	--	
		8/25/2000	0920		7.3	649	3.2	2.6	--	--	--	--	--	-105.40	-13.86	--	--	--	--	--	--	
413555103150901	24I-D 19N 51W19CCCC1	5/15/2000	1410	FB	7.3	631	3.1	2.6	--	--	.02	.06	<10	<2.2	-106.34	-13.84	17	.60	.06	20	.0	--
		7/13/2000	1330		7.4	649	3.1	2.6	--	--	--	--	--	-104.36	-13.85	--	--	--	--	--	--	
		8/25/2000	0850		7.3	655	3.2	2.6	--	--	--	--	--	-104.87	-13.91	--	--	--	--	--	--	
413503103145401	24J-S 19N 51W30CCCC1	5/15/2000	1320	FB	7.5	535	6.6	3.3	--	--	.02	*.06	<10	<2.2	-101.44	-13.36	16	.60	3.1	13	.0	--
		7/13/2000	1300		7.5	528	6.7	3.2	--	--	--	--	--	-100.64	-13.39	--	--	--	--	--	--	
		8/24/2000	1510		7.4	540	7.4	2.9	--	--	--	--	--	-101.20	-13.35	--	--	--	--	--	--	

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

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Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413609103140202	24L-S 19N 51W19DADD2	5/16/2000	1050	FB	7.4	708	1.1	1.6	--	--	0.03	0.09	<10	<2.2	-100.24	-12.98	18	0.61	0.06	26	0.0	1.0
		7/13/2000	1500		7.3	700	1.2	1.8	--	--	--	--	--	-99.86	-12.99	--	--	--	--	--	--	
		8/24/2000	1410		7.2	722	1.4	1.6	--	--	--	--	--	-98.96	-12.96	--	--	--	--	--	--	
413609103140201	24L-D 19N 51W19DADD1	5/16/2000	1020	B	8.0	487	3.4	3.0	--	--	.21	.65	<10	<2.2	-99.21	-13.15	--	--	--	--	--	--
		7/13/2000	1440		7.9	456	3.8	2.1	--	--	--	--	--	-98.70	-13.06	--	--	--	--	--	--	
		8/24/2000	1350		7.8	452	4.0	1.5	--	--	--	--	--	-96.34	-13.04	--	--	--	--	--	--	
413503103120003	25I-S 19N 51W29DDDD3	5/16/2000	0930	A	7.5	759	6.5	10	--	--	.02	.07	<10	<2.2	-101.28	-13.46	17	.62	1.6	22	.0	--
		7/17/2000	1150		7.4	774	6.8	10	--	--	--	--	--	-100.93	-13.52	--	--	--	--	--	--	
		8/23/2000	1550		7.3	832	9.9	5.0	--	--	--	--	--	-104.36	-13.77	--	--	--	--	--	--	
413503103120002	25I-M 19N 51W29DDDD2	5/16/2000	0900	A	7.6	647	5.7	7.2	--	--	.02	.05	<10	<2.2	-103.65	-13.64	18	.62	1.4	17	.0	--
		7/17/2000	1130		7.5	647	6.0	7.4	--	--	--	--	--	-102.66	-13.66	--	--	--	--	--	--	
		8/23/2000	1530		7.4	669	8.5	6.7	--	--	--	--	--	-101.72	-13.72	--	--	--	--	--	--	
413503103120001	25I-D 19N 51W29DDDD1	5/16/2000	0840	FB	7.6	557	4.9	5.1	--	--	<.01	--	<10	<2.2	-103.43	-13.76	18	.63	2.1	13	.0	--
		7/17/2000	1110		7.5	579	5.3	5.8	--	--	--	--	--	-103.02	-13.77	--	--	--	--	--	--	
		8/23/2000	1520		7.5	601	7.8	5.3	--	--	--	--	--	-102.63	-13.75	--	--	--	--	--	--	
413411103124703	25J-S 19N 51W33CCCD3	5/17/2000	1340	A	7.7	497	7.8	4.1	--	--	.02	.06	<10	<2.2	-96.88	-12.96	15	.57	2.3	11	.0	--
		7/13/2000	1540		7.6	501	8.3	4.1	--	--	--	--	--	-98.30	-13.01	--	--	--	--	--	--	
		8/23/2000	1610		7.6	519	12	3.9	--	--	--	--	--	-96.79	-12.97	--	--	--	--	--	--	

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium;  $\delta^{15}\text{N}$ , nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron;  $\mu\text{g/L}$ , micrograms per liter; Mn, manganese;  $\delta^2\text{H}$ , hydrogen-isotope ratios in per mil Vienna standard mean oceanic water;  $\delta^{18}\text{O}$ , oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413502103103703	26K-S 19N 51W27DDDD3	5/16/2000	1310	A	7.3	775	6.3	6.3	--	--	0.02	0.07	<10	<2.2	-102.74	-13.53	16	0.61	2.4	31	0.0	--
		7/17/2000	1320		7.3	780	6.5	6.6	--	--	--	--	--	--	-102.45	-13.54	--	--	--	--	--	--
		8/23/2000	1450		7.2	813	9.1	6.4	--	--	--	--	--	--	-103.66	-13.48	--	--	--	--	--	--
413502103103702	26K-M 19N 51W27DDDD2	5/16/2000	1240	A	7.4	678	4.2	5.2	--	--	.02	.07	<10	<2.2	-103.28	-13.70	17	.62	.68	21	.0	--
		7/17/2000	1300		7.4	686	4.4	5.2	--	--	--	--	--	--	-103.96	-13.74	--	--	--	--	--	--
		8/23/2000	1430		7.3	715	6.3	5.0	--	--	--	--	--	--	-104.46	-13.76	--	--	--	--	--	--
413502103103701	26K-D 19N 51W27DDDD1	5/16/2000	1210	FB	7.4	676	4.2	5.2	--	--	.02	.05	<10	<2.2	-103.80	-13.74	17	.62	.18	22	.0	--
		7/17/2000	1240		7.4	684	4.4	5.2	--	--	--	--	--	--	-104.44	-13.77	--	--	--	--	--	--
		8/23/2000	1420		7.3	712	6.2	5.0	--	--	--	--	--	--	-103.76	-13.79	--	--	--	--	--	--
413502103103704	26K-T 19N 51W27DDDD4	5/16/2000	1140	FB	7.5	668	4.9	6.2	--	--	.01	.04	<10	<2.2	-106.28	-13.73	18	.63	.99	20	.0	--
		7/17/2000	1220		7.4	670	5.2	6.2	--	--	--	--	--	--	-103.21	-13.72	--	--	--	--	--	--
		8/23/2000	1400		7.4	698	7.1	5.8	--	--	--	--	--	--	-104.04	-13.81	--	--	--	--	--	--
413501103082203	27K-S 19N 51W36AAAA3	5/23/2000	1520	A	7.3	684	3.5	8.3	--	--	.04	.11	<10	<2.2	-103.24	-13.63	--	--	--	--	--	--
		7/17/2000	1430		7.3	693	3.6	9.0	--	--	--	--	--	--	-102.27	-13.58	--	--	--	--	--	--
		8/23/2000	1340		7.3	719	4.9	11	--	--	--	--	--	--	-103.56	-13.58	--	--	--	--	--	--
413501103082202	27K-M 19N 51W36AAAA2	5/23/2000	1500	A	7.5	556	5.2	5.9	--	--	.02	.05	<10	<2.2	-103.86	-13.70	--	--	--	--	--	--
		7/17/2000	1410		7.5	557	5.5	6.4	--	--	--	--	--	--	-102.82	-13.73	--	--	--	--	--	--
		8/23/2000	1320		7.4	581	7.6	5.8	--	--	--	--	--	--	-102.68	-13.70	--	--	--	--	--	--

**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

[All concentrations in milligrams per liter unless otherwise noted; ID, identification number; AT, aquifer type; pH in standard units; SC, specific conductance in microsiemens per centimeter at 25 degrees Celsius; DO, dissolved oxygen; NO<sub>3</sub>, nitrate as nitrogen; NH<sub>4</sub>, ammonium; δ<sup>15</sup>N, nitrogen-isotope ratios in per mil; P, phosphorus; PO<sub>4</sub>, phosphate; Fe, iron; µg/L, micrograms per liter; Mn, manganese; δ<sup>2</sup>H, hydrogen-isotope ratios in per mil Vienna standard mean oceanic water; <sup>18</sup>O, oxygen-isotope ratios in per mil Vienna standard mean oceanic water; N, nitrogen; Ar, Argon; O<sub>2</sub>, Oxygen; CO<sub>2</sub>, Carbon Dioxide; CH<sub>4</sub>, methane; --, no results; Cr, creek; <, less than, E, estimated; B, Brule Formation; A, alluvial; FB, fractured Brule Formation; A/B, alluvial/Brule Formation; \*, environmental and quality assurance sample varied by more than 5 percent]

Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413501103082201	27K-D 19N 51W36AAAA1	5/23/2000	1440	B	7.5	548	5.0	5.5	--	--	0.01	0.04	<10	<2.2	-104.80	-13.76	--	--	--	--	--	--
		7/17/2000	1350		7.5	550	5.4	5.8	--	--	--	--	--	--	-104.55	-13.73	--	--	--	--	--	--
		8/23/2000	1300		7.4	568	7.2	5.4	--	--	--	--	--	--	-104.26	-13.81	--	--	--	--	--	--
413708103055701	28J-S 19N 50W17DADA1	5/23/2000	1550	B	7.9	686	.1	.12	0.23	--	.10	.32	41	506	-104.77	-13.90	--	--	--	--	--	--
		7/19/2000	1550		8.1	689	.2	.23	--	--	--	--	--	--	-103.07	-13.91	--	--	--	--	--	--
		8/23/2000	1110		8.0	682	1.2	.05	--	--	--	--	--	--	-105.76	-14.02	--	--	--	--	--	--
413510103060103	28L-S 19N 50W29DDAA3	5/16/2000	1530	A	7.4	601	2.7	4.6	--	--	.02	.06	<10	<2.2	-104.65	-13.61	18	0.61	0.09	20	0.0	1.0
		7/17/2000	1600		7.4	609	2.7	4.2	--	--	--	--	--	--	-103.27	-13.57	--	--	--	--	--	--
		8/23/2000	1240		7.3	630	3.4	3.5	--	--	--	--	--	--	-103.77	-13.59	--	--	--	--	--	--
413510103060102	28L-M 19N 50W29DDAA2	5/16/2000	1500	FB	7.4	588	3.5	5.0	--	--	.02	.05	<10	<2.2	-104.98	-13.65	18	.62	.55	18	.0	--
		7/17/2000	1540		7.4	597	2.8	1.1	--	--	--	--	--	--	-102.28	-13.60	--	--	--	--	--	--
		8/23/2000	1220		7.3	615	3.8	3.6	--	--	--	--	--	--	-102.53	-13.60	--	--	--	--	--	--
413510103060101	28L-D 19N 50W29DDAA1	5/16/2000	1430	FB	7.5	564	3.3	4.2	--	--	.01	.04	<10	<2.2	-103.76	-13.73	18	.62	.41	17	.0	--
		7/17/2000	1520		7.4	580	2.8	3.6	--	--	--	--	--	--	-103.58	-13.63	--	--	--	--	--	--
		8/23/2000	1200		7.3	609	3.9	2.8	--	--	--	--	--	--	-103.52	-13.58	--	--	--	--	--	--
413510103060104	28L-T 19N 50W29DDAA4	5/16/2000	1400	B	7.9	421	6.6	2.1	--	--	<.01	<.01	<10	<2.2	-102.25	-13.77	16	.60	3.8	6.8	.0	--
		7/17/2000	1500		7.9	423	6.4	2.1	--	--	--	--	--	--	-103.74	-13.74	--	--	--	--	--	--
		8/23/2000	1150		7.7	440	8.6	2.0	--	--	--	--	--	--	-102.92	-13.77	--	--	--	--	--	--



**Table 8.** Results of water-quality analysis for field measurements, nutrients, stable isotopes, and dissolved gases in water samples, Pumpkin Creek Valley, western Nebraska, 2000.—Continued

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Station ID	Field ID (fig. 1) Legal ID	Date	Time	AT	pH	SC	DO	NO <sub>3</sub>	NH <sub>4</sub>	δ <sup>15</sup> N	P	PO <sub>4</sub>	Fe (µg/L)	Mn (µg/L)	δ <sup>2</sup> H	δ <sup>18</sup> O	Dissolved gases					
																	N	Ar	O <sub>2</sub>	CO <sub>2</sub>	CH <sub>4</sub>	Excess N <sub>2</sub>
Ground water—Continued																						
413726103023503	29I-S 19N 50W14AAAD3	5/17/2000	1550	A	7.5	768	2.1	2.8	--	13	0.09	0.28	<10	<2.2	-101.92	-12.90	18	0.60	0.06	19	0.0	1.0
		7/19/2000	1400		7.1	1,120	.9	4.4	--	--	--	--	--	--	-99.65	-12.63	--	--	--	--	--	--
		8/23/2000	0930		7.0	1,050	2.8	4.8	--	11	--	--	--	--	-101.02	-12.99	--	--	--	--	--	--
413726103023502	29I-M 19N 50W14AAAD2	5/17/2000	1510	A	7.6	752	4.5	3.0	--	5.6	.05	.16	<10	2.2	-105.94	-13.38	16	.55	.22	15	.0	1.0
		7/19/2000	1340		7.5	746	4.4	2.9	--	--	--	--	--	--	-104.50	-13.36	--	--	--	--	--	--
		8/23/2000	0910		7.3	773	6.8	2.7	--	6.0	--	--	--	--	-108.58	-13.42	--	--	--	--	--	--
413726103023501	29I-D 19N 50W14AAAD1	7/19/2000	1320	A	7.5	715	2.9	2.4	--	--	--	--	--	--	-106.12	-13.62	16	.56	.23	14	.0	1.0
		5/17/2000	1440		7.6	665	3.7	2.4	--	5.7	.02	.07	<10	2.2	-108.57	-13.64	--	--	--	--	--	--
		8/23/2000	0850		7.3	728	6.0	2.2	--	6.8	--	--	--	--	-108.06	-13.62	--	--	--	--	--	--
413651103023403	29J-S 19N 50W14DDDA3	5/24/2000	1050	A	7.6	720	3.8	3.2	--	--	.04	.13	<10	<2.2	-103.85	-13.11	--	--	--	--	--	--
		7/19/2000	1510		7.6	710	4.7	3.8	--	--	--	--	--	--	-101.54	-13.12	--	--	--	--	--	--
		8/23/2000	1030		7.5	729	6.8	3.2	--	--	--	--	--	--	-101.40	-13.11	--	--	--	--	--	--
413651103023402	29J-M 19N 50W14DDDA2	5/24/2000	1030	A	7.5	709	4.3	4.2	--	--	.02	.07	<10	E2.0	-102.46	-13.28	--	--	--	--	--	--
		7/19/2000	1450		7.5	701	3.8	3.5	--	--	--	--	--	--	-102.08	-13.38	--	--	--	--	--	--
		8/23/2000	1020		7.4	743	4.4	2.0	--	--	--	--	--	--	-103.50	-13.35	--	--	--	--	--	--
413651103023401	29J-D 19N 50W14DDDA1	5/24/2000	1000	A	7.4	633	3.1	9.3	--	--	.03	.09	<10	26	-104.60	-13.89	--	--	--	--	--	--
		7/19/2000	1430		7.5	638	2.9	9.7	--	--	--	--	--	--	-105.04	-13.83	--	--	--	--	--	--
		8/23/2000	1000		7.4	681	4.7	9.4	--	--	--	--	--	--	-105.09	-13.80	--	--	--	--	--	--

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