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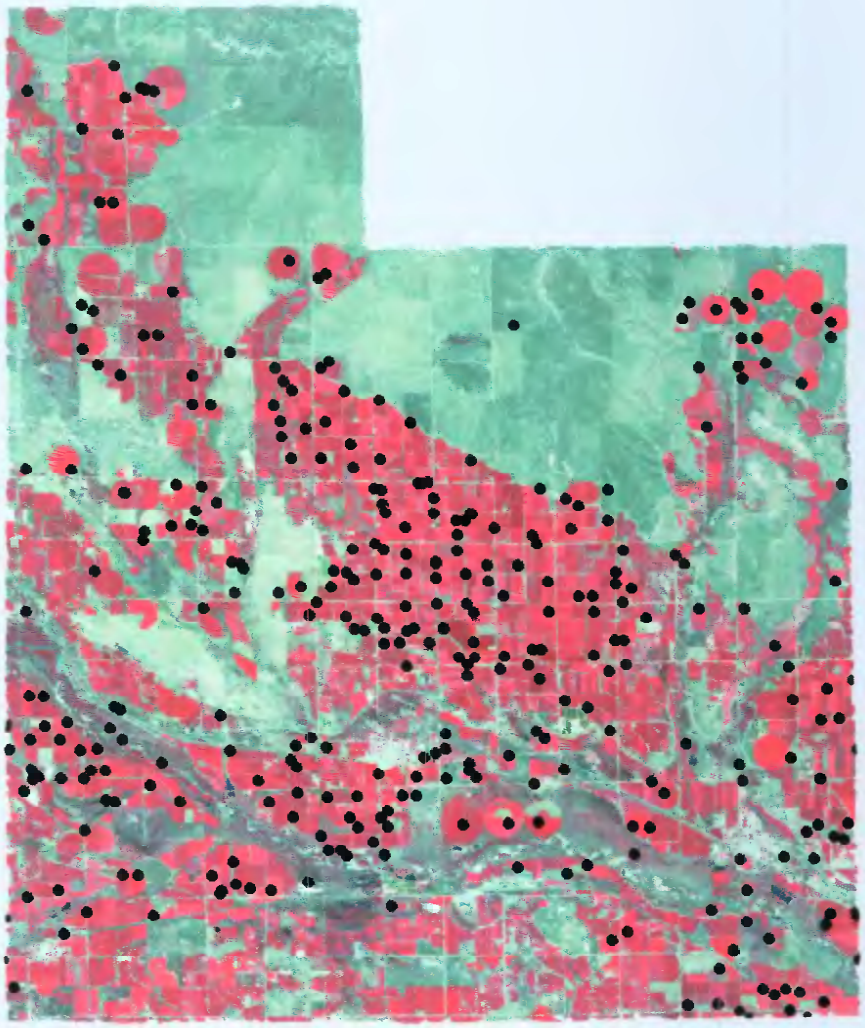
Interaction of Surface Water and Ground Water in the Dutch Flats Area, Western Nebraska, 1995–99

Water-Resources Investigations Report 01–4070



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

Cover: Landsat Thermal Mapper (TM) image. The false color composite is created by displaying the infrared band with the red color gun, red band with the green color gun, and green band with the blue color gun. Areas that appear red on the image tend to indicate areas of significant vegetation.

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U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director

Lincoln, Nebraska: 2001

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	4,047	square meter
square mile (mi^2)	2.590	square kilometer
	Volume	
acre-foot (acre-ft)	1,233	cubic meter
gallon (gal)	3.785	liter
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per day [(ft^3/s)/d]	0.02832	cubic meter per second per day
foot per mile (ft/mi)	0.1894	meter per kilometer
gallon per minute (gal/min)	0.06309	liter per second
inch per year (in/yr)	2.54	centimeter per year
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day

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

$$°F = (1.8 \times °C) + 32.$$

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

$$°C = (°F - 32) / 1.8.$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

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).

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Abstract

A study of the water resources of the Dutch Flats area in western Nebraska was conducted from 1995 through 1999 to describe the surface water and hydrogeology, the spatial distribution of selected water-quality constituents in surface and ground water, and the surface-water/ground-water interaction in selected areas. As part of this effort, 11 surface-water sites and 79 ground-water sites were selected, water levels were measured, and 130 surface-water and 1,960 ground-water samples were collected for chemical analyses.

Recharge to the ground-water system by precipitation is much less than recharge to the ground-water system by infiltration of water seeping from irrigation canals and laterals and by infiltration of water applied to fields for irrigation.

Specific conductance, calcium, magnesium, sulfate, nitrate, and uranium concentrations, and uranium activity ratios varied in space and time and were used in the evaluation of surface-water/ground-water interaction and determination of ground-water flow. The specific-conductance values in water from the Interstate Canal and in ground water immediately upgradient from the canal were different. However, differences in specific-conductance values between surface and ground water were not as obvious near the Tri-State Canal and were variable near the North Platte River. Differences in major-ion compositions indicated flow paths. Water from the northern alluvial aquifer generally moved from north to south and mixed in part with water from the Brule aquifer. In the southern alluvial aquifer south of the North Platte River, water moved from the southwest to the northeast and mixed in part with older water from the Chadron aquifer.

In ground water, a stratification of nitrate concentrations was detected, with large concentrations in shallow, young water at times exceeding 20 milligrams per liter and smaller concentrations less than 0.05 milligram per liter in deep, old water. The U.S. Environmental Protection Agency Maximum Contaminant Level of 10 milligrams per liter was exceeded in 17 of 116 samples from shallow water in the alluvial aquifer. Denitrification did not seem to be an important process in the alluvial aquifer but may be occurring near the contact with bedrock aquifers.

Uranium concentrations varied from 11 to 31 micrograms per liter in water from the North Platte River at Morrill and were smaller in the river at the State line. Uranium concentrations of as much as 44 micrograms per liter were detected in water samples from Owl Creek near Lyman. Uranium in water samples from the shallow alluvial aquifer ranged from about 2.0 micrograms per liter north of the Tri-State Canal to as much as 80 micrograms per liter in the southern part of the alluvial aquifer. Seventeen of 121 water samples from the alluvial aquifer exceeded the U.S. Environmental Protection Agency Maximum Contaminant Level of 30 micrograms per liter for uranium. The largest radon activity was observed in water from the Chadron aquifer. Radon

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[3]U.S. Geological Survey, North Platte, Nebraska.
[4]U.S. Geological Survey, Reston, Virginia.

activity in excess of 1,000 picocuries per liter often was present in water samples from wells completed in the Brule aquifer. Ninety-four of 117 samples from the alluvial aquifer exceeded the proposed U.S. Environmental Protection Agency Maximum Contaminant Level of 300 picocuries per liter for radon.

Water seeping through the unlined bottoms of canals into the alluvial aquifer caused rises in ground-water levels. The North Platte River generally gained streamflow throughout its reach in the study area. Recharge of ground water by surface water from the canals resulted in temporal changes in the quality of ground water. At the Interstate Canal, surface water appeared to replace ground water in about 1 month in the upper 30 feet of the alluvial aquifer within about 1 mile of the canal. The effect was less pronounced in the rest of the study area. Local indicators of surface-water/ground-water interaction included specific-conductance values, calcium, magnesium, sulfate, nitrate, and uranium concentrations, and uranium activity ratios. When water was flowing through the Interstate Canal, increases in specific-conductance values and sulfate concentrations and decreases in nitrate and uranium concentrations, and uranium activity ratios in the shallow ground water were observed.

Overall, surface-water/ground-water interaction recharged the alluvial aquifer in part and provided relief locally near the canals and laterals through dilution of nitrate concentrations in ground water with canal water. However, at greater distances from the canals and laterals, irrigation with canal water transported nitrogen from the land surface to the ground water.

INTRODUCTION

During the last 10 years, surface and ground water have become regarded as a single resource (Winter and others, 1998). Human activities commonly affect the distribution of surface and ground water, their interaction, and the quality of the water through, for example, a variety of irrigation practices and addition of fertilizer to the land for agricultural purposes. It has been demonstrated that contaminated aquifers discharging to streams can degrade surface-water quality and that streams discharging to ground water can degrade ground-water quality, especially when induced infiltration occurs (Verstraeten and others, 1999). Managers making decisions requiring withdrawals of surface or ground water and their addition to the land surface need to consider the extent to which different pumping conditions affect water availability both on the surface and in the ground (Alley and others, 1999) and the extent to which addition of fertilizer to the land can contaminate water. With knowledge of the available water resources, appropriate management approaches can be used to satisfy water demand and sustain water quality.

The hyporheic zone is the area where stream water flows through short segments of the adjacent streambed (Winter and others, 1998). The zone can vary greatly in time and space. Because surface-water/ground-water interaction has been difficult to quantify, historically these interactions generally have not been considered in Nebraska water-management policies. In 1996, the Nebraska legislature recognized this interaction and promulgated a law acknowledging its existence (State of Nebraska, 1998).

Surface-water/ground-water interaction is an important aspect of the hydrology of the Dutch Flats area, a locally prominent terrain feature in Scotts Bluff and Sioux Counties in the western part of the North Platte Natural Resources District (NRD) in Nebraska (fig. 1). Ground-water-quality investigations done in the North Platte NRD include those by Wenzel and others (1946), Durum (1950), Rainwater (1956), the Conservation and Survey Division (1980a, b), and Verstraeten and others (1995). Surface-water quality in the North Platte NRD was studied by Steele and Cannia (1997) and Druliner and others (1999). The authors of these water-quality studies suggested that large concentrations of nitrate are present in ground water but are not present in surface water. They also suggested that, in parts of the Dutch Flats area, large concentrations of uranium, radon, and gross alpha are present. Exceedances of U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Levels (MCLs) of nitrate and uranium were found. Concentrations of uranium in places and at times exceeded 30 µg/L in the North Platte River and nearby canals and drains. Babcock and Visher (1951) reported that water from the canals sometimes seeps into the ground and provides a temporary increase in local recharge rates, potentially affecting the quality of the ground water.

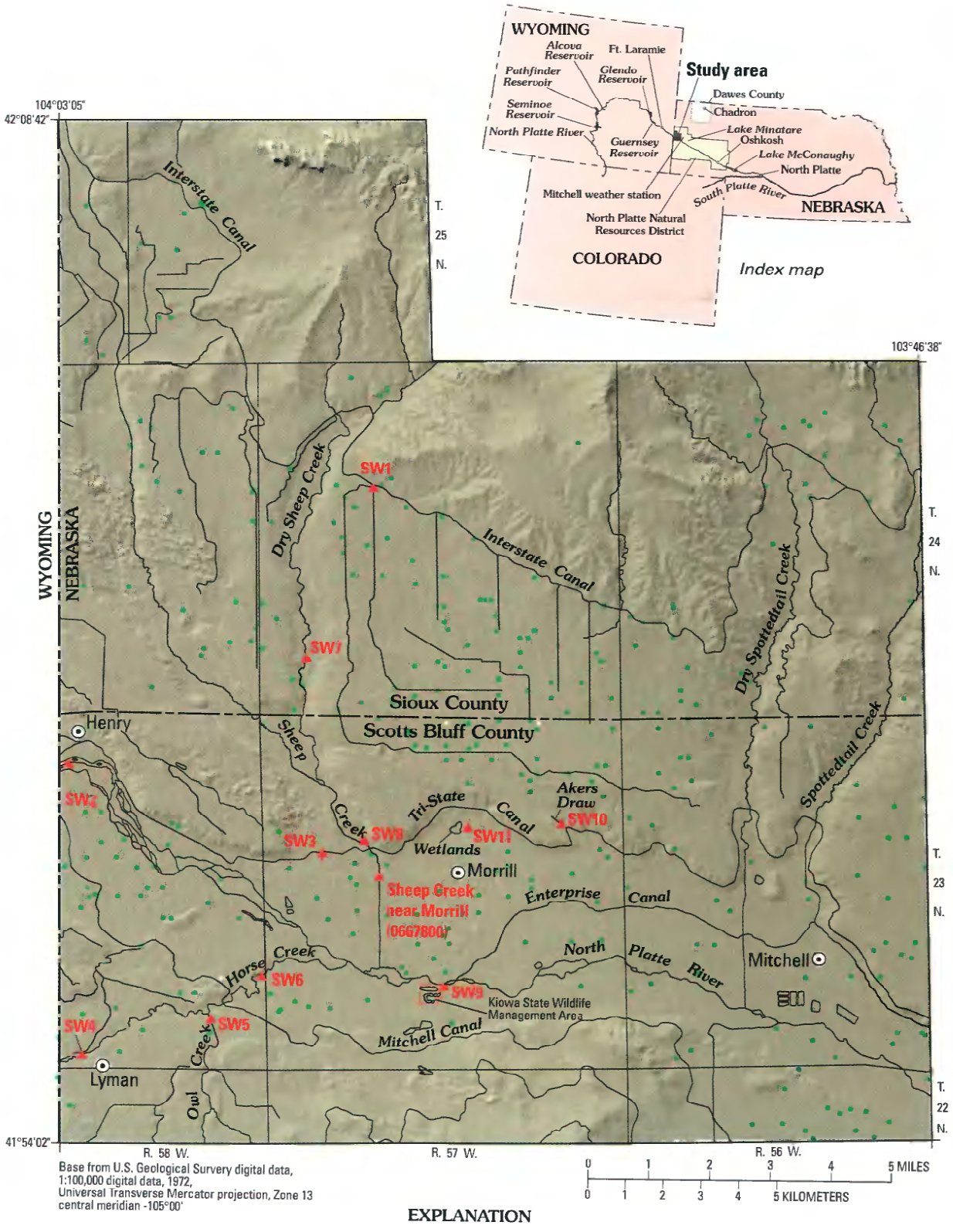


Figure 1. Location of the Dutch Flats study area, surface-water sampling sites, and irrigation wells, western Nebraska.

It is important for water managers to evaluate how surface and ground water interact because each hydrologic component affects the other. To make a reliable evaluation of the water resources in the Dutch Flats area, more information was needed about the quantity and quality of surface and ground water and their interaction. A study was conducted from 1995 through 1999 by the U.S. Geological Survey (USGS), in cooperation with North Platte NRD, to characterize surface-water/ground-water interaction and the potential effect of seepage from canals on ground-water quantity and quality in the Dutch Flats area. The specific objectives of the study were to describe:

- Surface water and hydrogeology,
- Spatial distribution of selected water-quality constituents in surface and ground water, and
- Surface-water/ground-water interaction in selected areas.

The Dutch Flats forms the majority of the study area. Areas north of the Interstate Canal and south of the North Platte River surrounding the actual flats also were included in the study area (fig. 1).

The purpose of this report is to present the interpretive results of the study. The analytical data from the study are presented in Boohar and Walczyk (1997, 1998), Boohar (2000), and Verstraeten and others (in press).

The authors thank the landowners for permission to construct wells and collect samples on their property. The authors also thank Sonja Sebree, Keith Kollasch, and Aaron Carnes of the USGS for their contributions with geographic information systems (GIS) and creation of figures included in the report, and John Miller of the USGS for his dedication during sampling. Thanks also are extended to Jackie Rick of the North Platte NRD for completion of required forms and creation of data tables during this study. Thanks also are extended to the Nebraska Department of Environmental Quality and the USEPA for their support of the study.

DESCRIPTION OF STUDY AREA

The study area is a 212-mi^2 area in the western part of the North Platte NRD, western Nebraska (fig. 1). The Dutch Flats area is in southwestern Sioux County and northwestern Scotts Bluff County in the North Platte River Valley. The study area is characterized by bottomland, a series of terraces with flat upland areas, and footslopes north of the North Platte River, and bottomland and footslopes south of the North Platte River. Towns in the study area are Henry, Lyman, Morrill, and Mitchell, with a total population of about 3,300. Mitchell has the largest population, about 1,750 residents (Clerk of the Legislature, 1999).

The Dutch Flats area has a semiarid climate with a diverse temperature range, which is characteristic of mid-latitude locations. The mean daily maximum temperature is 62.8 °F, and the mean daily minimum temperature is 34.1 °F. The average annual temperature of the study area in 1997 was 48.0 °F, with the highest average temperature in July (72.4 °F) and the lowest in January (24.8 °F) (M.D. Werner, High Plains Climate Center, University of Nebraska-Lincoln, written commun., 1998). The largest amounts of precipitation generally result from thunderstorms during the months of May and July (fig. 2). The mean annual precipitation at Mitchell (station 5590) was 13.6 in. from 1909 to 1999 (National Oceanic and Atmospheric Administration, 1998). Snowfall generally occurs between October and April. The mean annual snowfall received at the Mitchell station was 16.8 in. and is based on data collected from 1906 through 1997. The maximum monthly snowfall received at Mitchell in 1996 was 13 in. Evaporation generally is variable, with most evaporation occurring during the hot and dry summer months (23 in. during the growing season) (Benham, 1998). The mean annual evaporation at this station was 45 in. from 1949 through 1994 (National Oceanic and Atmospheric Administration, 1994).

Soils primarily are formed from eolian sand, alluvial deposits, or weathered siltstone and mudstone. Soils on the upland, terraces, and footslopes near the surface mainly consist of silt loam and sandy loam. The subsoils in these areas consist of silt loam to fine sand. The soils on the upland are well developed and deep. They are generally well to excessively well drained and have highly variable slopes (Yost and others, 1968).

Soils on the bottomland consist of loam to fine sandy loam near the surface. The bottomland has poorly to well-developed soils, which generally are poorly to somewhat poorly drained, are nearly level, with 0 to 3 percent slopes, and have 0.5 to about 3.0 percent organic matter. The subsoil generally consists of clay, silt, or sand and gravel (Yost and others, 1968).

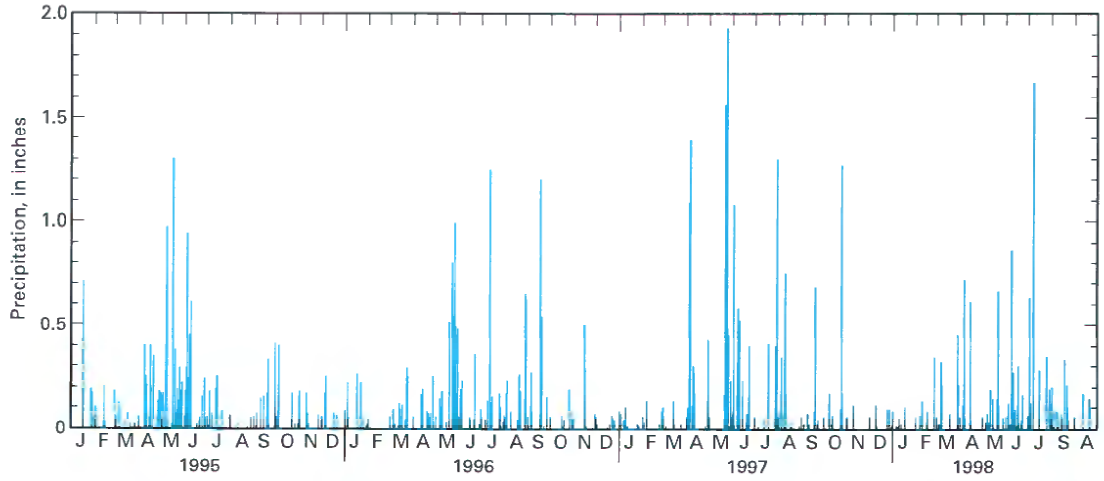


Figure 2. Precipitation at Mitchell, Nebraska (station 5590), January 1995 through September 1998. Data from National Oceanic and Atmospheric Administration (1998).

Land Use and Fertilizer Application

Agriculture is the primary land use in the study area (fig. 3). Major crops raised in the area are corn, dry beans, sugar beets, and alfalfa. A large part of the study area consists of rangeland. Land uses other than for agriculture include urban, light industry, recreation, a wildlife refuge, and infrastructure. Cattle and hog operations are in the area, as well as a small exotic-game farm. Light industry in the area consists of a sugar-beet processing plant in Mitchell, Nebraska, and a dry-bean processing and distributing plant in Morrill, Nebraska. South of Morrill is the Kiowa State Wildlife Management Area, which provides public hunting and educational activities. Other recreational activities in the area include fishing, bicycling, walking, hiking, and canoeing.

Application of fertilizers, mostly in the form of anhydrous ammonia or manure, has increased gradually over time with about a 15-fold increase in commercial fertilizer nitrogen use from 1950 to 1994 in Scotts Bluff County (fig. 4). In the study area, fertilizer mainly is applied to corn, dry beans, and sugar beets (fig. 4).

Water Use

Crops mainly are irrigated by surface water supplied by three major canal systems and laterals (fig. 1). Laterals are large unlined ditches that transport water from the canals to the cropped fields. The Interstate Canal, also known as the Pathfinder Canal, supplies water for 33,000 acres (Kevin Adams, Farmers Irrigation District, oral commun., 1999). The Tri-State Canal, also known as the Farmers Canal, supplies water for about 3,600 acres. The Mitchell Canal, in the southern part of the study area, supplies water for about 6,600 acres. A total of about 43,200 acres are irrigated from these canals. The Enterprise Canal supplies water for land outside the study area. Crops also are irrigated using ground water; about 14 percent of all the water used for irrigation in Scotts Bluff County in 1995 was supplied by irrigation wells (fig. 1). On the basis of Landsat thematic imagery, the estimated irrigated area in 1997 was between 41,000 and 54,500 acres or between 31 and 41 percent of the land in the study area (Brian Fisher, U.S. Geological Survey, written commun., 1999).

Water use for irrigation in Scotts Bluff County in 1985 was 318,300 acre-ft with a seasonal (June through September) application of 17.7 in. per irrigated acre in a season (Steele, 1988), which is 4 in. more than the mean annual precipitation of 13.6 in/yr. The seasonal irrigation requirement to grow corn has been estimated at 14.2 in. in a sandy loam soil in western Nebraska (Benham, 1998). In 1985, surface water contributed 273,600 acre-ft of the 318,300 acre-ft total, or about 86 percent of all the water applied. Amounts of surface and ground water used for agricultural purposes are dependent upon the precipitation and temperatures during a growing season. Municipalities and selected industries rely mainly on ground water.

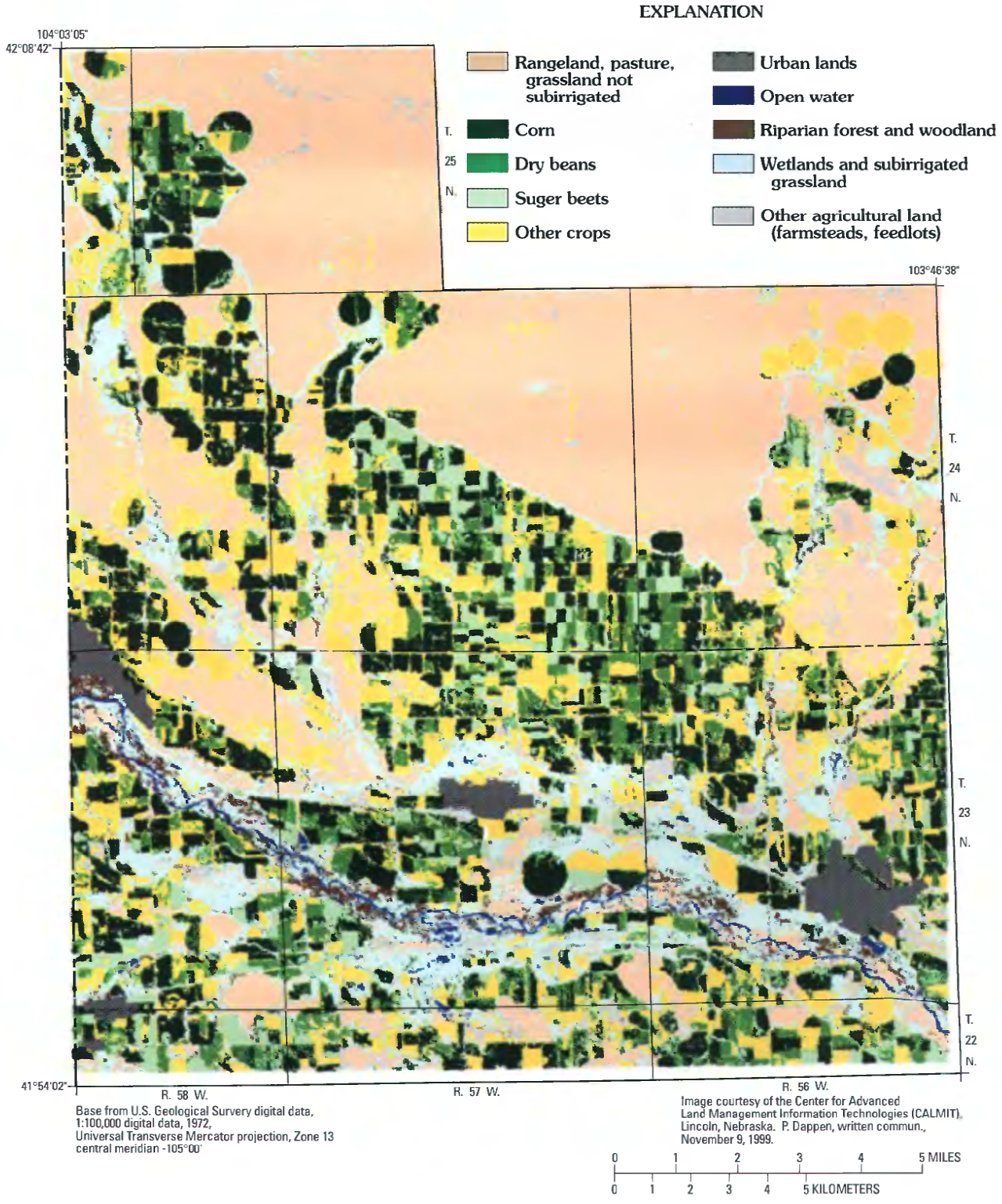


Figure 3. Land use in the Dutch Flats study area, 1997.

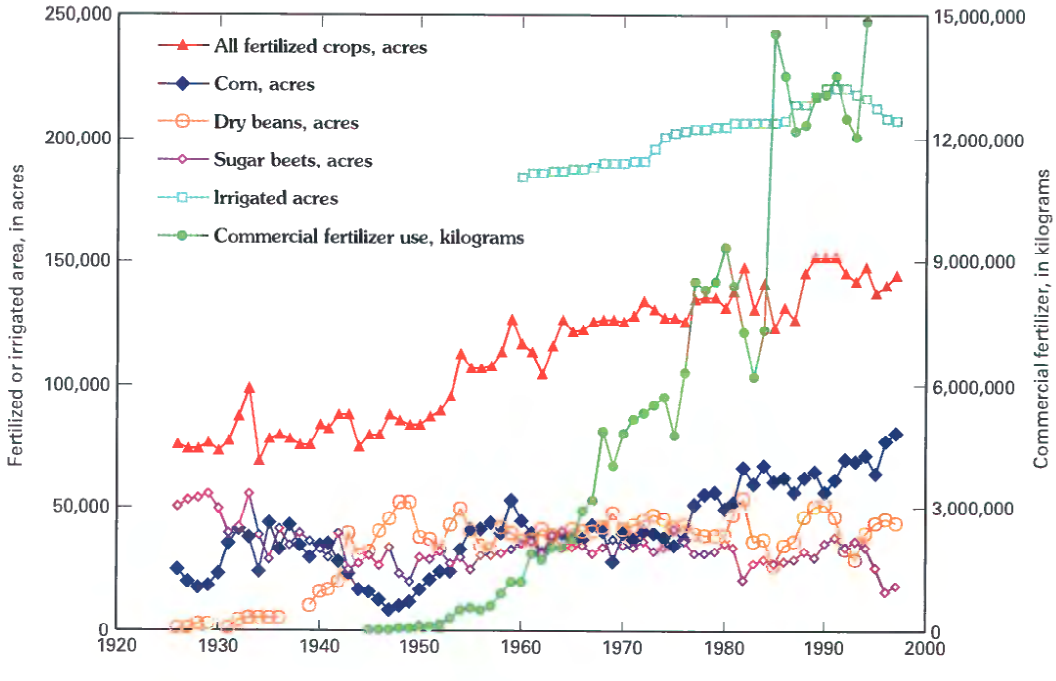


Figure 4. Fertilized and irrigated acreage and commercial fertilizer use in Scotts Bluff County, Nebraska, 1926 through 1998. Acreage data from Nebraska Department of Agriculture (1998). Fertilizer use data from Battaglin and Goolsby (1995).

METHODS

Site Selection and Identification

Eleven surface-water sampling sites were selected for this study because they represent the major hydrologic features in the Dutch Flats area (fig. 1; table 1). One wetland site north of the North Platte River was included to evaluate seepage along the Tri-State Canal. One spring, Akers Draw, also was included to evaluate ground-water seepage from the upland terrace. Water in the Interstate Canal is taken from the North Platte River about 50 mi upstream in Wyoming. Additional information about site selection is presented in Verstraeten and others (in press).

For identification of surface-water sampling sites, the first identifier is the USGS official site name (table 1). The second identifier, an eight digit surface-water USGS identification number, is assigned in a downstream direction along the main stream. The first two digits "06" of the identification number represent the major river basin, the Missouri River Basin. However, because wetlands (site SW11) are not a flowing stream, they were identified in a fashion similar to a ground-water site as described later in this section.

Four different methods of ground-water site identification were used in this report (table 2). Sites for ground-water monitoring wells installed for this study were selected to produce parallel transects of semilinear lines running approximately 0.5 mi apart from the Interstate Canal to about 2 to 3 mi south of the North Platte River and to allow easy access. Multiple wells at a site are referred to as "nested wells" in this report; a single well at a site or one of the wells at a nested well site is referred to as a "well." Initially, three well transects were installed in a north-south direction near the center of the study area. Sets of nested wells in a transect are about 1 mi apart. Two sites (wells 2A and 2E) are upgradient of the Interstate Canal; all other sites are in or near areas with active surface-water irrigation, downgradient of the Interstate Canal. Additional nested wells were installed at approximately 2-mi intervals in the study area.

The first site-identification method, the well identification number, is associated with the transect number for the wells. Each well in a transect was given a three- or four-character identification—number, letter, number format. The first number assigned was based on the transect number in which the well was located— first transect (1), second transect (2), and so forth. With some exceptions, the letter sequence was assigned in a manner that designated wells farthest north as A, then proceeding southward to B, C, and so forth. Terminal numbers were assigned to monitoring wells in a nest (such as 1A–1, 1A–2, and 1A–3) and were based on relative well depth—deepest–1, screened in or just above bedrock; intermediate–2 (or shallowest for a two-well nest); and shallowest–3, screened near the water table (for a three-well nest). Locations containing a single monitoring well were assigned a single terminal number (such as 1F–1) or no terminal number (5D).

Table 1. Surface-water sampling sites in Dutch Flats area, western Nebraska

Map index number (fig. 1)	Surface-water sampling site name	U.S. Geological Survey identification number	Latitude and longitude	Land-surface altitude (feet above sea level)
SW1	Interstate Canal 6 miles northwest of Morrill, Nebr.	06656630	420326 1035706	4,206
SW2	North Platte River at Wyoming-Nebraska State line	06674500	415925 1040257	4,020
SW3	Tri-State Canal 2 miles west of Morrill, Nebr.	06675100	415808 1035804	4,013
SW4	Horse Creek 0.5 mile downstream of Wyoming-Nebraska State line	06677120	415512 1040240	4,040
SW5	Owl Creek near Lyman, Nebr.[1]	06677300	415548 1040017	4,020
SW6	Horse Creek near Lyman, Nebr.	06677500	415621 1035913	3,992
SW7	Dry Sheep Creek near Morrill, Nebr.	06677985	420058 1035823	4,060
SW8	Sheep Creek north of Tri-State Canal, near Morrill, Nebr.	06677995	415814 1035714	4,008
SW9	North Platte River at Morrill, Nebr.	06678500	415612 1035544	3,978
SW10	Akers Draw near Morrill, Nebr.	06678610	415833 1035329	4,010
SW11	Wetlands 0.75 mile north of Morrill, Nebr.	415830103551701	415830 1035517	3,980

[1]This station is on the part of the stream previously called Kiowa Creek by the U.S. Geological Survey.

The second site-identification method uses the unique USGS site identification number, which is a 15-character number that contains no blanks or alphabetic characters and generally is used as an internal control number. Although the site identification number was formed initially from a latitude and longitude, the number is a numeric identifier and has no locational significance (Mathey, 1990, p. 2–10). Wells with first 13 characters of the site identification number in common are distinguished by adding a sequential digit to the number. Sequential numbers are assigned by order of inventory.

The third site-identification method, the legal description, is based on the land subdivisions from the U.S. Bureau of Land Management's (BLM) survey of Nebraska. The number preceding N (north) indicates the township or tier, the number preceding W (west) indicates the range, and the number preceding the terminal letters indicates 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. Like the USGS site identification number, two or more wells are distinguished further by adding a sequential digit to the well number, assigned by order of inventory. For example, 24N 57W 15 CBBD1 (fig. 5) would be in township 24 north, range 57 west, section 15, quarter section C, quarter-quarter section B, quarter-quarter-quarter section B, and quarter-quarter-quarter-quarter section D, inventory sequence 1.

The fourth site-identification method is the well registration number that is assigned by the Nebraska Department of Natural Resources (for example, G–085442).

Sample-Collection Procedures

Water samples were collected following USGS guidelines to ensure the collection of representative samples. Physical properties were measured onsite and included specific conductance, pH, temperature, and dissolved oxygen. In the latter part of August and the beginning of September 1998, when more detailed analysis of water was done along transect *B–B'*, alkalinity also was measured. Samples to be analyzed for organic carbon, major ions, nitrogen, dissolved gases, uranium concentrations, radon activities, and uranium activity ratios were collected, preserved, and transported in accordance with the methods described by Pritt and Jones (1990), Wells and others (1990), and Verstraeten and others (1995, 1999).

Table 2. Information for ground-water sampling sites in Dutch Flats area, western Nebraska

[ft, feet; bls, below land surface. Well identification number:–1, deepest; –2, intermediate depth, –3, shallowest of the well nest. Hydrogeologic condition: CF, confined aquifer; UCF, unconfined aquifer. Aquifer: BR, Brule aquifer; A, alluvial aquifer; CD, Chadron aquifer; LC, Lance aquifer. Well type: RM–registered monitoring well; RD–registered domestic well. --, uncased hole]

Site identification number (fig. 8)	U.S. Geological Survey site identification number	Legal description (fig. 5)	Well registration number[1]	Hydro-geologic condition	Aquifer	Well type	Latitude and longitude	Land surface altitude (ft above sea level)	Well depth (ft bls)	Top of screen (ft bls)	Bottom of screen (ft bls)
1A–1	420301103554801	24N 57W 15 CBBD1	G–085442	CF	BR	RM	420301 1035548	4,205	127	122	127
1A–2	420301103554802	24N 57W 15 CBBD2	G–085443	UCF	A	RM	420301 1035548	4,205	113.5	108.5	113.5
1A–3	420301103554803	24N 57W 15 CBBD3	G–085444	UCF	A	RM	420301 1035548	4,205	95	75	95
1B–1	420234103555501	24N 57W 22 BBCC1	G–085445	UCF	A	RM	420234 1035555	4,165	63	43	63
1B–2	420234103555502	24N 57W 22 BBCC2	G–088541	UCF	A	RM	420234 1035555	4,165	63	43	63
1C–1	420148103555201	24N 57W 22 CCCC1	G–085446	UCF	A	RM	420148 1035552	4,139	110	105	110
1C–2	420148103555202	24N 57W 22 CCCC2	G–085446	UCF	A	RM	420148 1035552	4,139	82	77	82
1C–3	420148103555203	24N 57W 22 CCCC3	G–085446	UCF	A	RM	420148 1035552	4,139	55	35	55
1C–4	420148103555204	24N 57W 22 CCCC4	G–088542	UCF	A	RM	420148 1035552	4,139	60	40	60
1D–1	420049103555501	24N 57W 33 AAAD1	G–088543	UCF	A	RM	420049 1035555	4,100	67	62	67
1D–2	420049103555502	24N 57W 33 AAAD2	G–088543	UCF	A	RM	420049 1035555	4,100	50	45	50
1D–3	420049103555503	24N 57W 33 AAAD3	G–088543	UCF	A	RM	420049 1035555	4,100	35	15	35
1E–1	420004103555301	24N 57W 33 DDDD1	G–088545	UCF	A	RM	420004 1035553	4,094	118	113	118
1E–2	420004103555302	24N 57W 33 DDDD2	G–088545	UCF	A	RM	420004 1035553	4,094	73	68	73
1E–3	420004103555303	24N 57W 33 DDDD3	G–088545	UCF	A	RM	420004 1035553	4,094	35	15	35
1F–1	415907103555301	23N 57W 9 AAAA1	G–088531	UCF	A	RM	415907 1035553	4,078	35	15	35
1G–1	415845103555201	23N 57W 9 ADDA1	G–088533	UCF	A	RM	415845 1035552	4,015	71	66	71
1G–2	415845103555202	23N 57W 9 ADDA2	G–088533	UCF	A	RM	415845 1035552	4,015	51	46	51
1G–3	415845103555203	23N 57W 9 ADDA3	G–088533	UCF	A	RM	415845 1035552	4,015	30	10	30
1H–1	415756103555401	23N 57W 16 ADAC1	G–091663	UCF	A	RM	415756 1035554	3,990	195	190	195
1H–2	415756103555402	23N 57W 16 ADAC2	G–091663	UCF	A	RM	415756 1035554	3,990	112	107	112
1H–3	415756103555403	23N 57W 16 ADAC3	G–091663	UCF	A	RM	415756 1035554	3,990	30	10	30
1I–1	415811103555801	23N 57W 16 AAAC1	G–088536	UCF	A	RM	415811 1035558	3,991	77	72	77
1I–2	415811103555802	23N 57W 16 AAAC2	G–088536	UCF	A	RM	415811 1035558	3,991	53	48	53

Table 2. Information for ground-water sampling sites in Dutch Flats area, western Nebraska—Continued

Site identification number (fig. 8)	U.S. Geological Survey site identification number	Legal description (fig. 5)	Well registration number[1]	Hydro-geologic condition	Aquifer	Well type	Latitude and longitude	Land surface altitude (ft above sea level)	Well depth (ft bls)	Top of screen (ft bls)	Bottom of screen (ft bls)
1I–3	415811103555803	23N 57W 16 AAAC3	G–088536	UCF	A	RM	415811 1035558	3,991	30	10	30
1J–1	415738103554701	23N 57W 15 CBCB1	G–088535	UCF	A	RM	415738 1035547	3,992	195	190	195
1J–2	415738103554702	23N 57W 15 CBCB2	G–088535	UCF	A	RM	415738 1035547	3,992	108	103	108
1J–3	415738103554703	23N 57W 15 CBCB3	G–088535	UCF	A	RM	415738 1035547	3,992	30	10	30
1K–1	415738103551601	23N 57W 22 ABAB1	G–091664	UCF	A	RM	415738 1035516	3,984	191	186	191
1K–2	415738103551602	23N 57W 22 ABAB2	G–091664	UCF	A	RM	415738 1035516	3,984	117	112	117
1K–3	415738103551603	23N 57W 22 ABAB3	G–091664	UCF	A	RM	415738 1035516	3,984	35	15	35
1L–1	415628103554901	23N 57W 28 AAAA1	G–088537	UCF	A	RM	415628 1035549	3,980	106	101	106
1L–2	415628103554902	23N 57W 28 AAAA2	G–088537	UCF	A	RM	415628 1035549	3,980	68	63	68
1L–3	415628103554903	23N 57W 28 AAAA3	G–088537	UCF	A	RM	415628 1035549	3,980	30	10	30
1M–1	420121103560501	24N 57W 28 DABA1	G–091668	UCF	A	RM	420121 1035605	4,110	200	195	200
1M–2	420121103560502	24N 57W 28 DABA2	G–091668	UCF	A	RM	420121 1035605	4,110	99	94	99
1M–3	420121103560503	24N 57W 28 DABA3	G–091668	UCF	A	RM	420121 1035605	4,110	40	20	40
1N–1	420244103561401	24N 57W 16 DCDD1	G–091666	UCF	A	RM	420244 1035614	4,185	88	68	88
2A–1	420316103563201	24N 57W 16 BDAA1	G–085448	UCF	A	RM	420316 1035632	4,211	103	83	103
2B–1	420313103563101	24N 57W 16 BDAD1	G–085450	UCF	A	RM	420313 1035631	4,202	110	105	110
2B–2	420313103563102	24N 57W 16 BDAD2	G–085450	UCF	A	RM	420313 1035631	4,202	91.5	87.5	91.5
2B–3	420313103563103	24N 57W 16 BDAD3	G–085450	UCF	A	RM	420313 1035631	4,202	85.5	65.5	85.5
2C–1	420234103564001	24N 57W 16 CDDA1	G–085447	UCF	A	RM	420234 1035640	4,188	100	95	100
2C–2	420234103564002	24N 57W 16 CDDA2	G–085447	UCF	A	RM	420234 1035640	4,188	90	85	90
2C–3	420234103564003	24N 57W 16 CDDA3	G–085447	UCF	A	RM	420234 1035640	4,188	80	60	80
2D–1	420148103563101	24N 57W 21 CDDD1	G–088540	UCF	A	RM	420148 1035631	4,137	181	176	181
2D–2	420148103563102	24N 57W 21 CDDD2	G–088540	UCF	A	RM	420148 1035631	4,137	120	115	120
2D–3	420148103563103	24N 57W 21 CDDD3	G–088540	UCF	A	RM	420148 1035631	4,137	59	39	59
2E–1	420516103562501	25N 57W 35 DCDD1	G–091670	UCF	BR[2]	RM	420516 1035625	4,248	80	--	--

Table 2. Information for ground-water sampling sites in Dutch Flats area, western Nebraska—Continued

Site identification number (fig. 8)	U.S. Geological Survey site identification number	Legal description (fig. 5)	Well registration number[1]	Hydro-geologic condition	Aquifer	Well type	Latitude and longitude	Land surface altitude (ft above sea level)	Well depth (ft bls)	Top of screen (ft bls)	Bottom of screen (ft bls)
2F–1	420005103562801	24N 57W 33 DCCC1	G–088544	UCF	A	RM	420005 1035628	4,100	100	95	100
2F–2	420005103562802	24N 57W 33 DCCC2	G–088544	UCF	A	RM	420005 1035628	4,100	70	65	70
2F–3	420005103562803	24N 57W 33 DCCC3	G–088544	UCF	A	RM	420005 1035628	4,100	45	25	45
2G–1	415854103561101	23N 57W 9 ACAA1	G–088532	UCF	A	RM	415854 1035611	4,075	55	15	55
2H–2	415823103561602	23N 57W 9 DCC2	G–088534	UCF	A	RM	415823 1035616	4,010	30	10	30
2J–1	415721103561501	23N 57W 21 ABBA1	G–091364	UCF	A	RM	415721 1035615	3,990	183	178	183
2J–2	415721103561502	23N 57W 21 ABBA2	G–091364	UCF	A	RM	415721 1035615	3,990	116	111	116
2J–3	415721103561503	23N 57W 21 ABBA3	G–091364	UCF	A	RM	415721 1035615	3,990	40	20	40
2L–1	415628103562401	23N 57W 28 BAAA1	G–088538	UCF	A	RM	415628 1035624	3,982	86	81	86
2L–2	415628103562402	23N 57W 28 BAAA2	G–088538	UCF	A	RM	415628 1035624	3,982	58	53	58
2L–3	415628103562403	23N 57W 28 BAAA3	G–088538	UCF	A	RM	415628 1035624	3,982	30	10	30
2T–1	415547103561704	23N 57W 28 DCCC1	G–101646	CF	CD	RM	415547 1035617	3,986	130	90	130
3B–1	420325103570901	24N 57W 17 AAAD1	G–085451	UCF	BR	RM	420325 1035709	4,200	90	85	90
3B–2	420325103570902	24N 57W 17 AAAD2	G–085451	UCF	A	RM	420325 1035709	4,200	80.5	60.5	80.5
3C–1	420243103570701	24N 57W 16 CCCB1	G–088539	UCF	A	RM	420243 1035707	4,181	147	142	147
3C–2	420243103570702	24N 57W 16 CCCB2	G–088539	UCF	A	RM	420243 1035707	4,181	119	114	119
3C–3	420243103570703	24N 57W 16 CCCB3	G–088539	UCF	A	RM	420243 1035707	4,181	90	70	90
3E–1	420056103570301	24N 57W 28 CCCC1	G–091667	UCF	A	RM	420056 1035703	4,110	89	84	89
3E–2	420056103570302	24N 57W 28 CCCC2	G–091667	UCF	A	RM	420056 1035703	4,110	67	62	67
3E–3	420056103570303	24N 57W 28 CCCC3	G–091667	UCF	A	RM	420056 1035703	4,110	45	25	45
3F–1	420005103570301	24N 57W 32 DDDD1	G–091366	UCF	A	RM	420005 1035703	4,100	68	63	68
3F–2	420005103570302	24N 57W 32 DDDD2	G–091366	UCF	A	RM	420005 1035703	4,100	54	49	54
3F–3	420005103570303	24N 57W 32 DDDD3	G–091366	UCF	A	RM	420005 1035703	4,100	40	20	40
4A–1	420333103574001	24N 57W 8 DCCC1	G–091665	UCF	A	RM	420333 1035740	4,210	97.5	77.5	97.5
4B–1	420307103574001	24N 57W 17 ACCC1	G–091365	UCF	A	RM	4203071 035740	4,192	157	152	157

Table 2. Information for ground-water sampling sites in Dutch Flats area, western Nebraska—Continued

Site identification number (fig. 8)	U.S. Geological Survey site identification number	Legal description (fig. 5)	Well registration number[1]	Hydro-geologic condition	Aquifer	Well type	Latitude and longitude	Land surface altitude (ft above sea level)	Well depth (ft bls)	Top of screen (ft bls)	Bottom of screen (ft bls)
4B–2	420307103574002	24N 57W 17 ACCC2	G–091365	UCF	A	RM	4203071 035740	4,192	130	125	130
4B–3	420307103574003	24N 57W 17 ACCC3	G–091365	UCF	A	RM	4203071 035740	4,192	95	75	95
5A–1	420128103514801	24N 56W 30 ACAA1	G–099874	UCF	A	RM	420129 1035148	4,228	170	120	170
5B–1	420053103512701	24N 56W 31 ABAA1	G–091669	UCF	A	RM	420053 1035127	4,158	163	158	163
5B–2	420053103512702	24N 56W 31 ABAA2	G–091669	UCF	A	RM	420053 1035127	4,158	125	120	125
5B–3	420053103512703	24N 56W 31 ABAA3	G–091669	UCF	A	RM	420053 1035127	4,158	98	78	98
5C–1	420002103511101	23N 56W 6 AAAA1	G–092640	UCF	A	RM	420002 1035111	4,098	160	85	160
5C–2	420002103511102	23N 56W 6 AAAA2	G–092640	UCF	A	RM	420002 1035111	4,098	65	45	65
5D	415829103511001	23N 56W 7 DDDD1	G–092641	UCF	BR	RM	415829 1035110	4,050	50	40	50
5E–1	415643103505201	23N 56W 20 CCAA1	G–092643	UCF	A	RM	415643 1035052	3,960	190	50	190
5E–2	415643103505202	23N 56W 20 CCAA2	G–092643	UCF	A	RM	415643 1035052	3,960	30	10	30
5F	415553103504101	23N 56W 29 CDBD1	G–093234	UCF	A	RM	415553 1035041	3,949	35	10	35
6A	420757104024701	25N 58W 13 CDBC1	G–093083	UCF	BR	RM	420757 1040247	4,206	30	10	30
6B	420628104021001	25N 58W 25 DABB1	G–094662	CF	BR	RM	420628 1040210	4,170	60	35	60
6C	420514104015101	25N 57W 31 CCCC1	G–094661	UCF	BR	RM	420514 1040151	4,163	85	50	85
6D–1	420338104014401	24N 58W 10 DDDD1	G–094659	UCF	A	RM	420338 1040144	4,125	200	60	200
6D–2	420338104014402	24N 58W 10 DDDD2	G–094659	UCF	A	RM	420338 1040144	4,125	30	10	30
6E	420145104025001	24N 58W 27 BBBC1	G–093242	UCF	A	RM	420145 1040250	4,153	65	55	65
6F	420003104023801	23N 58W 3 BBAC1	G–094681	UCF	BR	RM	420003 1040238	4,070	50	10	50
6G–1	415739104021101	23N 58W 15 CDAD1	G–092647	UCF	A	RM	415739 1040211	4,021	175	35	175
6G–2	415739104021102	23N 58W 15 CDAD2	G–092647	CF	A	RM	415739 1040211	4,021	30	10	30
6H–1	415852104024801	23N 58W 9 ADDA1	G–094679	UCF	A	RM	415852 1040248	4,027	180	50	180
6H–2	415852104024802	23N 58W 9 ADDA2	G–094679	UCF	A	RM	415852 1040248	4,027	30	10	30
6I	415402104015501	22N 58W 3 DCCD1	G–092638	UCF	LC	RM	415402 1040155	4,054	60	10	30
6M–1	415525104023801	23N 58W 34 BCCB1	G–092648	UCF	A	RM	415525 1040238	4,053	115	50	115

Table 2. Information for ground-water sampling sites in Dutch Flats area, western Nebraska—Continued

Site identification number (fig. 8)	U.S. Geological Survey site identification number	Legal description (fig. 5)	Well registration number[1]	Hydro-geologic condition	Aquifer	Well type	Latitude and longitude	Land surface altitude (ft above sea level)	Well depth (ft bls)	Top of screen (ft bls)	Bottom of screen (ft bls)
6M–2	415525104023802	23N 58W 34 BCCB2	G–092648	UCF	A	RM	415525 1040238	4,053	30	10	30
7A–1	420657104010301	25N 57W 19 DCDD1	G–093082	UCF	BR	RM	420657 1040103	4,192	95	75	95
7A–2	420657104010302	25N 57W 19 DCDD2	G–093082	CF	BR	RM	420657 1040103	4,192	30	10	30
7B	420524104003901	25N 57W 32 CCBB1	G–093081	UCF	BR	RM	420524 1040039	4,175	60	30	60
7C–1	420334104003201	24N 58W 13 BBBB1	G–094660	UCF	A	RM	420334 1040032	4,173	190	100	190
7C–2	420334104003202	24N 58W 13 BBBB2	G–094660	UCF	A	RM	420334 1040032	4,173	80	60	80
7D–1	420153104002401	24N 58W 24 CCCC1	G–093241	UCF	A	RM	420153 1040024	4,135	155	100	155
7D–2	420153104002402	24N 58W 24 CCCC2	G–093241	UCF	A	RM	420153 1040024	4,135	80	60	80
7E–1	420006104004401	23N 58W 2 AABB1	G–094678	UCF	BR	RM	420006 1040044	4,124	90	50	90
7E–2	420006104004402	23N 58W 2 AABB2	G–094678	UCF	A	RM	420006 1040044	4,124	36	26	36
7F–1	415730104002301	23N 58W 13 CCCC1	G–092646	UCF	A	RM	415730 1040023	4,011	193	35	193
7F–2	415730104002302	23N 58W 13 CCCC2	G–092646	UCF	A	RM	415730 1040023	4,011	30	10	30
7G–1	415837104000601	23N 58W 12 CDCB1	G–093238	UCF	BR[2]	RM	415837 1040006	4,092	95	45	95
7G–2	415837104000602	23N 58W 12 CDCB2	G–093238	UCF	A	RM	415837 1040006	4,092	30	10	30
7H	415544104003701	23N 58W 35 AABA1	G–093239	UCF	A	RM	415544 1040037	4,025	38	8	38
8A–1	420333103583401	24N 57W 18 AAAA1	G–094658	UCF	A	RM	420333 1035834	4,165	125	75	125
8A–2	420333103583402	24N 57W 18 AAAA2	G–094658	UCF	A	RM	420333 1035834	4,165	52.5	32.5	52.5
8B	420148103583101	24N 57W 30 AABB1	G–093240	UCF	A	RM	420148 1035831	4,100	30	10	30
8C	420004103581401	23N 57W 6 AAAA1	G–093235	UCF	BR	RM	420004 1035814	4,082	80	--	--
8D–1	415814103581201	23N 57W 7 DDDD1	G–093087	UCF	A	RM	415814 1035812	4,016	152	50	152
8D–2	415814103581202	23N 57W 7 DDDD2	G–093087	UCF	A	RM	415814 1035812	4,016	30	10	30
8E	415719103583601	23N 57W 19 ABBA1	G–093089	UCF	A	RM	415719 1035836	4,003	45	20	45
8F–1	415640103591201	23N 57W 19 CCCC1	G–094677	UCF	A	RM	415640 1035912	4,000	190	51	190
8F–2	415640103591202	23N 57W 19 CCCC2	G–094677	UCF	A	RM	415640 1035912	4,000	30	10	30
8G	415545103575801	23N 57W 32 BBBB1	G–093237	UCF	A	RM	415545 1035758	4,002	40	10	40

Table 2. Information for ground-water sampling sites in Dutch Flats area, western Nebraska—Continued

Site identification number (fig. 8)	U.S. Geological Survey site identification number	Legal description (fig. 5)	Well registration number[1]	Hydro-geologic condition	Aquifer	Well type	Latitude and longitude	Land surface altitude (ft above sea level)	Well depth (ft bls)	Top of screen (ft bls)	Bottom of screen (ft bls)
9B	415944103532901	23N 57W 1 ACBC1	G–093086	UCF	A	RM	415944 1035329	4,079	60	40	60
9C	415840103533101	23N 57W 11 DAAA1	G–093088	UCF	A	RM	415840 1035331	4,030	37	17	37
9D–1	415722103532401	23N 57W 24 BBBB1	G–093090	UCF	A	RM	415722 1035324	3,965	190	50	190
9D–2	415722103532402	23N 57W 24 BBBB2	G–093090	UCF	A	RM	415722 1035324	3,965	30	10	30
9E–1	415546103532201	23N 57W 36 BBBB1	G–094680	UCF	CD	RM	415546 1035322	3,978	50	30	50
9E–2	415546103532202	23N 57W 36 BBBB2	G–094680	CF	A	RM	415546 1035322	3,978	15	10	15
10A–1	420259103481601	24N 56W 10 CDCA1	G–093089	UCF	BR	RM	420259 1034816	4,190	100	80	100
10A–2	420259103481602	24N 56W 10 CDCA2	G–093089	UCF	BR	RM	420259 1034816	4,190	55	20	55
10C	420003103410301	23N 56W 4 AABA1	G–093084	UCF	BR	RM	420003 1034903	4,125	120	100	120
10D–1	415742103482001	23N 56W 16 DADA1	G–092642	UCF	A	RM	415742 1034820	3,972	80	70	80
10D–2	415742103482002	23N 56W 16 DADA2	G–092642	UCF	A	RM	415742 1034820	3,972	35	10	35
10E–1	415525103484601	23N 56W 34 BCCB1	G–092645	UCF	A	RM	415525 1034846	3,941	212	50	212
10E–2	415525103484602	23N 56W 34 BCCB2	G–092645	UCF	A	RM	415525 1034846	3,941	30	10	30
10F	415406103484301	22N 56W 03 CCCC1	G–092636	UCF	A	RM	4154061034843	3,970	73	34	73
10G–1	415607103484801	23N 56W 28 DAAA1	G–093085	UCF	A	RM	415607 1034848	3,940	200	50	200
10G–2	415607103484802	23N 56W 28 DAAA2	G–093085	UCF	A	RM	415607 1034848	3,940	30	10	30
10K–1	415817103492401	23N 56W 16 BAAA1	G–101648A	UCF	BR	RM	415817 1034924	4,036	96.5	81.5	96.5
10M–1	415625103480201	23N 56W 27 ABDC1	G–092644	UCF	A	RM	415625 1034802	3,948	115	35	115
10M–2	415625103480202	23N 56W 27 ABDC2	G–092644	UCF	A	RM	415625 1034802	3,948	30	10	30
10N–1	415910103493701	23N 56W 09 BABA1	G–101643A	UCF	A	RM	415910 1034937	4,050	199	194	199
10N–2	415910103493702	23N 56W 09 BABA2	G–101643B	UCF	A	RM	415910 1034937	4,050	60	40	60
C. Morrill	415816103513201	23N 56W 17 BBBA1	G–093042	CF	CD	RD	415816 1035132	4,050	300	280	300
1K–94–1 (Kiowa 1–1)	415547103561701	23N 57W 28 DCCC1	G–082124B	UCF	CD	RM	415547 1035617	3,986	29	28	28.5
1K–94–2 (Kiowa 1–2)	415547103561702	23N 57W 28 DCCC2	G–082124B	UCF	A	RM	415547 1035617	3,986	14	13.5	14

Table 2. Information for ground-water sampling sites in Dutch Flats area, western Nebraska—Continued

Site identification number (fig. 8)	U.S. Geological Survey site identification number	Legal description (fig. 5)	Well registration number[1]	Hydro-geologic condition	Aquifer	Well type	Latitude and longitude	Land surface altitude (ft above sea level)	Well depth (ft bls)	Top of screen (ft bls)	Bottom of screen (ft bls)
26K–94–1 (Kiowa 26–1)	415535103554501	23N 57W 28 DDDD1	G–082124C	UCF	A	RM	415550 1035547	3,981	18	17.5	18
26K–94–2 (Kiowa 26–2)	415535103554502	23N 57W 28 DDDD2	G–082124C	UCF	A	RM	415550 1035547	3,981	16.5	16	16.5

[1]Well registration numbers are assigned by the Nebraska Department of Natural Resources.
[2] Sand lens in Brule Formation.

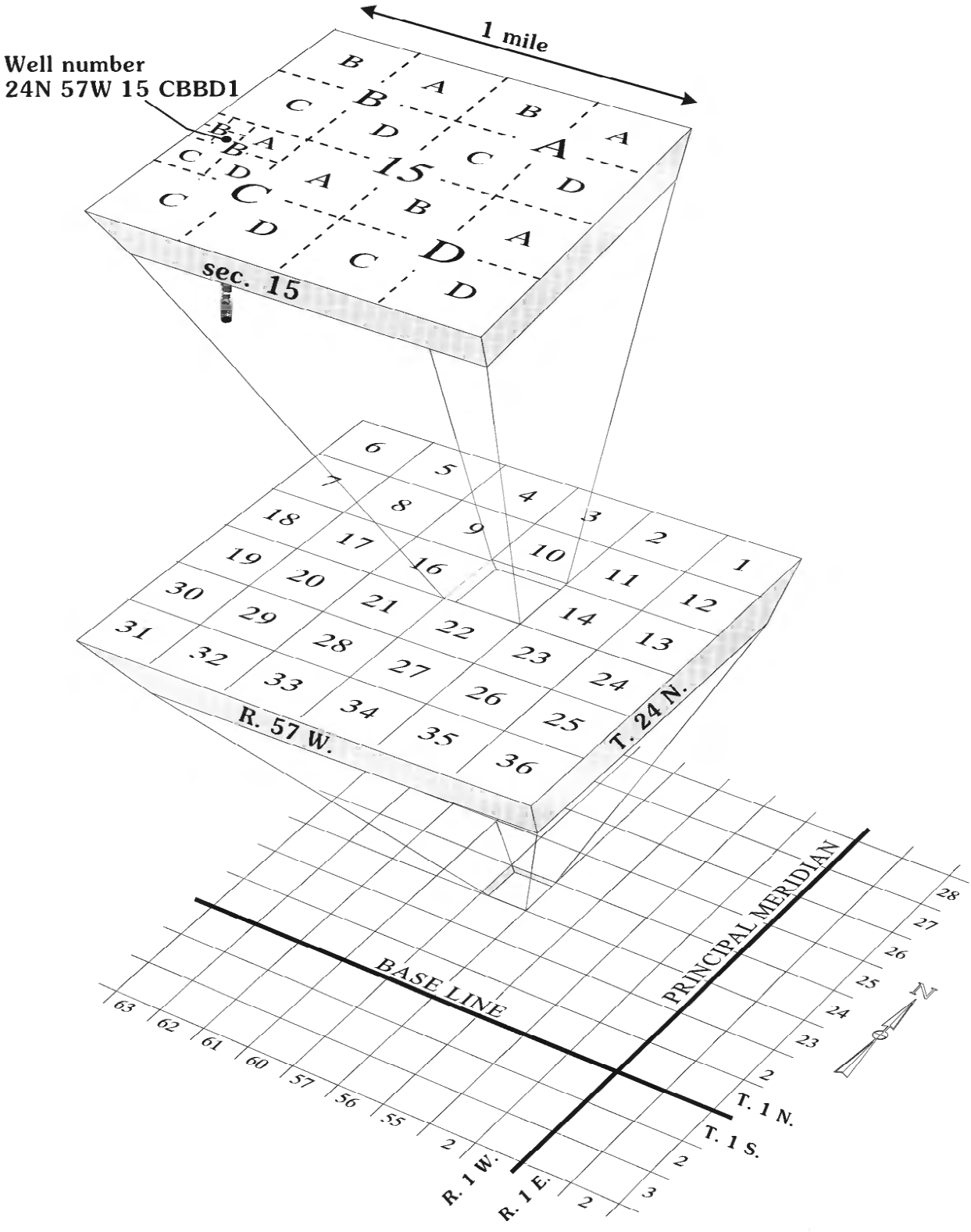


Figure 5. Legal-description numbering system.

The sampling schemes were created on the basis of location and depth of wells constructed, the timing of water present in the canals, and perceived gaps in previously collected information. The spatial and temporal distributions of the samples collected mainly focused on obtaining data perceived to help define surface-water/ground-water interaction and other data of interest to the North Platte NRD and the State of Nebraska. The samples were analyzed for a subset of constituents thought to be useful indicators of surface-water/ground-water interaction in the study area, including, but not limited to, specific conductance, sodium, calcium and magnesium (hardness), sulfate, nitrate, uranium, and radon. These elements, ions, or isotopes also have the potential to affect the suitability of water supplies in the study area.

The sampling schemes and analytes were modified each year as to frequency and timing of collection, especially near the Interstate Canal and North Platte River. The sampling schemes were followed unless weather conditions prohibited sample collection or unless sites were not accessed because of recent pesticide applications on nearby fields, causing a potential health hazard.

Surface-Water Samples

One hundred and thirty samples were collected from 11 surface-water sites from 1996 through 1999 (fig. 1). The most frequent sampling occurred on the North Platte River at Morrill (site SW9, 37 samples). In 1998 and 1999, sampling of the surface-water bodies contributing water to the North Platte River in the study area, except the wetlands, was conducted to help evaluate the sources of uranium in surface water (Verstraeten and others, 2000).

Surface-water samples were collected using equal-width increment (EWI) sampling procedures or centroid-of-flow (COF) sampling procedures as described by Wells and others (1990). At the wetlands site near Morrill (site SW11), only a dip sample was collected. COF samples were collected from both canal sites (SW1 and SW3). Water in these canals is considered well mixed with minimal inflow from other surface-water bodies (Steele and Cannia, 1997). EWI sampling was used at the remainder of the sites where streamflow was not considered well mixed. All water-quality samples were collected by wading the stream or suspending the sampler by hand from a bridge.

Ground-Water Samples

About 1,960 ground-water samples were collected from 152 ground-water sites from 1996 through 1999 (fig. 8 in section on "Hydrogeology"). The number of samples collected at a ground-water site varied from 1 sample at site 2T, constructed in 1999, to 36 samples at site 1C–3, constructed in 1994. Samples were collected from the nested-well sites described previously using a stainless-steel submersible pump. Specific conductance, pH, water temperature, and dissolved oxygen were measured onsite at 5-minute intervals using a flow-through chamber. Samples were collected after these readings stabilized within preset limits or after at least three well volumes of water had been pumped out of the well.

Laboratory Procedures

Water samples generally were analyzed at the USGS National Water-Quality Laboratory in Denver, Colorado, following standard procedures (Verstraeten and others, in press). Water samples to be analyzed for uranium were sent to the USGS Uranium Research Laboratory in Reston, Virginia. Samples to be analyzed for dissolved gases were sent to the USGS Chlorofluorocarbon Research Laboratory in Reston, Virginia. Quality-assurance and quality-control procedures and data validation are summarized in Verstraeten and others (in press).

Creation of Water-Table and Saturated-Thickness Maps

The water-table and saturated-thickness maps in this report were created using historical data and data collected during this study. Water-table data from monitoring and irrigation wells were referenced to a common vertical datum (sea level). The data estimated from 1:24,000-scale topographic maps were contoured using an existing water-table map of the area as a reference (Babcock and Visher, 1951).

A map of the configuration of bedrock surface was created to generate the saturated-thickness map. The map showing the configuration of the bedrock surface in the study area was compiled using depth-to-bedrock data obtained during the installation of the monitoring wells and well-registration information for irrigation wells. The altitude of the bedrock surface was subtracted from the altitude of the water table to create the

saturated-thickness map. Where little or no data were available, both the altitude of the water table and the saturated thickness were inferred.

SURFACE WATER AND HYDROGEOLOGY

This section describes in detail the surface water and hydrogeologic characteristics of the study area. The surface water and hydrogeologic characteristics affect the water movement through the study area.

Surface Water

The predominant surface-water systems in the study area are the North Platte River and the Interstate and Tri-State Canals (fig. 1). The North Platte River enters Nebraska at the Wyoming-Nebraska State line near Henry, Nebraska, and continues on a southeasterly path to its confluence with the South Platte River near the city of North Platte (fig. 1). The general gradient of the North Platte River through its reach in Nebraska is 0.0014 ft/mi (Goodwin and Diffendal, 1987).

Discharge in the North Platte River system (figs. 6 and 7) has been affected by human activities since the late 19th century (Kircher and Karlinger, 1983). These activities include transmountain diversions of the headwaters of the North Platte River, dams such as Seminoe, Pathfinder, Alcova, Glendo, and Guernsey in Wyoming and Kingsley Dam (forming Lake McConaughy) in Nebraska, and canals such as the Interstate and Tri-State Canals. Other human activities affecting river flow include diversions to satisfy surface-water irrigation rights, ground-water pumpage near surface-water bodies to meet demands of increasing population, and irrigated agriculture, which require water for growing crops in the river valley. Humans also have affected flow in the North Platte River by reshaping or channelizing. All of these human activities generally result in flattening of daily flow-duration curves (fig. 7) or shifting in the levels of low or high flows in the North Platte River (Kircher and Karlinger, 1983).

The North Platte River is the source water for the Interstate and Tri-State Canals. Flow for the Interstate Canal is diverted from the North Platte River at the Whalen diversion dam near Fort Laramie, Wyoming (fig. 1). The course of the Interstate Canal runs parallel to the North Platte River for about 50 mi where it intersects the Nebraska-Wyoming border, about 10 mi north of the active river channel. The Interstate Canal follows a more irregular course along the contours of the land for an additional 29 mi to the eastern edge of the study area. The mean daily flow of the Interstate Canal typically ranges from about 1,000 to 1,200 ft^3/s but depends on flows in the North Platte River (Dennis Strauch, Pathfinder Irrigation District, oral commun., 1999). It also is affected by precipitation and runoff. The Interstate Canal typically carries water for irrigation of hay and filling downstream lakes in April and May, and for irrigation of cropland from June through September. Timing of flows through the canal varies from year to year depending on climatic conditions.

The Tri-State Canal receives its water from a diversion dam on the North Platte River 1 mi east of the Wyoming-Nebraska State line. Mean daily flow in the Tri-State Canal typically ranges from 900 to 1,000 ft^3/s (Kevin Adams, Farmers Irrigation District, oral commun., 1999). The Tri-State Canal also receives water from diversion dams on four tributaries of the North Platte River. From May 1 to September 30, 1998, the Tri-State Canal received diverted water from Sheep Creek [about 67 $(ft^3/s)/d$], Acres Draw [about 11 $(ft^3/s)/d$], Dry Spottedtail Creek [about 12 $(ft^3/s)/d$], and Spottedtail Creek [about 11 $(ft^3/s)/d$] (Nebraska Department of Water Resources, 1998). Timing of flow into the Tri-State Canal is similar to that of the Interstate Canal, with the exception that there are no upstream impoundments for storage served by this system.

Tributaries of the North Platte River, which are much smaller in terms of discharge than the Interstate or Tri-State Canals, drain much of the study area north of the North Platte River. The largest tributary north of the river, Sheep Creek (fig. 1), is perennial only in the downstream reaches. In the upstream reaches, Sheep Creek typically flows only when ground water in the area is recharged with seepage from the Interstate Canal. Seepage from this canal causes ground-water levels to rise, resulting in discharge of ground water to the upstream reaches of Sheep Creek. Other tributaries of the North Platte River that lie north of the river are Dry Sheep Creek, which is perennial, and Spottedtail and Dry Spottedtail Creeks (fig. 1), which are seasonal. South of the North Platte River, Horse Creek is the predominant natural perennial surface-water feature (fig. 1). From 1995 through 1998, flows of the North Platte River varied from less than 200 to more than 5,000 ft^3/s; flows of Sheep Creek varied from less

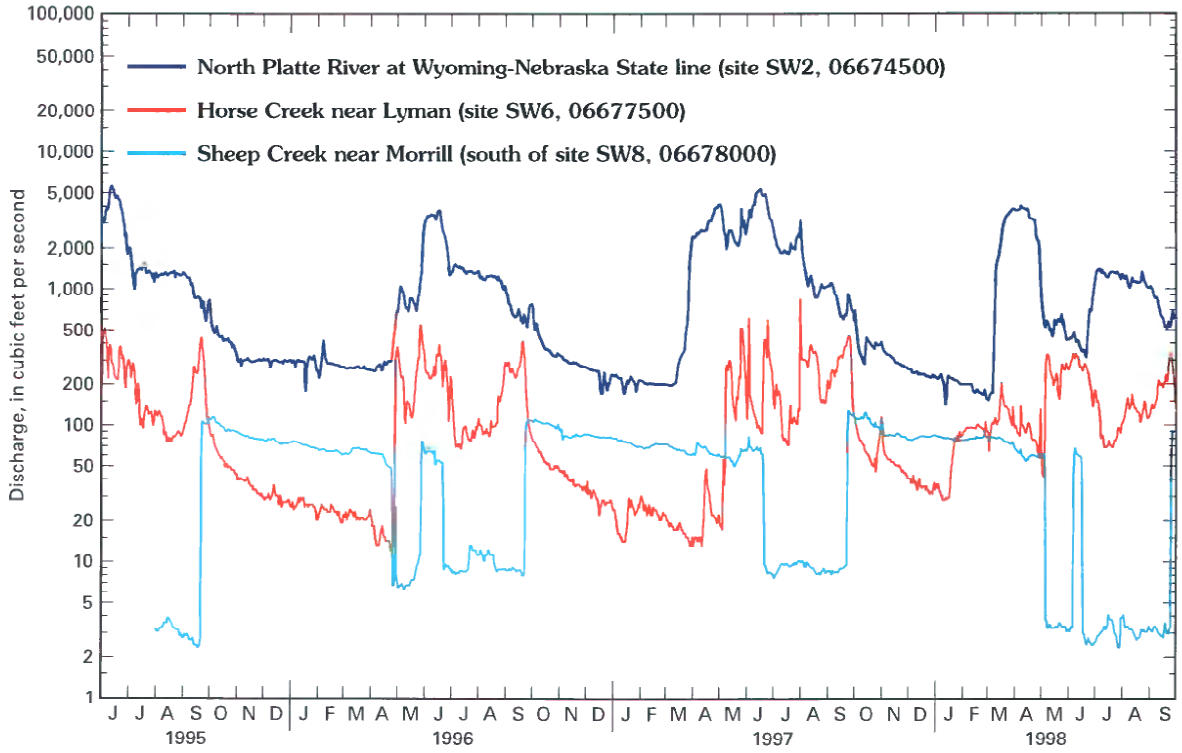


Figure 6. Discharge of North Platte River at Wyoming-Nebraska State line (site SW2, 06674500), Horse Creek near Lyman (site SW6, 06677500), and Sheep Creek near Morrill (06678000), Nebraska, 1995 through 1998. Locations of surface-water sampling sites are shown in figure 1.

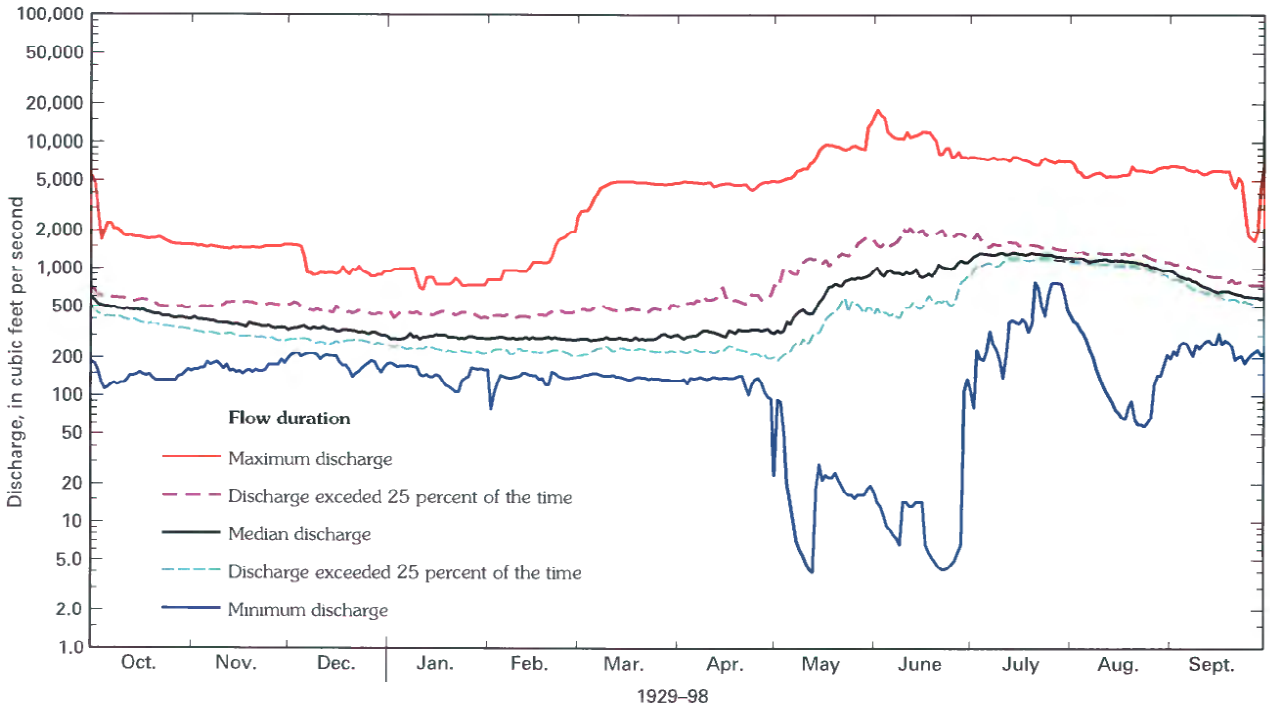


Figure 7. Daily flow duration of North Platte River at Wyoming-Nebraska State line (site SW2, fig. 1), 1929 through 1998.

than 5 to more than 100 ft^3/s; and flows of Horse Creek varied from less than 20 to as much as 700 ft^3/s (fig. 6). Generally, flows at the natural surface-water sites increased near the beginning of May and began to decline sometime in August (fig. 6). However, as shown in figure 6, Sheep Creek departs from the normal tendency. This departure is caused by the diversion of surface water from Sheep Creek to the Tri-State Canal upstream from sampling site 06678000 (fig. 1). Otherwise, the tendency for streamflow to increase in May and decline in August likely would be the same during the irrigation season.

Hydrogeology

Aquifers in the study area include the alluvial aquifer and the Brule, Chadron, and Lance bedrock aquifers. Previous investigations describe the geology and occurrence of ground water in the study area (Darton, 1903a, b; Wenzel and others, 1946; Babcock and Visher, 1951; Smith and Souders, 1975; Souders, 1986; Verstraeten and others, 1995). A summary of the principal hydrogeologic units in the study area is given in table 3. A map showing the surficial geology of the Dutch Flats area and the traces of generalized hydrogeologic sections is presented in figure 8. Generalized hydrogeologic sections are presented in figure 9.

This report uses USGS nomenclature to describe most bedrock units. However, the terms "Lance" and "Fox Hills aquifers" are used by the University of Nebraska-Lincoln Conservation and Survey Division. The USGS currently has not identified the presence of the Lance and Fox Hills Formations in Nebraska. However, they are thought to exist in extreme western Nebraska (Condra and Reed, 1959).

Alluvial Aquifer

The alluvial aquifer in the study area is unconfined (table 3), and for the purposes of this report, has been divided into a northern and southern aquifer separated by a bedrock high. This bedrock high separates the ancestral North Platte River Valley north of the bedrock high (the upland) from the present North Platte River Valley (the bottomland). It is parallel to the North Platte River and generally just north of the Tri-State Canal, providing a distinguishable topographic relief of as much as 100 ft.

Depth to the water table typically is less than 5 to 80 ft below the land surface in the northern alluvial aquifer and typically is less than 20 ft below the land surface in the southern alluvial aquifer. The saturated thickness of the alluvial aquifer in the study area (fig. 10) varies from less than 5 ft near the valley walls to more than 200 ft near the present day North Platte River. Babcock and Visher (1951) report a hydraulic conductivity of 300 ft/d and a specific yield of about 0.32 from an aquifer test in the northern alluvial aquifer. Two unpublished aquifer tests conducted by the USGS and the North Platte NRD in the southern alluvial aquifer indicate hydraulic conductivities of 99 and 463 ft/d at Morrill (ground-water sampling site 1H, fig. 8) and at Mitchell (site 10M, fig. 8), respectively. Values of specific yield at these two sites probably are representative of the southern alluvial aquifer, but actual values can vary locally at least 10 fold (data on file with U.S. Geological Survey, Lincoln, Nebraska).

Most ground-water movement in the Dutch Flats area is toward the North Platte River (fig. 11). In the northern alluvial aquifer, partial obstruction of ground-water movement by the bedrock high in the Brule Formation locally can cause ground water to deviate from the predominant north-south direction of flow. In the part of the southern alluvial aquifer north of the North Platte River, ground water moves predominantly from areas recharged by ground water from the northern alluvial aquifer toward the North Platte River. In the southern alluvial aquifer south of the North Platte River, ground water predominantly moves east-northeasterly and toward the North Platte River. As ground water approaches the North Platte River, ground-water flow paths generally turn, and ground water moves east-southeast down the valley until discharging into the North Platte River when the stage of the river is lower than the ground-water level.

Previous studies have reported that the North Platte River and the alluvial aquifer are hydraulically connected and exchange water. Herrmann (1976) reported that the North Platte River Valley in Wyoming does not gain or lose substantial water to the alluvial aquifer. Lappala and others (1979) reported that downstream of the study area the Platte River and the underlying alluvial aquifer are hydraulically connected. The hydraulic connection allows the North Platte River to act as a control on the water levels in the ground-water system, and changes in ground-water levels are observed within minutes of a rise in river stage. When ground-water levels change, the levels will be maintained as long as the change in river stage exists. Thus, locally, a high river stage will result in

Table 3. Principal hydrogeologic units in Dutch Flats area, western Nebraska

[Modified from Swinehart and others, 1985; gal/min, gallons per minute; <, less than; >, greater than; ~, approximately]

System	Series	Geologic unit	Description	Maximum thickness (feet)	Hydrogeologic unit	Hydrogeologic characteristics
Quaternary	Holocene/ Pleistocene	Undifferentiated alluvial, colluvial, and eolian deposits	Undifferentiated alluvial, colluvial, and eolian sand and gravel deposits, with isolated lenses of silt and clay deposits along the North Platte Valley. Eolian sand in isolated areas of the North Platte Valley and residuum from sandstone and siltstone near this valley.	210	Alluvial aquifer and eolian aquifer	Unconfined water-bearing units. Wells potentially yield more than 1,000 gal/min. Depth to water commonly is shallow. The eolian aquifer is used primarily for stock and domestic purposes.
Tertiary	Miocene	Arikaree Group	Silty, very fine- to medium-grained sandstone rich in volcanic glass shards. Local areas of coarse sand.	<100	Arikaree aquifer	Localized unconfined unit when water is present. Typically dry or yields sufficient only for stock wells.
	Oligocene	Brule Formation of the White River Group	Massive siltstone and mudstone rich in volcanic glass shards. Regionally correlative ash beds are present. Local lenses of sandstone and consolidated to moderately consolidated gravel are present. The unit occurs throughout the area.	>500	Brule aquifer	Generally unconfined water-bearing units. May yield large volumes of water with little drawdown in localized areas of the North Platte Valley. Localized consolidated to moderately consolidated alluvial sand channel deposits, which are generally unconfined, can yield water in small areas. Rocks void of fractures and sand generally compose a confining unit.
	Eocene	Chadron Formation of the White River Group	Gray to greenish-gray bentonitic mudstone and claystone.	<100	Chadron confining unit	Regional confining unit for the underlying aquifer.
			Major channel deposits of fine- to coarse-grained sandstone and locally occurring conglomerates.	>100, locally	Chadron aquifer	Confined water-bearing units. Rarely used for irrigation and domestic purposes because water quality is unsuitable for most uses.
Cretaceous	Upper Cretaceous	Lance Formation[1]	Greenish-gray argillaceous sand and interbedded gray shale and lignite.	~120	Lance aquifer	Confined water-bearing units. Used for stock and domestic purposes in areas where no other source of ground water is available. Used mainly in Scotts Bluff County.
		Fox Hills Formation[1]	Massive, yellow to yellowish-green, fine- to medium-grained sandstone. Some interbedded dark-gray shale.	~190	Fox Hills aquifer	Same as Lance aquifer.
		Pierre Shale	Gray to brown sandy siltstone and shale with fine-grained sandstone layers in the upper part.	~500	Transitional zone	Regional basal confining unit.

[1]Currently unrecognized in Nebraska by the U.S. Geological Survey but thought to exist in the subsurface by the University of Nebraska, Conservation and Survey Division (Condra and Reed, 1959).

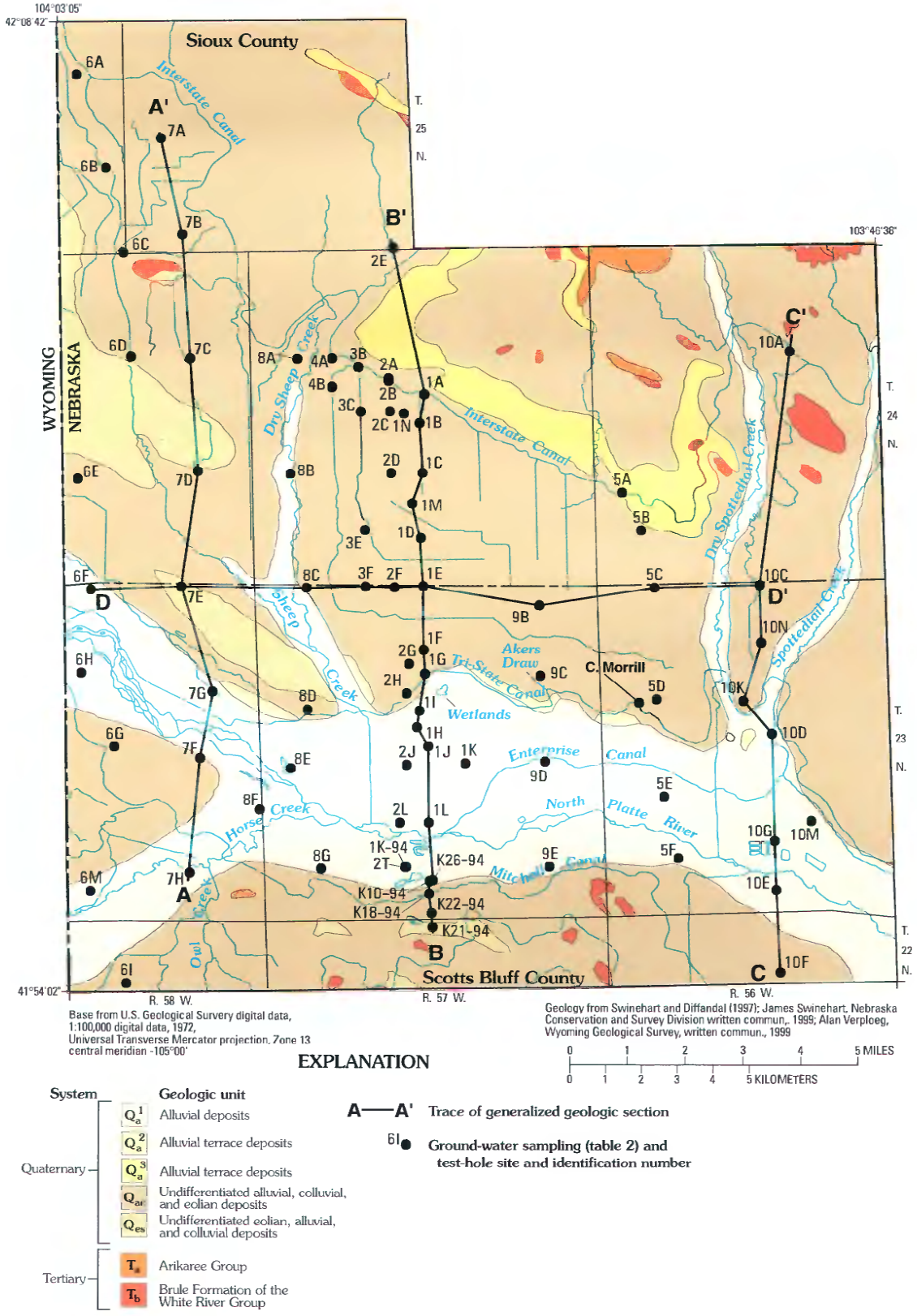


Figure 8. Surficial geology and traces of generalized geologic sections, ground-water sampling sites, and test holes, Dutch Flats area.

higher ground-water levels, and a low river stage will result in lower ground-water levels. Consequently, if the river stage returns to its original stage, long-term residual effects on ground-water levels will not occur (Hurr, 1981). Hurr (1981) reported that withdrawals of ground water near the Platte River may affect ground-water levels in at least two ways—first, by initiating drawdowns of ground-water levels, and second, by causing river-stage decline, which may result in further declines in ground-water levels and surface-water streamflow farther downstream.

Stresses on the ground-water system from pumping or recharge are subject to magnitude and timing (Burns, 1983). The effects of these stresses (pumpage or recharge) largely are dependent upon the aquifer's hydraulic characteristics, such as transmissivity, specific yield (for water-table aquifers), the hydraulic connection between the stream and aquifer, and the distance from the point of stress to the stream. Sophocleous and others (1995) reported that quantifying the primary hydraulic characteristics of the aquifer—transmissivity and storage coefficient—might not be as critical in surface-water/ground-water interactions because local streambed "clogging" plays an important part in the degree of interaction. The more fine materials in the streambed, the less interaction between the stream and aquifer. Streambed clogging also affects the magnitude of streamflow accretion or depletion caused by surface-water/ground-water interaction.

Recharge to the ground-water system in the Dutch Flats area by precipitation is much less than recharge to the ground-water system by infiltration of water seeping from irrigation canals and laterals and by infiltration of water applied for irrigation (Babcock and Visher, 1951). Consequently, any rises in ground-water levels caused by precipitation likely are obscured by the much greater rises in ground-water levels from infiltration of surface-water seeping from the canals and water applied to the fields for irrigation. In this study, direct recharge of the ground-water system caused by infiltration of water seeping from the canals and laterals was reflected in water-level rises in some monitoring wells, including wells 1A–3 and 2A–1 adjacent to the Interstate Canal (fig. 12). Water-level rises appeared shortly after surface water was diverted into the Interstate and Tri-State Canals. Within about 20 days of filling the canals, water levels rose as much as 4 ft in monitoring well 1A–3 (fig. 12) adjacent to and downgradient from the Interstate Canal. After the surface-water diversions stopped and the flow in the canals ceased, water levels began to decline in monitoring wells near the canals that showed responses to canal seepage.

Freeze (1969) reported that antecedent soil moisture is likely the most important characteristic that affects the amount of ground-water recharge. Therefore, it was presumed for the Dutch Flats study area that because the canals seep, the soil generally is totally saturated and allows for substantial recharge to the aquifer. Hence, recharge was estimated using the projected downward trend in water levels in the monitoring wells as described in Babcock and Visher (1951). The downward trends were projected from the decline during the previous winter to the time when water levels reached a seasonal high. The difference between the projected low and the seasonal high water levels multiplied by the specific yield was assumed to equal the gross recharge occurring at that monitoring well site. Using this method, estimation of recharge at monitoring well 1A–3 generally agreed with the estimate of Babcock and Visher (1951) of 3 ft per summer (June, July, and August).

Bedrock Aquifers

Bedrock aquifers in the study area include the Brule, Chadron, and Lance aquifers. The bedrock aquifers typically are used when appreciable yields from the alluvial aquifer cannot be obtained.

Brule Aquifer

The Brule aquifer (table 3) generally is unconfined with sustainable yields only in areas that contain secondary porosity from fissures and cracks or, less commonly, fluvial sand units. Ground water in the localized fluvial sand units typically can be encountered at depth but generally is not considered areally extensive and largely is unmapped. In areas where the Brule aquifer is near the land surface, depths to water vary from less than 5 ft near the perennial drainages to 25 to 40 ft near the Tri-State Canal. In areas where the aquifer is not near the land surface, depth to water can be 130 ft. Porosity of two core samples of the Brule Formation collected in the study area was reported to be 52.5 percent (Wenzel and others, 1946). Permeability of the consolidated material is so low that water does not flow into a well developed in areas where fissures, cracks, or sand units are not present. Over time,

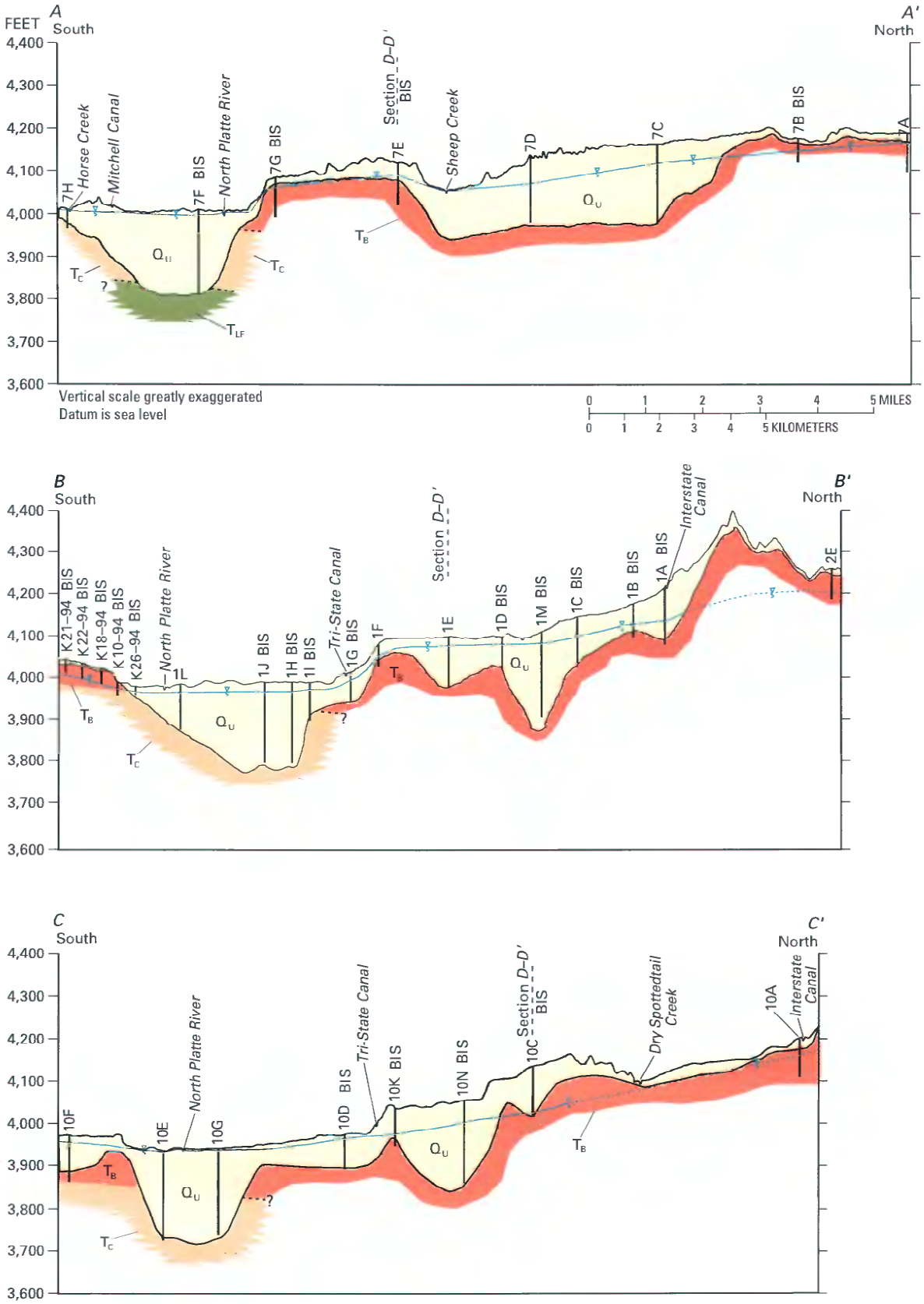


Figure 9. Generalized geologic sections *A–A'* through *D–D'* showing principal geologic units transected by ground-water sampling sites and test holes, Dutch Flats area. Traces of sections are shown in figure 8.

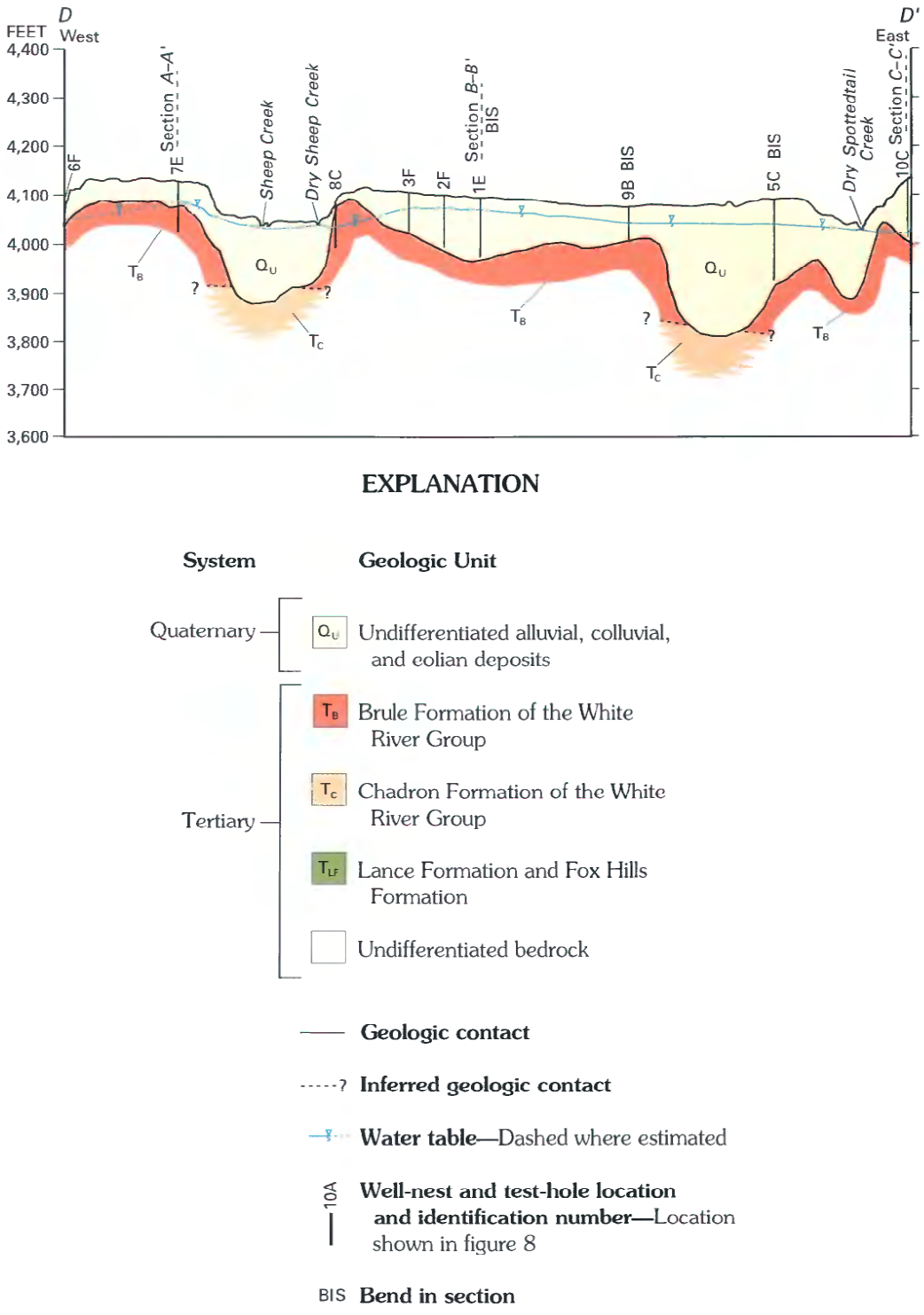


Figure 9. Generalized geologic sections *A–A'* through *D–D'* showing principal geologic units transected by ground-water sampling sites and test holes, Dutch Flats area—Continued. Traces of sections are shown in figure 8.

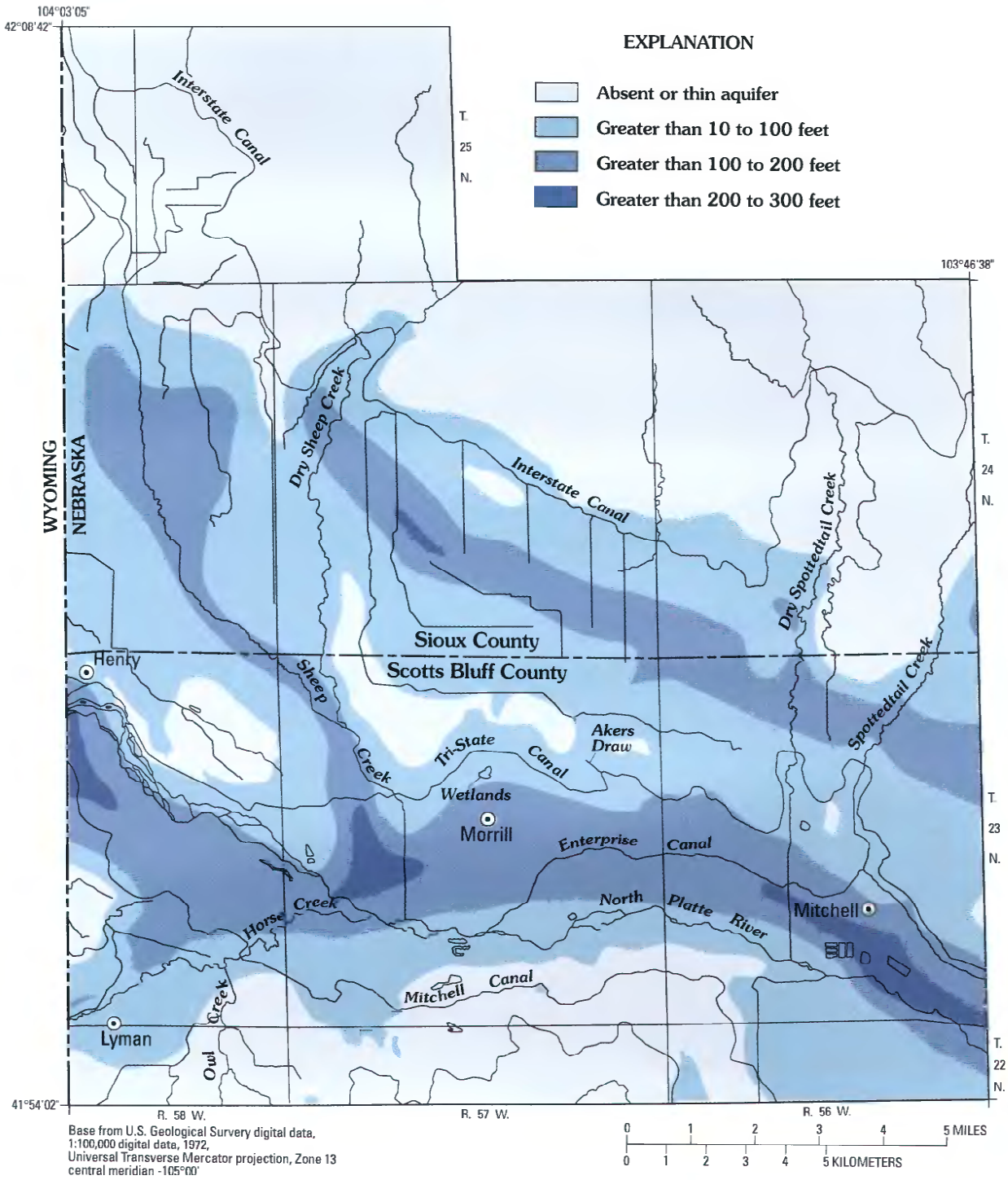


Figure 10. Saturated thickness of alluvial aquifer, Dutch Flats area, summer 1998.

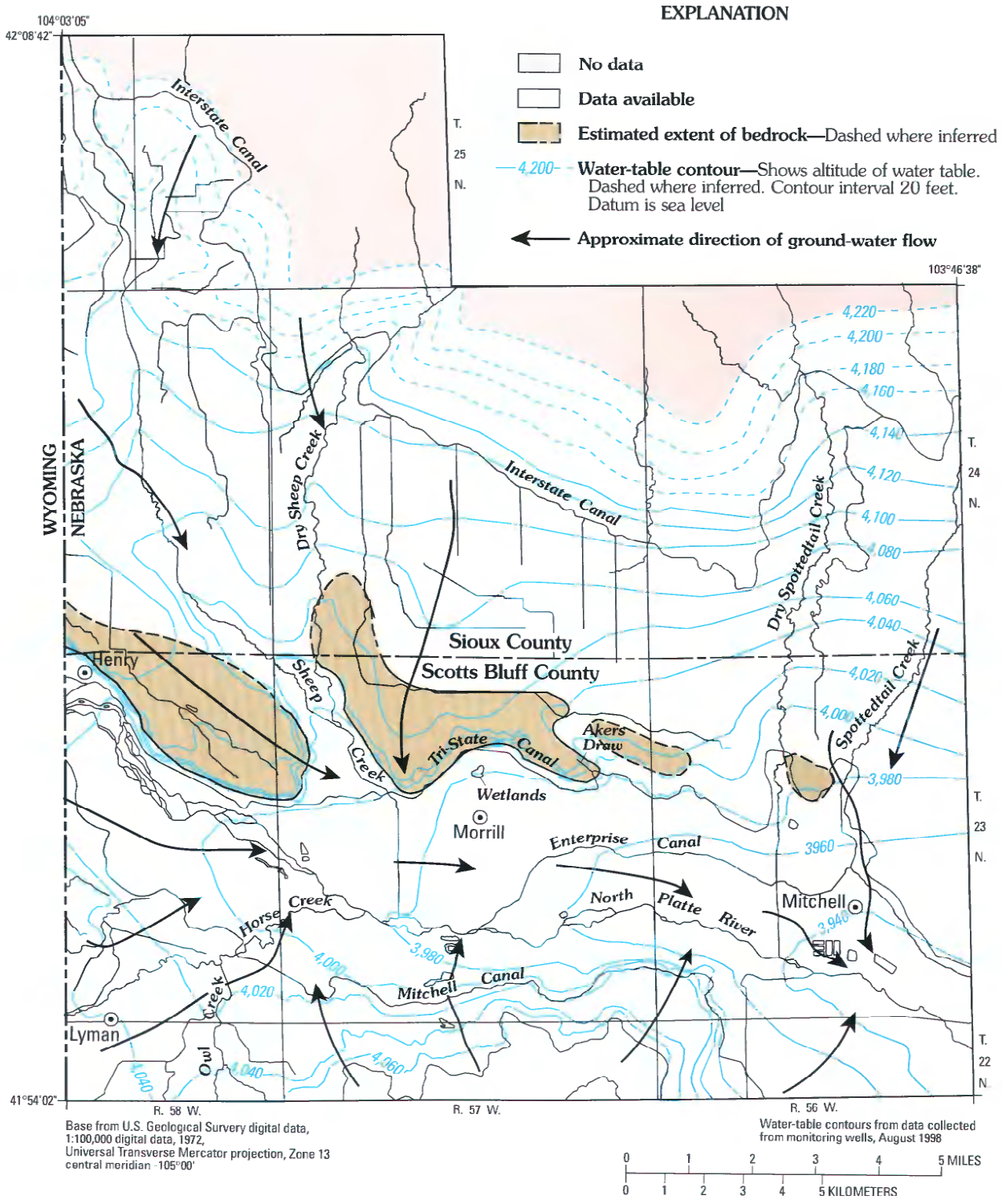


Figure 11. Configuration of water table in alluvial aquifer, Dutch Flats area, summer 1998.

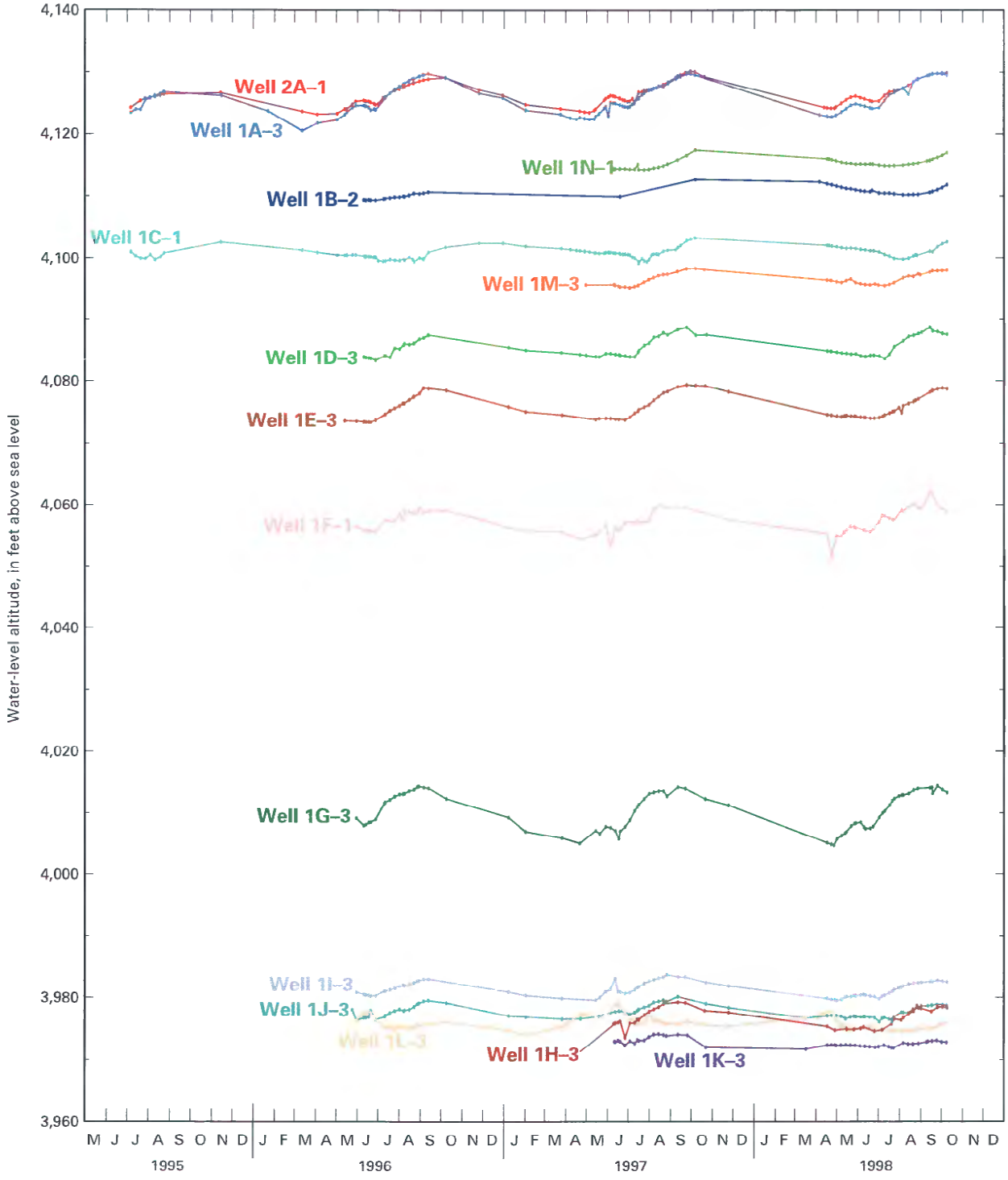


Figure 12. Water levels in selected monitoring wells along section B–B', Dutch Flats area, May 1995 through September 1998. Locations of wells are shown in figure 8.

water will percolate slowly into a well, and the water level will rise to the level of the water table.

In the study area, yields to wells in the Brule aquifer typically are sufficient for domestic and stock use. Locally, however, yields to wells can differ considerably. Sustainable yields to wells are dependent upon the amount of recharge and the number, size, and continuity of the fractures. Water supplies from the Brule aquifer are greatest in areas nearest the irrigation canals (Wenzel and others, 1946). In these areas, seepage from the irrigation canals and the irrigated fields results in large volumes of recharge to the aquifer. This recharge is typically much larger than in areas where the only recharge to the aquifer is from precipitation.

Chadron Aquifer

The Chadron aquifer is confined by bentonitic mudstone and claystone of the Chadron confining unit (Verstraeten and others, 1995). The confining unit has not been mapped in detail but is thought to underlie most of the study area. The basal water-bearing unit of the Chadron aquifer consists of sandstone and conglomerate deposited in paleovalleys. Where present, the Chadron aquifer generally underlies the alluvial aquifer and the Brule aquifer. Because the Chadron aquifer is confined, depth to water in wells completed in the Chadron aquifer in the study area is typically 5 to 20 ft below the land surface. This aquifer is rarely developed because of the great depth to the aquifer or unsuitable water quality (Verstraeten and others, 1995).

Lance Aquifer

In the study area, the Lance aquifer is confined and underlies the Chadron aquifer (table 3). Former river systems incised the overlying bedrock formations and exposed the Lance Formation at depth, such as in the southwestern part of the study area. Typical depth to water in wells completed in the Lance aquifer in the study area is about 15 ft below land surface. Yields to wells developed in the Lance aquifer typically are small—as much as 1 gal/min (Wenzel and others, 1946). Wells in the Lance aquifer generally are used only for stock and domestic supplies and only when other sources of water are unavailable.

SELECTED WATER-QUALITY CONSTITUENTS IN SURFACE AND GROUND WATER

Water, especially ground water, acts as a geologic agent by its ability to interact with the environment, the sediment or solid phase, and biota. Water chemistry generally is described by its ionic composition but, recently, also has been described and better understood through evaluation of dissolved gases and selected isotopes as tracers of water or contaminants. Isotopes are atoms of the same element that have different masses; they have the same number of protons and electrons but a different number of neutrons. Variations of isotope ratios generally are small and, therefore, are commonly expressed as the parts-per-thousand difference between the isotope ratio of a standard (δ units). Radionuclides are isotopes of elements that change into other elements by radioactive decay. Uranium-238 (^{238}U) and uranium-234 (^{234}U) are long-lived radioactive nuclides that have been used to identify mixing of water masses and to investigate surface-water/ground-water interaction. Radon-222 (^{222}Rn) is a decay product of ^{234}U.

In this report, the discussion of the spatial distribution of the selected water-quality consituents generally is limited to the data collected during the summer of 1998 when almost all wells were sampled within a 2-week period. However, the discussion of the spatial distribution of uranium concentrations mainly focuses on data collected in the summers of 1998 and 1999. Minimum, median, and maximum concentrations mentioned generally are for data collected from 1995 through 1999, unless it is specified that they are 1998 or 1999 data. Changes in chemistry with time, although occasionally mentioned in this section, generally are discussed in the section on surface-water/ground-water interaction. All water-quality data referred to in this report are included in USGS reports (Boohar and Walczyk, 1997, 1998; Boohar, 2000; Verstraeten and others, in press) and can be retrieved from the USGS National Water Information System database.

Physical Properties

Onsite measurements of specific-conductance values and dissolved oxygen varied widely between surface-water and ground-water sampling sites. The pH, which tended to be more than 7.7 in surface water,

ranged from 7.1 to 7.8 in the alluvial aquifer and was as much as 8.5 in the bedrock aquifers.

Specific Conductance

Specific-conductance values in water from the North Platte River (sites SW2 and SW9) or in water from the canals (sites SW1 and SW3) diverted from the river ranged from 400 to 1,050 µS/cm at 25 °C from 1995 through 1999. Larger values were recorded during the winter, and smaller values were recorded during the spring and early summer. Specific-conductance values in water from the Interstate Canal (site SW1) varied from 427 to 733 µS/cm. Specific-conductance values in water from the wetlands site (SW11) were relatively large, generally greater than 1,000 µS/cm, especially during dry periods. They ranged from 832 to 2,930 µS/cm. Specific-conductance values in water from Sheep (site SW8) and Dry Sheep (site SW7) Creeks, which receive their water during base flow from the alluvial aquifer, varied from 774 to 896 µS/cm; these values are typical for shallow ground water in this area. Specific-conductance values in water from Horse Creek (sites SW4 and SW6) were larger than those in water from Dry Sheep (site SW7) and Sheep (site SW8) Creeks and ranged from 838 to 1,080 µS/cm.

In ground water, the largest specific-conductance value was measured in water from well 6I completed in the Lance aquifer (1,770 µS/cm in August 1998). Water from the alluvial, Chadron, and Lance aquifers had larger specific-conductance values than water from the Brule aquifer and the surface-water sampling sites. Water from wells completed in bedrock tends to have large amounts of dissolved solids, which result in large specific-conductance values, and water from wells completed in the alluvial aquifer tends to have small specific-conductance values. Specific-conductance values in water from the northern alluvial aquifer in the study area were smaller than in water from the southern alluvial aquifer. The largest specific-conductance values generally collected during the summer of 1998 were measured in shallow ground water near the North Platte River (well 1L–3 with 1,380 µS/cm; well 7H with 1,570 µS/cm) and near and in water from the bedrock aquifers (well 26K–94 with 1,510 µS/cm; well 8F–1 with 1,690 µS/cm; and well 6I with 1,770 µS/cm) (fig. 13). In water from the northern alluvial aquifer, specific-conductance values generally were less than 1,000 µS/cm.

Specific-conductance values in water from the Interstate Canal and in ground water immediately upgradient from the canal were different. However, differences in specific-conductance values between surface and ground water were not as obvious near the Tri-State Canal and were variable near the North Platte River. Large specific-conductance values in ground water near the bedrock south of the North Platte River may indicate ground-water flow from the bedrock aquifers into the alluvial aquifer from the south to the northeast (fig. 13).

Dissolved Oxygen

Dissolved-oxygen concentrations in the surface water generally were larger than 7.0 mg/L. Dissolved-oxygen concentrations in shallow ground water were highly variable, ranging from near zero near bedrock, near the North Platte River, or near wetland areas, to about 13 mg/L in other areas. Along and south of the North Platte River, where the bottomland sediment is fine and tends to contain abundant organic matter, or in the Chadron aquifer, the ground water was totally depleted of dissolved oxygen in places. At depth, especially in the southern alluvial aquifer, the dissolved-oxygen concentrations in water samples were less than 2.0 mg/L, and in some places were zero (water from wells 1J–1, 1L–1, 1K–94–1, and 26K–94–1).

Dissolved-oxygen concentrations near zero suggest that near-reducing to reducing conditions may exist or that these water samples were collected at a redoxcline—a region where an oxidizing environment gradually changes with depth into a reducing environment with small amounts of dissolved oxygen or no dissolved oxygen (anoxic) present. Ground water in the alluvial and Brule aquifers tends to be the most oxic on the basis of data collected during the summers of 1998 and 1999. Water from the alluvial aquifer had a median dissolved-oxygen concentration of 5.4 mg/L (117 samples); water from the Brule aquifer had a median dissolved-oxygen concentration of 7.4 mg/L (18 samples); and water from the Chadron aquifer tended to be anoxic (median dissolved-oxygen concentration of 0.2 mg/L for four samples). Water collected from well 6I, completed in the Lance aquifer, had a dissolved-oxygen concentration of 1.4 mg/L.

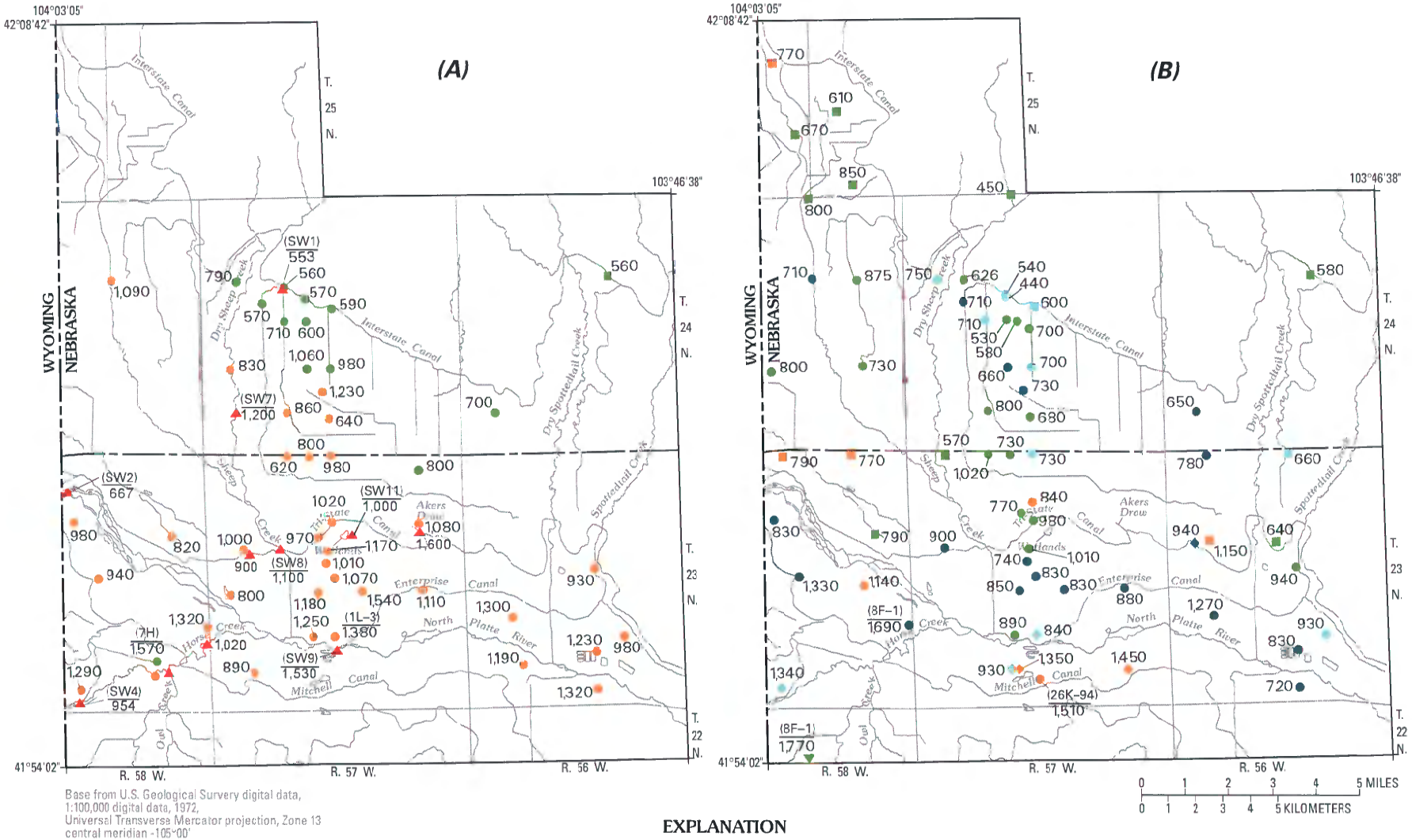


Figure 13. Distribution of specific-conductance values in surface water and water from *(A)* wells completed near water table and *(B)* wells completed in or just above bedrock, Dutch Flats area, summers of 1998 or 1999.

Selected Major Ions

Major ions also varied between surface-water and ground-water sampling sites and along flow paths. In the study area, the aquifer lithology is the predominant factor affecting the ground-water chemistry as dilute water from precipitation and surface water interact with aquifer materials.

Large concentrations of sodium and sulfate in the water from the southern alluvial aquifer near the North Platte River suggest mixing of water in the alluvial aquifer with water from the underlying shale or dissolution of salt, gypsum minerals, or sulfides such as pyrite in the sediment. These large sulfate concentrations occurred in water near a redoxcline or near the Chadron and Lance Formations, indicating that oxidation of pyrite could be taking place.

The ionic composition of water from the alluvial aquifer generally showed a calcium sulfate signature, and the ionic composition of water from the Brule, Chadron, and Lance aquifers generally showed a sodium bicarbonate signature (fig. 14). Water from the North Platte River was intermediate between the ionic compositions of the calcium and sodium bicarbonate types. Mixing of water from the Chadron and Lance aquifers with water from the alluvial aquifer was evident (fig. 14) (water from wells 1H–1 and 26K–94–1).

Water from the Lance aquifer (well 6I) had large sodium, chloride, sulfate, silica, and bicarbonate concentrations. Larger concentrations of sodium, chloride, and bicarbonate were present in samples collected from the Chadron aquifer (well 1K–94–1) than in samples collected from the alluvial and Brule aquifers. Water from the Brule, Chadron, and Lance aquifers had smaller concentrations of calcium and magnesium than water from the alluvial aquifer. Finally, water from the alluvial aquifer near the North Platte River (well 1J–1) had smaller concentrations of silica and larger concentrations of sulfate (200 mg/L), sodium (64 mg/L), and fluoride (0.43 mg/L) than water from the rest of the alluvial aquifer.

Bicarbonate, alkalinity, and sulfate concentrations indicate that ground water from the north-central part of the study area (well 2E–1) evolved towards water with larger concentrations of bicarbonate as it moved from the north to the south from the Brule aquifer, through the northern alluvial aquifer, and into the southern alluvial aquifer where it mixed in part with water from the Chadron and Lance aquifers. In the southern alluvial aquifer, ground water also was affected by the chemistry of the Chadron and Lance aquifers at depth in water from wells completed near the contact with bedrock [water from wells 6G–1 (320 mg/L sulfate and 123 mg/L sodium), 7H (340 mg/L sulfate and 191 mg/L sodium), and 8F–1 (400 mg/L sulfate and 191 mg/L sodium)] and in shallow water [water from wells 1I–3 (300 mg/L sulfate and 90 mg/L sodium), 1L–3 (310 mg/L sulfate and 115 mg/L sodium), and 2L–3 (290 mg/L sulfate and 95 mg/L sodium)] near the contact with the Chadron and Lance Formations.

Ground-water-quality data from water near bedrock support the water-level data and age dating of the water (Verstraeten and others, 2000), suggesting ground-water flow from the bedrock into the alluvial aquifer. In the northern alluvial aquifer, water moves generally from north to south, and ground water from the Brule aquifer mixes with younger alluvial ground water. In the southern alluvial aquifer on the south side of the North Platte River, ground water moves from the southwest to the northeast, and some older water from the Chadron aquifer mixes with younger water from the alluvial aquifer.

During base flow and during the winter when spring melt water is absent and precipitation generally is minimal, surface water from the North Platte River at Morrill had an intermediate composition between the ground water in the Brule aquifer and ground water in the Chadron and Lance aquifers on the basis of sulfate and chloride data. As a generally gaining stream, the North Platte River receives water from runoff where the eroded Lance Formation is exposed outside the study area and receives water through underflow from the alluvial aquifer and from the Brule, Chadron, and Lance aquifers. During snowmelt in the spring, water in the North Platte River mainly comes from areas upstream in Wyoming, which results in a different water chemistry. Specifically, specific-conductance values and calcium, magnesium, and sulfate concentrations tend to be larger during this time than during the remainder of the year.

Surface water from the Interstate Canal had a distinct signature with small calcium, magnesium, chloride, and silica concentrations. Surface water from the Tri-State Canal was similar to the chemistry of water from the North Platte River at the State line and was intermediate between the chemical composition of surface water from the Interstate Canal and from the North Platte River at Morrill.

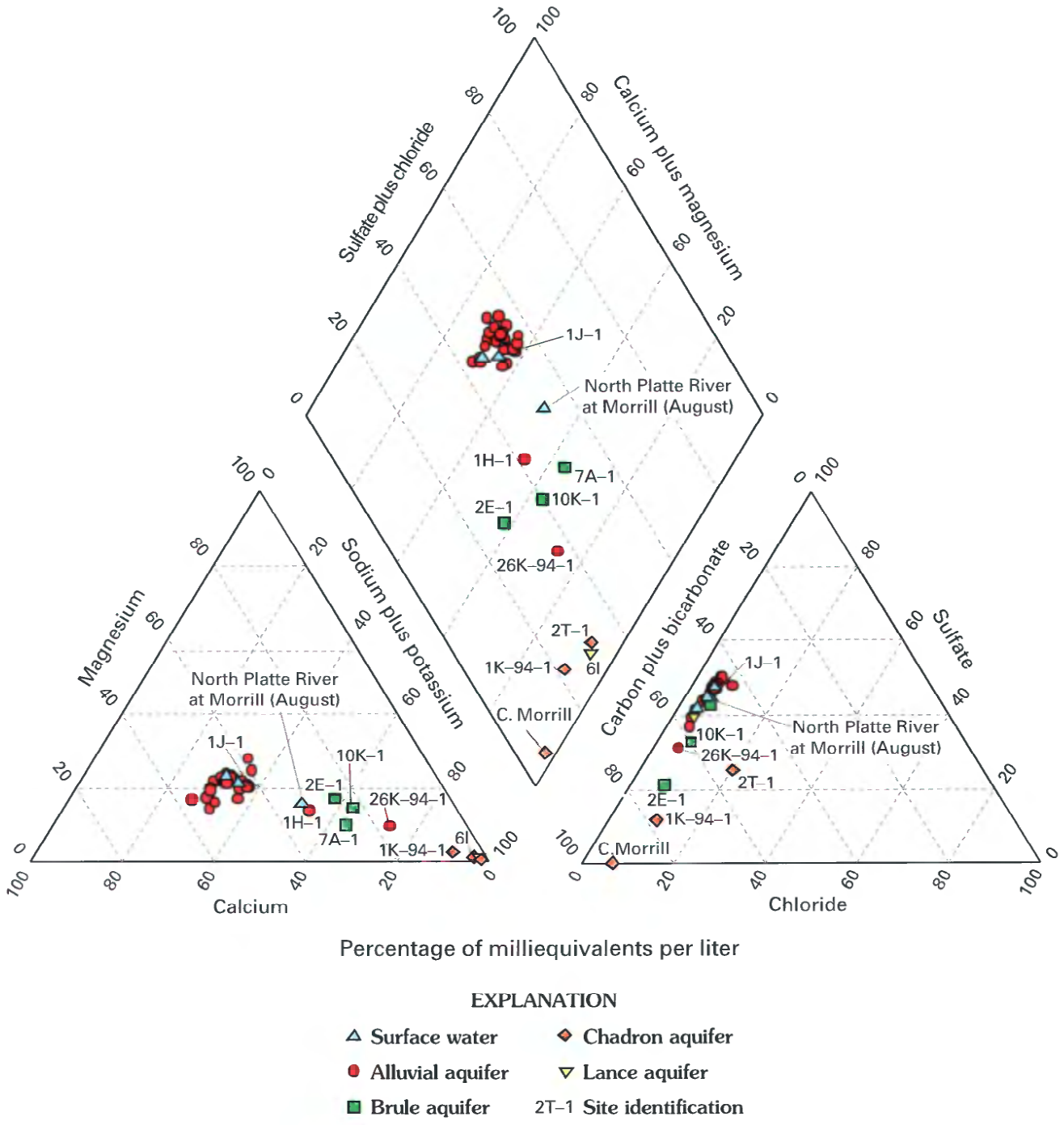


Figure 14. Ionic composition of water from selected surface-water and ground-water sampling sites along geologic section *B–B'*, Dutch Flats area, summer 1998.

Nitrogen

Nitrogen species analyzed during the study included nitrate, nitrite, ammonia, organic nitrogen, and nitrogen gas (Verstraeten and others, in press). Although fertilizer is applied to the land in the form of ammonia, it generally is transformed to nitrate through oxidation in the unsaturated zone. Nitrate is transported to the water table with recharge after precipitation, transported along flow paths through the aquifer, and then, in part, discharged into surface water.

In surface water, the maximum observed nitrate concentration was 11 mg/L in surface water from Akers Draw (site SW10), a spring discharging water

from the alluvial aquifer. Water from Sheep Creek (site SW8) contained nitrate concentrations of as much as 7.6 mg/L. Nitrate concentrations in water from the North Platte River at Morrill (site SW9), generally remained less than 3.0 mg/L. The largest nitrate concentrations in the North Platte River generally were observed during the winter months from December through February. During the summer months (June, July, and August), nitrate at times remained undetected in water from the North Platte River at Morrill. During the irrigation season (June through September), nitrate concentrations generally were undetected in water from the Interstate Canal. In 1998, the maximum nitrate concentrations during the summer months were observed in water from Akers Draw (site SW10) at 9.1 mg/L and from Sheep Creek (site SW8) at 6.1 mg/L (fig. 15).

In ground water, a stratification of nitrate was observed, with larger concentrations (at times exceeding 20 mg/L) in shallow water less than 5 years old, mainly from the alluvial aquifer, and small concentrations (less than 0.05 mg/L) in deep water older than 20 years, especially in water from the Chadron aquifer (figs. 15, 16, and 17) (Verstraeten and others, 2000). Concentrations as large as 28 mg/L in water from well 1F–1 in 1997, 27 mg/L in water from well 1J–3 in 1997, 24 mg/L in water from well 10E–2 in 1998, and 24 mg/L in water from well 2F–3 in 1998 (fig. 15) were detected; all four wells are shallow wells completed in the alluvial aquifer. Nitrate concentrations less than 2.0 mg/L were observed locally in shallow ground water: (1) near wetlands and near the North Platte River, where ground-water levels were shallow and ground water was depleted of dissolved oxygen; (2) in places near the contact with shallow bedrock; and (3) near the canals during the irrigation season and, to a lesser extent, near laterals where recharge through seepage of surface water to the aquifer was evident (figs. 15 and 16).

A direct relation exists between fertilizer use and nitrate concentration over time in the alluvial aquifer. Fertilizer use increased by a factor of about 15 from 1950 through 1994 (fig. 4). Nitrate concentrations in ground water from the alluvial and Brule aquifers also increased during this time frame (Verstraeten and others, 2000).

Increases in nitrate concentrations have been observed near Oshkosh, Nebraska, 70 to 95 mi downstream from the study area (Exner and Spalding, 1994) (index map, fig. 1). On the basis of $\delta^{15}N\text{-}NO_3^-$ (a nitrogen isotope), Exner and Spalding (1994) determined that nitrate in water from the shallow aquifer near Oshkosh mainly was derived from commercial fertilizer rather than animal waste. In the Dutch Flats area along transect *B–B'*, the $\delta^{15}N\text{-}NO_3^-$ in ground water ranged from -0.5 per mil (per thousand) to 11.5 per mil (Verstraeten and others, 2000). Most terrestrial materials have a composition of $\delta^{15}N\text{-}NO_3^-$ between -20 and +30 per mil. Atmospherically derived nitrogen and fertilizer-derived nitrogen typically have $\delta^{15}N$ values less than 6 per mil, whereas animal-derived nitrogen has $\delta^{15}N$ values more than 9 per mil (Gormly and Spalding, 1979; Exner and Spalding, 1994; McMahon and others, 1999). The $\delta^{15}N$ values of less than 6 per mil are consistent with other occurrences of nitrate contamination beneath fertilized fields (Verstraeten and others, 2000). Locally, however, ground water has been affected by nitrogen from animal waste or a mixture of both sources.

During the summers of 1998 and 1999, the median nitrate concentration in water samples from the alluvial aquifer was 4.3 mg/L (116 samples). Concentrations ranged from less than 0.05 to 24 mg/L. In water from the Brule aquifer, nitrate concentrations varied from 0.23 to 11 mg/L with a median of 5.0 mg/L (18 samples). The USEPA MCL of 10 mg/L (U.S. Environmental Protection Agency, 2000) was exceeded in 17 of 116 samples (15 percent) from all wells completed in the alluvial aquifer and in 11 of 48 samples (23 percent) from shallow wells completed in the alluvial aquifer. Nitrate concentrations in water from the Chadron aquifer varied from less than 0.05 to 8.4 mg/L (four samples). Water from well 6I, completed in the Lance aquifer, had a nitrate concentration of 7.0 mg/L in the summer of 1998 (fig. 15).

Well 1C–4, completed at a depth similar to well 1C–3 (table 2), was constructed near a lateral to evaluate whether shallow ground water near a lateral would have different water chemistry depending upon the proximity of the lateral to the well. Water from well 1C–4 was sampled 29 times generally within 1 hour of when water from well 1C–3 was sampled. Samples from these two wells were analyzed for nitrate (24 samples) and other constituents. Large differences were observed between nitrate concentrations in water from shallow ground water obtained from these wells. Differences in nitrate concentrations ranged from 0.26 to 5.5 mg/L, with a median difference of 1.7 mg/L. Relative differences in nitrate

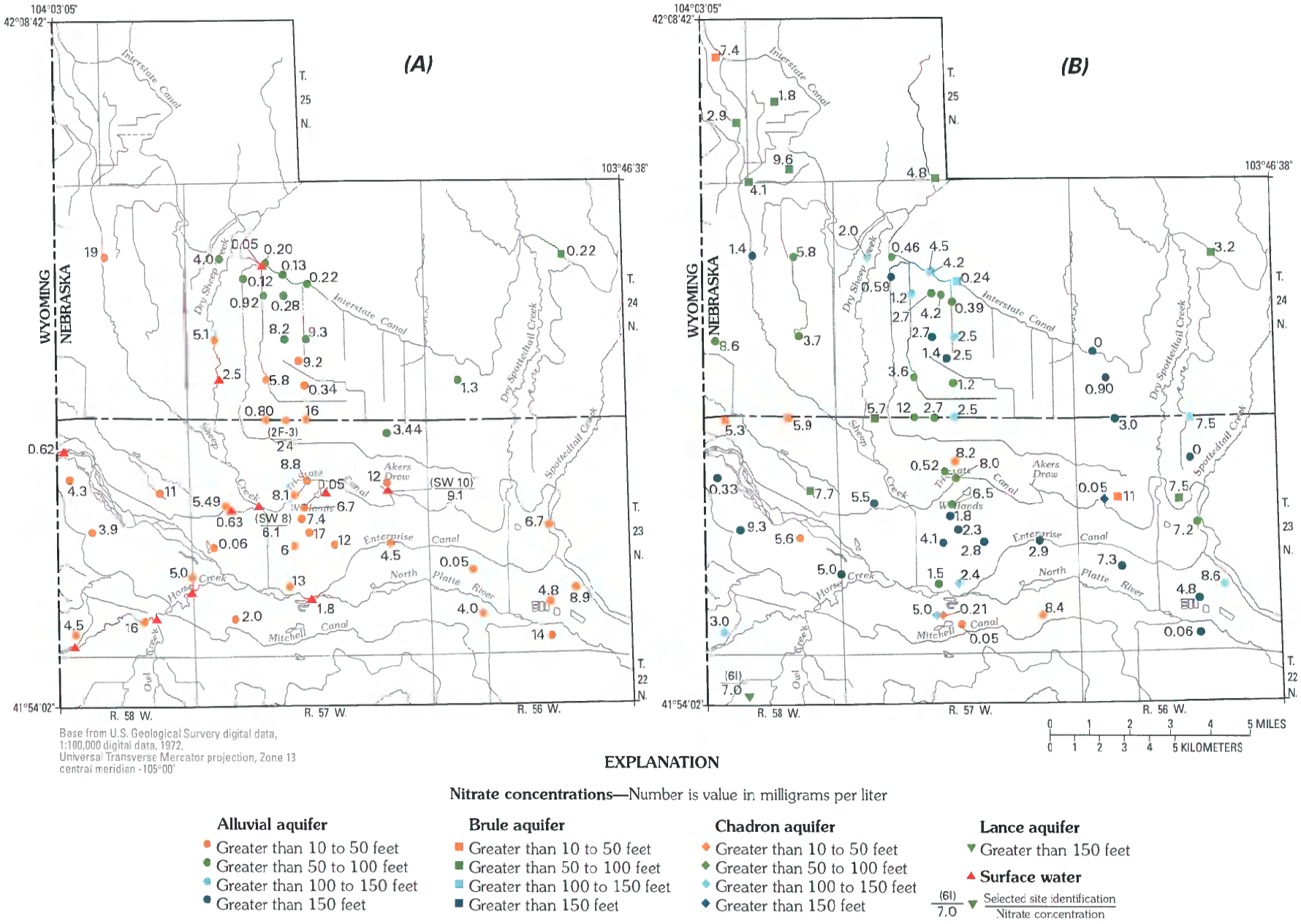


Figure 15. Distribution of nitrate concentrations in surface water and water from *(A)* wells completed near water table and *(B)* wells completed in or just above bedrock, Dutch Flats area, summers of 1998 and 1999.

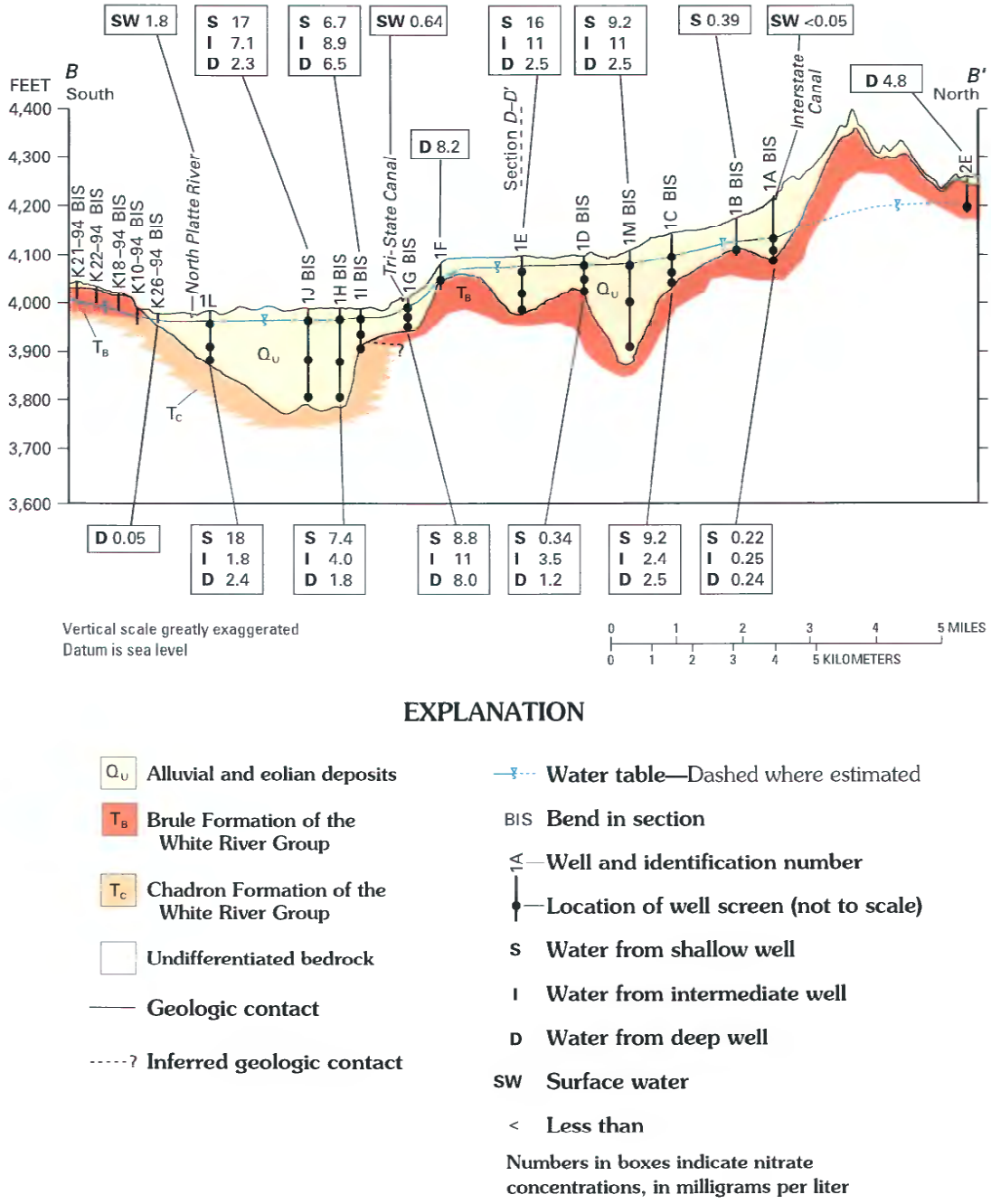


Figure 16. Generalized geologic section *B–B'* showing nitrate concentrations, Dutch Flats area, summer 1998. Locations of sampling sites are shown in figure 8.

concentrations of water collected within 1 hour from wells 1C–3 and 1C–4 varied from 4 to 55 percent with a median difference of 19 percent. These results indicate that nitrate concentrations in shallow ground water can vary as much as 5 mg/L over short distances because of seepage of surface water containing small nitrate concentrations from the laterals to the ground water. No denitrification was apparent at these sites.

The occurrence of nitrite, ammonia, and nitrogen gas was limited in surface-water and ground-water samples. In surface water, nitrite and ammonia concentrations generally were near or less than the reporting level. The maximum concentrations were 0.08 mg/L nitrite as N in water from the North Platte River at Morrill (site SW9) and 0.06 mg/L ammonia as N in water from Sheep Creek (site SW8) (summer

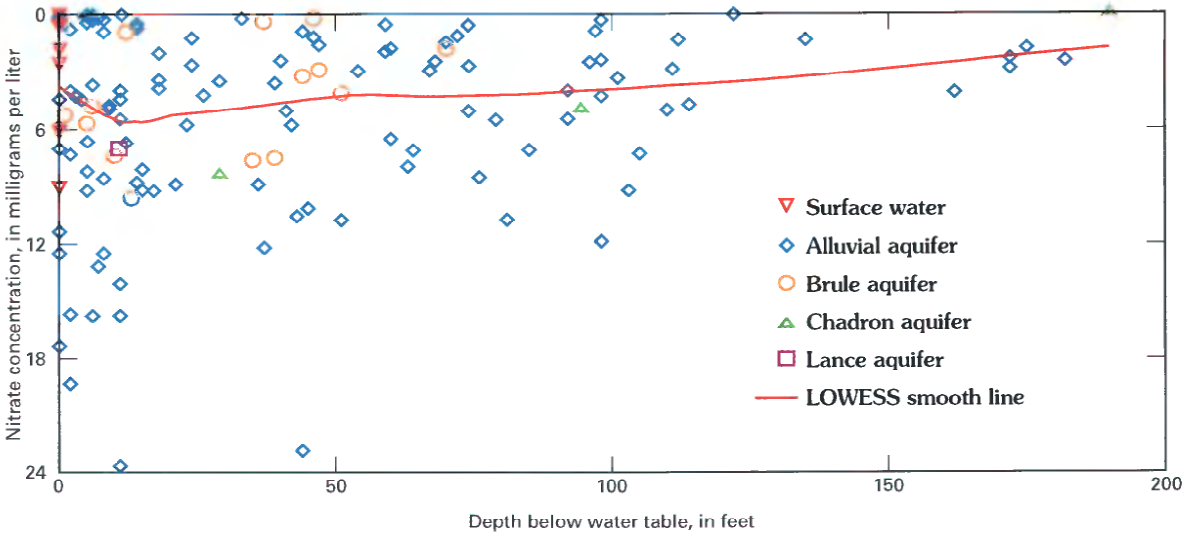


Figure 17. Distribution of nitrate concentrations by depth below water table, Dutch Flats area, summer 1998.

1998). Because the water in the river tends to be aerobic, most nitrite and ammonia apparently oxidized readily to nitrate. Because the North Platte River is mostly a gaining stream, it is conceivable that part of the nitrate load in the river, especially during low stages, might be the result of contributions of shallow ground water with elevated nitrate concentrations. Surface-water sampling sites with large nitrate concentrations, Sheep Creek (site SW8) and Akers Draw (site SW10), generally had a large ground-water component (estimated at nearly 100 percent) from shallow water in the alluvial aquifer.

At places, detectable nitrite and ammonia concentrations, as well as dissolved organic matter, were present in ground water. For example, a water sample from well 26K–94–1 contained as much as 21 mg/L dissolved nitrogen gas, 0.92 mg/L ammonia, and 0.58 dissolved organic matter as N in the summer of 1998. Nitrate or nitrite concentrations were not detected in this sample. In ground water in the southern alluvial aquifer near the base of the sediment or near the contact with the Chadron and Lance Formations, dissolved-oxygen concentrations were zero.

Nitrite generally was not present in shallow ground water near the water table, indicating that denitrification generally is not an important process in the alluvial aquifer. However, on the basis of dissolved-gas data, including nitrogen, oxygen, and methane (CH_4) gases, some evidence for denitrification may exist near the contact with bedrock (wells 1H–1, 1L–1, and 26K–94–1) or in the Chadron aquifer (wells 1K–94–1 and C. Morrill) (Verstraeten and others, 2000; Verstraeten and others, in press). Methane was present in ground water from the Chadron aquifer near wells 2T–1, 1K–94–1, 26K–94–1, and C. Morrill. The odor of hydrogen sulfide (H_2S) was detected during sampling at these sites.

Denitrification has been identified along the South Platte River in northeastern Colorado (McMahon and others, 1999). McMahon and others (1999) reported that the Pierre Shale was a sink for a minor fraction of nitrate in the alluvial aquifer transported by diffusion into the shale through denitrification. They suggested that, if advection was the dominant process, the fraction of nitrate lost to denitrification might have been large. More detailed work would be useful in identifying the specific reactions that occur near the redoxcline along the North Platte River.

Uranium, Radon, and Uranium Activity Ratio

Uranium occurs in solution, primarily as 5+ and 6+ species, in an oxidizing environment with pH similar to those observed in the study area (7.0 to 9.0) (Maynard, 1983, p. 151–156). Solubility of uranium also is enhanced when it forms carbonate and phosphate complexes. Uranium (6+ species) can become adsorbed to solid organic matter or clay (Langmuir, 1978). Most materials such as mudstone, shale, and sandstone in the White River Group (Brule and Lance Formations) contain traces of uranium in the Dutch Flats area. The playa facies of the Brule Formation near Chadron, Nebraska (fig. 1), is an excellent example of a lithologic facies containing trace amounts of

uranium (Dickinson, 1990). The most common primary minerals of uranium are uraninite (UO_2) and coffinite ($USiO_4$). Uranium also is associated with phosphate fertilizer (Snow and Spalding, 1994).

Uranium and radon concentrations varied substantially in the Dutch Flats area. Uranium concentrations in surface water were flow and time dependent. Uranium concentrations generally were larger in samples from the North Platte River at Morrill (22 µg/L, site SW9) than in samples from the North Platte River at the Wyoming-Nebraska State line (13 µg/L, site SW2) in August 1999 (figs. 18 and 19). Uranium concentrations in water from the North Platte River at Morrill (site SW9) varied from 11 to 31 µg/L. At the State line, uranium concentrations in water from the North Platte River were less than 13 µg/L. Smaller concentrations of uranium (7.9 µg/L, site SW1) were detected in water from the Interstate Canal (fig. 18). The largest uranium concentrations (44 µg/L) generally were measured in water from Owl Creek near Lyman (site SW5). Uranium concentrations in water from Horse Creek near the State line (site SW4) were about 2.5 µg/L less than at the site near Lyman (site SW6) on August 23, 1999.

During high-flow conditions in the spring and early summer, uranium is diluted in the river by snowmelt water, occasionally supplemented by water from thunderstorms. During those times, uranium concentrations were less than 30 µg/L in samples from the North Platte River at Morrill (site SW9). However, during the late fall and winter from November until February, uranium concentrations in samples from the North Platte River at Morrill peaked at 31 µg/L. Additional investigations are currently (2001) underway to identify the sources of uranium in the surface water.

In ground water, uranium concentrations also varied considerably (figs. 18 and 19). Uranium concentrations in the alluvial aquifer varied from about 2.0 µg/L (water from well 2F–3) in shallow ground water in the northern alluvial aquifer to about 80 µg/L (water from well 9E–2) in the basal southern alluvial aquifer (fig. 18). As much as 88 µg/L of uranium (water from well 1K–94–2) was present in shallow ground water near the North Platte River and as much as 89 µg/L (water from well 9E–1) in ground water near the contact with the Chadron and Lance aquifers (fig. 18). The median uranium concentration in the alluvial aquifer was 16 µg/L. Seventeen of 121 samples (14 percent) from wells completed in the alluvial aquifer exceeded the USEPA MCL of 30 µg/L (U.S. Environmental Protection Agency, 2000). Uranium concentrations of as much as 88 µg/L were detected in water samples from the alluvial aquifer near the contact with the Chadron aquifer. As much as 33 µg/L, exceeding the USEPA MCL for uranium, was detected in water from well 7G–1 completed in the Brule aquifer. As much as 71 µg/L of uranium were detected in a sample from well 6I completed in the Lance aquifer (fig. 18). Water in the Chadron aquifer, especially at depth, had concentrations of uranium that ranged from less than 0.07 µg/L (water from well C. Morrill) because water was depleted of oxygen, which caused uranium to remain precipitated in this environment, to 89 µg/L (water from well 9E–1) in an oxygenated environment (fig. 18). Water from two of six wells completed in the Chadron aquifer exceeded the USEPA MCL of 30 µg/L. During the irrigation season near the irrigation canals, uranium concentrations in ground water decreased to less than 10 µg/L, concentrations similar to those of water from the Interstate and Tri-State Canals (about 6.0 to 8.0 µg/L) (Verstraeten and others, 2000).

Radon-222 is a daughter product of uranium with a short half-life and a tendancy to be enhanced by water from or near bedrock rich in uranium. USEPA has proposed an MCL of 300 pCi/L and an alternative MCL (AMCL) of 4,000 pCi/L (U.S. Environmental Protection Agency, 2000), which can be adopted by a State. Radon activities in surface water tended to be small (less than 80 pCi/L ^{222}Rn) because radon readily volatilizes when exposed to the atmosphere (figs. 20 and 21). Volatilization was not as important for surface-water samples from Akers Draw (as much as 420 pCi/L, site SW10), Sheep Creek (as much as 120 pCi/L, site SW8), Dry Sheep Creek (as much as 133 pCi/L, site SW7), and the wetlands site (as much as 160 pCi/L, site SW11). These data reflect the fact that surface water at these sites recently consisted mostly of ground-water discharge. About 6,100 ft upstream from the sampling site at Akers Draw, ground water is discharged intermittently to the surface.

Ninety-four of 117 samples (80 percent) collected from wells completed in the alluvial aquifer had radon activities less than 300 pCi/L. A radon activity of 1,699 pCi/L was detected in water from well 1G–1 (figs. 20 and 21). The largest radon activity (4,190 pCi/L) was measured in water from well 1K–94–1 completed in the Chadron aquifer (fig. 20). Radon activities in excess of 1,000 pCi/L

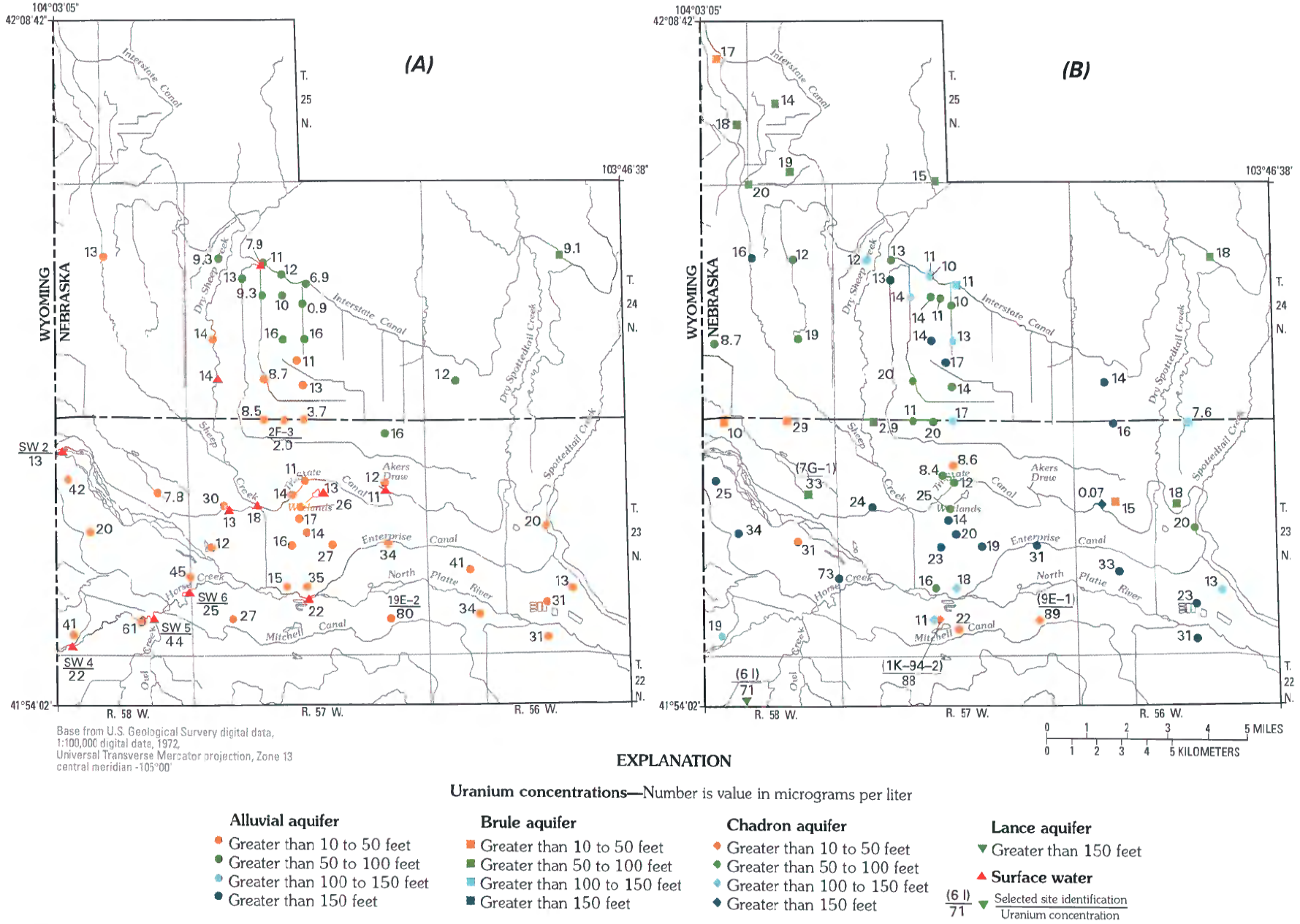


Figure 18. Distribution of uranium concentrations in surface water and in water from *(A)* wells completed near water table and *(B)* wells completed in or just above bedrock, Dutch Flats area, summers of 1998 and 1999.

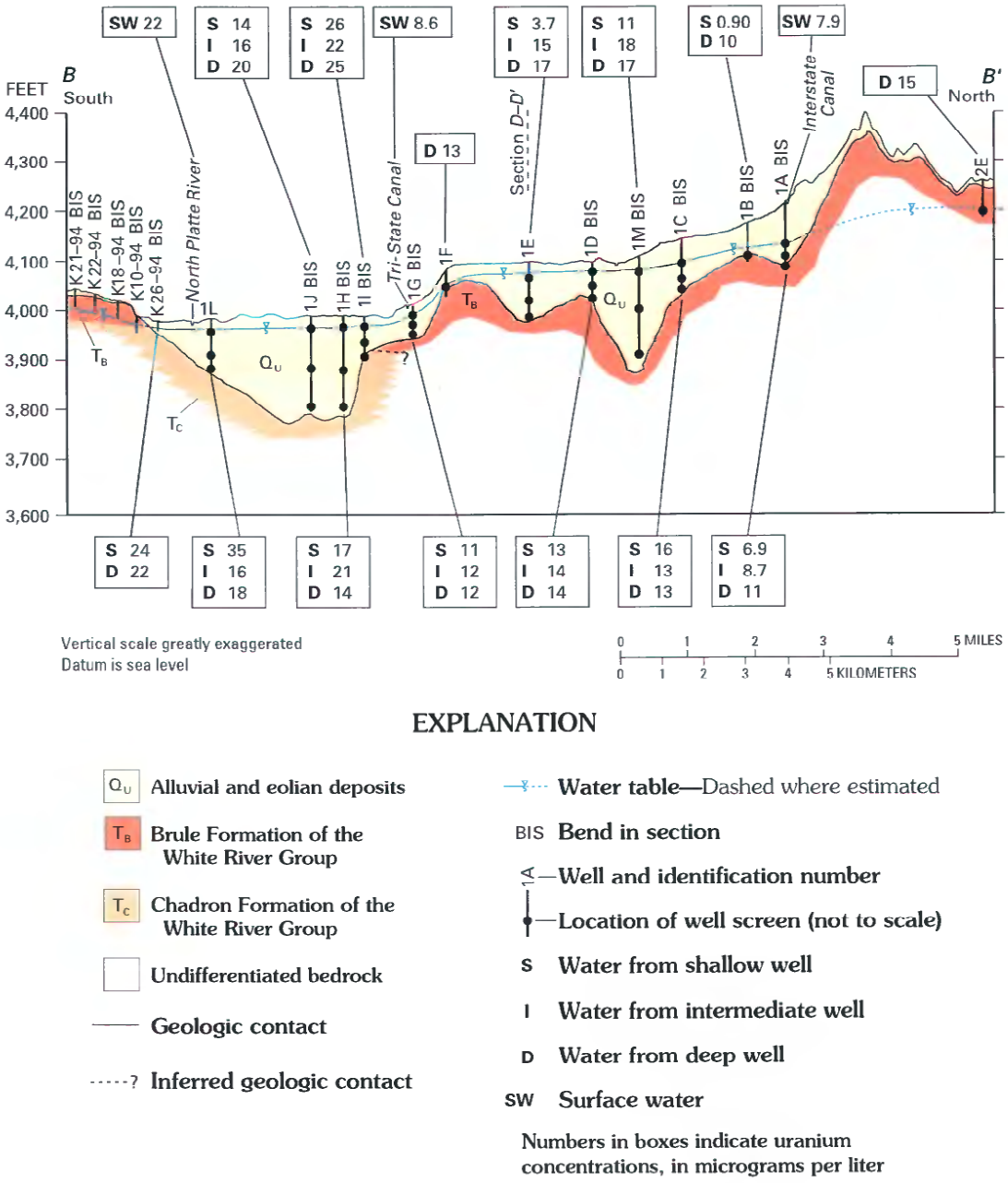


Figure 19. Generalized geologic section *B–B'* showing uranium concentrations, Dutch Flats area, summers of 1998 and 1999.

(fig. 20) are present in the northwest part of the study area where wells are completed in the Brule aquifer (fig. 20). Water from 15 of 16 wells (94 percent) completed in the Brule aquifer exceeded 300 pCi/L, and water from 5 of 16 wells (31 percent) completed in the Brule aquifer exceeded 1,000 pCi/L. Wells completed in the Chadron aquifer had large ranges in radon activities (493 pCi/L in water from well 1L–1 to 4,190 pCi/L in water from well 1K–94–1). Overall, uranium concentrations and radon activities indicate that water in the alluvial aquifer consists partly of water that has moved from the Brule, Chadron, or Lance aquifers.

The uranium activity ratio ($^{234}U/^{238}U$) or UAR varied among surface-water and ground-water samples (Verstraeten and others, 2000). The UAR in water from the North Platte River at the Wyoming-Nebraska State line (site SW2) was 1.6 (fig. 22). In water from the North Platte River at Morrill (site SW9), the UAR was 1.7, and the UAR in water from Horse Creek at

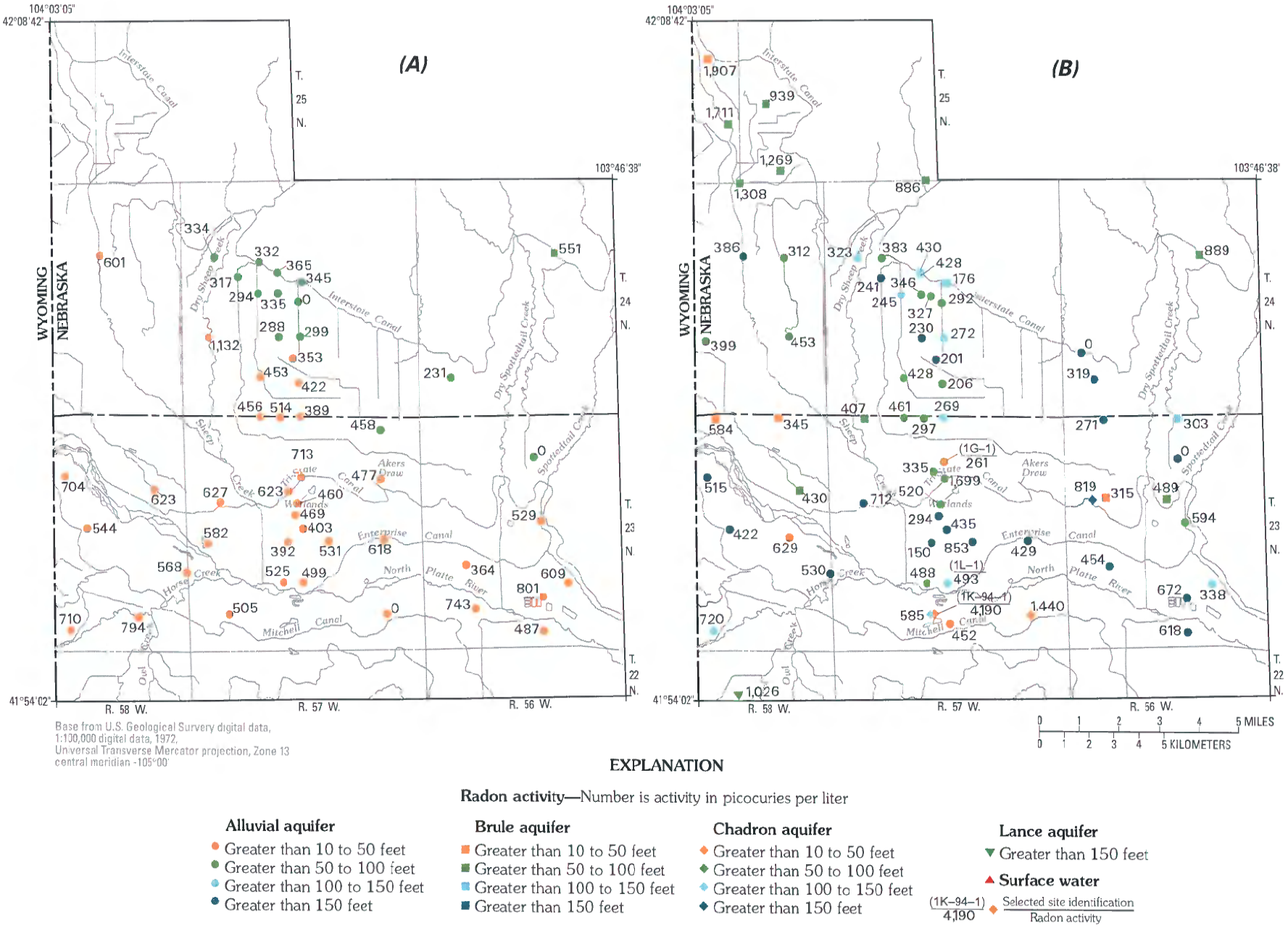


Figure 20. Distribution of radon activities in surface water and water from *(A)* wells completed near water table and *(B)* wells completed in or just above bedrock, Dutch Flats area, summers of 1998 and 1999.

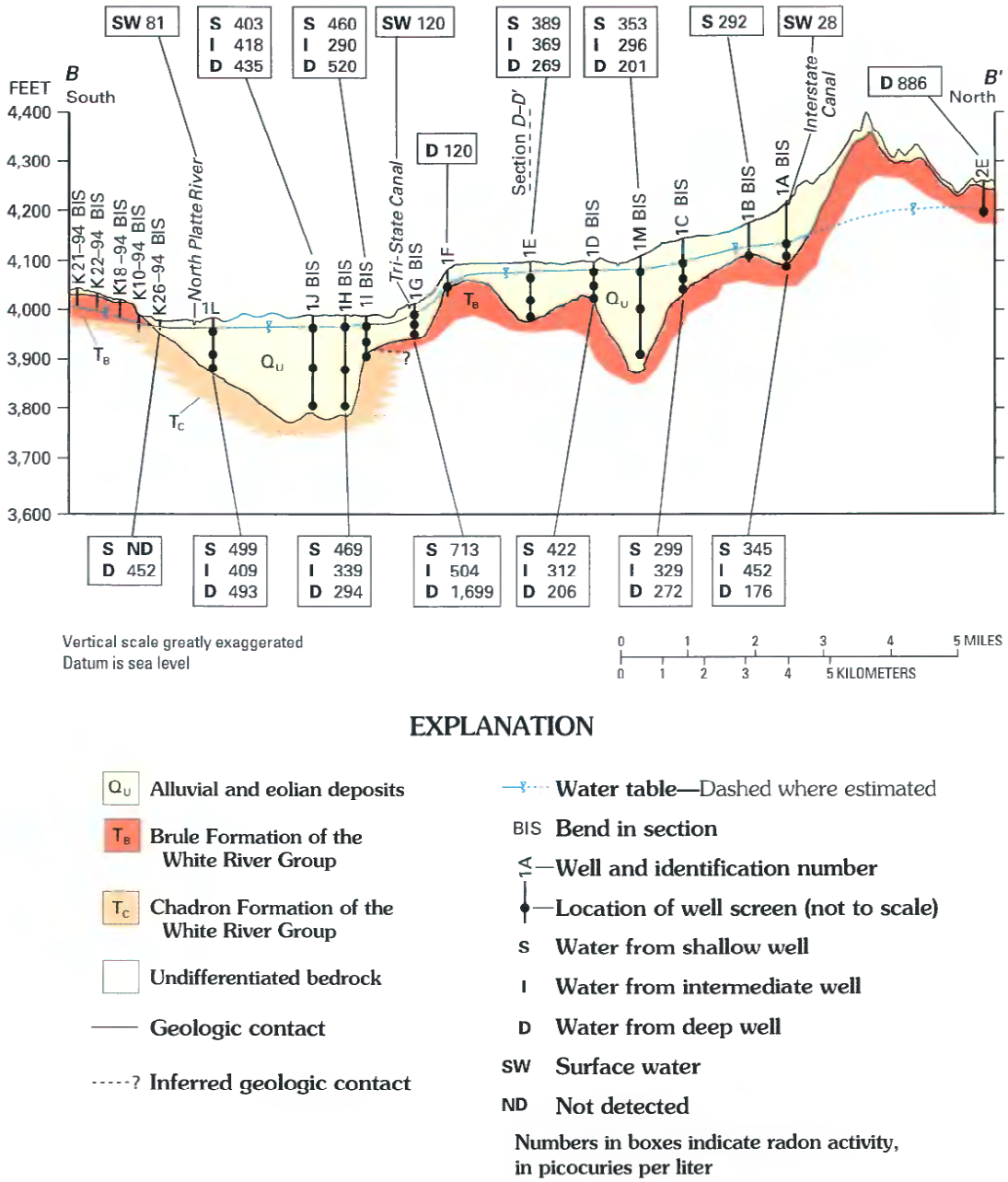


Figure 21. Generalized geologic section *B–B'* showing radon activities, Dutch Flats area, summer 1998.

Lyman (site SW6) was 1.8 (figs. 22 and 23). The UAR generally varied from 1.2 (water from well 2F–3) to 2.1 (water from well 2A–1) in water from the alluvial aquifer and varied from 1.6 (water from well 1A–1) to 2.3 (water from well 7A–1) in water from the Brule aquifer. Large UARs in water from the alluvial aquifer (maximum 2.2 in water from well 2F–1) were detected at depth near the contact with the Brule Formation. Small UARs in water from the alluvial aquifer were detected in shallow water (1.2 in water from well 2F–3). The UAR appeared variable in water from the Chadron aquifer, from 1.3 (water from well 9E–1) to 2.0 (water from well 2T–1).

Fractionation of ^{234}U from ^{238}U, resulting in radioactive disequilibria (UARs different than 1.0),

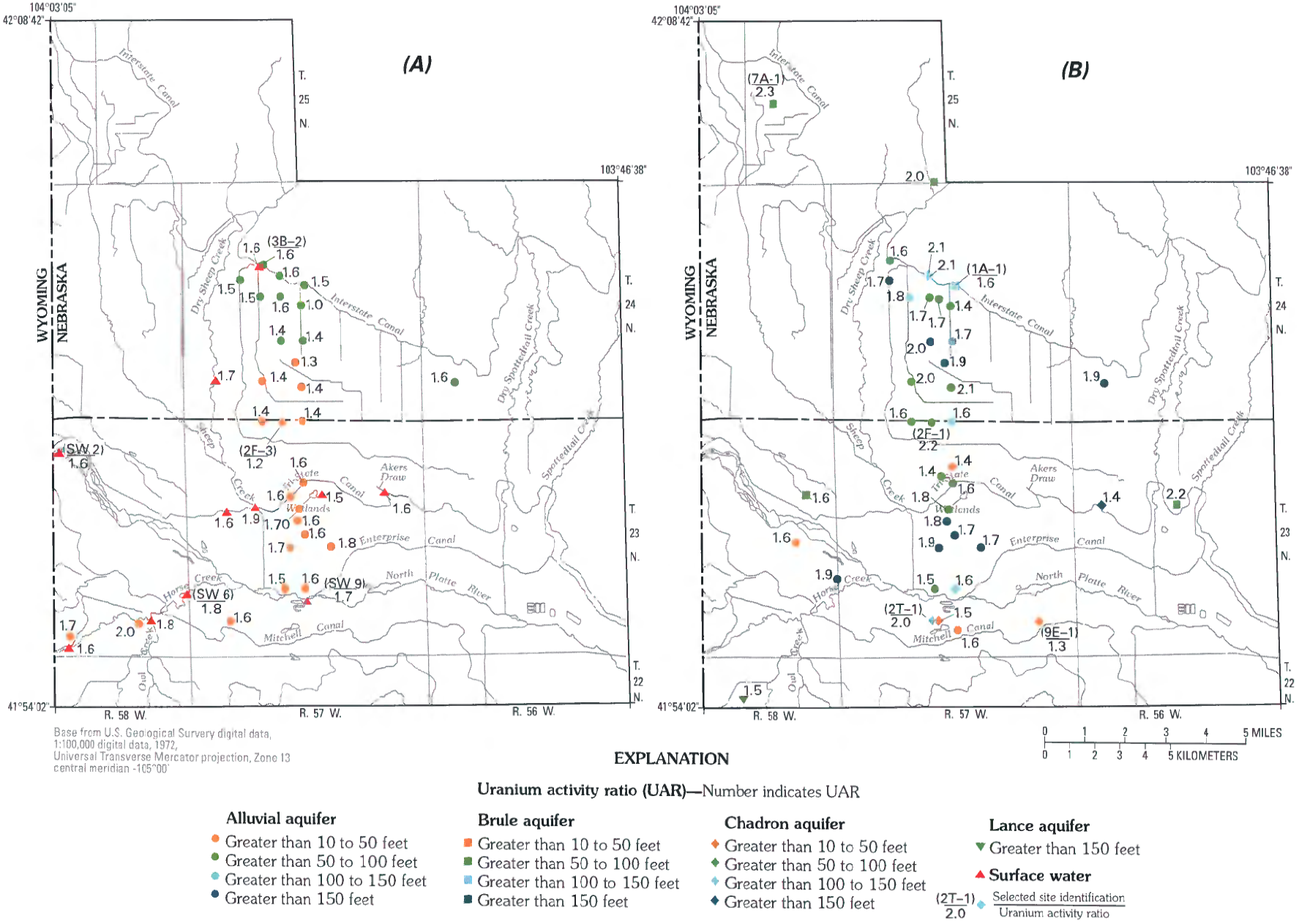
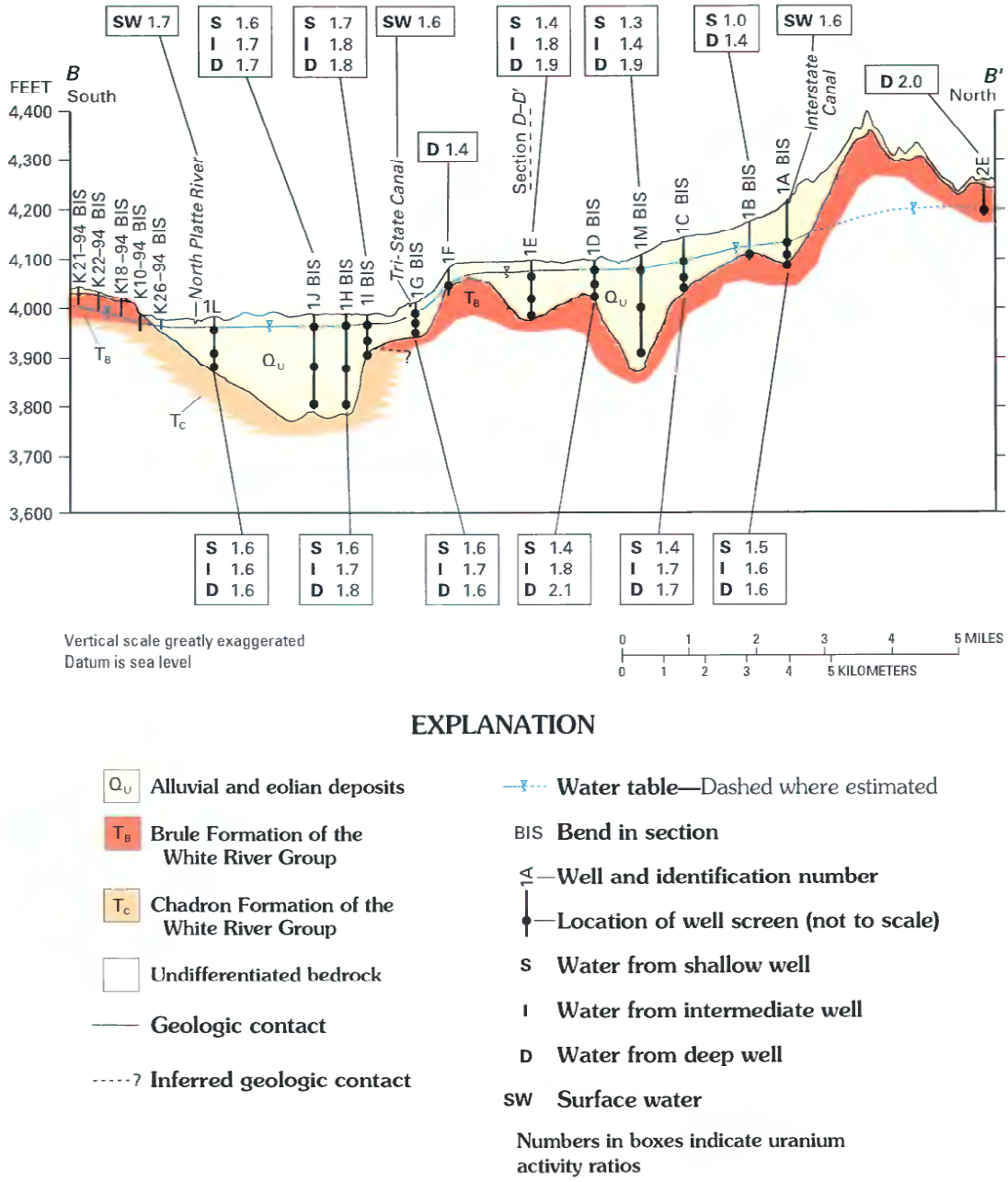


Figure 22. Distribution of uranium activity ratios in surface water and water from *(A)* wells completed near water table and *(B)* wells completed in or just above bedrock, Dutch Flats area, summers of 1998 and 1999.



EXPLANATION

- Q_U Alluvial and eolian deposits
- T_B Brule Formation of the White River Group
- T_C Chadron Formation of the White River Group
- Undifferentiated bedrock
- Geologic contact
- Inferred geologic contact
- Water table—Dashed where estimated
- BIS Bend in section
- 1A—Well and identification number
- Location of well screen (not to scale)
- S Water from shallow well
- I Water from intermediate well
- D Water from deep well
- SW Surface water

Numbers in boxes indicate uranium activity ratios

Figure 23. Generalized geologic section *B–B'* showing uranium activity ratios, Dutch Flats area, summers of 1998 and 1999.

gives rise to variable UAR signatures dependent upon the source of the water. The longer the contact time with rocks or sediment containing uranium minerals, the more chance for fractionation and creation of UARs larger than 1.0 (Snow and Spalding, 1994). Therefore, UARs in surface water under high-flow conditions are expected to have UARs closest to equilibrium (UAR equal to 1.0) compared to water in alluvial sediment with moderate residence times and water in shale bedrock with long residence times (UAR greater than 2.0). Additional investigations are being performed to evaluate these differences, to determine the sources of uranium, and to evaluate sources of uranium-containing water.

INTERACTION OF SURFACE AND GROUND WATER IN SELECTED AREAS

Interaction of surface and ground water have been shown to be of significant concern (Winter and others, 1998). Contaminated ground water that discharges to surface-water systems can result in long-term contamination of surface water. Contaminated surface water also can be a major source of contamination to aquifers depending on the flow regime of the surface water. Historically in Nebraska, the interaction of surface and ground water has not been considered in the implementation of water-management practices because the hydraulic connection between surface and ground water was unknown. This section elaborates on the physical and chemical interaction of the North Platte River, the canals, and the ground water in the Dutch Flat area.

Physical Interaction

The ability of water to move between the stream and the aquifer through the streambed is the driving force of surface-water/ground-water interaction. If water cannot move through the streambed or bank, then no interaction of water between one system and the other can occur. The direction of the water movement generally depends on local or regional stresses on the systems. In addition, it is not uncommon for direction of movement to change seasonally (Winter and others, 1998).

In the Dutch Flat area, two prominent types of surface-water features—one manmade and the other natural—control the surface-water/ground-water interaction. The two primary canals—Interstate and Tri-State Canals—contribute substantial amounts of recharge to the alluvial aquifer, and this aquifer, in turn, generally discharges to the North Platte River. Surface water moving downward through the beds of the two canals affects the movement of ground water in the study area by increasing hydraulic heads in the aquifer. The highest water-level altitudes were observed near the Interstate Canal (fig. 12, well 1A–3), and the lowest ones were observed near the North Platte River (fig. 12, well 1K–3).

Most of the monitoring wells in the northern alluvial aquifer and the northern part of the southern alluvial aquifer experienced water-level rises during the summer months. Water levels in monitoring wells 1L–3 (fig. 12), 2L–3, and 8E in the southern part of the southern alluvial aquifer showed the effects of bank storage from spring flooding of the North Platte River. Water levels in monitoring wells in the northern alluvial aquifer rose (fig. 12, wells 1A–3 and 2A–1) under the effects of seepage from surface-water irrigation systems. Water levels in monitoring wells in the northern part of the southern alluvial aquifer rose (fig. 12, for example well 1G–3) under the effects of seepage from both the Tri-State Canal and movement of ground water from the northern alluvial aquifer. Monitoring wells in which water levels declined (fig. 12, well 1L–3) during the summer months typically were not adjacent to surface-water irrigation sources and were not in the northern alluvial aquifer.

Interstate Canal

Seepage of surface water from part of the Interstate Canal in the study area occurs during the transport of surface water from the diversion point to Lake Minatare (fig. 1) east of the study area. This seepage occurs as the hydraulic head in the canal builds up and eventually provides sufficient downward force to push the water through the bed of the canal. Thus, the Interstate Canal loses some of its flow to the northern alluvial aquifer. Babcock and Visher (1951) estimated loss during transit at about 25 percent of the total flow.

Herrmann (1976) reported that substantial amounts of recharge to the alluvial aquifer in eastern Wyoming were introduced by seepage from the Interstate Canal and its laterals. In the study area, water-level data from monitoring wells showed that surface water seeps through the bottoms of the canals and into the aquifer. This is evident because the largest rises in ground-water levels (fig. 12, well 1A–3) directly followed the start of diversions into the canal. Water levels in monitoring wells farther away from the canals typically either did not rise as much as those near the canals or declined during the summer months when ground water is withdrawn for irrigation.

Evaluation of ground-water-level data in the study area indicates that water levels in monitoring wells near the canals rose about 9 ft during the summer months (fig. 12, well 1A–3). Water levels in monitoring wells placed farther away from the canals did not rise more than about 2 to 3 ft (fig. 12, well 1M–3). Statistical evaluation of water-level data using the Wilcoxon rank-sum test and based on distance from the canal indicates that water-level rises in monitoring wells within 1,000 ft of the Interstate Canal

were significantly greater ($\alpha = 0.05$, p-value = 0.0) during the course of the summer than water levels in monitoring wells farther than 1,000 ft from the Interstate Canal.

Tri-State Canal

Water-level changes in monitoring wells near the Tri-State Canal did not indicate as much canal seepage as was indicated near the Interstate Canal. Water levels in monitoring wells immediately downgradient from the Tri-State Canal reacted like those downgradient from the Interstate Canal—they rose during the summer months when the canal was full and then declined when diversions ceased and the canal emptied. Most of the rises in water levels in monitoring wells near the Tri-State Canal probably can be attributed to movement of ground water from the northern alluvial aquifer into the southern alluvial aquifer and to seepage of surface water from the Tri-State Canal.

In September 1998, a potentiometer was used to measure hydraulic-head differences between the southern alluvial aquifer and the wetlands (site SW11). The measurements indicated that hydraulic head in the southern alluvial aquifer was 1.1 ft greater than the hydraulic head in the wetlands (site SW11). Therefore, this difference suggests that an influx of water was moving into the southern alluvial aquifer. Because the differences in hydraulic head were so great, this influx probably originated from sources having much higher hydraulic heads— the northern alluvial aquifer and, possibly, the Tri-State Canal (when operating).

The large hydraulic head in the southern alluvial aquifer likely resulted from the large head gradient from the Tri-State Canal to the southern alluvial aquifer, from the northern alluvial aquifer to the southern alluvial aquifer, or a combination of both. Thus, an upward hydraulic gradient exists between the wetlands (site SW11) and the southern alluvial aquifer. It is likely that this upward hydraulic head created the wetlands—all of which occur near the break in slope of the ground-water table between the northern and southern alluvial aquifers—and are similar to the system described by Winter (1976) and Winter and others (1998).

Onsite inspections of the Dutch Flats area identified numerous springs and seeps along the bedrock high between the northern and southern alluvial aquifers just north of the Tri-State Canal. Discharge from springs and seeps in this area are dependent on surface-water flows in the canals that supply recharge to the ground-water system. Near Morrill and the wetlands site (SW11) during late winter months (about 5 months after the irrigation season), ground water was observed to seep into reaches of the Tri-State Canal that lie below the water table of the northern alluvial aquifer and higher than the water table of the southern alluvial aquifer. These observations were made when air temperatures were subfreezing and ice quickly formed in low spots on the bed of the canal. Thus, during late winter, ground water likely moved from the northern alluvial aquifer through or over bedrock and discharged into the Tri-State Canal. When surface water was diverted into the Tri-State Canal during the irrigation season, surface water likely flowed through the bottom of the Tri-State Canal into the southern alluvial aquifer. It is likely that, at that time, ground water still flowed from the northern to the southern alluvial aquifer. However, it also is probable that ground-water flow was hindered somewhat when water was present in the Tri-State Canal.

North Platte River

The altitude of the North Platte River is lower than the altitude of any canals, which helps cause ground water derived from canal seepage to move toward the North Platte River. Most of the surface-water/ground-water interaction that occurs with the North Platte River likely takes place in the hyporheic zone. The total depth of the hyporheic zone of the North Platte River is unknown but probably extends no more than several feet.

Additional surface-water/ground-water interaction likely occurs as the result of bank storage when the North Platte River is at a high stage. During high-stage conditions (fig. 6), surface water infiltrates the banks of the river causing ground-water levels in the vicinity of the river to rise. After the stage of the North Platte River recedes, ground-water levels near the North Platte River decline when ground water flows back into the river.

Chemical Interaction

Recharge of ground water by water from the canals resulted in temporal variations in the quality of ground water in the study area. Time-series data were collected along transect *B–B'* and along a transect about 0.5 mi west of *B–B'*. Temporal changes in nitrate and uranium concentrations and UARs in

response to streamflow at varying depths in ground water were examined. Other water-quality constituents, such as specific conductance and selected major ions, also were evaluated. The water-quality variables showing the largest differences in chemistry between surface and ground water were used as indicators of surface-water/ground-water interaction.

Temporal changes in the water quality of the Interstate Canal (site SW1) during the irrigation season were small (fig. 24). Along the North Platte River [North Platte River at the Wyoming-Nebraska State line (site SW2) and at Morrill (site SW9)], temporal changes in flow of the river caused temporal changes in water quality. The quality of water in the Tri-State Canal (site SW3) during the summer also changed similar to the changes observed in water from the North Platte River at the Wyoming-Nebraska State line (site SW2). Changes in the water quality of the North Platte River were seasonally dependent, with the larger differences in water quality measured during spring and winter and smaller changes measured during the irrigation season (fig. 24). The largest relative changes in surface-water quality were detected in uranium concentrations in samples from the North Platte River at Morrill (site SW9). Uranium concentrations in water collected from the North Platte River at Morrill decreased from 31 µg/L on February 17, 1998, to 15 µg/L on March 18, 1998. Smaller changes in nitrate concentrations were measured. Small variations in UARs were detected in water samples from the North Platte River (fig. 24). Differences in UARs have been used in other studies to determine sources of uranium (Snow and Spalding, 1994; Zielinski and others, 1997; Verstraeten and others, 2000).

Interstate Canal

The largest seasonal changes in the quality of the shallow ground water in the alluvial aquifer near the Interstate Canal occurred in response to seepage from

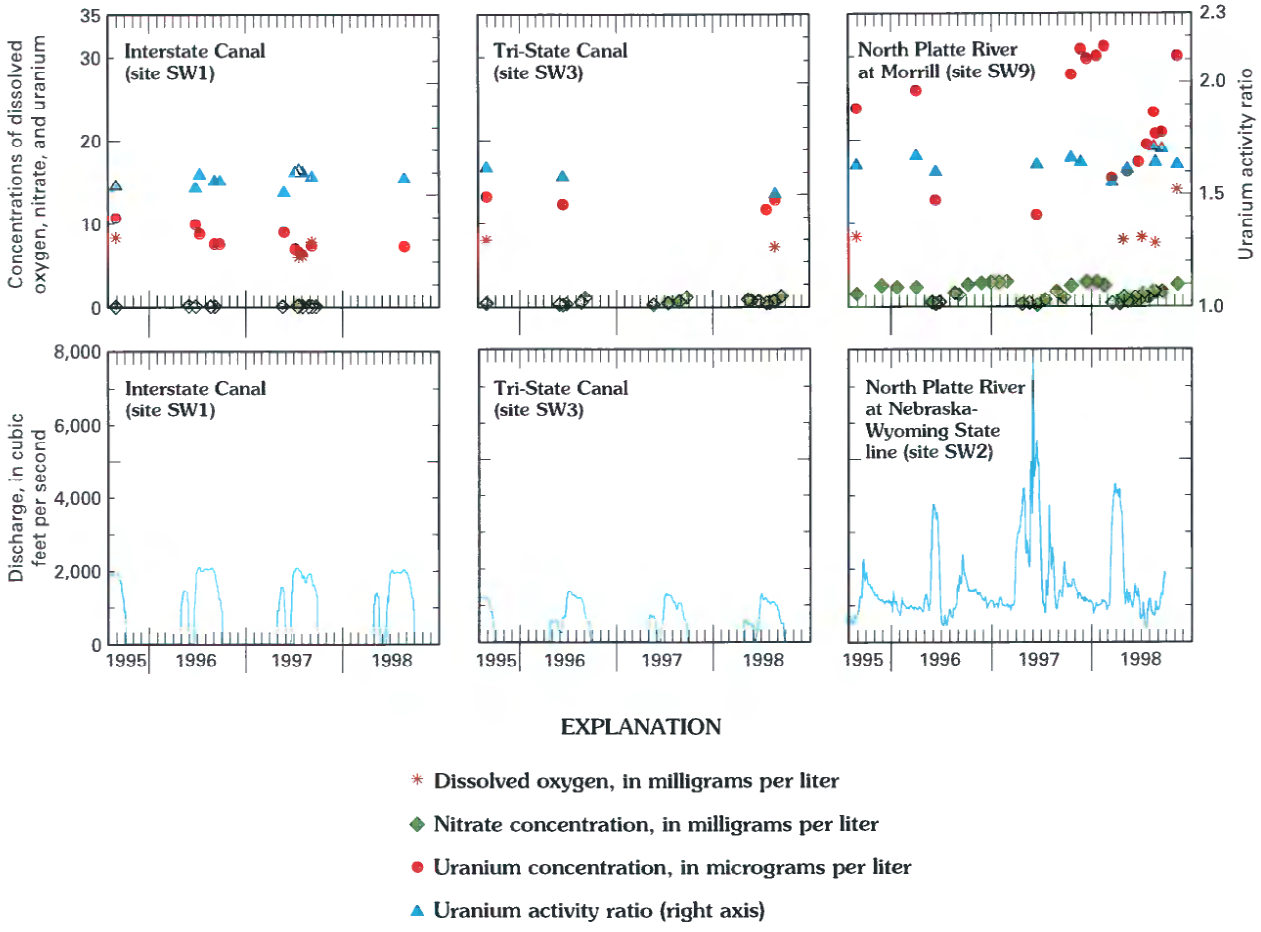


Figure 24. Comparison of trends in dissolved oxygen, nitrate, and uranium concentrations, and uranium activity ratios and discharge for Interstate Canal, Tri-State Canal, North Platte River at Morrill, and North Platte River at Wyoming-Nebraska State line, 1995 through 1998. Locations of sampling sites are shown in figure 1.

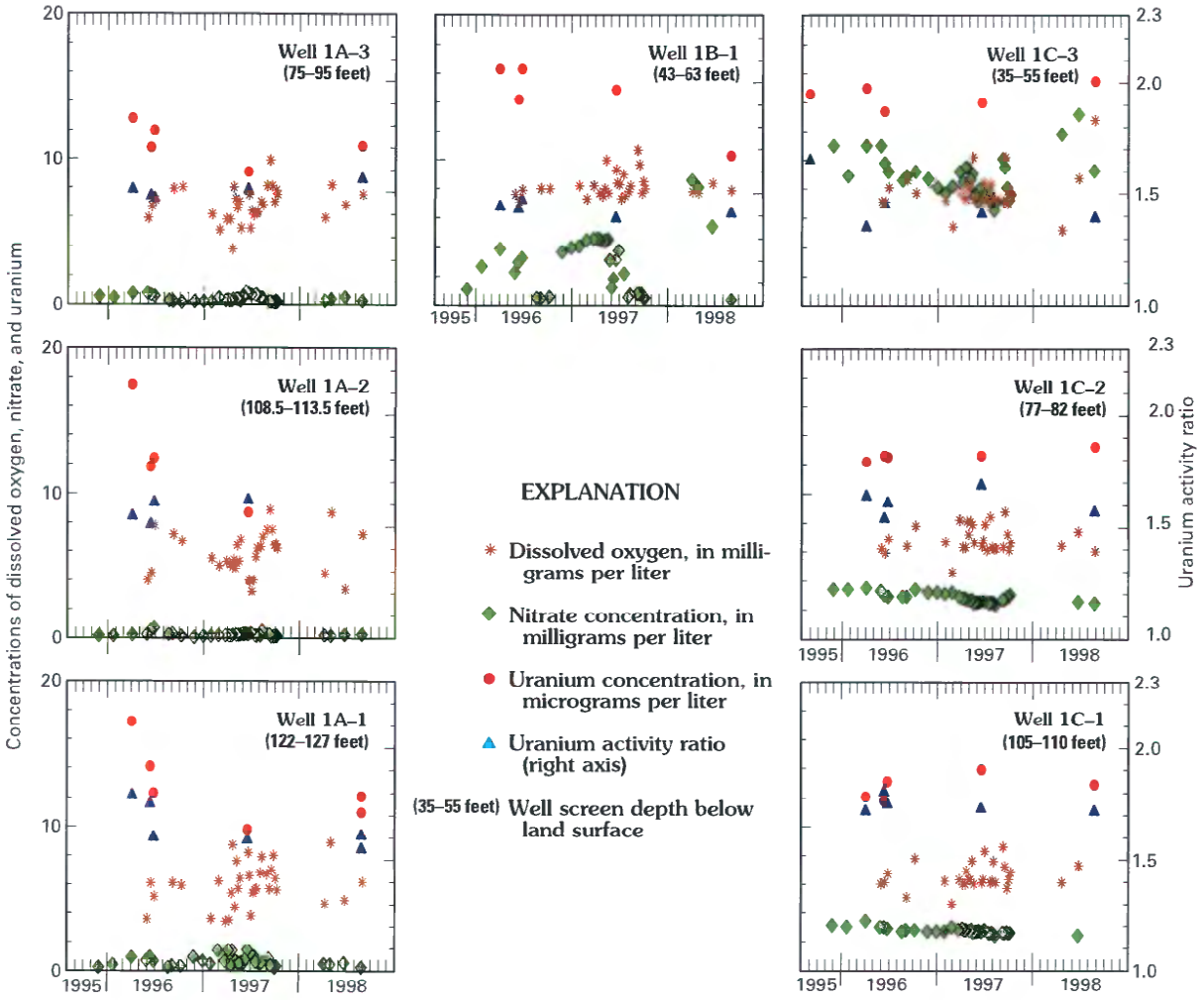


Figure 25. Comparison of trends in dissolved oxygen, nitrate, and uranium concentrations, and uranium activity ratios in water from nested wells 1A, 1B, and 1C, Dutch Flats area, 1995 through 1998. Locations of wells are shown in figure 8.

this canal (figs. 24–26). Nitrate concentrations in shallow ground water south of the Interstate Canal were larger (greater than 6 mg/L, for example, in water from well 1C–3, fig. 25) than in water from the Interstate Canal (site SW1) (generally less than 2 mg/L, fig. 24) during the irrigation season. A few feet north of the Interstate Canal, beneath cultivated land, the shallow ground water (83 to 103 ft below the land surface) contained more than 6.0 mg/L nitrate (fig. 26, water from well 2A–1). However, data from nested well 1A (fig. 25), beneath uncultivated land, indicated nitrate concentrations in ground water were less than 1.0 mg/L about 80 ft south of the Interstate Canal at all depths (75 to 127 ft below the land surface and less than 50 ft below the water table) independent of time of year. Thus, nitrate concentrations near the canal were variable over short distances.

Nitrate concentrations in shallow ground water in the alluvial aquifer near the Interstate Canal decreased to levels similar to those in surface water during the irrigation season (water from wells 2B–3 and 2B–2). On the basis of this nitrate data, surface water appeared to replace shallow ground water completely within about 1 month. These changes were observed in the upper 30 ft of the aquifer within about 1 mi of the canal (figs. 25 and 26; water from wells 1B, 2B–1, and 2C).

At distances less than 2 mi south of the Interstate Canal, where the water table is shallow (less than 40 ft deep) (fig. 9), noticeable temporal changes in nitrate concentrations were detected during the irrigation season. These changes were in response to seepage and mixing of water from the Interstate Canal with local ground water and, in places, seepage from nearby

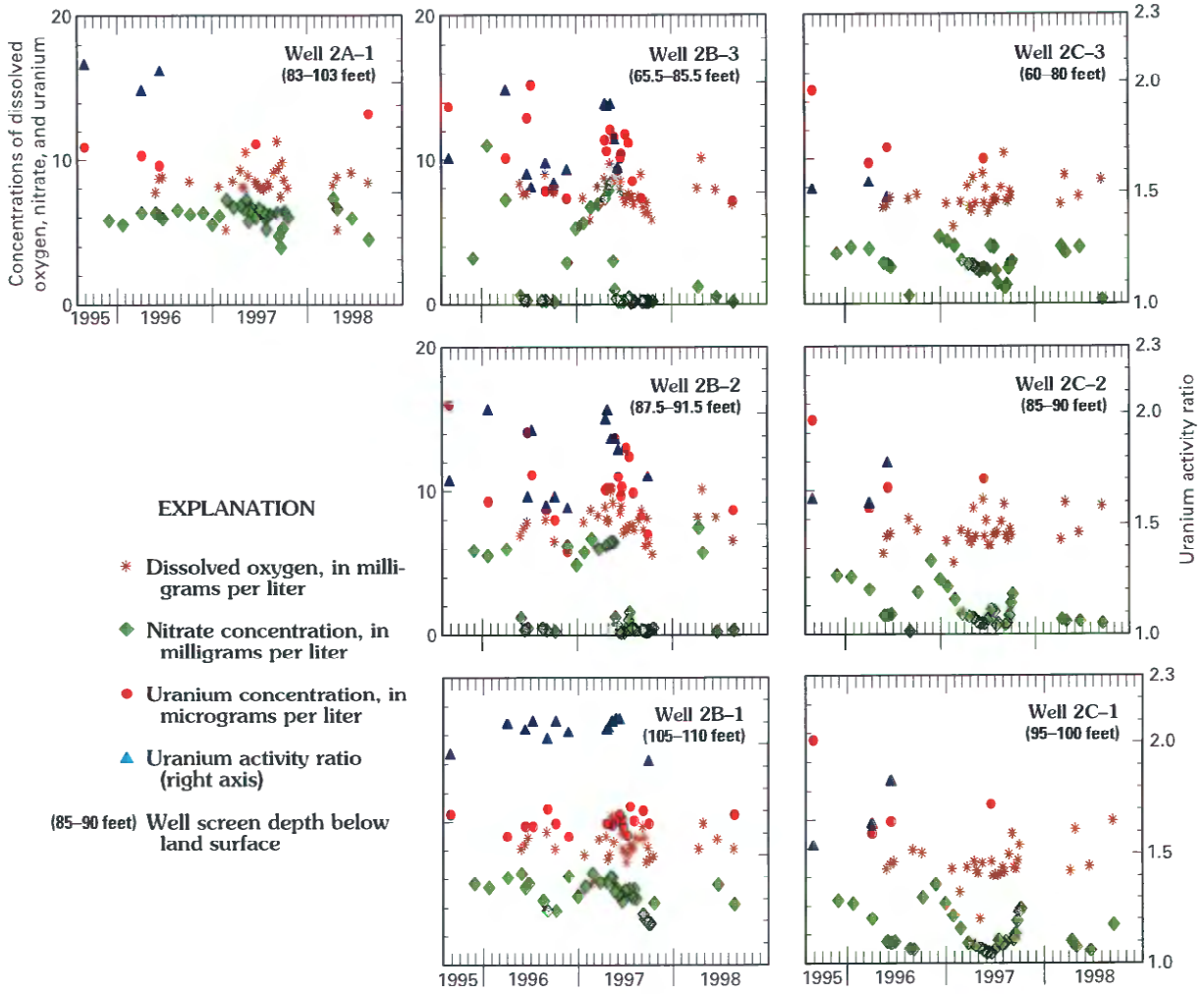


Figure 26. Trends in dissolved oxygen, nitrate, and uranium concentrations, and uranium activity ratios in water from well 2A–1 and nested wells 2B and 2C, Dutch Flats area, 1995 through 1998. Locations of wells are shown in figure 8.

laterals. These changes, however, were less obvious than closer to the canal and were detected mainly near the water table (fig. 25, well 1C–3) and in the proximity of laterals but not at depth (fig. 25, well 1C–1).

At distances greater than 2 mi south of the Interstate Canal, decreasing nitrate concentrations as a consequence of seepage and mixing of surface water from the Interstate Canal or seepage from laterals were not as obvious. Instead, irrigation water, distributed onto the fields, may have aided in transporting nitrogen from the land surface through the unsaturated zone to the ground water, contributing to increases in nitrate concentrations in ground water (Verstraeten and others, 2000). Verstraeten and others (2000) suggested that a large part of the local ground water was derived from surface-water irrigation, on the basis of age-dating information, nitrogen data, and data on isotopes of water (hydrogen and oxygen), nitrogen, and uranium.

In addition, at distances greater than 2 mi south of the Interstate Canal and in the southern alluvial aquifer, large fluctuations in nitrate concentrations were detected in samples from wells completed at or near the water table (wells 1F–1, 1H–3, 1J–3, 1L–3, 1M–3, 2F–2, 2F–3, and 2J–3 (fig. 27). These changes in nitrate concentrations could have been associated with the large changes in water levels during the irrigation season, which affected the depth below the water table from which the samples were collected. Sampling at the same depth below land surface but at varying depths below the water table could result in apparent changes in nitrate concentrations over time because of the stratified nature of nitrate in ground water (figs. 15 and 16).

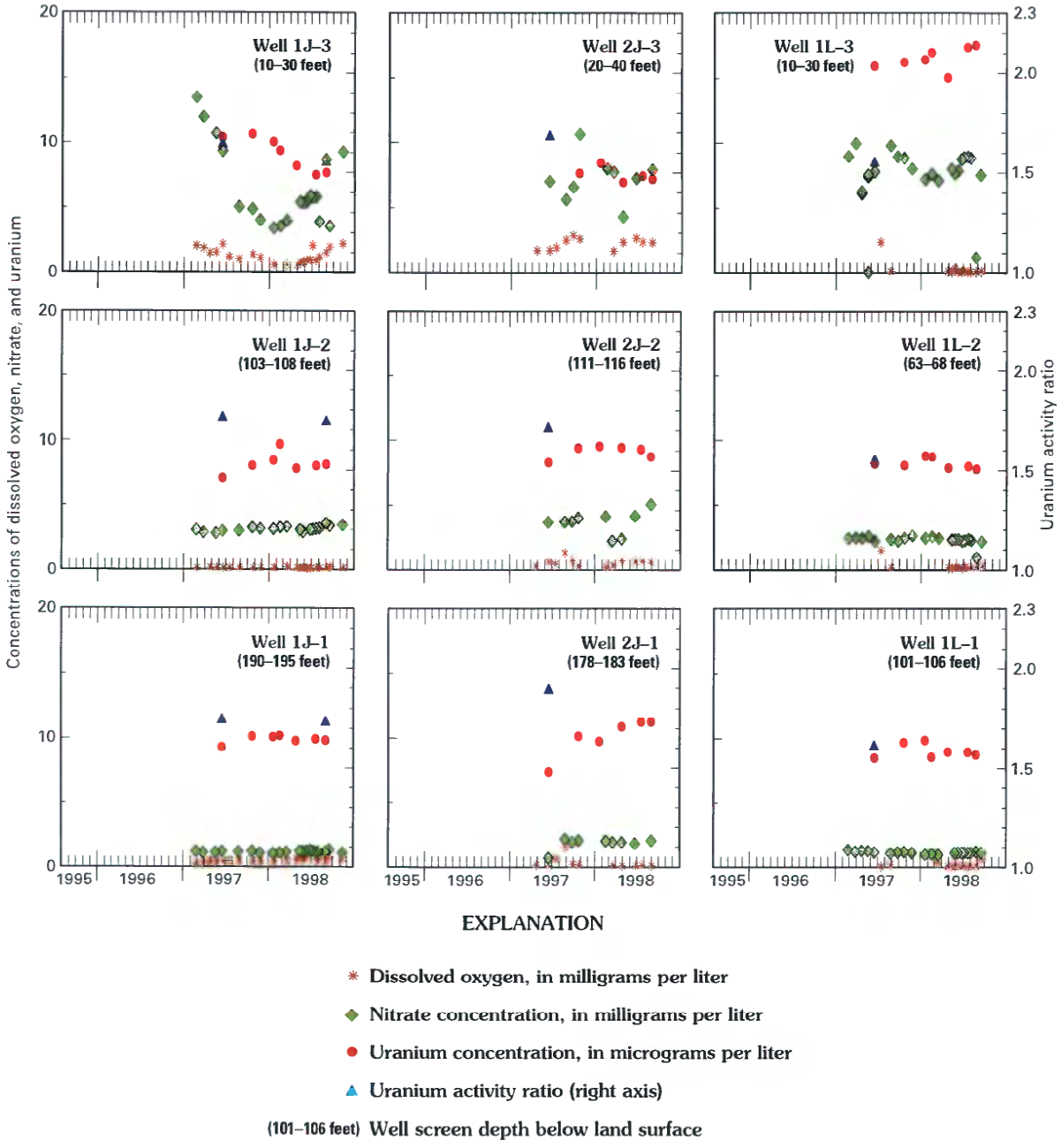


Figure 27. Trends in dissolved oxygen, nitrate, and uranium concentrations, and uranium activity ratios in water from nested wells 1J, 2J, and 1L, Dutch Flats area, 1995 through 1998. Locations of wells are shown in figure 8.

Additional local indicators of surface-water/ground-water interaction were specific-conductance values and sulfate (fig. 28) and uranium concentrations and UARs (figs. 25 and 26), and calcium and magnesium concentrations (not shown). Specific-conductance values and sulfate concentrations were generally larger in water samples from the Interstate Canal than in those from the shallow ground water (fig. 28, well 2B). When water was flowing through the Interstate Canal, increases in specific conductance and sulfate concentrations in shallow ground water occurred. These increases in concentrations, however, were not as pronounced and rapid as the changes observed in nitrate concentrations near the Interstate Canal. Calcium and magnesium concentrations also were larger in water from the Interstate Canal than in water from the alluvial aquifer, resulting in similar changes in the local ground-water chemistry.

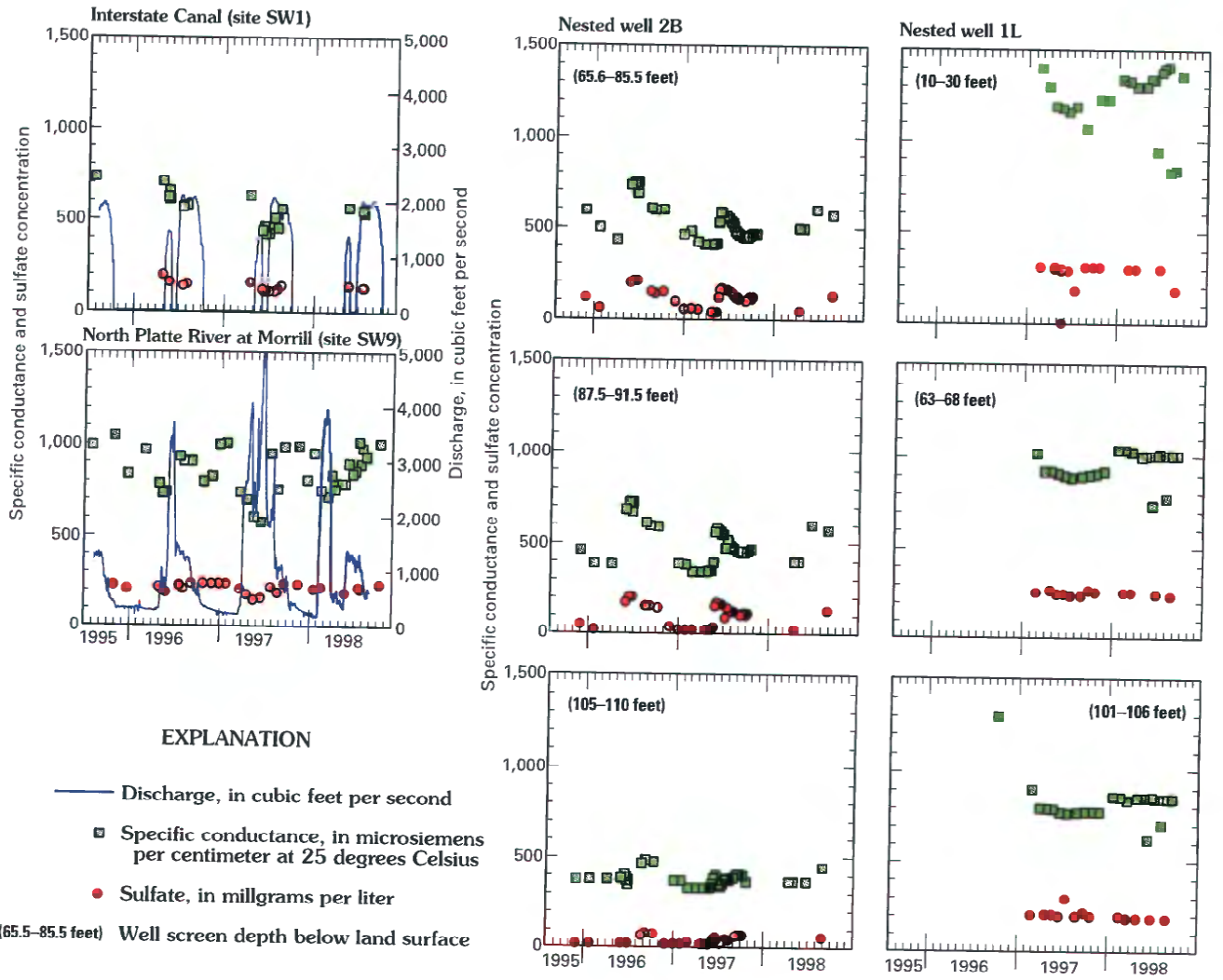


Figure 28. Trends in specific-conductance values and sulfate concentrations in water samples from Interstate Canal, North Platte River, and nested wells 2B and 1L, Dutch Flats area, 1995 through 1998. Locations of sampling sites are shown in figures 1 and 8.

Uranium concentrations in local shallow ground water (10.0 to 12.0 µg/L) near the Interstate Canal decreased to concentrations of 6.0 to 8.0 µg/L when water from the Interstate Canal containing smaller uranium concentrations than the Interstate Canal (6.0 to 9.0 µg/L) reached nested well 2C (figs. 24 and 26). On the basis of uranium concentrations in surface and ground water, mixing did not appear as significant at depth, which is probably a reflection of the different adsorptive-desorptive capacities of nitrate (a negative ion that is repelled by clay minerals) and uranium (uranium complexes that can adsorb to clay and organic matter) in solution. Similar changes in uranium and UARs were noted (fig. 26). Radon (not shown) did not show these temporal changes, even over short periods (days) and at shallow depth. The results indicate that radon is not a good indicator of surface-water/ground-water interaction in the Dutch Flats area, in part because of its short half-life and, therefore, short time available to establish new equilibria with the atmosphere, sediment, and ground water.

Tri-State Canal and North Platte River

Effects of surface-water chemistry on ground-water chemistry south of the Tri-State Canal and along the North Platte River were not as obvious as those near the Interstate Canal. A possible explanation of this difference could be that less seepage occurs from the Tri-State Canal than from the Interstate Canal because the flows in the Tri-State Canal tend to be about 60 percent of the flows in the Interstate Canal at their maximum flow rates (fig. 24). Another potential explanation is that the flow of water from the northern alluvial aquifer locally diminished the effect of

Tri-State Canal water. In addition, substantial amounts of water from the Tri-State Canal may seep into the wetlands, as was discussed previously. Nitrate, uranium, and UAR data in samples from the wetlands site (SW11) are more similar to those found in the Tri-State Canal than to those of local ground water in the alluvial aquifer, either shallow or deep, suggesting that the largest component of water present at the wetlands site during the irrigation season was Tri-State Canal water.

Near the North Platte River, the water chemistry is different and more difficult to understand. The complexity of the water chemistry probably is associated partly with the wide range in flow conditions of the river. Generally, the river is gaining water and has base flows of about 400 ft^3/s. During base-flow and near-base-flow conditions, river water probably originates in part from ground water. However, during spring peak flows, flooding sometimes occurs. At such times, surface water becomes bank storage.

As mentioned previously, the water quality of the North Platte River fluctuated over time (fig. 24). The quality of water from wells completed near the river (fig. 27, water from wells 1J, 2J, and 1L) and the water table also fluctuated (fig. 12). Because the nested wells are more than 0.5 mi from the river, it is difficult to establish a relation between temporary changes in surface-water and ground-water quality. More information on the interaction of surface and ground water could be obtained by constructing nested wells closer to the river and by collecting time-series data from nested wells 1K–94 and 26K–94. Uranium concentrations in the river during the winter tended to be large (more than 30 µg/L) (fig. 24). The concentrations in shallow water near the river (water from wells 1J, 2J, and 1L) generally also were large (more than 20 µg/L) (fig. 27) throughout the year. Decreases in specific conductance, sulfate concentrations, and UARs in water from the North Platte River at Morrill were detected during snowmelt runoff in the spring and early summer compared to those observed during the winter. These changes were not observed in water from nested wells near the North Platte River.

During high stage, uranium concentrations in water from the North Platte River were less than during low stage (fig. 24). During low stage, the large uranium concentrations in water from the river probably are associated with ground-water sources as suggested by Snow and Spalding (1994). The data collected during this study support their conclusions (fig. 24). The large uranium concentrations in the shallow alluvial water from well 1L–3 are not well understood. Additional investigations are underway to determine the sources of uranium in the surface water and shallow ground water.

Near the North Platte River, shallow ground water characterized by large nitrate concentrations probably is diluted with river water characterized by small nitrogen concentrations during periods of high stage. Locally, reduction of nitrate to other species of nitrogen also is possible, especially when flooding occurs and anaerobic conditions may exist. Additional wells installed in closer proximity to the river may be able to provide more information on local interaction of surface and ground water. Nevertheless, the nitrate data support the interpretation that uranium in shallow ground water near the North Platte River is derived primarily from ground-water sources and not from the river.

SUMMARY AND CONCLUSIONS

A study of the water resources of the Dutch Flats area in western Nebraska was conducted from 1995 through 1999 to describe the surface water and hydrogeology, the spatial distribution of selected water-quality constituents in surface and ground water, and the surface-water/ground-water interaction in selected areas. As part of this effort, 11 surface-water sites and 79 ground-water sites were selected, water levels were measured, and 130 surface-water and 1,960 ground-water samples were collected for chemical analyses.

The predominant surface-water systems in the study area are the North Platte River and the Interstate and Tri-State Canals. The North Platte River is the source water for the Interstate, Tri-State, and Mitchell Canals, which irrigate about 43,200 acres in the study area. Discharge in the North Platte River system has been affected by human activities since the late 19th century.

Aquifers in the study area include the alluvial aquifer and the Brule, Chadron, and Lance aquifers. The alluvial aquifer is unconfined, with saturated thicknesses ranging from less than 5 to more than 200 ft, hydraulic-conductivity values ranging from about 17 to 589 ft/d, and specific yields from 0.17 to 0.32. Most ground-water movement generally is toward the North Platte River. The North Platte River and the underlying alluvial aquifer are hydraulically connected. Recharge to the ground-water system by

precipitation is much less than recharge to the ground-water system of the Dutch Flats area by infiltration of water seeping from irrigation canals and laterals and by infiltration of water applied for irrigation. Direct recharge of the ground-water system caused by infiltration of water seeping from the canals and laterals was reflected in water-level rises of as much as 9 ft in monitoring wells adjacent to the canals. In areas where the Brule aquifer is near the land surface, depths to water vary from less than 5 ft near the perennial drainages to 25 to 40 ft near the Tri-State Canal. The Chadron aquifer is confined by a bentonitic mudstone and claystone of the Chadron confining unit. The depth to water in wells completed in the Chadron aquifer in the Dutch Flats area typically is 5 to 20 ft below land surface. The Lance aquifer is confined, with depths to water in wells completed in this aquifer of about 15 ft below the land surface, and generally is used only for stock and domestic supplies.

The specific conductance, calcium, magnesium, sulfate, silica, nitrate, uranium, and uranium activity ratios varied in space and with time and were used to evaluate surface-water/ground-water interaction and determination of ground-water flow. The specific-conductance values in water from the Interstate Canal and ground water immediately upgradient from the canal were different. However, differences in specific-conductance values between surface and ground water were not as obvious near the Tri-State Canal and were variable near the North Platte River. Major ions also varied between surface-water and ground-water sampling sites and along flow paths. Water from the northern alluvial aquifer generally moved from north to south and mixed in part with water from the Brule aquifer. In the southern alluvial aquifer south of the North Platte River, water moved from the southwest to the northeast and mixed in part with older water from the Chadron aquifer. An examination of major-ion chemistry contributed to a better understanding of the quality of water from tributaries and ground water. For example, water from the North Platte River at Morrill had an intermediate composition between ground water in the southern Brule aquifer and water in the Chadron and Lance aquifers.

In the Dutch Flats area, elevated nitrate concentrations are a concern in the ground water but not in surface water. The maximum nitrate concentrations in surface water were observed in samples from Akers Draw (11 mg/L) and Sheep Creek (7.6 mg/L), whereas water from the North Platte River at Morrill generally remained less than 3.0 mg/L. In ground water, a stratification of nitrate was detected, with large nitrate concentrations at times exceeding 20 mg/L in shallow, young water and small nitrate concentrations (less than 0.05 mg/L) in deep, old water. The median nitrate concentration in water from the alluvial aquifer was 4.3 mg/L, and concentrations ranged from less than 0.05 to 24 mg/L during the summers of 1998 and 1999. The median nitrate concentration in water from the Brule aquifer was 5.0 mg/L, and concentrations ranged from 0.23 to 11 mg/L during the summers of 1998 and 1999. The USEPA MCL of 10 mg/L was exceeded in 47 of 116 samples (15 percent) from all wells completed in the alluvial aquifer and in 11 of 48 samples (23 percent) collected from shallow wells completed in the alluvial aquifer. Nitrate generally was not present in shallow ground water near the water table, indicating that denitrification was not an important process in the alluvial aquifer. However, some evidence for denitrification may occur near the contact with bedrock.

Elevated uranium concentrations are a concern in both surface and ground water. Uranium concentrations ranged from 11 to 31 µg/L in water from the North Platte River at Morrill and were smaller in water from the North Platte River at the State line. The largest concentrations of uranium in surface water were detected in samples from Owl Creek near Lyman (as much as 44 µg/L). Smaller concentrations of uranium (7.9 µg/L) were detected in water from the Interstate Canal. Uranium concentrations in water from the alluvial aquifer ranged from about 2.0 µg/L in shallow ground water in the northern alluvial aquifer to as much as 80 µg/L in water from the southern alluvial aquifer. The median uranium concentration in water from the alluvial aquifer was 16 µg/L. Seventeen of 121 samples collected from wells completed in the alluvial aquifer exceeded the USEPA MCL of 30 µg/L for uranium.

Radon activity mainly is a concern in water from the bedrock aquifers, including the Brule aquifer. Radon activity in surface water tends to be low because radon readily dissipates under atmospheric pressure. Ninety-four of 117 samples (80 percent) collected from wells completed in the alluvial aquifer had radon concentrations that exceeded the proposed USEPA MCL of 300 pCi/L. Concentrations in water from 15 of 16 wells completed in the Brule aquifer exceeded 300 pCi/L. The largest radon activity was observed in ground water from well 1K–94–1 completed in the Chadron aquifer (4,190 pCi/L).

Radon activity in excess of 1,000 pCi/L often was present in water from wells completed in the Brule aquifer. Uranium concentrations and radon activity indicate that water in the alluvial aquifer has been affected by water from the Brule, Chadron, and Lance aquifers.

In the study area, two prominent types of surface-water features—one manmade and the other natural—control surface-water/ground-water interaction. Two primary canals—the Interstate and Tri-State Canals—contribute substantial amounts of recharge to the alluvial aquifer, which generally discharges to the North Platte River. Surface water moving downward through the beds of the two canals affects the movement of ground water in the study area by increasing hydraulic heads in the underlying aquifer.

Surface-water/ground-water interaction was determined from water-level and water-quality data. Surface water diverted from the North Platte River into the canals seeped through the bottoms of the canals into the underlying aquifer, causing rises in ground-water levels. Most monitoring wells in the alluvial aquifer experienced water-level rises during the summer months. Ground-water levels declined when diversions ceased and canals were emptied. Ground water derived from canal seepage moved toward the North Platte River. Monitoring wells that experienced water-level declines in the summer months typically were not adjacent to surface-water irrigation sources and were not in the northern alluvial aquifer. Additional surface-water to ground-water interaction likely occurs as the result of bank storage when the North Platte River is at a high stage and surface water infiltrates the banks of the river, causing ground-water levels to rise in the vicinity of the river.

Recharge of ground water by surface water from the canals resulted in temporal changes in the quality of ground water in the study area. The most significant seasonal changes in the quality of the shallow ground water in the alluvial aquifer near the Interstate Canal occurred in response to seepage from the canal. Nitrate concentrations illustrated that surface water appeared to replace ground water in about 1 month in the upper 30 ft of the alluvial aquifer within about 1 mi of the canal. At distances less than 2 mi south of the Interstate Canal, changes in ground-water chemistry were less obvious and were detected mainly near the water table and in the proximity of laterals. At distances greater than 2 mi, temporal declines of nitrate concentrations were not as obvious.

Additional local indicators of surface-water/ground-water interaction were specific-conductance values, calcium, magnesium, sulfate, and uranium concentrations and uranium activity ratios. When water was flowing through the Interstate Canal, increases in specific conductance and sulfate were observed and decreases in nitrate and uranium concentrations, and uranium activity ratio in the shallow ground water were observed. Effects of surface-water chemistry on ground-water chemistry south of the Tri-State Canal and along the North Platte River were not as definitive. Water from the Tri-State Canal appeared to have less effect on the local water quality, probably because smaller amounts of Tri-State Canal water were lost to the ground water. A relation between the temporary water-quality changes in surface and ground water near the North Platte River was difficult to determine because the nested wells are not on the bank of the river and are more than 0.5 mi away from the river.

In summary, surface-water/ground-water interaction recharged the alluvial aquifer and improved the water quality locally near the canals and laterals through dilution of nitrate concentrations in ground water with canal water near the canals and laterals. However, at great distances from the canals, irrigation with canal water transported nitrogen from the land surface to the ground water, and dilution with canal water at depth could not be established. The information gathered during this study provides local managers with the tools to improve the management of the quantity and quality of their water resources. This study also aids in strategic planning for future drinking-water supplies.

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