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Nitrate and Other Water-Quality Characteristics, and Nitrogen in the Unsaturated Zone, in the Red Willow and Hitchcock Counties Special Protection Area, Southwest Nebraska, 1993–95

U.S. Geological Survey
Water-Resources Investigations Report 98–4138

Prepared in cooperation with
MIDDLE REPUBLICAN NATURAL RESOURCES DISTRICT

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By G. V. STEELE

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Lincoln, Nebraska
1998

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
acre	4,047	square meter
acre	0.4047	hectare
square foot (ft^2)	929.0	square centimeter
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
gallon (gal)	3.785	liter
gallon per minute (gal/min)	0.06309	liter per second
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second (ft^3/s)	28.32	cubic decimeter per second
acre-foot (acre-ft)	1,233	cubic meter
inch per hour (in/hr)	16.39	centimeter per hour
foot per day (ft/d)	0.3048	meter per day
pounds per acre (lb/acre)	1.121	kilograms per hectare

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 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).

Nitrate and Other Water-Quality Characteristics, and Nitrogen in the Unsaturated Zone, in the Red Willow and Hitchcock Counties Special Protection Area, Southwest Nebraska, 1993–95

by G. V. Steele

ABSTRACT

In 1992, the U.S. Geological Survey entered into a 4-year cooperative study to monitor ground-water quality in the Red Willow and Hitchcock Counties Special Protection Area. In 1993, six monitor-well sites—three with nests of two wells and three with nests of three wells—were installed at representative land-use areas in the Special Protection Area. From 1993 to 1995, monthly water samples were collected and analyzed for nitrate as N. In addition, each monitor well was sampled three times to determine concentrations of major ions and once to determine concentrations of herbicides. Also, in July 1994 and August 1995, water samples collected from 61 irrigation wells and 6 surface-water sites were analyzed for nitrate concentrations; 3 of the 6 surface-water sites also were sampled for concentrations of major ions.

Most nitrate concentrations in surface-water samples were less than or equal to 1.6 mg/L (milligrams per liter) as N. Concentrations of nitrate in ground-water samples varied from less than the reporting limit of the analytical method (0.01 mg/L) to 30 mg/L. The median nitrate concentration in samples from all monitor wells was 10 mg/L.

The largest median nitrate concentrations were detected in ground-water samples in the Republican River valley at two sites (17 mg/L each). Two other sites had median nitrate concentrations in water samples of 12 and 11 mg/L. The remaining two sites had median nitrate concentrations less than 10 mg/L. Nitrate concentrations in most monitor wells seemed to be smallest in the spring months and largest from May to August.

In 1994, water samples from 59 irrigation wells showed nitrate concentrations ranging from 0.01 to 22 mg/L, with a median value of 8.4 mg/L. In 1995, nitrate concentrations in water samples from 54 irrigation wells (including 2 alternates and totaling 61 wells for both years) ranged from 0.40 to 20 mg/L with a median value of 6.8 mg/L.

Soil samples in the study area indicated that the average core interval nitrogen content per site ranged from 122 to 570 pounds per acre and varied in all five sites. One site had a nitrogen content of 570 pounds per acre, whereas the four other sites had nitrogen contents ranging from 122 to 220 pounds per acre.

Field measurements for specific conductance ranged from 383 to 927 microsiemens per centimeter at 25 degrees Celsius in the surface water and from 110 to 2,230 microsiemens per centimeter in the ground water. Measurements of pH ranged from 7.8 to 8.6 standard units in surface-water samples and from 6.4 to 9.0 standard units in the ground water. The surface water was predominantly a calcium magnesium bicarbonate type, whereas the ground water varied from a calcium magnesium bicarbonate to a calcium magnesium sulfate bicarbonate type.

Atrazine was detected in 40 percent (6 of 15) of the ground-water samples, with all concentrations less than the Maximum Contaminant Level of 3.0 micrograms per liter. Deethylatrazine, a metabolite of atrazine, was detected in 53 percent (8 of 15) of the water samples.

INTRODUCTION

Local officials have become concerned about elevated concentrations of nitrate in the ground water of Red Willow and Hitchcock Counties, Nebraska. Four communities (Bartley, Danbury, Indianola, and Lebanon) (fig. 1) whose municipal water supplies are

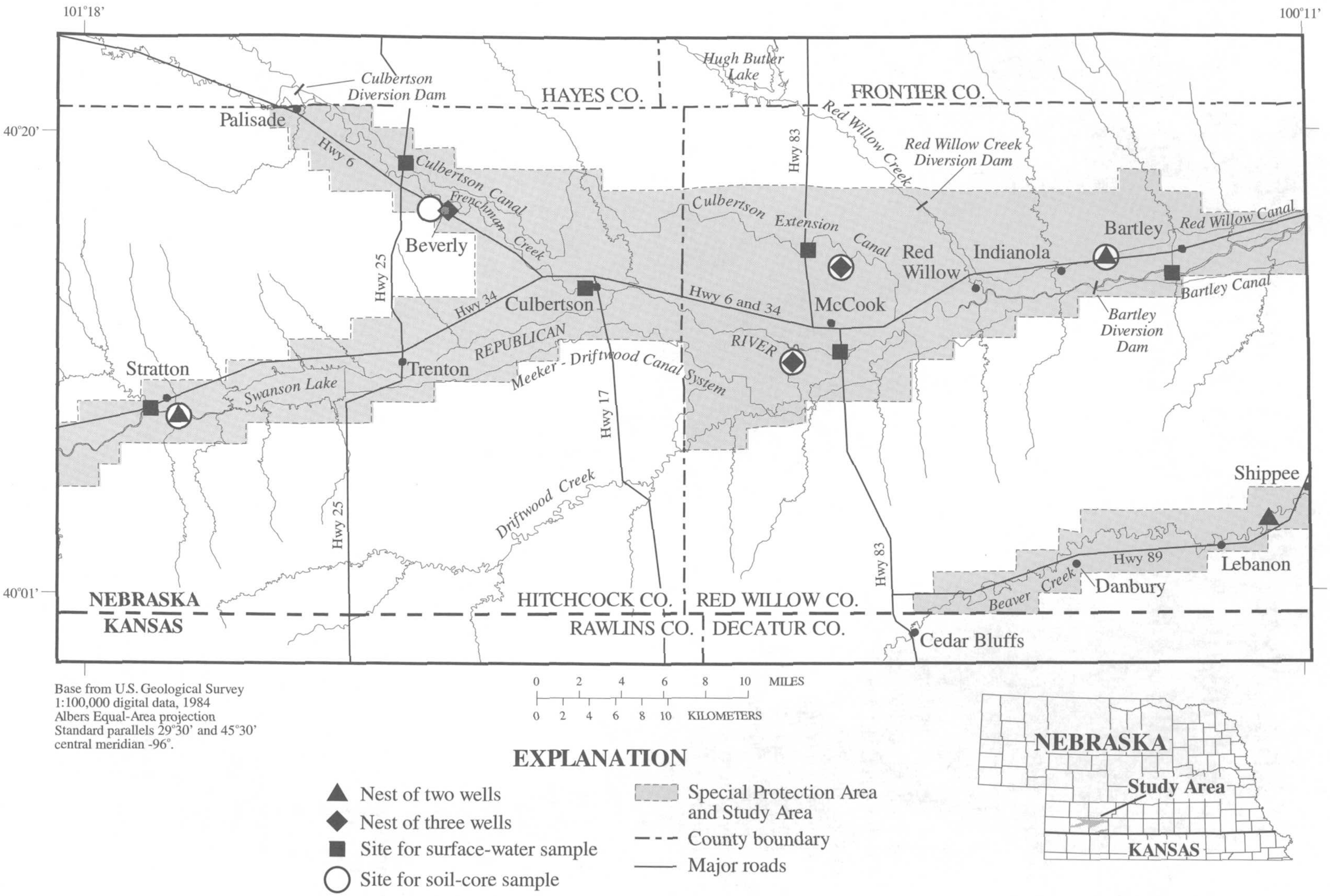


Figure 1. Location of study area, monitor wells, and surface-water and soil-core sampling sites, Red Willow and Hitchcock Counties Special Protection Area, southwest Nebraska.

derived from wells completed in the alluvial aquifers along the Republican River and Beaver Creek in Red Willow and Hitchcock Counties, have had concentrations of nitrate in ground-water samples that exceeded the U.S. Environmental Protection Agency's (USEPA) (1996) Maximum Contaminant Level (MCL) of 10 mg/L (milligrams per liter) and, subsequently, were placed on the Nebraska Department of Health and Human Services public notice list. As a result, in 1988 the Middle Republican Natural Resources District (MRNRD) requested the Nebraska Department of Environmental Quality (NDEQ) to do a Special Protection Area (SPA) study in Red Willow and Hitchcock Counties. The NDEQ evaluated the results of their ground-water quality investigation and determined that nonpoint-source contamination is present and the factors contributing to nonpoint-source contamination exist in the river valleys of the SPA (Link, 1991). As a result of this study, in 1991 the NDEQ recommended the formation of an SPA in two areas in Red Willow and Hitchcock Counties (Link, 1991). In 1992, the U.S. Geological Survey (USGS) entered into a 4-year cooperative study with the MRNRD to design and operate a ground-water quality monitoring network in the SPA.

The objectives of the study were to: (1) establish a network of monitor wells to determine spatial, temporal, and vertical variations in concentrations of nitrates in ground-water, (2) determine nitrogen content in soils in the unsaturated zone at sites representative of local hydrologic and land-use conditions, (3) determine the potential contribution of surface water (including irrigation-canal water and irrigation runoff) to nitrate concentrations in the ground water, and (4) document the general chemistry of the surface water and ground water and concentrations of herbicides in the ground water.

Purpose and Scope

The purpose of this report is to present the results of the study. The report describes the methods used to select and install the monitor wells and the collection and analysis of water and soil samples. The report presents areal distribution of concentrations of nitrate in ground water and seasonal and vertical variation in concentrations of nitrate in samples from monitor wells. Data describing the concentrations of nitrate in soil samples and concentrations of major ions in selected ground-water and surface-water samples also are discussed.

Site Identification

This report uses three different methods of site identification. The first method uses the USGS station identification number. USGS assigns a unique number to each site (such as 06837000 for surface-water sites, and 401145100310601 for ground-water wells).

For surface-water sites, the eight digit number is assigned by downstream direction along the main stream. The first two digits "06" represent the major river basin; which in this case is the Missouri River Basin. The next six digits, occasionally extended up to nine digits, represent the downstream order number.

The USGS ground-water station identification number is a 15-character number derived from the international system of latitude and longitude. This number contains no blanks or alphabetic characters and generally is used as an internal control number. Although the station identification number is initially derived from the site location, the number is an identifier and not a locator. The station identification number is a pure number and has no locational significance (Mathey, S.B., ed., 1990, p. 2-10).

The second method, local identifier, which is not used for identifying surface-water sites, is based on the land subdivisions in the U.S. Bureau of Land Management's (BLM) survey of Nebraska (fig. 2). The number preceding N (north) indicates the township or tier, the numeral 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. If two or more wells exist within the same subdivision, they are distinguished by adding a sequential digit to the well number. Sequential numbers are assigned by order of inventory.

The third method, name, is associated with the name of the nearest town. At surface-water sites, the official station name is used. If a surface-water site did not have a name at the beginning of the study, one was assigned concurrently with the station identification number. For this study, all ground-water monitor wells

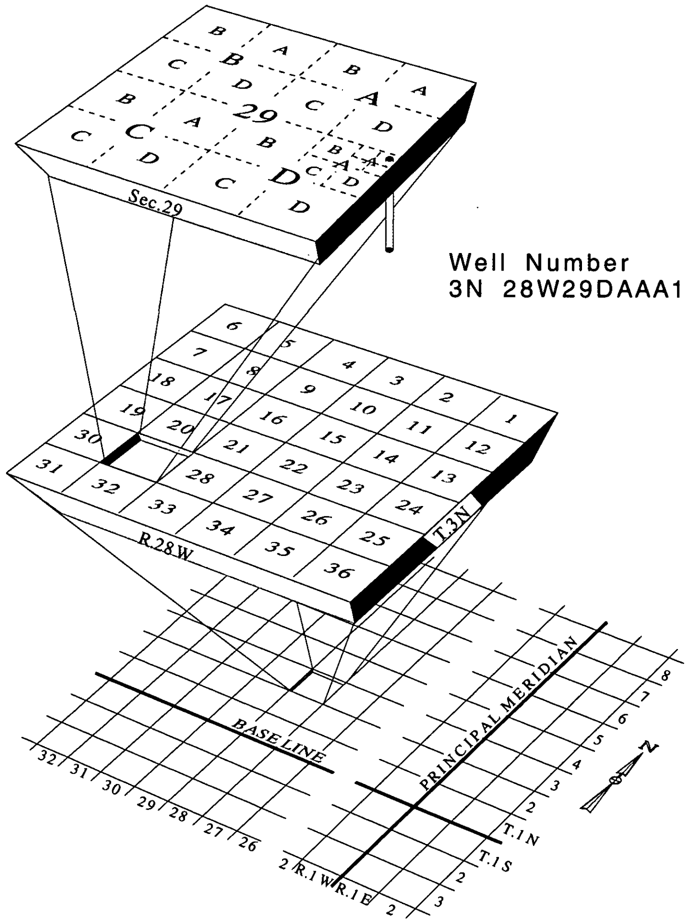


Figure 2. Local identifier well-number system.

were assigned a name and an associated well depth (shallow, medium-depth, or deep) and, for two sites, a direction—north or south. Therefore, the well McCook North Shallow represents the shallowest well at the site north of McCook.

Previous Investigations

Condra (1907) was one of the first to investigate the geology and water resources of the Republican River valley and surrounding areas. Additional work on the geology and water resources was conducted Waite and others (1944a, 1944b), Waite and Swenson (1948), Bradley and Johnson (1957), Keech (1957), Johnson (1960), Sander (1965), Eversoll (1977), Grosskopf (1978), Lappala (1978), Lappala and others (1978), Ellis (1981), Goeke (1983), Pettijohn and Chen (1983), Eversoll and others (1988), Hibbs (1988), Link (1991), Goeke and others (1992), and the Middle Republican Natural Resources District (1992). All of these reports describe, in varying detail, some of the geology and physical features of Red Willow and Hitchcock Counties or the Republican and Frenchman River valleys. Early water-quality studies focused on the hardness or type of water present within Red Willow and Hitchcock Counties—Waite and Swenson (1948), Bradley and Johnson (1957), Eversoll (1977), Hibbs (1988), and Goeke and others (1992). However, reports by Engberg and Spalding (1978), Link (1991), and the Middle Republican Natural Resources District (1992) further describe the water quality of the region or the water quality of Red Willow and Hitchcock Counties.

Acknowledgments

Appreciation is extended to the land owners and tenants who provided access for installation and sampling of the monitor wells or for sampling of irrigation wells. Appreciation also is extended to Ms. Donna Hinz, U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS), for assistance in describing the soil horizons at unsaturated zone sample sites, to Dr. Warren Lynn, NRCS, for assistance in interpreting soil horizons, and to Ms. Marty Link (NDEQ) for technical review of this document.

DESCRIPTION OF STUDY AREA

Location and Physiography

The SPA consists of two areas in Red Willow and Hitchcock Counties, Nebraska (fig. 1). The first and larger of these areas generally encompasses the alluvial valleys of the Republican River and Frenchman Creek and extends into the uplands north of the Republican River valley below the confluence with Frenchman Creek. The second and smaller area generally encompasses the alluvial valley of Beaver Creek in southeastern Red Willow County.

The study area, encompassing about 450 square miles, lies in the Highland Plains Section of the Great Plains Physiographic Province (Fenneman, 1946). Altitudes for Red Willow and Hitchcock Counties range from 2,300 ft (feet) above sea level in the eastern part of Red Willow County to approximately 3,000 ft above sea level in the northwestern corner of Hitchcock County. The valley floors generally are several miles wide with high terraces to the north and south. The terraces and uplands (uplands being the highest landforms north and south of the Republican River and Frenchman Creek valleys) commonly are 100 ft or more above the valley floors (Huber and others, 1967; Hoppes and others, 1970). Alluvial silt and sand deposits commonly are found in the river valleys, whereas Peoria and Loveland loess deposits generally are limited to the uplands (Huber and others, 1967; Hoppes and others, 1970). Well developed drainageways have been incised in the underlying bedrock by both perennial—the Republican River, and Frenchman and Beaver Creeks—and ephemeral and seasonal streams. Most of the study area is well drained.

Land Use

Land use in the study area is predominantly irrigated and nonirrigated agriculture (row crops, alfalfa, and wheat) and rangeland (fig. 3). The valleys of the Republican River, Frenchman Creek, and Beaver Creek, as well as the uplands, are generally used for crop production and pastureland for cattle operations. Generally, where surface-water irrigation canals have not been constructed, the uplands are used as rangeland and to raise wheat. In areas of irrigation (using surface water, ground water, or both), the irrigation season generally lasts from May through September with most (75 percent) of the surface water diverted in July and August.

Ground-water irrigation first was developed in the river valleys where the water table is near the land surface. Currently (1997), these valleys contain most of the irrigation wells in the study area. A majority of these systems use gated pipe with furrow irrigation. Development of the center-pivot irrigation system in the 1970s and 1980s allowed ground water to be used for irrigation in the uplands, mainly north of the Republican River and Frenchman Creek valleys (Link, 1991). Although center-pivot irrigation is prominent in some areas of the uplands, gated pipe for furrow irrigation still is used extensively in areas of the uplands that are relatively flat (Link, 1991).

Geology and Hydrology

The geologic deposits in the study area are predominantly Quaternary- through Cretaceous-age unconsolidated to consolidated sediments. The Quaternary-age deposits typically are unconsolidated material, whereas in the Tertiary-age White River Group and Ogallala Formation, and in Cretaceous-age Niobrara Formation and Pierre Shale, deposits make up the semi-consolidated to consolidated bedrock units.

The Niobrara Formation is the oldest bedrock unit in the study area that directly underlies the unconsolidated sediments. The Niobrara Formation is a orange-white to gray-green marine chalk, and was deposited during the Late Cretaceous (Goeke and others, 1992). The Pierre Shale is a dark-colored marine shale, and also was deposited during the Late Cretaceous. Both the Niobrara Formation and the Pierre Shale probably would yield water to wells only where fractured (Goeke and others, 1992). The White River Group directly underlies the unconsolidated sediments only in the extreme southeastern corner

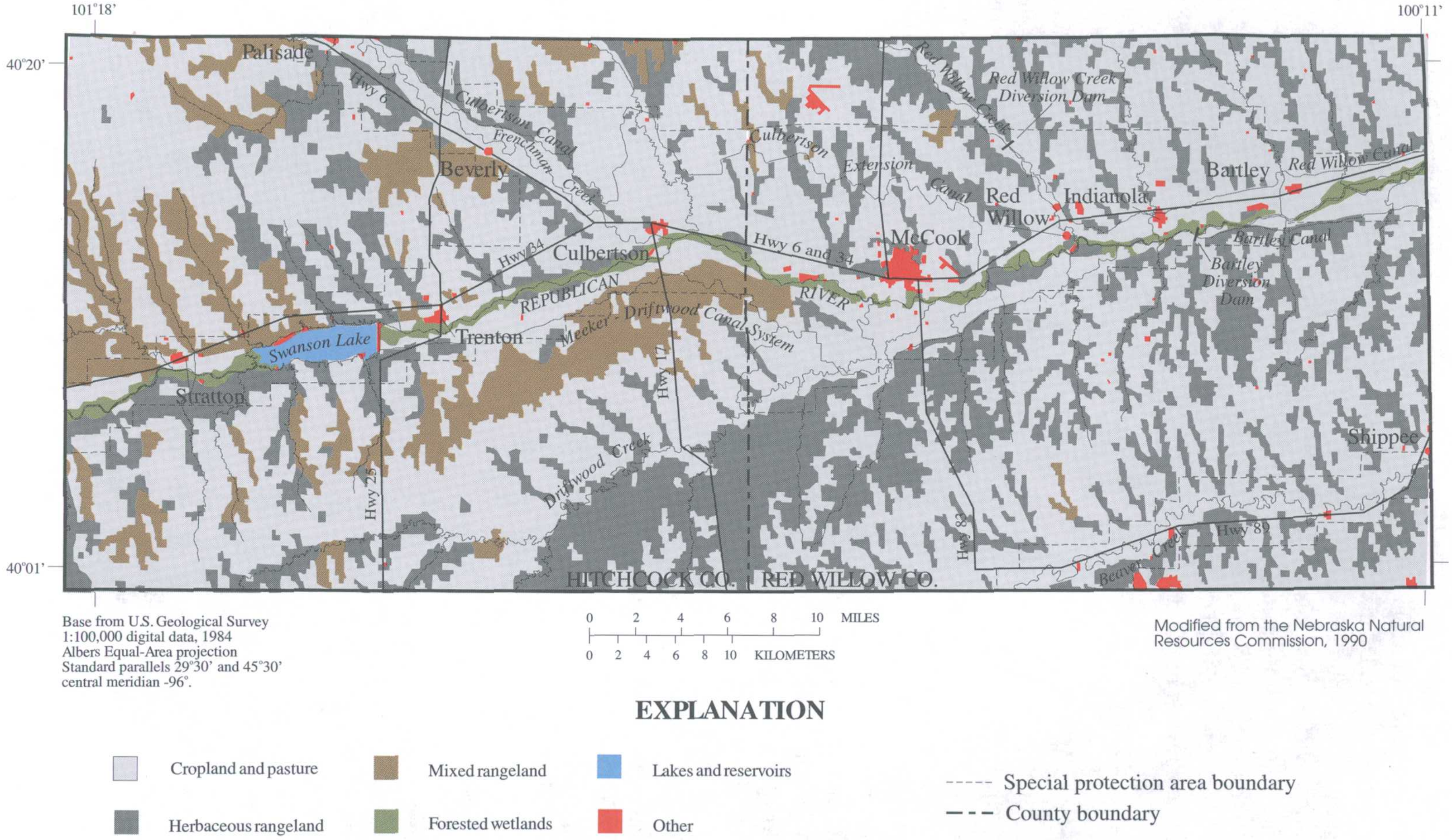


Figure 3. Land use in and near the study area, southwest Nebraska.

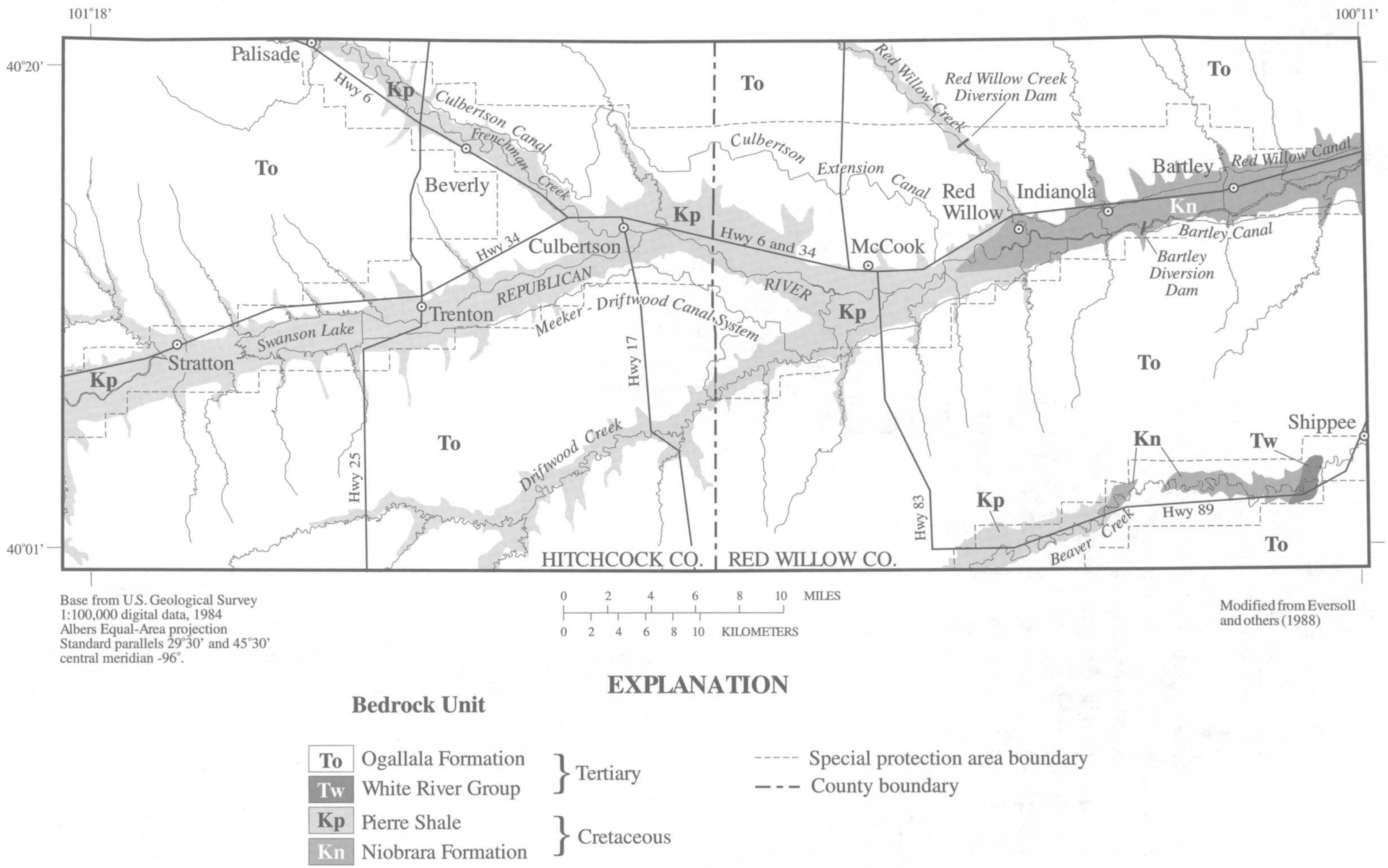


Figure 4. Distibution of units at the bedrock surface in and near the study area, southwest Nebraska.

of the study area (fig. 4) (Eversoll and others, 1988). The White River Group consists of clay and claystone to siltstone, probably does not exceed 50 ft in thickness, and is not considered a source of water. The Ogallala Formation consists of semi-consolidated to consolidated sand and gravel deposits with interstitial cements (calcium carbonate). The Ogallala Formation is predominantly located in the uplands and thicknesses can exceed 150 ft.

Unconsolidated deposits consist of alluvially and colluvially derived sediments, clay through gravel sized, as well as eolian (wind blown) deposits—Loveland and Peoria loess. The alluvial deposits are predominantly located in the river valleys and thicknesses typically do not exceed 90 ft, whereas the loess deposits typically overlie the Ogallala Formation on the uplands.

Loveland loess is easily recognized by its pinkish hue (Bradley and Johnson, 1957). Loveland loess generally mantles the Ogallala Formation and underlies the younger Peoria loess. Peoria loess mantles the valley walls of the Republican River (Bradley and Johnson, 1957) and is the most widely exposed unit in the uplands. Peoria loess is typically uniform in color—gray to buff (Bradley and Johnson, 1957). Thicknesses of both loess deposits, Loveland and Peoria, can exceed 100 ft (Eversoll, 1977) and they typically lie above the water table. In the study area, the chief hydraulic function of the Loveland and Peoria loess is to act as conduits for recharging water (Bradley and Johnson, 1957). However, if the loess deposits are saturated, typically only locally, they can yield small amounts of water.

Surface-Water Systems

Ground-water flow directions in spring 1994 (fig. 5), indicate that the Republican River is gaining in terms of streamflow, at least during that time of the year when pumpage of ground-water for irrigation does not stress the system. Surface-water flow is increased by ground water moving downgradient from the uplands and into the Republican River or adjacent tributaries. Data analysis from several series of low-flow measurements (U.S. Geological Survey, 1969, 1970, 1980, and 1981; Jamison, 1971) indicate that, depending on local conditions, surface water can move into the ground-water system or ground water can move into the surface-water system. Grosskopf (1978), using selected short-term periods, found small net gains in streamflow in the Republican River from McCook to the eastern edge of the study area (fig. 1). These small net gains were reflected on water-table contour maps of the area.

Frenchman Creek also is normally a gaining, perennial stream (U.S. Bureau of Reclamation, 1974). When flow in Frenchman Creek above the Culbertson Diversion Dam is low, ground water flows into the creek. As flow increases, less ground water moves into the creek, and at about 200 ft^3/s (cubic feet per second), there is no gain in flow from the ground water to the creek (U.S. Bureau of Reclamation, 1974). At maximum channel capacity, water is lost from Frenchman Creek into bank storage. Interaction of the surface-water and ground-water systems in Frenchman Creek below the Culbertson Diversion Dam probably is similar to the interaction above the dam, because the geology does not change substantially.

One of the first surface-water rights obtained in the area was from the Frenchman Valley Irrigation District, 1890 (U.S. Bureau of Reclamation, 1974). This district is dependent upon flow diverted from Frenchman Creek at the Culbertson Diversion Dam (upstream of the study area) (fig. 1) and delivered through the Culbertson and Culbertson Extension Canals. Development of surface water for irrigation began about 1912 (Huber and others, 1967) when a series of surface-water canals were created.

Natural and man-made surface-water features interlace the study area. The four largest natural surface-water systems in the study area, in downstream order, are the Republican River and the Frenchman, Red Willow, and Beaver Creeks. Mean annual daily flows in 1994 were as follows: Republican River at McCook, 101 ft^3/s; Frenchman Creek at Culbertson, 53.6 ft^3/s; Red Willow Creek near Red Willow, 13.3 ft^3/s; and Beaver Creek at Cedar Bluffs, Kansas (just upstream of the study area), 7.42 ft^3/s (Boohar and others, 1995). Low-flow measurements conducted in 1980 on the main stem of the Republican River and Frenchman and Red Willow Creeks indicated that they gained flow in a downstream direction. However, low-flow measurements conducted in 1979 indicated that these same systems lost flow in a downstream direction. Gains or losses may be affected by local ground-water levels, which, in turn, can be influenced by climate and ground-water pumpage.

Regulated surface-water canals, dams, and diversion dams are found throughout the area. The largest surface-water impoundment, Swanson Lake, is

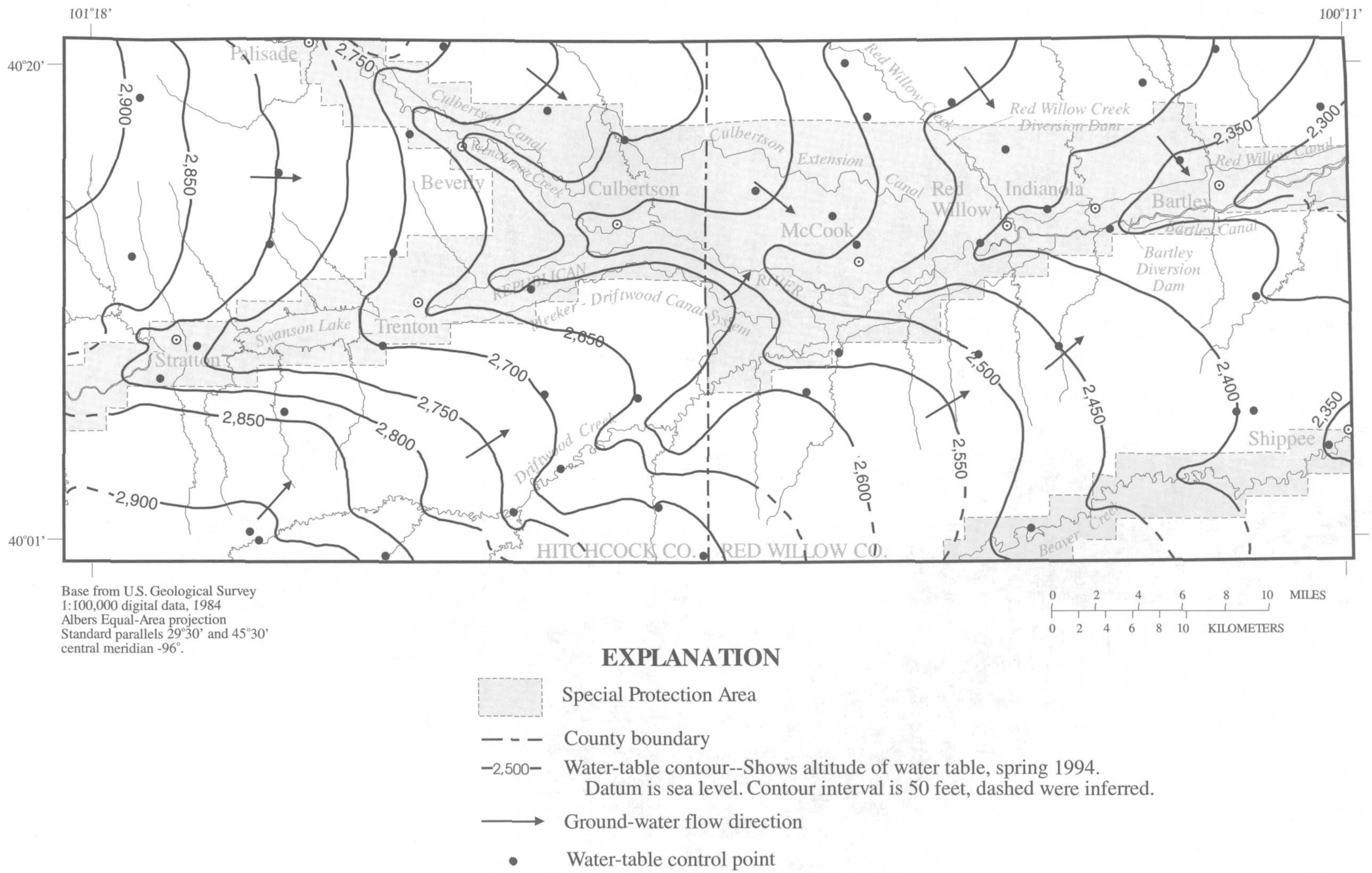


Figure 5. Altitude of the ground-water table in and near the study area, southwest Nebraska, spring 1994.

in the western part of the study area (fig. 1). The regulated dams provide irrigation water for several surface-water irrigation projects.

Four major surface-water canals are in the study area (fig. 1)—Bartley Canal, Culbertson and Culbertson Extension Canals, Meeker-Driftwood Canal System, and the Red Willow Canal. The largest canals north of the Republican River, in terms of acre-feet carried, are the Culbertson and Culbertson Extension Canals, which are northwest to northeast of McCook in the uplands. These canals, like the others, only operate during the summer irrigation season, generally May to September (table 1). Water supply for the Culbertson and Culbertson Extension Canals is diverted from Frenchman Creek. The largest canal south of the Republican River, and the largest in the study area, is the Meeker-Driftwood Canal System. This system generally follows the south side of the Republican River valley from the release point at Swanson Lake (fig. 1). This canal system also provides surface water for irrigation to the lower part of Driftwood Creek valley.

The Red Willow and Bartley Canals are the other two major canal systems in the study area. The Red Willow Canal uses water diverted from the Red Willow Creek Diversion Dam in Red Willow valley. Red Willow Canal provides surface water for irrigation to eastern parts of the study area lying north of the Republican River. The Bartley Canal is south of the Republican River in the eastern part of the study area. Water diverted from the Bartley Diversion Dam on the Republican River is used for irrigation.

Ground-Water Systems

Ground-water flow, as well as water supplies, within the study area varies with location and the medium within which the flow occurs. Eversoll (1977) described ground-water flow in Red Willow County. Although Eversoll (1977) limited his discussion to Red Willow County, ground-water flow in Hitchcock County is believed to be similar in direction to that in Red Willow County.

The primary water-bearing units in the study area—the Ogallala Formation and the unconsolidated alluvial deposits—provide the two largest sources of ground water in the study area—the Ogallala and alluvial aquifers. Huber and others (1967) report that parts of the alluvial aquifer are in direct hydraulic contact with the Ogallala aquifer. Where this occurs, ground water can flow from the Ogallala aquifer into the alluvial aquifer. However, Ellis (1981) reported that the Cretaceous-age bedrock units crop out or are near land surface along most of the Republican River valley. Where this occurs, the hydraulic connection between the alluvial and Ogallala aquifers may be restricted.

Ground water generally flows from the uplands to the river valleys (fig. 5). North of the Republican River, ground water generally flows east-southeast from the uplands toward the river valley, and then follows the river (fig. 5). South of the Republican River, ground water generally flows east-northeast to the valley, and then follows the river.

The alluvial aquifer that partially fills the river valleys was incised into the shales or chalk bedrock (Eversoll, 1977). Wells developed in the alluvial aquifer are capable of yields of up to 1,200 gal/min

Table 1. Dates of flow and total acre-feet carried for major canals in the study area, 1994-95
[Modified from Nebraska Department of Water Resources, 1995, 1996]

Canal System	1994 Date flow started	1994 Date flow stopped	1994 Acre-feet carried	1995 Date flow started	1995 Date flow stopped	1995 Acre-feet carried
Bartley Canal	05-16	09-02	10,140	06-07	09-15	10,680
Culbertson and Culbertson Extension Canals	04-13	08-30	24,020	05-02	09-05	21,560
Meeker-Driftwood Canal	05-19	09-02	35,850	06-19	09-15	35,380
Red Willow Canal	05-11	09-02	8,430	06-01	09-30	[1]10,690

[1]Incomplete data.

(gallons per minute). Most of the recharge to the alluvial aquifer comes from the Republican River, precipitation, and infiltration of water diverted for irrigation.

Areas near the sides of the river valleys, where bedrock lies at or near the surface, is generally unfavorable for water supply except in local deposits of sand- and gravel-filled channels (Eversoll, 1977). This area contains both natural and man-made springs. Man-made springs generally occur as a result of leakage from canals and seepage from irrigated lands (Eversoll, 1977). Whether the springs are natural or man-made, ground water accumulates above the underlying, nearly impervious, shale and discharges to the surface.

The Ogallala aquifer occupies the uplands of the study area. The uplands contain approximately one-third of the registered irrigation wells in the study area and these wells yield moderate volumes of water (Eversoll, 1977). Wells here range from 90 to over 200 ft deep and are capable of yielding 500 to 1,000 gal/min. Precipitation is the primary source of recharge in this area. However, because of the increased depth to the water table (compared to the alluvial aquifer), the volume of soil the water must pass through is greater and it takes longer for recharge water to reach the aquifer. Surface-water features such as canals and reservoirs may provide secondary sources of recharge to the aquifer.

The Ogallala aquifer also exists south of the Republican River, generally between the valleys of the Republican River and Beaver Creek. However, in this area few irrigation wells are developed because well yields typically are less than 50 gal/min (Eversoll, 1977).

Lappala and others (1978) reported some of the characteristics and hydraulic properties of the alluvial and Ogallala aquifers. The most productive aquifer in the study area is the alluvial aquifer along the Republican River and Frenchman Creek valleys (Lappala, 1978). The second most productive is the Ogallala aquifer; a heterogeneous distribution of saturated sand and gravel deposits (Lappala and others, 1978). The alluvial aquifer has hydraulic conductivities that are as high as 270 ft/d (feet per day) and average about 135 ft/d (Eversoll, 1977). The saturated thickness of the alluvial aquifer averages about 50 ft, but can be as much as 80 ft. Hydraulic conductivities for the Ogallala aquifer are about 13 ft/d.

Lappala and others (1978) also reported that the aquifers of the alluvial deposits and Ogallala Formation are in hydraulic contact with each other; exceptions are where bedrock highs separate the two on the north side of the Republican River, also reported by Ellis (1981). Hydraulic contact also generally exists between surface-water and ground-water systems. However, Driftwood Creek may be isolated from the alluvial aquifer because of clay deposits in the alluvium along its lower reaches (Lappala, 1978).

Water Levels

Lappala and others (1978) reported that increased deep percolation from surface-irrigated lands and seepage from irrigation canals raised the natural water table in aquifers of both the alluvial deposits and the Ogallala Formation. As of 1978, the water table between Driftwood Creek and the Republican River had locally risen as much as 42 ft. However, since the early 1980s, most of the laterals used for surface-water irrigation have been converted to buried pipelines, thus slowing or stopping much of the seepage from the laterals (Link, 1991). Water levels in other parts of the area generally have risen 5 to 20 ft.

The water table in the study area generally ranges from less than 6 ft below land surface (Dugan, 1984) in the valleys (alluvial aquifer) to greater than 200 ft below land surface in the uplands (Ogallala aquifer). Water levels measured in the monitor wells during this study ranged from about 15 ft to 118 ft below land surface (fig. 6).

Some water levels in the six monitor-well sites (figs. 1 and 6) showed the effects of ground-water irrigation. Five of these sites—Beverly, McCook North and South, Shippee, and Stratton—showed effects of ground-water withdrawals during the irrigation season. Water levels typically started to decline in June following the onset of heavy irrigation. Following the conclusion of the irrigation season, typically in September, water levels began to rise again. This rise continued throughout the winter and into the next summer when irrigation started again.

In contrast to the ground-water level declines during the irrigation season at those five sites, water levels at Bartley monitor-well site showed rises instead of declines (fig. 6). At Bartley, water levels rose after the start of surface-water diversions, typically May to June, and continued to rise through September, when surface-water diversion for irrigation typically ceased. The rises in water levels were likely the effect of seepage from surface-water irrigation canals.

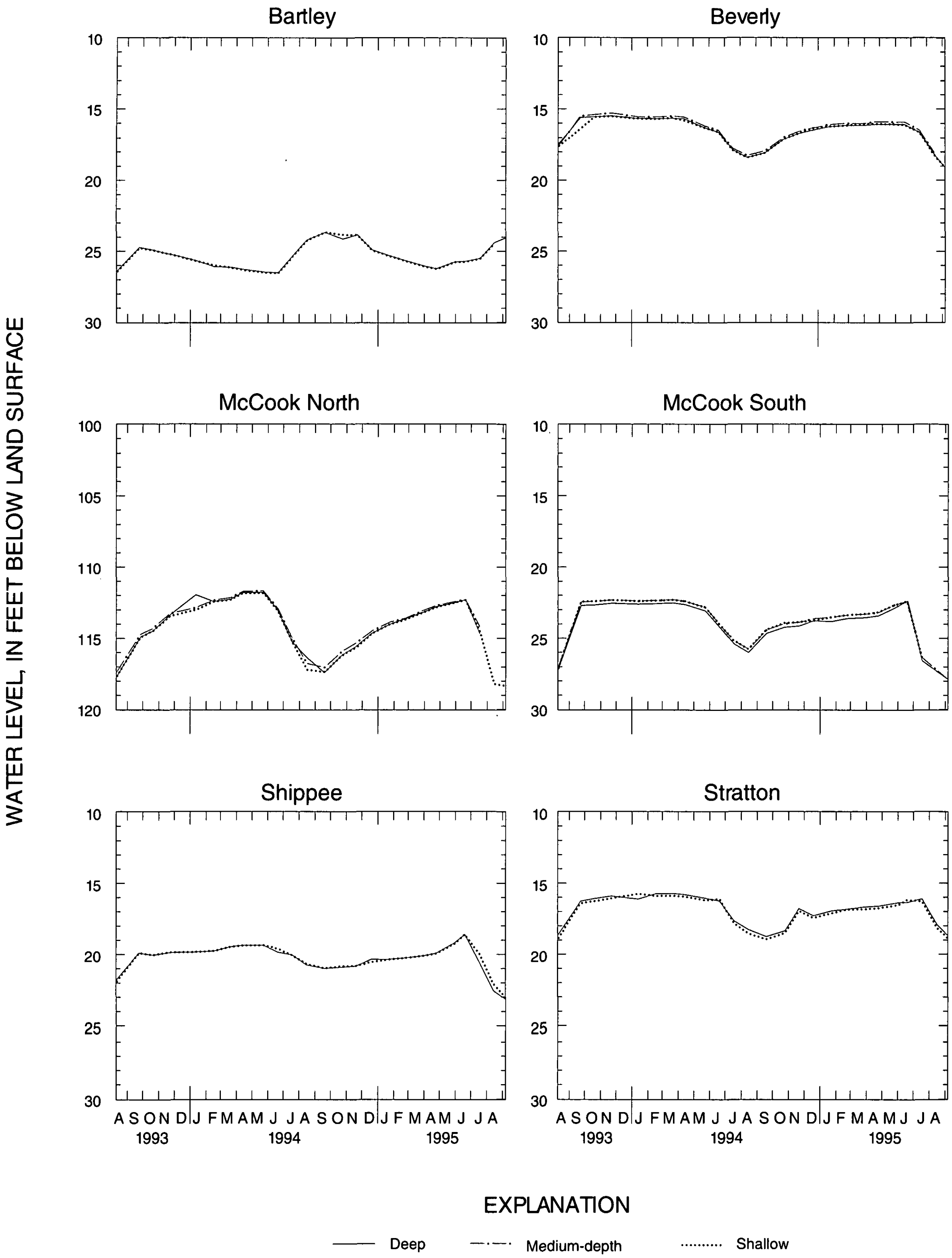


Figure 6. Water levels in monitor wells of the study area, southwest Nebraska, 1993-95.

Water levels in all wells fluctuated throughout the study period. For most wells, the greatest depth to water occurred in the summer months, June through September, when ground-water irrigation was at its peak. Moreover, in most monitor wells the greatest declines in water levels occurred or started to occur toward the end of the study period, July to August 1995 (fig. 6). Precipitation during June through August 1995 was not as great as during June to August 1994; therefore, ground-water irrigation was used more in 1995 to supplement this lack of water.

Water levels at the McCook North site showed the greatest fluctuations of any of the sites, with annual water-level fluctuations of about 7 ft (fig. 6). Annual water-level fluctuations were about 5.5 ft at McCook South, 3.5 ft at Beverly, and 3 ft at Stratton. Annual water-level fluctuations at the Shippee site generally were about 2.5 ft during 1993-94, but over 4 ft in 1995.

Surface Soils

Surface soils, as used in this report, refer to the soil associations described by the NRCS (Huber and others, 1967; Hoppes and others, 1970). These soils are found on the land surface, and hence are different from the soil profiles of the unsaturated zone (described more in detail in the section Soils of the Unsaturated Zone).

The surface soils in the study area were mostly derived from alluvial, colluvial, and eolian deposits. The surface soils found along the valley floors predominately are represented by the Haverson-Tripp-Glenberg and Hobbs-Hord-Cozad associations (Dugan, 1984). These associations are generally silt loams to fine sandy loams with permeabilities from 1.5 to 5 in/hr (inches per hour) and very gentle slopes of 2 to 5 percent. These surface soils are generally well drained and used extensively for agricultural purposes. The surface soil occurring on the thalweg (line following the lowest parts of a valley whether under water or not, commonly the stream channel) and flood plains of the Republican River valley is predominantly represented by the Gothenburg-Platte and Loup-Elsmere-Dunday associations. This surface soil commonly has permeabilities exceeding 10 in/hr and maximum slopes of 1 to 3 percent (Dugan, 1984). Downstream of Red Willow, but still in the Republican River valley and its terraces, the surface soil associations generally become fine sandy loams to fine sands. Here the surface soil is represented by the Cass-Inavale and Glenberg-Bankard-Yockey associations with permeabilities from 5 to 10 in/hr and maximum slopes of 1 to 3 percent.

Surface soils located on the uplands in the southern and northern parts of the study area generally consist of silty clay loams, silt loams, and loams. Permeabilities for these surface soils generally are 1 to 2 in/hr. The maximum slope on the uplands varies greatly: 1 to 3 percent—Hord-Hall and Holdrege-Hall associations; 10 to 20 percent— Holdrege-Coly-Uly and Ulysses-Keith-Colby associations; 20 to 30 percent—Coly-Uly-Holdrege and Monona-Ida associations; and greater than 30 percent—Colby-Ulysses and Coly-Uly associations (Dugan, 1984).

Climate

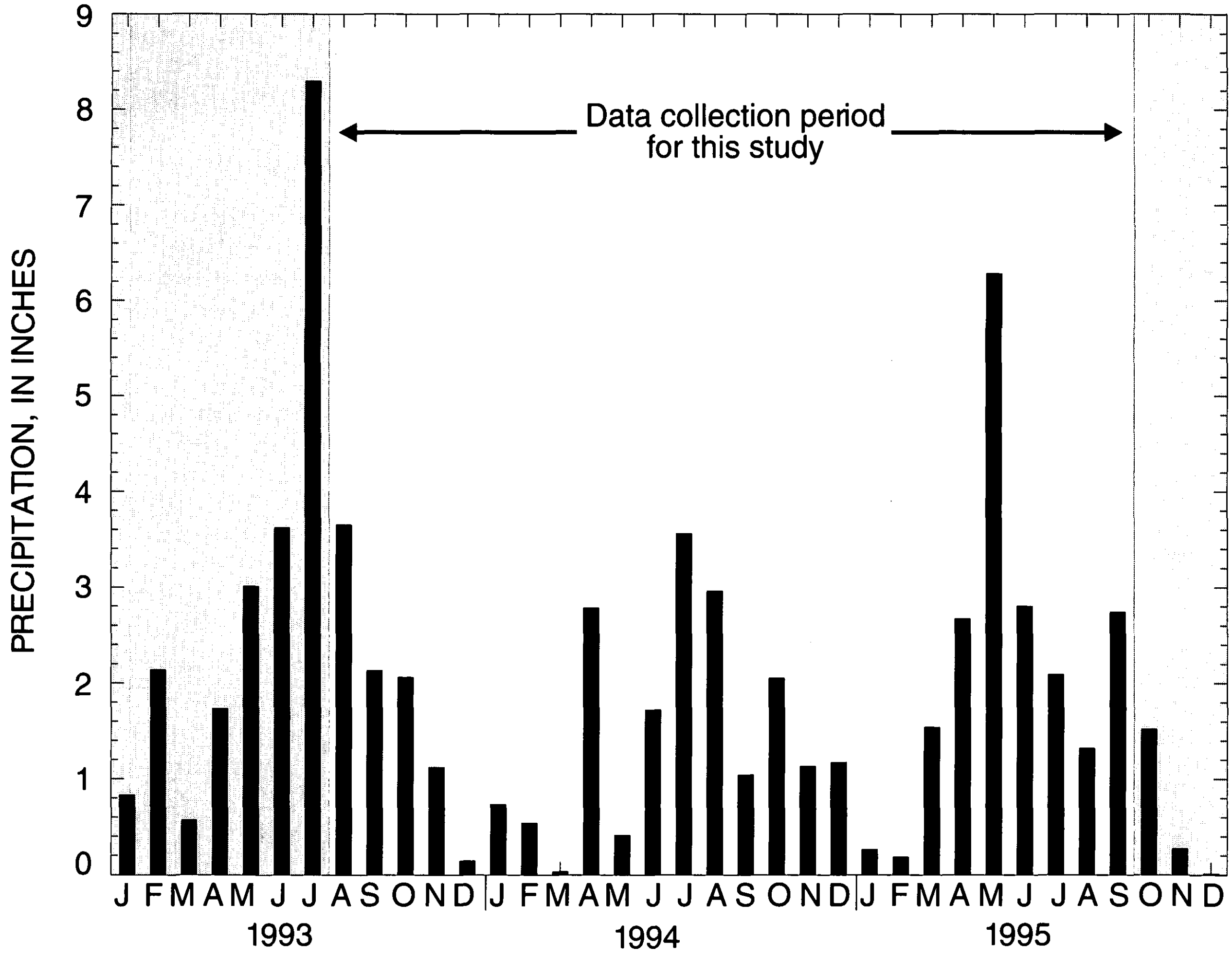
The climate of the study area is characterized by severe winters and hot summers. The growing season is approximately 150 to 160 days in length and generally lasts from mid-April to late September. July generally is the hottest month of the year, when temperatures typically range from 50 to 90 °F (degrees Fahrenheit) (Huber and others, 1967; Hoppes and others, 1970). January, generally the coldest month of the year, has typical temperature ranges from about -10 to 40 °F. Thunderstorms often occur between the months of April and July. The average annual precipitation (1961-90) is approximately 21 in. (inches) (National Oceanic and Atmospheric Administration, 1995). During the data-collection period for this study, precipitation ranged from 0.03 in. in March 1994 to 6.28 in. in May 1995 (fig. 7).

METHODS

This section presents an overview of the methods used for the study. Well-selection procedures used for this study are discussed, as well as some of the specific sampling techniques for surface-water, ground-water, and soil in the unsaturated zone. This section also describes the methods used to analyze the data, and the quality-control measures taken to ensure data reliability.

Site Selection and Installation of Monitor Wells

Because of the expense associated with the installation of an adequate number of nested monitor wells needed to identify the spatial, vertical, and temporal distribution of nitrate concentrations in ground water in the



Data from National Oceanic and Atmospheric Administration database (accessed February 3, 1997, on the world wide web at URL http://www.ncdc.noaa.gov/pub/data/coop-precip)

Figure 7. Mean monthly precipitation at McCook and McCook Northwest weather stations, southwest Nebraska, 1993-95

study area, a combination of monitor wells and irrigation wells were used. Annual collection of samples from the irrigation wells was intended to represent the spatial distribution of concentrations of nitrate, whereas monthly collection of water samples from nested monitor wells completed at different depths and placed at locations representative of the study area was intended to identify vertical and temporal trends in concentrations of nitrates.

The locations for nested monitor wells were selected by analyzing the historical and spatial nitrate concentrations reported in previous studies, as well as investigating land use in the study area to determine typical sites. Specific criteria for site selection for monitor wells included historical nitrate concentrations, aquifer depth, proximity to agricultural lands and irrigation wells, and spatial distribution. Available ground-water-level data and lithologic logs from irrigation wells were used to provide approximate depth to water and to bedrock.

In June 1993, 15 monitor wells were installed at 6 sites (fig. 1). All wells in the nest at five of the six sites—Bartley, Beverly, McCook South, Shippee, and Stratton—were installed in the alluvial aquifer (table 2). All of the wells at the sixth site, McCook North, were installed in the Ogallala aquifer. Three of the sites (Bartley, Shippee, and Stratton) were constructed with a nest of two wells— one screened in the upper half of the aquifer (herein referred to as shallow well) and the other screened in the lower half of the aquifer (herein referred to as deep well). The Beverly, McCook North, and McCook South sites included nests of three wells—

Table 2. Summary of monitor-well construction data in the study area, southwest Nebraska

[all units in feet below land surface unless listed otherwise; USGS, U.S. Geological Survey; NA, not applicable]

USGS station identification number	Local identifier	Name	Test hole depth	Well depth	Well diameter (inches)	Screened interval	Screen slot size (inch)	Static water level	Aquifer in which well is completed
401454100215401	3N 27W 9AAAA1	Bartley Deep	45	40	2.5	34.5-39.5	0.014	26.5	Alluvial
401454100215402	3N 27W 9AAAA2	Bartley Shallow	NA	32	2.5	26.5-31.5	.014	26.5	Alluvial
401655100583201	4N 32W30DCBB1	Beverly Deep	67	61	2.5	51.4-61	.014	16.5	Alluvial
401655100583202	4N 32W30DCBB2	Beverly Medium-depth	NA	45	2.5	35.4-45	.014	16.5	Alluvial
401655100583203	4N 32W30DCBB3	Beverly Shallow	NA	25	2.5	15.4-25	.014	16.5	Alluvial
401412100364201	3N 29W 8DDBA1	McCook North Deep	182	175	2.5	165-174	.014	114.5	Ogallala
401412100364202	3N 29W 8DDBA2	McCook North Medium-depth	NA	160	2.5	149.8-159.4	.014	114.5	Ogallala
401412100364203	3N 29W 8DDBA3	McCook North Shallow	NA	135	2.5	125-135	.014	114.5	Ogallala
401016100391801	2N 30W 1ACDD1	McCook South Deep	75	72	2.5	62-72	.010	24.5	Alluvial
401016100391802	2N 30W 1ACDD2	McCook South Medium-depth	NA	55	2.5	45-55	.010	24.5	Alluvial
401016100391803	2N 30W 1ACDD3	McCook South Shallow	NA	36	2.5	26-36	.010	24.5	Alluvial
400357100135201	1N 26W11CBBB1	Shippee Deep	75	64	2.0	54-64	.010	22	Alluvial
400357100135202	1N 26W11CBBB2	Shippee Shallow	NA	36	2.0	26-36	.010	22	Alluvial
400818101124001	2N 35W13AAAD1	Stratton Deep	51	46	2.5	36-46	.014	16.4	Alluvial
400818101124002	2N 35W13AAAD2	Stratton Shallow	NA	30	2.5	20-30	.014	16.4	Alluvial

shallow and deep wells in about the upper and lower thirds of the saturated thickness of the aquifer, and a third well screened in the middle third of the aquifer (herein referred to as medium-depth well).

Each site consists of two or three 6.5-inch holes drilled using direct rotary methods; the deepest hole (test hole) was drilled to bedrock and the shallow or medium-depth holes were drilled to the necessary depths (table 2). Each hole contains either a single 2-inch or 2.5-inch inside diameter, schedule-40, flush joint, polyvinyl chloride (PVC) casing and screen. Perforation for each screened section is either 0.010-inch or 0.014-inch slot.

Annular space from the bottom of the hole to the top of the screen was filled with 20-40 silica sand, then capped with 2 ft of bentonite (hole plug). The annular space from the top of the hole plug to three feet below land surface was backfilled with a bentonite slurry. Wells were developed using compressed air, then test pumped with a submersible pump. A 3-ft diameter cement well pad was placed at the land surface around each well and extended to a depth of 3 ft. Each well is secured with a lockable steel well protector.

Each monitor-well site represents the predominant land-use type—irrigated or nonirrigated row crops—in a unique physiographic area within the study area. The Beverly site is farthest north, in the Frenchman Creek valley, and just downstream of a major surface-water irrigation diversion dam—Culbertson Canal near Palisade (fig. 1). Stratton, the westernmost site, is in the Republican River valley just upstream from Swanson Lake, the largest surface-water impoundment in the study area. McCook North is on the uplands north of McCook, where agricultural row crops generally are irrigated with ground water and water diverted from the Culbertson Extension Canal. McCook South is in the lowlands of the Republican River valley south of McCook. Bartley, the easternmost site in the Republican River valley, represents land-use areas downstream of the confluence of the Culbertson Extension Canal and the Republican River. Shippee, the only site in the alluvium along Beaver Creek, represents land use for predominately ground-water irrigated row crops.

To identify the spatial distribution of concentrations of nitrate in ground water in the study area, 80 irrigation wells were identified for water sample collection in 1994 and 1995. To ensure an even distribution, the study area was divided into subareas of about 5.6 square miles. Each irrigation well in the subarea was assigned a random number. The irrigation well with the highest random number was chosen to represent each subarea. This process ensured a fairly even distribution over the study area with a random component in the selection. Although 80 sites were selected for sampling, access and availability reduced the total number of irrigation wells sampled to 61. Water samples were collected from 59 of these wells in 1994 and from 54 in 1995. Seven wells sampled in 1994 were not operating during the time samples were collected in 1995; however, two alternate wells were selected to replace two of the seven wells, bringing the total number of individual wells to 61.

High-capacity irrigation wells have been proven to be a cost-effective way to monitor water quality in established areas of nonpoint-source agricultural contamination (Zlotnik and others, 1995). However, use of high-capacity irrigation wells in areas with early stages of nonpoint-source contamination can affect the detection of the nonpoint-source contamination (Gottula, 1996). As a contaminant moves from the land surface through the soil and into the ground water, a certain concentration gradient exists. These gradients typically produce larger concentrations at the top of the aquifer than in the middle or lower parts. Dilution of nitrate concentrations likely occurs when the contaminant moves to greater depths in the aquifer by advection, dispersion, and diffusion (Gottula, 1996). Pumping of high-capacity irrigation wells, which typically are screened in the lower part of the aquifer or well below the water table, causes steep hydraulic gradients around the screen. Agricultural contaminants often move with the ground water and become diluted. Therefore, the concentration of a contaminant seen in a sample from a high-capacity irrigation well likely is smaller than the concentration at the top of the aquifer. For this reason, irrigation wells may not contain concentrations of a contaminant in areas with early stages of nonpoint-source contamination (Gottula, 1996). Use of high-capacity irrigation wells, however, often will represent the aquifer as a system (overall site-specific water quality).

Water-Quality Sampling

To determine if surface-water systems were having an impact on nitrate concentrations in ground water in the study area, surface-water samples were collected twice from six surface-water sites. These sites represent some of the typical surface-water systems found there—Republican River at Stratton; Republican River at McCook; Republican River at Bartley; Frenchman Creek at Culbertson; Culbertson Canal at Highway 25, 5 miles below diversion, near Palisade; and the Culbertson Extension Canal at county road, 3 miles north of McCook (fig. 1). In July 1994 and August 1995, samples for nitrate analysis were collected from the six sites. Concurrently, samples for major-ion analysis were collected at three of the six surface-water sites—the Culbertson Extension Canal at county road, 3 miles north of McCook; Frenchman Creek at Culbertson; and the Republican River at McCook. All surface-water samples were collected using equal-width integrated (EWI) methods described by Wells and others (1990). EWI sample collection involves dividing the stream or canal into no less than five equal widths or sections. A hand-held sampler containing a 1-liter bottle is then lowered and raised to and from the streambed at the center of each section and at an equal transit rate. Water from each section was composited in a 3-liter polyethylene churn splitter. Subsamples from the churn were filtered and processed like the ground-water samples, as described next.

Procedures described by Kolpin and Burkart (1991) were modified for ground-water-quality sample collection. Water samples were collected from monitor wells monthly from August 1993 to September 1995. These samples were analyzed for nitrate as N. Semi-annual (in April and November 1994 and March 1995) samples from the monitor wells also were analyzed for major ions. In September 1995 water samples from all monitor wells were analyzed for triazine herbicides as agreed upon with the MRNRD. In July 1994 and August 1995, water samples for analysis for nitrate as N were collected from 61 irrigation wells.

Water levels were measured in monitor wells prior to sample collection. Water levels were not measured in irrigation wells, because water samples were collected only from irrigation wells that were operating. If the irrigation well was not operating, an attempt was made either to revisit the well when it was operating, or choose an alternate site near the well.

Because the irrigation wells sampled during this study had been pumping hundreds of gallons per minute for hours or days prior to sample collection, water samples were collected immediately following the collection of field measurements (specific conductance, pH, and temperature). This approach is in agreement with Zlotnik and others (1995) who reported that the chemistry of water samples from irrigation wells does not change significantly after about 0.25 hour of operation. Sample preparation, if needed, was done as described next.

Water-quality samples from the monitor wells were collected using a submersible stainless-steel pump with polypropylene tubing. The submersible pump was lowered into the screened area, or approximately 10 ft above the bottom of the well. The discharge hose from the submersible pump was connected to a flow-through chamber holding the water-quality field probes (to measure specific conductance, pH, and water temperature). Pumping continued until at least three casing volumes were flushed and all field measurements stabilized to the tolerances described by Kolpin and Burkart (1991). Stabilization of the field measurements generally occurred following 15 to 20 minutes of pumping, depending upon the depth of the well. Decontamination procedures described by Kolpin and Burkart (1991) were modified and used to decontaminate filtration and processing equipment prior to and following collection of the water-quality sample.

Ground-water samples were collected directly into a 250-mL (milliliter) polyethylene jar and immediately chilled to 4 °C (degrees Celsius). Samples for cation analysis were filtered with a 0.45-micron membrane filter, immediately adjusted to a pH of 2 or less using 1.0 mL of nitric acid, and stored at ambient temperature. Water samples for major anion analysis were filtered and were stored at ambient temperature. Water samples for triazine herbicide analysis were collected in an appropriate container as described by Kolpin and Burkart (1991), filtered through a 1.0-micron fiber, glass filter into a 125-mL baked glass bottle, and immediately chilled to 4 °C.

Water samples collected for nitrate analysis at Olsen's Agricultural Laboratory in McCook, Nebraska were left unfiltered and chilled immediately to 4 °C. Replicate samples for nitrate analysis by the USGS National Water Quality Laboratory (NWQL) in Arvada, Colorado were filtered using a 0.45-micron membrane filter, treated with mercuric chloride, and chilled immediately to 4 °C.

Water samples generally were collected within a 2- to 3-day period and taken either to Olsen's Agricultural Laboratory on the day of the collection or sent to the NWQL at the end of the collection period. Samples collected for triazine herbicide analysis were sent directly to the NWQL.

Unsaturated Zone Sampling

Soil cores were collected from five sites in November 1994 for analysis of nitrate and ammonium concentrations and percent of organic matter in the unsaturated zone. Four of the five sites were near monitor-well sites, excluding Shippee, which was not sampled. A hollow-stem auger with a split-spoon sampler was used to collect soil cores to the saturated zone. Total depths from which the soil cores were collected varied from 18 to 117 ft. This method requires coring the first 3 ft with the 5-ft split-spoon sampler (height of the Kelly on the drill rig prevents obtaining a complete 5-ft section of soil). Subsequent 5-ft sections of soil are bored and sampled using the hollow-stem auger and the 5-ft split-spoon sampler. The split-spoon sampler was disassembled and one representative soil sample was collected per 5-ft section and above and below major lithologic changes, if present. In addition to the regular samples, duplicate samples were collected about 50 percent of the time. All soil cores were analyzed by the University of Nebraska-Lincoln's agronomy laboratory.

Analytical Methods

Nitrite (NO_2^-) is relatively unstable in aerated water (Hem, 1985) and usually is oxidized to nitrate in aerobic conditions; therefore, all analyses for nitrate plus nitrite were considered to be nitrate. Nitrate analysis was done by Olsen's Agricultural Laboratory using slightly modified standard cadmium reduction procedures (U.S. Environmental Protection Agency, 1983). Samples were analyzed for nitrate as N, major cations and anions, and selected triazine herbicides by NWQL using standard methods described by Fishman and Friedman (1989). Triazine herbicides were analyzed using gas chromatography/mass spectrum (Fishman and Friedman, 1989). All data collected during this study are stored in the USGS National Water Information System (NWIS) data base.

Data Analysis

Statistical methods generally were used to describe and interpret the general water chemistry of the study area. Some data were analyzed and described in terms of statistical quartiles (percentiles): data values less than 25, 50, or 75 percent of the sample observations. Percentiles are more descriptive than minimum and maximum because they more accurately represent the distribution of data.

Nonparametric statistical analysis of the data was performed to determine variations between data sets. Nonparametric statistical methods rely on the conversion of data to ranked values and do not require that the data be distributed normally (Dowdy and Wearden, 1991).

Data were grouped into appropriate subgroups and each "censored datum" was assigned a value equal to one-half the reporting limit. Censored data have values less than the reporting limit of the analytical procedure. A value of one-half the reporting limit assures that the censored data are smaller than the smallest number above the reporting limit. Because the tests performed are nonparametric and compare two independent populations by ranking the data, assigning a minimum value to the censored data does not affect the test results (Helsel and Hirsch, 1992).

The Mann-Whitney rank-sum test (Helsel and Hirsch, 1992) and the Wilcoxon signed-rank test for large sample sets (more than 15 samples) (Dowdy and Wearden, 1991; Helsel and Hirsch, 1992) were the two nonparametric tests used to compare the data. The Mann-Whitney rank-sum test was used to determine if median chemical concentrations were significantly different for independent population, such as nitrate concentrations from the bottom of the aquifer compared with concentrations from the top of the aquifer. The Wilcoxon signed-rank test was used to determine if paired chemical concentrations are significantly different; such as data collected from the same well, but on separate days. All statistical analyses used a confidence level of 95 percent ($\alpha = 0.05$) and were evaluated using a p-value (the probability of getting a value of the test statistic equal to, or more extreme than, the value computed from the data when the true difference in the medians of the two populations is zero). For this study, if the p-value is less than or equal to 0.05, it is assumed that there is a significant difference between the two populations. If the p-value is greater than 0.05, it cannot be concluded there is a significant difference between the two populations.

Analysis of unsaturated-zone data was done by computing total nitrogen content for each soil sample. Total nitrogen content in the soils of the unsaturated zone was determined by converting the reported constituents in mg/kg (milligrams per kilogram) to lb/acre (pounds per acre) by applying the following formula (modified from Follett and others, 1991):

Total nitrogen content (as N) (lb/acre) =
Total Nitrogen as N (mg/kg) x 0.3 x
length of core (inches)

where total nitrogen as N (mg/kg) is the sum of ammonium-N and nitrate-N, 0.3 is the unit conversion factor, and the lengths refer to respective core increments.

Quality Assurance and Quality Control

Two replicate water samples were collected during each sampling trip and submitted to Olson's Agricultural Laboratory for nitrate analysis using a fictitious sample identification number. Additionally, one replicate sample was collected per trip and was sent to the NWQL for nitrate analysis, to compare results with those of Olsen's Agricultural Laboratory. Other quality assurance (QA)/quality control (QC) methods for this study included checking the ion balance for major-ion analyses. Samples for major-ion analysis were reanalyzed by the NWQL if their anion and cation concentrations did not balance within about 5 percent of each other.

In addition to the use of replicate samples, blind reference samples were sent to Olsen's Agricultural Laboratory for nitrate analysis as part of an interlaboratory evaluation. Furthermore, the NWQL QA program includes submission of blind standard reference water samples into its own sample stream (Friedman and Fishman, 1982; Jones, 1987) and participation in an interlaboratory evaluation with the USEPA.

CONCENTRATIONS OF NITRATE IN WATER AND NITROGEN IN SOIL

This section discusses the nitrate concentrations in the surface water and ground water, and the nitrogen content in soil samples from the unsaturated zone. Discussion of nitrate concentrations in the ground water is divided into two subsections: nitrate concentrations in water from monitor wells, and nitrate concentrations in water from irrigation wells. Nitrate concentrations in water samples collected from the monitor wells are listed in table 15, Supplemental Data section, at the end of this report.

Surface Water

Surface-water samples from six sites (fig. 1) were collected concurrently with ground-water samples from irrigation wells in July 1994 and August 1995. Analysis (table 3) showed that, except for one concentration in Frenchman Creek near Culbertson (6.5 mg/L), all nitrate concentrations were less than or equal to 1.6 mg/L. The median nitrate concentration in surface-water samples was 0.8 mg/L.

In August 1995, discharge in Frenchman Creek was 1.8 ft^3/s (table 3) and the nitrate concentration from the surface-water sample was 6.5 mg/L. Such a low-flow condition is considered to be baseflow for this reach of Frenchman Creek. Therefore, it is likely that most of the flow in the creek was derived from ground-water discharge, overland runoff from irrigation, or a combination of the two. Specific conductance values in Frenchman Creek were almost twice the 1994 values, when flows were considerably greater, and were about half the specific conductance values in the Beverly Shallow monitor well, August 1995.

A comparison of ground-water and surface-water specific conductance values helps indicate the source of the water. Because baseflow conditions existed at this site, August 1995 nitrate data from Frenchman Creek and from ground water near the Frenchman Creek site were compared. The ground water contained nitrate concentrations in excess of 10 mg/L (Beverly monitor-well site, table 15). Therefore, nitrate concentrations in Frenchman Creek during this time appear to be affected by nitrate concentrations in the ground water.

Like the Frenchman Creek site, the largest nitrate concentration in samples from the Republican River at Stratton was measured during the time when the flows were lowest. The discharge in August 1995 was only 0.15 ft^3/s; however, the nitrate concentration was 0.10 mg/L compared to 0.01 mg/L in July 1994, when the flow was 16 ft^3/s. Nitrate concentrations in the four other surface-water sites remained small, less than or equal to 1.6 mg/L (table 3).

Table 3. Discharge rates and nitrate concentrations in surface-water samples collected in the study area, southwest Nebraska, July 1994 and August 1995

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; mg/L, milligrams per liter]

USGS station identification number	Name	Date	Discharge (ft^3/s)	Nitrate (mg/L)
06828500	Republican River at Stratton	7-18-94	16	0.01
		8-14-95	.15	.10
06835010	Culbertson Canal at Highway 25, 5 miles below	7-18-94	92	.60
	diversion, near Palisade	8-14-95	131	.50
06835040	Culbertson Extension Canal at County Road,	7-18-94	16	.50
	3 miles north of McCook	8-14-95	28	.30
06835500	Frenchman Creek at Culbertson	7-18-94	32	1.6
		8-14-95	1.8	6.5
06837000	Republican River at McCook	7-18-94	173	1.0
		8-14-95	126	1.3
06838560	Republican River at Bartley	7-19-94	155	1.1
		8-15-95	42	1.4

Ground Water

Concentrations of nitrate in ground water were much larger than concentrations in surface water. The concentrations of nitrate in ground water from monitor and irrigation wells ranged from less than the detection limit for the analytical method (0.01 mg/L) to 30 mg/L and the median concentration for all ground-water samples was 10 mg/L.

Nitrate Concentrations in Water From Monitor Wells

Nitrate concentrations in water samples collected from monitor wells varied spatially, vertically, and temporally. The following three sections describe these variations.

Spatial Variation

Spatially, concentrations varied from less than the reporting limit for the analytical method (0.01 mg/L) at the Shippee Deep well, to 30 mg/L at the McCook North Shallow well (table 4; fig. 8). At least 75 percent of the samples collected from the Beverly, McCook South, and Stratton monitor-well sites exceeded the USEPA MCL for nitrate of 10 mg/L (table 4). Nearly 50 percent of the samples collected at the McCook North monitor-well site exceeded the MCL, two samples equaled or exceeded the MCL at Shippee, and all samples were less than the MCL at Bartley. Median concentrations of nitrate in water samples collected from the monitor wells varied from less than 5 mg/L at the Bartley and Shippee sites to greater than 10 mg/L at some wells at the other four sites (fig. 9).

Two of the four monitor-well sites with the largest average median nitrate concentrations in ground-water samples were in the Republican River valley—McCook South and Stratton, each with 17 mg/L (table 4). The third site, McCook North, with an average median nitrate concentration of 12 mg/L, lies in the uplands north of McCook. At this site depths to water were greater than 100 ft, but nitrate migrated

Table 4. Statistical summary of nitrate concentrations in water from monitor wells in the study area, southwest Nebraska, 1993–95

[in milligrams per liter, unless otherwise noted; <, less than]

Name	Well depth (feet)	Local identifier	Number of samples	Minimum	Percentile 25th	Percentile 50th (Median)	Percentile 75th	Maximum
Bartley Deep	40	3N 27W 9AAAA1	24	1.6	1.8	2	2	4.9
Bartley Shallow	32	3N 27W 9AAAA2	23	2.2	3.7	4.5	5.2	6.7
Average median						3.3		
Beverly Deep	61	4N 32W30DCBB1	25	9.5	11	11	12	12
Beverly Medium-depth	45	4N 32W30DCBB2	24	10	11	12	13	14
Beverly Shallow	25	4N 32W30DCBB3	23	7.3	7.9	8.7	12	14
Average median						11		
McCook North Deep	174	3N 29W 8DDBA1	23	2.9	3.4	3.6	3.6	3.9
McCook North Medium-depth	159	3N 29W 8DDBA2	23	7.5	8.8	9.4	10	12
McCook North Shallow	135	3N 29W 8DDBA3	24	21	22	24	25	30
Average median						12		
McCook South Deep	72	2N 30W 1ACDD1	24	17	20	23	26	29
McCook South Medium-depth	55	2N 30W 1ACDD2	24	15	18	19	20	21
McCook South Shallow	36	2N 30W 1ACDD3	24	6.8	8.4	9.9	12	13
Average median						17		
Shippee Deep	64	1N 26W11CBBB1	22	<.01	.01	.01	.1	3.5
Shippee Shallow	36	1N 26W11CBBB2	23	.6	2	3.2	5.3	15
Average median						1.6		
Stratton Deep	46	2N 5W13AAAD1	25	12	14	14	15	16
Stratton Shallow	30	2N 5W13AAAD2	25	14	19	19	20	23
Average median						17		

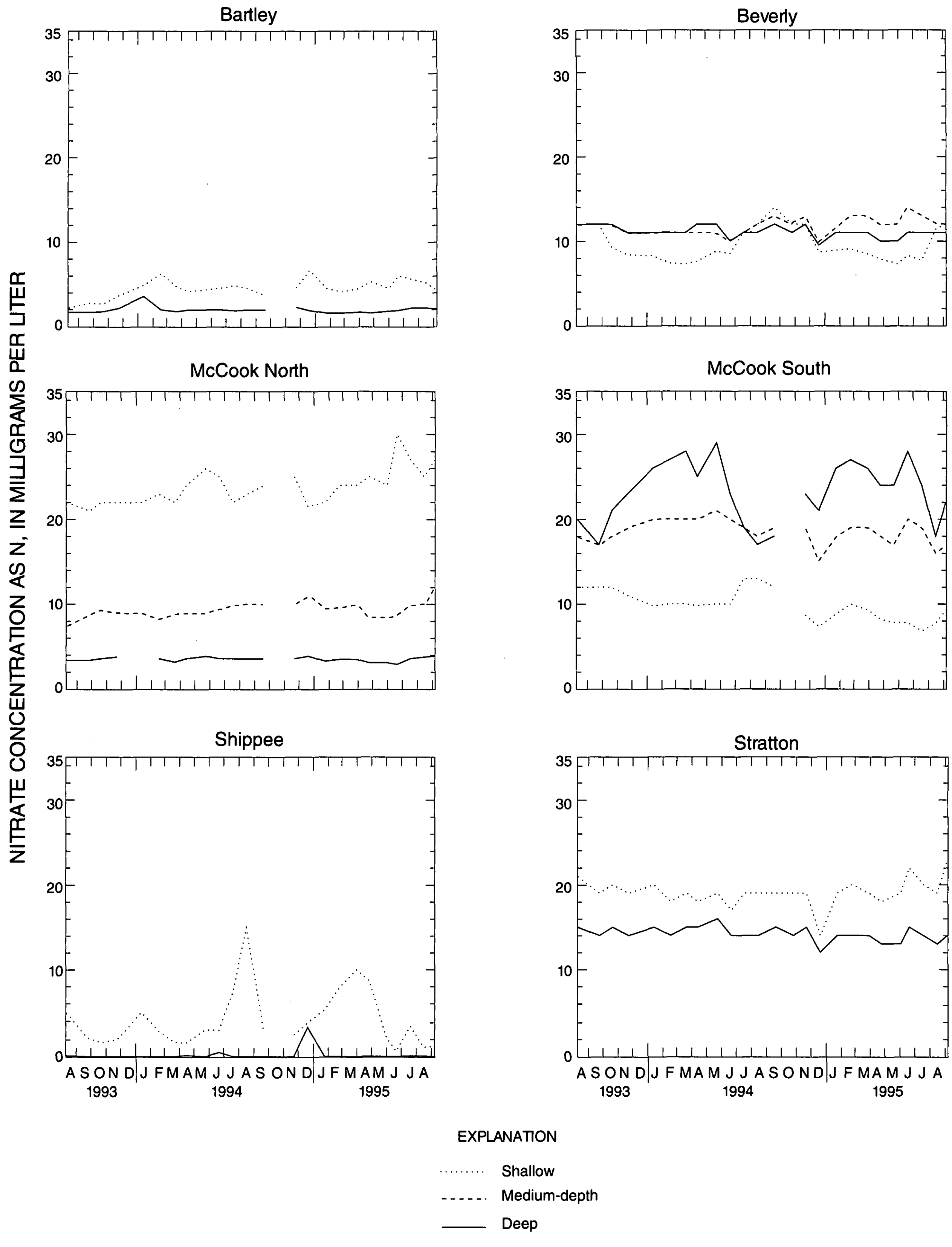


Figure 8. Nitrate concentrations in water from monitor wells in the study area, southwest Nebraska, 1993-95 [breaks indicate missing data].

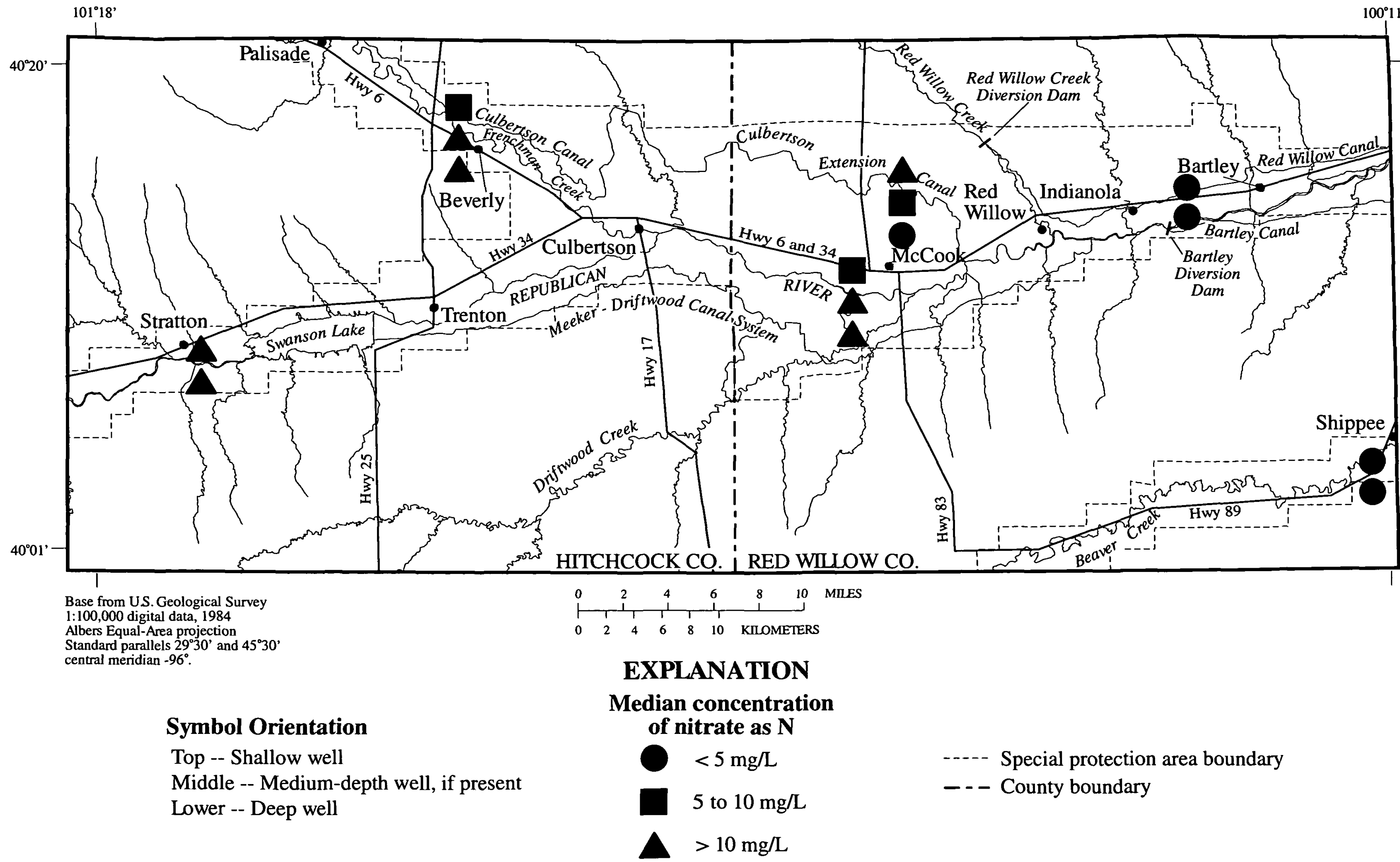


Figure 9. Spatial distribution of median nitrate concentrations in ground-water samples from monitor wells in the study area, southwest Nebraska, 1993-95.

downward with soil moisture. The fourth monitor-well site, Beverly, with an average median nitrate concentration of 11 mg/L, was in Frenchman Creek valley, where ground-water is used extensively for irrigation. Three of these four sites are in areas where row crops are the predominant crop, ground water and surface water are used extensively for irrigation, depths to water are shallow (fig. 6), the soil is well drained (shallow, fine grained, sandy loams overlying sand and gravel deposits), and commercial fertilizers are used in the cultivation of row crops. The McCook North monitor-well site has the same characteristics as the other three, except depths to ground water are much greater.

The other two sites—Bartley and Shippee— had average median nitrate concentrations less than the MCL. The Bartley site, with an average median nitrate concentration of 3.3 mg/L, and the Shippee site, with a median nitrate concentration of 1.6 mg/L, are in the eastern part of the study area. The low median concentrations of nitrate detected at the Bartley site probably resulted from a combination of influx of ground water containing smaller concentrations of nitrate and recharge of the shallow water table from canal leakage; the same influences or factors that caused this site to be lower in dissolved solids, as discussed in the Other Selected Water-Quality Characteristics section later in the report. Ground-water irrigation at the Shippee monitor-well site is not as prominent as in the Republican River valley. Therefore, nitrate concentrations were less affected by downward percolation of irrigation water.

Vertical Variation

Vertically, the maximum nitrate concentrations in the shallow samples (30 mg/L) were larger than the maximum concentrations in the deep samples (29 mg/L), and the medium-depth samples (21 mg/L). The median concentration of nitrate in water samples was largest in the medium-depth monitor wells (12 mg/L), intermediate in the shallow monitor wells (11 mg/L), then smallest in the deep monitor wells (10 mg/L). The two exceptions were the monitor-well sites at Beverly and McCook South where, at least during part of the time, water from the deeper monitor wells contained larger nitrate concentrations than either the medium-depth or shallow monitor wells.

The largest differences in nitrate concentrations between water from the shallowest and the deepest wells were detected in the McCook North monitor wells (fig. 8). Nitrate concentrations at this site were consistently above 20 mg/L in water samples collected from the shallow monitor well and less than 4 mg/L in samples collected from the deep monitor well. Like McCook North, water samples collected from the Shippee and Stratton monitor-well sites showed a stratification of nitrate concentrations, larger in the shallow wells and smaller in the deeper wells.

Statistical analysis did not indicate a significant difference in nitrate concentrations between samples collected from the medium-depth (median 11 mg/L) and deep wells (median 10 mg/L) (Mann-Whitney p-value = 0.22). However, there was a significant difference between the medium-depth samples (median 11 mg/L) and shallow samples (median 12 mg/L) (Mann-Whitney p-value = 0.002) and between the deep samples (median 10 mg/L) and shallow samples (median 12 mg/L) (Mann-Whitney p-value = 0.000), thus providing further evidence of the existence of nitrate stratification in the ground water.

Temporal Variation

Water samples collected from the six monitor-well sites showed that nitrate concentrations at the end of the data-collection period generally were similar to those reported at the beginning of the period (fig. 8). Nitrate concentrations in water samples from most of the monitor wells varied little during the period. Bartley was the only monitor-well site at which nitrate concentrations in water samples remained under the MCL for nitrate. In contrast, Stratton was the only monitor-well site at which nitrate concentrations in water samples remained above the MCL.

For many monitor wells, temporal variations of nitrate concentrations from water samples were largest from May to August, and smallest in February and March (fig. 8). The detection of larger nitrate concentrations in mid-summer generally followed application of commercial fertilizers, and often corresponded to the irrigation season during which water was available to leach nitrate through the unsaturated zone and into the aquifer. From November to March commercial fertilizers were not widely used and irrigation and precipitation were substantially less, providing fewer opportunities for leaching of nitrate.

Nitrate concentrations in samples collected from the monitor wells at the Bartley site showed effects of canal leakage and the resulting infiltration of surface water containing small nitrate concentrations. After surface-water irrigation and leakage through the unlined canals ceased, nitrate concentrations in the ground water rose and then peaked during the winter months.

Nitrate concentrations in water samples collected at the Beverly site also indicated seasonal variations. Figures 6 and 8 show that when the water levels were lowest, nitrate concentrations generally were largest in the upper part of the aquifer. During the summer, the nitrate appeared to be leached into the shallow ground water, as indicated by a general increase in nitrate concentrations throughout the summer months (fig. 8). During the fall, diversion of water from Frenchman Creek ceased and flows in Frenchman Creek increased. The increase in surface water preceded a decrease in nitrate concentrations in water from the shallow monitor well. Possibly, ground-water levels were lower toward the end of the irrigation season and surface water infiltrated the ground-water system (even though Frenchman Creek could be a gaining stream during the other times of the year), subsequently diluting nitrate concentrations in the shallow parts of the aquifer. As mentioned earlier in the Surface-Water Systems section, low-flow measurements conducted in 1979 and 1980 show that Frenchman Creek can gain or lose flow.

Unlike the Beverly monitor-well site, the nitrate concentrations in ground-water samples collected from the McCook South monitor wells were typically largest in the deep well, intermediate in the medium-depth well, and smallest in the shallow well. Analysis of ground-water level data and nitrate concentrations from the McCook South Deep monitor well indicated that when the water table lowered from nearby pumping, nitrate concentrations in the ground water decreased, and when the water table rose, nitrate concentrations increased. This may indicate that irrigation wells in the area pulled fresher water into the deeper parts of the aquifer; this pulling in of fresher water diluted local nitrate concentrations. Once pumping near this site slowed or stopped, water containing larger nitrate concentrations was introduced back into the deep part of the aquifer, and nitrate concentrations increased again. The source of the fresher water has not been identified, but more than likely came from other areas through zones of high transmissivity. A lack of data and the complexities of the system preclude definitive conclusions as to the source of the fresher water.

Pronounced seasonal fluctuations in nitrate concentrations at one depth and little at another, like at the McCook South monitor-well site (fig. 8), indicate the possible presence of zones of high transmissivity in the alluvial aquifer. Zones of high transmissivity such as these have been identified in alluvial sediments in central Kansas (Sophocleous, 1991) and were evident in drilling logs of alluvial sediments in western Nebraska (Steele and others, 1998). These zones possibly can allow water to flow through a particular zone in one area, depth in this case, without affecting an adjacent or overlying area. A result could be the dilution of nitrate concentrations at one depth and not another.

Concentrations of nitrate at the McCook North site were largest in the shallow well (maximum of 30 mg/L), intermediate in the medium-depth well, and lowest in the deep well. No seasonal trends in concentrations of nitrate were apparent in wells at this site. A slight pattern of increasing nitrate concentrations over time in water samples from the McCook North Shallow well appeared to be occurring. This pattern was not as pronounced in the other two wells.

Nitrate concentrations in water samples from the Shippee site generally were less than 6 mg/L (fig. 8). Nitrate concentrations at Shippee Shallow monitor well were lowest in the fall, but peaked as early as March or as late as August (fig. 8). Excluding one sample, December 1994 (3.5 mg/L), water samples from Shippee Deep contained nitrate concentrations largely under the reporting limit (0.01 mg/L).

Stratton was the only site where all nitrate concentrations in water samples were greater than 10 mg/L. At this site, the smallest concentrations occurred in December 1994 and largest at the beginning and end of the data-collection period. Nitrate concentrations appeared to increase slightly in the summer months and decrease slightly in the winter months.

Nitrate Concentrations in Water from Irrigation Wells

Water samples from 61 irrigation wells (59 in 1994 and 52 plus 2 alternates in 1995) were collected in July 1994 and August 1995 to determine how nitrate concentrations varied spatially. Concentrations of nitrate from 59 water samples collected in July 1994 ranged from a minimum of 0.01 mg/L to a maximum of 22 mg/L (table 5), with a median of 8.4 mg/L. In August 1995, concentrations of nitrate from 54 water samples ranged from a minimum of 0.40 mg/L to a maximum of 20 mg/L (table 5), with a median of 6.8 mg/L.

Nitrate concentrations exceeding 10 mg/L were detected in water samples collected from some irrigation wells in the Republican River valley from east of McCook to east of Stratton (figs. 10 and 11), on the uplands northeast of McCook to northwest of McCook, and in the Frenchman Creek valley during both 1994 and 1995.

Table 5. Well depth and nitrate concentrations in water from irrigation wells in 1994 and 1995, and change in nitrate concentrations between 1994 and 1995 in the study area, southwest Nebraska

[Values in milligrams per liter, unless otherwise noted, USGS, U.S. Geological Survey; --, no data]

USGS station identification	Local identifier	Well depth (feet)	Nitrate concentration July 1994	Nitrate concentration August 1995	Change in nitrate concentration	Year drilled
400449100121701	1N 26W 2DD 1	68	8.8	7.6	-1.2	1972
400330100150601	1N 26W15BB 1	80	.8	3.7	2.9	1972
400316100242901	1N 27W18ADA1	50	.01	.4	.39	1972
400237100244401	1N 27W19AB 1	52	8.4	6.6	-1.8	1987
400210100272701	1N 28W23CB 1	90	5.3	5.1	-.2	1971
401013100360101	2N 29W 4AC 1	100	15	14	-1.0	1974
401014100391601	2N 30W 1AC 1	72	19	19	0	1954
400909100423501	2N 30W 9D 1	77	14	13	-1.0	1977
400830100430801	2N 30W16BC 1	68	12	11	-1.0	1976
400659100452101	2N 30W30BB 1	53	12	--	--	1979
401014100571601	2N 32W 5AC 1	68	10	10	0	1979
401016101025201	2N 33W 4AC 1	60	1.4	1.9	.50	1942
401013101023601	2N 33W 4AD 1	36	9.6	--	--	--
400918101023201	2N 33W 9ADD1	37	11	6.5	-4.5	1937
400934101020301	2N 33W10B 1	--	3.0	3.4	.40	1954
400859101115101	2N 34W 7DC 1	--	19	20	1.0	--
400842101114101	2N 34W18AA 1	--	.5	1.1	.60	1946
400802101155901	2N 35W16DD 1	47	7.4	--	--	1979
400749101175601	2N 35W20BB 1	51	1.1	1.7	.60	1966
401529100144901	3N 26W 3BD 1	57	4.5	6.2	1.7	1976
401424100143201	3N 26W10DB 1	170	2.2	2.1	-.10	1966
401541100230401	3N 27W 4BBC1	145	3.7	3.7	0	1974
401410100232101	3N 27W 8DD 1	40	9.8	8.7	-1.1	1977
401410100192001	3N 27W12CD 1	58	5.2	5.3	.10	1956
401342100301601	3N 28W17AC 1	80	8.8	9.8	1.0	1957
401211100315101	3N 28W30BB 1	77	2.6	2.0	-.60	1974
401145100310601	3N 28W30DA 1	35	10	9.6	-.4	1974
401539100345401	3N 29W 3BA 1	200	10	--	--	1974
401434100380201	3N 29W 7ACC1	190	8.0	8.6	.60	1972
401447100333101	3N 29W11AB 1	143	8.5	8.1	-.40	1970
401342100352801	3N 29W16AD 1	175	16	16	0	1977
401040100351101	3N 29W34CC 1	78	13	--	--	1971
401513100450401	3N 30W 6CA 1	108	13	14	1.0	1970
401329100405501	3N 30W14CBB1	114	13	15	2.0	--
401355100441401	3N 30W17BBC1	51	9.9	9.9	0	1958

Table 5. Well depth and nitrate concentrations in water from irrigation wells in1994 and 1995, and change in nitrate concentrations between 1994 and 1995 in the study area, southwest Nebraska--Continued

USGS station identification	Local identifier	Well depth (feet)	Nitrate concentration July 1994	Nitrate concentration August 1995	Change in nitrate concentration	Year drilled
401240100424701	3N 30W21CAA1	39	11	--	--	1975
401132100403901	3N 30W26CD 1	45	3.6	3.1	-0.50	1977
401119100420201	3N 30W34BBC1	53	1.3	1.6	.30	1943
401525100464501	3N 31W 2AD 1	176	12	9.2	-2.8	1957
401459100542501	3N 32W 2CD 1	60	15	7.3	-7.7	1972
401459100544201	3N 32W 3DD 1	--	8.1	3.8	-4.3	1956
401612100203501	4N 27W35CA 1	191	7.8	6.4	-1.4	1976
401632100310601	4N 28W31AA 1	163	3.6	3.3	-.30	1966
401637100294401	4N 28W33BB 1	233	2.6	2.9	.30	1971
401619100265401	4N 28W35AC 1	175	2.9	2.7	-.20	1971
401632100252901	4N 28W36AA 1	173	4.3	4.1	-.20	1968
401553100374301	4N 29W31DB 1	252	2.0	2.3	.30	1976
401617100350001	4N 29W34CA 1	207	22	19	-3.0	--
401723100412901	4N 30W27AB 1	318	2.2	2.9	.70	1979
401631100425101	4N 30W33BA 1	210	2.9	4.2	1.3	1979
401748100520801	4N 31W19CB 1	208	14	--	--	1955
401722100455401	4N 31W25AB 1	243	12	10	-2.0	1975
401556100502701	4N 31W32DC 1	125	4.6	8.2	3.6	1990
401551100495101	4N 31W33CC 1	106	12	11	-1.0	1971
401713100582501	4N 32W30AD 1	--	10	10	0	--
401944101041601	4N 33W 8BD 1	64	13	13	0	1978
401931101031001	4N 33W 9CA 1	80	6.8	7.7	.90	1956
401839101011201	4N 33W14CB 1	80	12	9.2	-2.8	1979
402036101065201	4N 34W 1BC 1	116	2.2	2.8	.60	1973
[1]401249100431501	3N 30W21BC1	60	--	6.9	--	1990
[1]401643100513301	4N 31W30DC 1	152	--	5.1	--	1978

[1]Alternate well in 1995.

Nitrate concentrations in water samples collected from 61 irrigation wells (113 samples) in the study area varied among locations (table 5). Most nitrate concentrations above 10 mg/L occurred in water samples collected in 1994 from wells located between Culbertson and McCook, with isolated occurrences from wells in the Frenchman Creek and Republican River valleys upgradient from Trenton (fig. 10). Nitrate concentrations less than 10 mg/L generally were found in samples from wells located from just east of McCook to the eastern border of the study area, in Beaver Creek valley, north-northwest of McCook along the Culbertson Extension Canal, and also in areas within the Republican River valley west of Trenton and in the Frenchman Creek valley. Spatial distribution of nitrate concentrations in water samples collected from irrigation wells in the study area in 1995 (fig. 11) was similar to that of 1994.

Water samples collected from irrigation wells near McCook contained larger nitrate concentrations in both 1994 and 1995 than samples from wells in the vicinity of Bartley. In the vicinity of Bartley, Culbertson, and McCook, ground-water depths are shallow, corn is the predominant crop, ground-water irrigation is extensive, commercial fertilizer is commonly used on the crops, and soils are sandy and well drained. All of these factors contributed to the large nitrate concentrations found in the ground water. In addition, surface-water irrigation canals are present near Bartley—Red

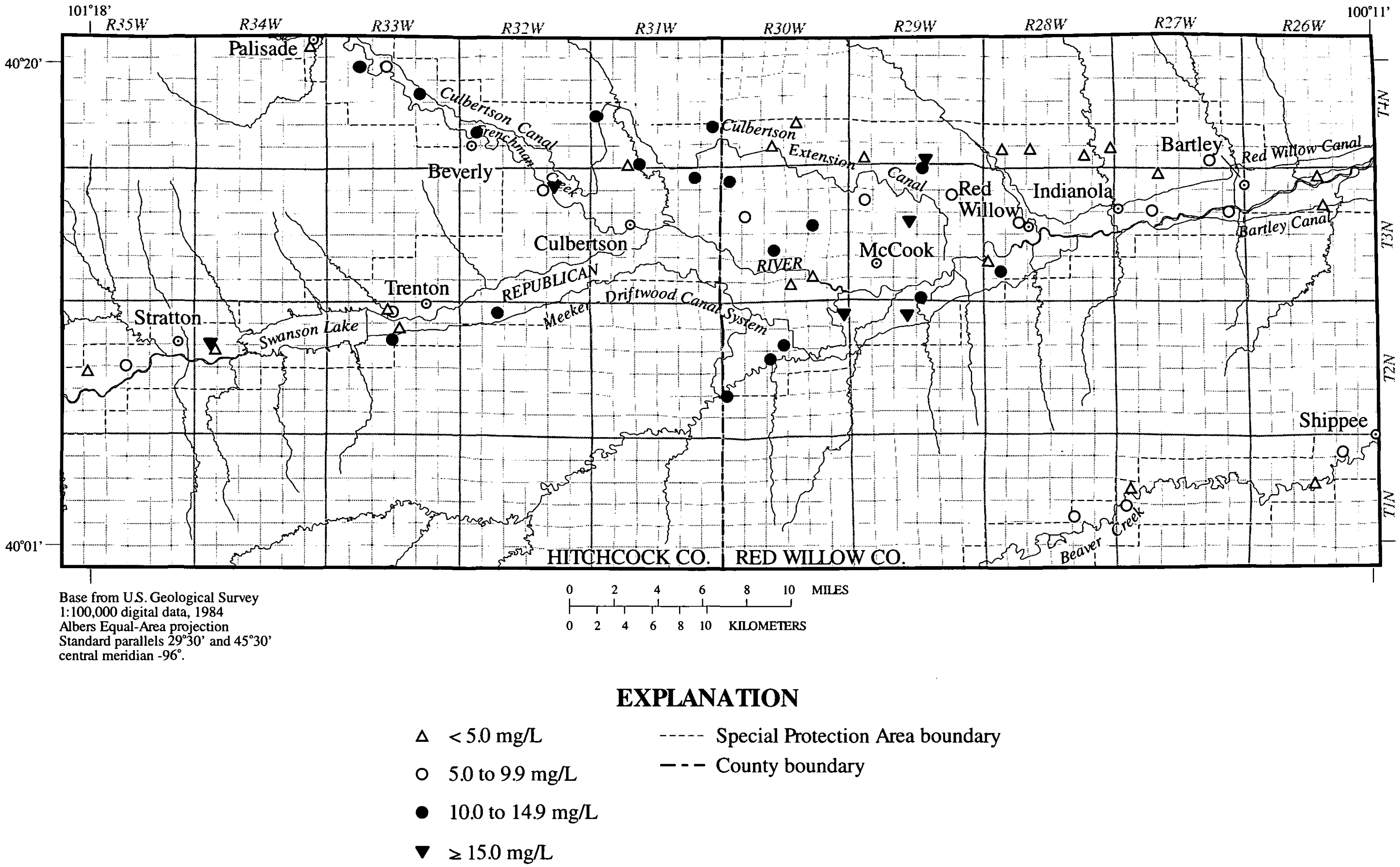


Figure 10. Nitrate concentrations in water from irrigation wells in the study area, southwest Nebraska, 1994.

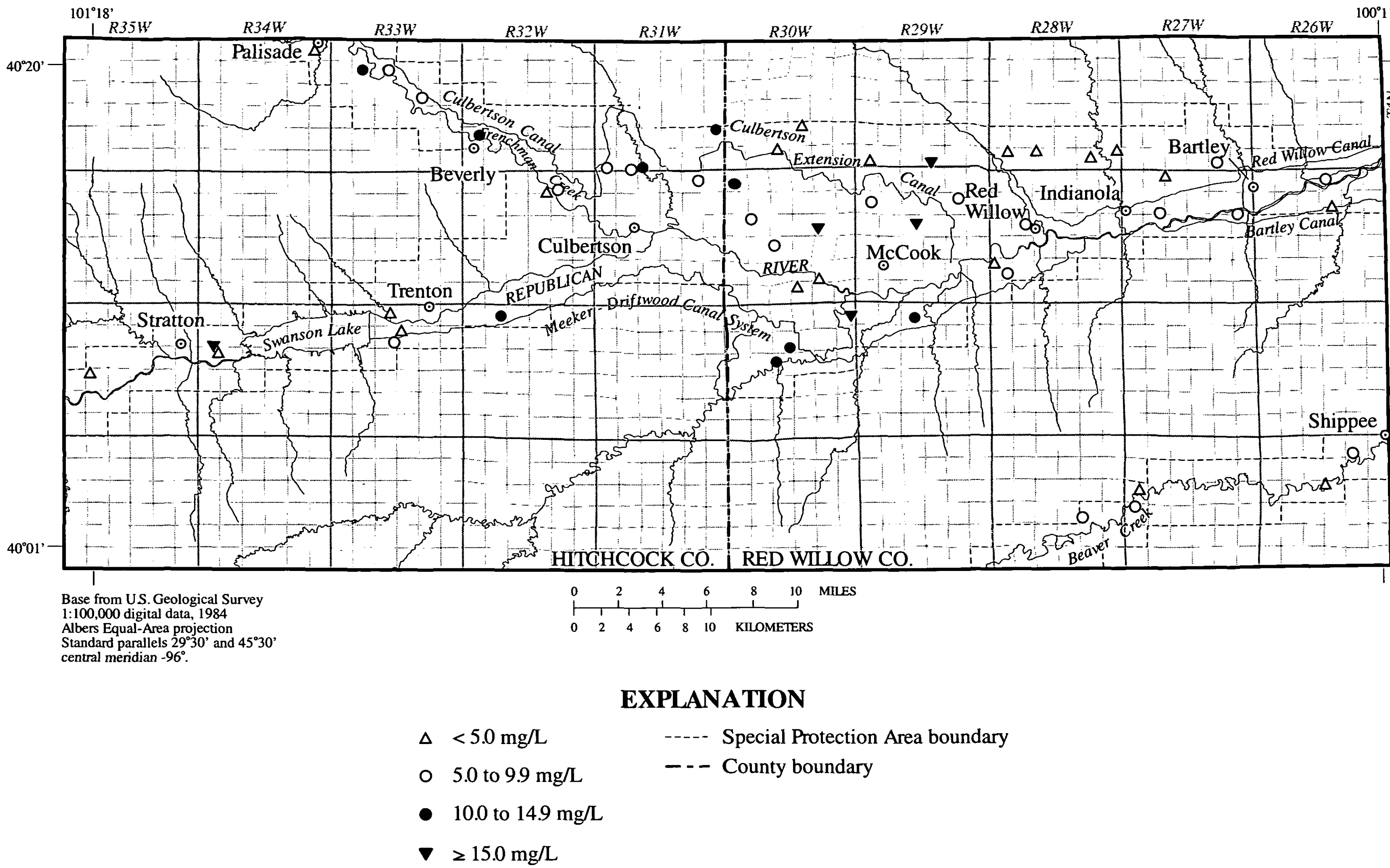


Figure 11. Nitrate concentrations in water from irrigation wells in the study area, southwest Nebraska, 1995.

Willow Canal on the north side of the Republican River and Bartley Canal on the south side (fig. 1). Leakage from these canals probably provides local areas with water containing smaller nitrate concentrations.

The Wilcoxon signed-rank statistical test did not indicate a significant difference between nitrate concentrations of deep or shallow irrigation wells. Evaluation of data suggests that irrigation well depth (less than 75 ft deep as opposed to greater than 75 ft deep) did not show an association with concentrations of nitrate (Mann-Whitney p-value = 0.24).

Changes in nitrate concentrations in water samples collected from the 61 irrigation wells do not seem to be related to well depth or water level (fig. 12) as much as to location. Water samples from irrigation wells in the Frenchman Creek valley and the western two-thirds of the Republican River valley contained the largest nitrate concentrations, whereas samples collected from irrigation wells in the eastern third of the Republican River valley and Beaver Creek valley contained the smallest nitrate concentrations (figs. 10 and 11).

Variations in nitrate concentrations were observed in water samples collected from irrigation wells in 1994 and 1995 (fig. 13). Although these variations were not significant (Wilcoxon p-value = 0.358), nitrate concentrations in water samples collected from irrigation wells showed that most increases from 1994 to 1995 occurred in the uplands north of McCook and above and below Swanson Lake (fig. 13). The largest decrease in nitrate concentrations from 1994 to 1995 was 7.7 mg/L southeast of Beverly (3N 32W 2CD1) (table 5). The largest increase in nitrate concentrations was 3.6 mg/L north of Culbertson (4N 31W32DC1). Nitrate concentrations in samples from the irrigation wells in 1994 to 1995 generally varied by not more than 3 mg/L.

Data indicate that no correlation exists between the age of the irrigation well and the median nitrate concentration (r^2 (correlation coefficient) = 0.1). Thus, the magnitude of the nitrate concentrations in the ground water does not appear to be associated with the age of the well.

Soils of the Unsaturated Zone

Soil samples were collected at five sites in the study area as described in the Analytical Methods section. Excluding the Stratton site, organic matter generally decreased from the soil surface to the water table (table 6). At the Stratton site, soil cores indicate at least three separate soil surfaces (two of which have been buried) (table 7). The average core-interval total nitrogen content per site ranged from 122 lb/acre to 570 lb/acre (table 6). The other four sites contained substantially smaller nitrogen concentrations in the soils of the unsaturated zone, ranging from 122 to 220 lb/acre. For this report total nitrogen includes only ammonium as N and nitrate as N. The formula for total nitrogen content is given in the Data Analysis section.

Total nitrogen content and concentrations in the unsaturated zone varied at all five sites (fig. 14) as did the vertical soil horizons (table 7) and some of the surface soils. Soil-core samples collected from the Bartley site contained larger nitrogen concentrations in the upper half of the unsaturated zone, whereas larger nitrogen concentrations at the Beverly, McCook South, and Stratton sites generally were detected in the lower half. Soil profiles varied from silt loam at the Bartley and McCook South sites, to silt loam and very fine sandy loam at Stratton (table 7). Soil-core samples at the McCook North site also contained larger nitrogen concentrations in the upper half than in the lower; however, depths to ground water at this site were much greater.

Soil-core samples at the Bartley site showed total nitrogen concentrations were largest in the upper 5 ft (fig. 14). Below this depth, total nitrogen concentrations in the unsaturated zone fluctuated between 10 and 13 mg/kg. This site contains soil that has permeabilities of 5 to 10 in/hr, one of the largest in the study area. Therefore, because the larger nitrogen concentration is shallow, less than 5 ft, the shallow concentration may be the result of fertilizer applications during the 1994 growing season.

At the Beverly site, total nitrogen concentrations in the unsaturated zone were fairly uniform, 10 to 12 mg/kg, down to approximately 18 ft (fig. 14). At this depth, total nitrogen concentrations in the unsaturated zone decreased to 7.5 mg/kg before increasing to 12 mg/kg at 23 ft. Like the Bartley site, the increase at this depth could be the result of the downward migration of a slug of nitrogen applied to the fields in the spring.

Total nitrogen concentration at the McCook North site was largest near the 33-ft depth, 22 mg/kg (fig. 14). At this depth, the lithology indicates very little clay. However, clay lenses do occur at about 58 ft below the land surface. At a depth of 73 ft, nitrogen concentrations began to rise again and generally

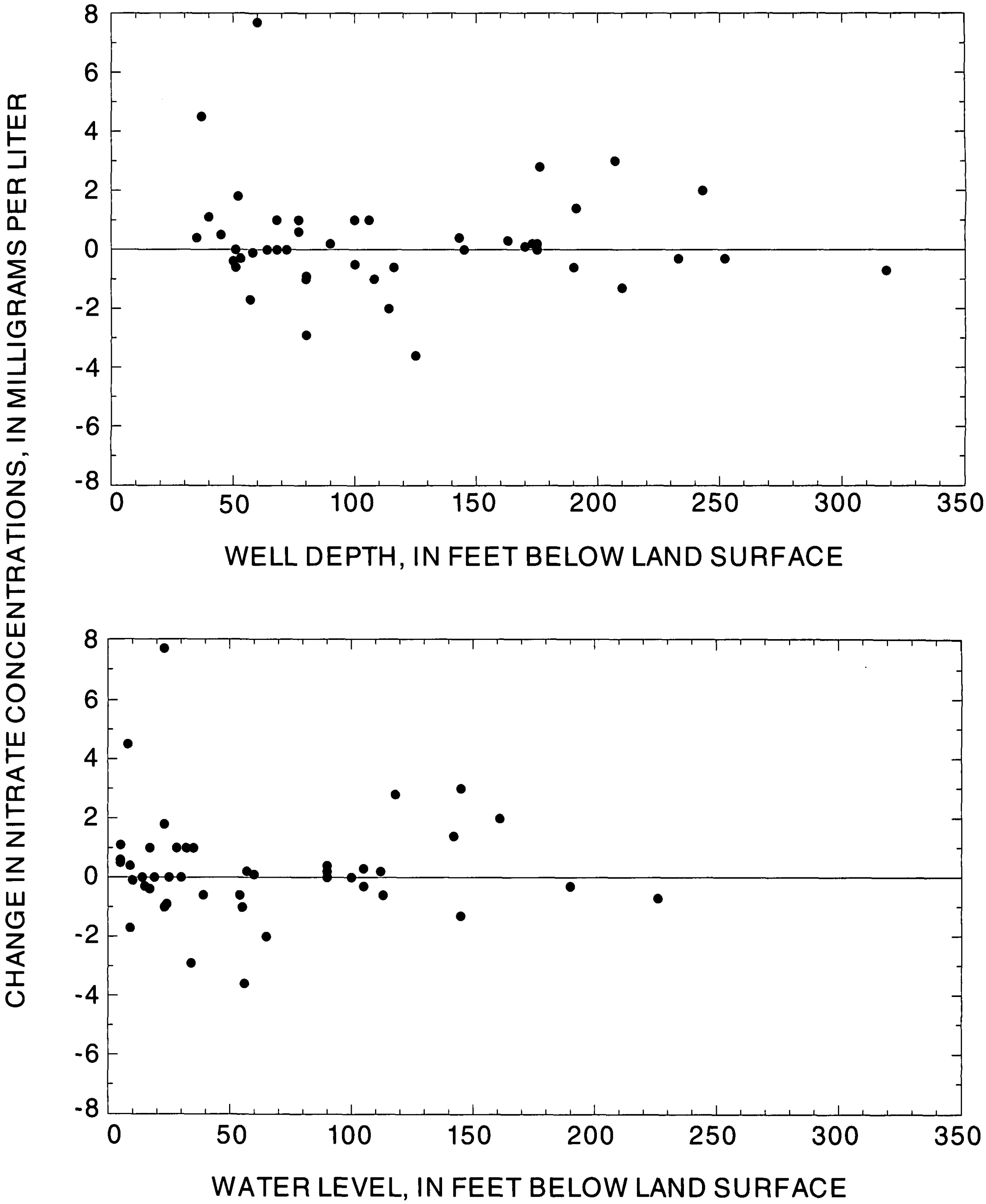


Figure 12. Relation of changes in nitrate concentrations from July 1994 to August 1995 in water from irrigation wells to well depth and water level in irrigation wells in the study area, southwest Nebraska.

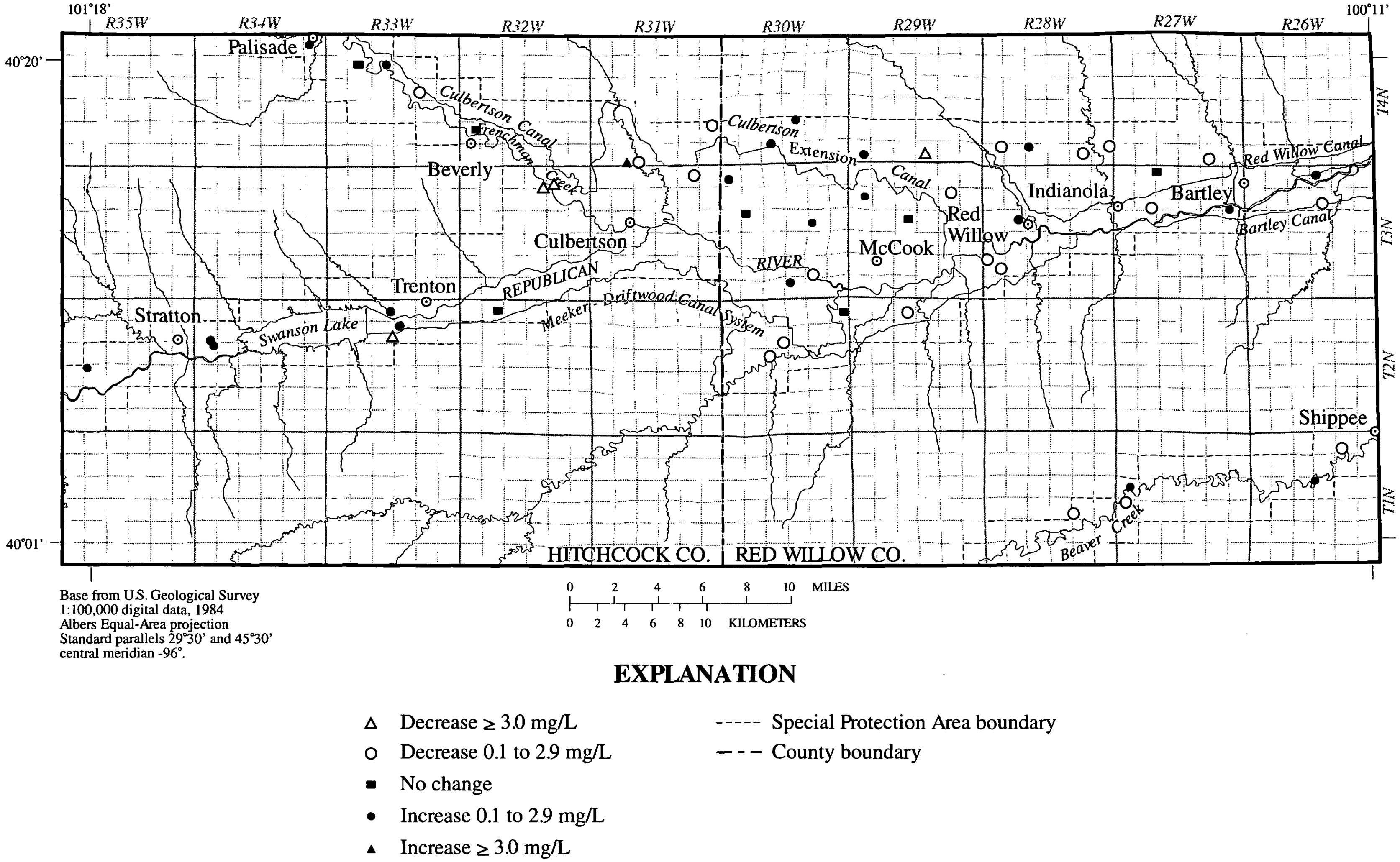


Figure 13. Differences in nitrate concentrations from July 1994 to August 1995 in water from irrigation wells in the study area, southwest Nebraska.

Table 6. Organic matter, ammonium, nitrate, and total nitrogen in soil-core samples collected in the study area, southwest Nebraska, November 1994

[Analyses by University of Nebraska-Lincoln Agronomy Laboratory; mg/kg, milligrams per kilogram; lb/acre, pounds per acre]

Name	Depth (feet)	Organic matter (percent)	Ammonium, as N (mg/kg)	Nitrate, as N (mg/kg)	Total nitrogen as N (mg/kg)	Total nitrogen content, by interval (lb/acre)
Bartley	3	1.07	3.3	21	24	260
	8	.60	4.3	7.7	12	220
	13	.57	3.9	8.8	13	230
	18	.29	4.2	7.8	12	220
	23	.20	3.9	7.8	12	210
	25	.06	3.6	6.0	10	69
Average of intervals						202
Beverly	3	.93	4.4	6.3	11	120
	8	.09	3.3	7.2	10	190
	13	.07	3.3	6.7	10	180
	14	.12	2.7	9.1	12	[1]43
	18	.62	4.2	3.3	7.5	110
	20	.17	5.0	5.8	11	78
	23	.09	4.3	8.1	12	130
Average of intervals						122
McCook North	3	1.1	3.5	3.8	7.3	53
	8	.22	3.3	4.2	7.5	140
	13	.24	3.4	4.9	8.3	140
	18	.29	3.2	5.6	8.8	160
	23	.22	2.5	6.4	8.9	160
	28	.20	3.2	16	19	340
	33	.24	3.8	18	22	400
	38	.32	3.4	13	16	290
	43	.33	3.8	5.6	9.4	170
	48	.14	3.1	4.0	7.1	130
	53	.09	2.9	3.1	6.0	110
	58	.07	3.2	2.8	6.0	110
	63	.17	4.1	5.5	9.6	170
	68	.03	3.1	3.4	6.5	120
	73	.14	3.8	7.1	11	200

Table 6. Organic matter, ammonium, nitrate, and total nitrogen in soil-core samples collected in the study area, southwest Nebraska, November 1994--Continued

Name	Depth (feet)	Organic matter (percent)	Ammonium, as N (mg/kg)	Nitrate, as N (mg/kg)	Total nitrogen as N (mg/kg)	Total nitrogen content, by interval (lb/acre)
McCook North--Continued	78	0.09	3.2	5.5	8.7	160
	83	.06	2.9	7.0	9.9	180
	88	.12	4.4	8.6	13	230
	93	.07	3.7	8.8	12	220
	98	.09	3.7	7.7	11	210
	103	.07	4.4	8.1	12	230
	108	.12	3.4	5.4	8.8	160
	113	.11	4.0	6.6	11	190
	117	.22	4.6	5.7	10	150
Average of intervals						184
McCook South	3	1.5	4.4	4.1	8.5	92
	8	.40	4.0	6.4	10	190
	13	.22	4.1	18	22	390
	18	.31	4.1	13	17	300
	21	.17	3.7	8.5	12	130
Average of intervals						220
Stratton	3	.44	3.6	29	33	360
	8	1.5	4.5	38	42	760
	13	.33	5.1	47	52	930
	18	.04	4.1	8.7	13	230
Average of intervals						570

[1]Smaller total nitrogen content because of the 12-inch soil column (see Data Analysis section for formula).

Table 7. Description of vertical soil horizons in soil cores from the study area, southwest Nebraska, November 1994

[Information from Donna Hinz, U.S. Department of Agriculture, written commun., 1995; Soil horizons: A, A horizon; B, B horizon; C, C horizon; b, buried genetic horizon; k, accumulation of carbonates, p, tillage or other disturbance; w, development of color or structure; 1-6, vertical subdivision; R, red; Y, yellow; YR, yellow red; $CaCO_3$, calcium carbonate; %, percent; --, no data]

Name	Soil horizon	Depth (inches)	Moist color[1]	Description	Texture
Bartley	Ap	0-15	10YR 3/2 10YR 3/3	very dark grayish brown and dark brown	silt loam
	Bk1	15-26	10YR 5/3	brown, effervescent, few (0-2%), fine threads of $CaCO_3$	silt loam
	Bk2	26-39	10YR 4/2	dark grayish brown, effervescent, few (0-2%), fine threads of $CaCO_3$	silt loam
	Bk3	39-54	10YR 3/2	very dark grayish brown, strongly effervescent, common (2-20%), fine threads of $CaCO_3$	silt loam
	Bk4	54-73	2.5Y 5/3	light olive brown, violently effervescent, common (2-20%), fine threads of $CaCO_3$	silt loam
	Bk5	73-87	10YR 5/3 10YR 4/3	brown, violently effervescent, common (2-20%), fine accumulation of $CaCO_3$ in pore linings	silt loam
	Bk6	87-108	2.5Y 5/3	light olive brown, strongly effervescent, common (2-20%), fine accumulation of $CaCO_3$ in pore linings	silt loam
Beverly	Ap	0-8	10YR 3/2 10YR 4/3	very dark grayish brown and brown	silt loam
	A1	8-16	10YR 3/2	very dark grayish brown, effervescent	silt loam
	A2	16-25	10YR 3/2	very dark grayish brown	silt loam
	Bk	25-32	10YR 4/3	brown, effervescent, few (0-2%), fine soft masses of $CaCO_3$	silt loam
	C1	32-87	2.5Y 5/3	light olive brown, strongly effervescent	very fine sandy loam
	C2	87-104	2.5Y 6/3	light yellowish brown	very fine sandy loam
	C3	104+	2.5Y 5/2	grayish brown, strongly effervescent	very fine sandy loam
McCook North	Ap1	0-9	10YR 3/2	very dark grayish brown	silt loam
	Ap2	9-15	10YR 3/2 10YR 3/3	very dark grayish and dark brown	silt loam
	Bw	15-41	10YR 3/2 10YR 3/3	very dark grayish brown and dark brown, few, thin, discontinuous clay films on ped facies in upper part	silt loam
	Bk1	41-47	10YR 4/2	dark grayish brown, few fine, soft, rounded concretions of $CaCO_3$, strongly effervescent matrix	silt loam

Table 7. Description of vertical soil horizons in soil cores from the study area, southwest Nebraska, November 1994--Continued

Name	Soil horizon	Depth (inches)	Moist color[1]	Description	Texture
McCook North --Continued	Bk2	47-74	10YR 5/3	brown, common (2-20%), fine threads of $CaCO_3$, violently effervescent matrix	very fine sandy loam
	Bk3	74-96	--	brown, few, fine threads of $CaCO_3$, strongly effervescent matrix	silt loam
	B/C	96-120	--	brown, few $CaCO_3$ accumulations lining large pores, strongly effervescent matrix	
McCook South	Ap1	0-5	10YR 4/2	dark grayish brown	silt loam
	Ap2	5-9	10YR 4/2	dark grayish brown, effervescent	silt loam
	A1	9-17	10YR 3/2	very dark grayish brown, strongly effervescent	silt loam
	Bk1	17-37	10YR 3/1	very dark gray, strongly effervescent, common (2-20%), fine threads of $CaCO_3$	silt loam
	Bk2	37-60	10YR 5/4	yellowish brown, effervescent, few (0-2%), fine soft masses of $CaCO_3$	silt loam
	Bk3	60-84	2.5Y 5/4	light olive brown, strongly effervescent, few, fine threads of $CaCO_3$ lining pores	silt loam
	C	84-108	2.5Y 5/4	light olive brown, strongly effervescent, few, fine threads of $CaCO_3$ lining pores	stratified silt loam with thin lens of very fine sandy loam
Stratton	Ap	0-10	10YR 3/3	dark brown	silt loam
	A	10-15	10YR 3/2 10YR 3/3	very dark grayish brown and dark brown, strongly effervescent	silt loam
	C1	15-32	10YR 5/3	brown, strongly effervescent	very fine sandy loam
	C2	32-38	10YR 6/4	light yellowish brown, strongly effervescent	very fine sandy loam
	Ab	38-45	2.5Y 4/3	olive brown, strongly effervescent	silt loam
	Bkb	45-73	2.5Y 5/3	light olive brown, strongly effervescent, few (0-2%), fine threads of $CaCO_3$	very fine sandy loam
	Ab2	73-85	10YR 4/3 10YR 5/4	brown and yellowish brown, strongly effervescent	silt loam
	Cb1	85-93	10YR 4/3	brown, strongly effervescent	sandy loam
	Cb2	93-111	10YR 5/3	brown, strongly effervescent	silt loam

[1]Munsell notation (described in Soil Survey Division Staff, 1993, p. 149-153).

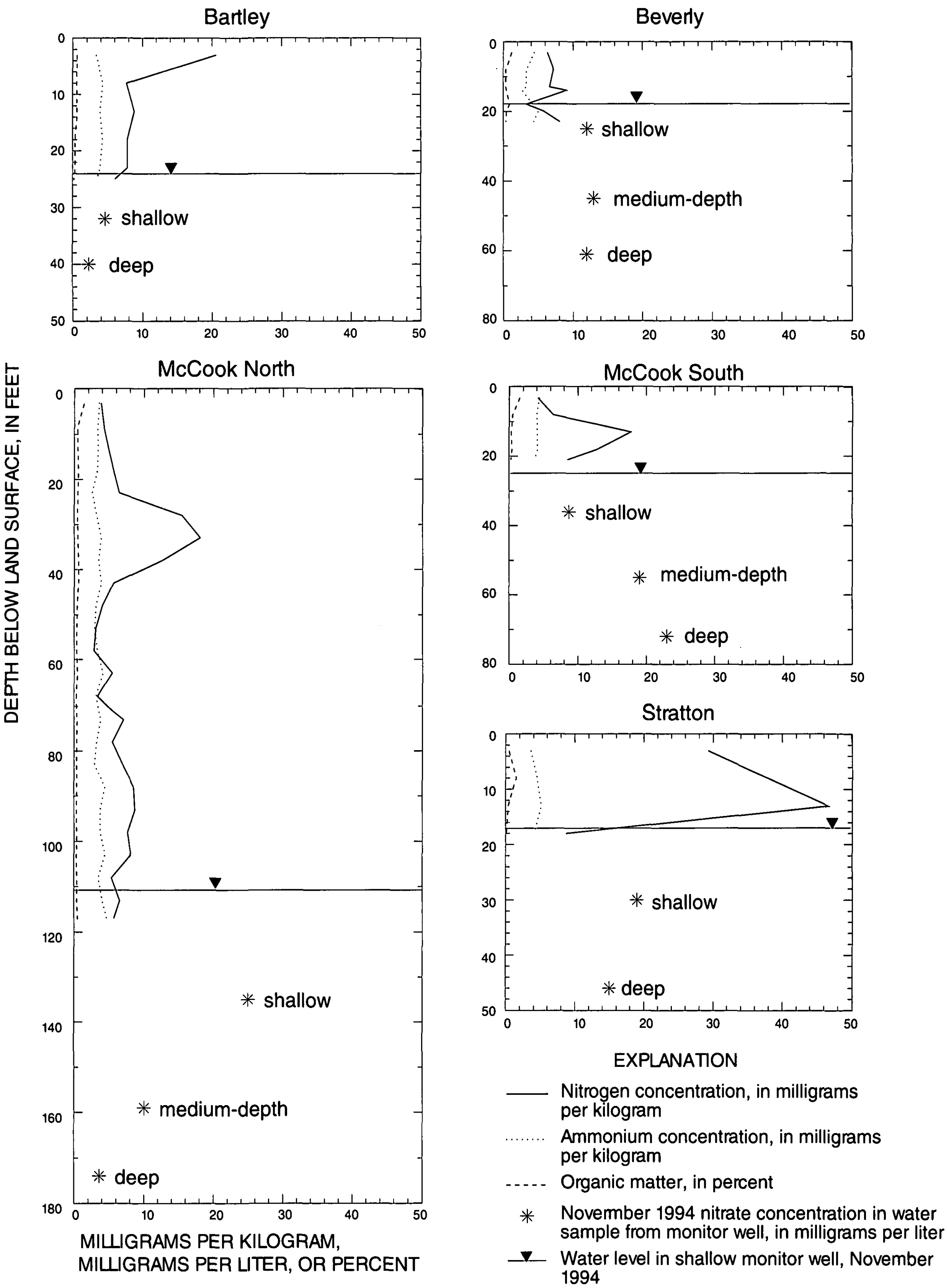


Figure 14. Concentration of nitrogen, ammonium, and organic matter in soil samples near monitor wells and concentrations of nitrate in ground water from monitor wells in the study area, southwest Nebraska, November 1994.

remained between 8.7 to 13 mg/kg or near the concentrations detected in the upper part of the unsaturated zone. Therefore, except for the larger nitrate concentrations near the 33-ft depth, nitrate concentrations throughout the unsaturated zone were not largely variant.

Samples from the unsaturated zone at the McCook South site indicated rises in total nitrogen concentrations from 3 to 13 ft below the land surface and declines from 13 to 21 ft below the land surface (fig. 14). This likely indicates the movement of nitrate through the unsaturated zone from fertilizer application in spring 1994.

The Stratton site contained the largest average core-interval total nitrogen content, 570 lb/acre, whereas the other four sites had substantially smaller contents (fig. 14, table 6). The soil at this site is sandier than the other four sites and there are three separate soil surfaces, two of which are now subsurface. This site also is near (within 50 ft of) the headwaters area where flood irrigation is used. Because flood irrigation requires water to flow from the head of the field to the tail, through time more water seeps through the unsaturated zone and into the aquifer at the head of the field than at the tail. The more water that seeps through the unsaturated zone, the more nitrogen, if present, that can be leached from the root zone. This may explain the large nitrogen content detected at the Stratton site. Also, usage of nitrogen fertilizers in a sandier soil can account for some of the large nitrogen contents. Generally, chemicals are easier to leach through sandier soils so commonly more is applied than on other, less sandy, soils. However, historical chemical usage at this site has not been determined.

Quality Assurance/Quality Control Results

Results of the QA/QC analyses for nitrate ranged from poor to excellent (table 8). Replicate analyses for nitrates between Olsen's Agricultural Laboratory and the NWQL were generally within 8 percent of the original determination; however, some replicate analyses between the two labs varied by 30 percent or more (one QA/QC sample varied by 1,900 percent from the original sample—0.01 to 0.20 mg/L). Ranges in differences between replicate samples analyzed at Olsen's Agricultural Laboratory were -28 to 41 percent. The range in differences between the original nitrate sample analyzed at Olsen's Agricultural Laboratory and the replicate sample analyzed at the NWQL was -14 to 30 percent (not including the 1,900 percent variation at Shippee Deep).

The reason for the discrepancy of 30 percent could not be determined readily (the 1,900 percent variation at Shippee Deep was not used in statistical analysis because of the very small concentrations; table 8). However, the median variation between the original and the replicate samples analyzed at Olsen's Agricultural Laboratory was 0 percent and between the original and the replicate samples analyzed at the NWQL was 0 percent (table 8).

To compare the relative accuracy of both laboratories in their analyses for nitrate, four blind reference samples were submitted to each laboratory for nitrate analysis. The blind reference samples were of known nitrate concentrations and were disguised as environmental samples before submission to the laboratories. All analyses of the blind reference samples were within the 95-percent confidence interval of 5.66 to 7.06 mg/L, as set by the manufacturer of the blind reference sample (table 9).

OTHER SELECTED WATER-QUALITY CHARACTERISTICS

This section addresses the chemistry of the surface- and ground-water samples collected during the study. The focus is on the field measurements, water chemistry, and herbicide concentrations.

Field Measurements

Field measurements collected during this study included three constituents—specific conductance, pH, and water temperature. The summary statistics for the field measurements are presented in table 10. Monthly collection of ground-water field measurements indicated seasonal variations in all three constituents (fig. 15). Median specific conductance values were largest in the winter months, December through April, and smallest in October. Median values of pH, on the other hand, were smallest in July and largest in October. Median ground-water temperatures varied with the atmospheric temperature, largest in August and smallest during the winter months.

Table 8. Quality assurance and quality control results of analysis for nitrate concentrations in water samples from the monitor wells in the study area, southwest Nebraska, 1993–95

[units in milligrams per liter unless specified; USGS, U.S. Geological Survey; %, percent; NWQL, U.S. Geological Survey National Water Quality Laboratory; <, less than; ND, no data; --, no comparison was possible]

USGS station identification number	Name	Date	Olsen's Agricultural Laboratory (original)	Olsen's Agricultural Laboratory replicate	Difference between original and Olsen's replicate (%)	NWQL replicate	Difference between Olsen's original and NWQL replicate (%)
401454100215401	Bartley Deep	11-22-93	2.2	2.0	-9.1	1.9	-14
		04-14-94	2.0	2.0	0	1.9	-5.0
		08-16-94	2.0	2.1	5.0	2.2	10
401454100215402	Bartley Shallow	05-24-94	4.4	4.1	-6.8	4.3	-2.3
		08-16-94	4.5	4.5	0	4.8	6.7
		04-25-95	5.3	5.3	0	5.8	9.4
401655100583201	Beverly Deep	09-23-93	12	12	0	13	8.3
		01-12-94	11	12	9.1	12	9.1
		10-25-94	11	11	0	12	9.1
		12-19-94	9.5	9.4	-1.1	11	16
		01-23-95	11	11	0	12	9.1
		07-18-95	11	11	0	11	0
		09-05-95	11	11	0	12	9.1
401655100583202	Beverly Medium-depth	09-23-93	12	12	0	12	0
		01-12-94	11	11	0	11	0
		10-25-94	12	13	8.3	13	8.3
		12-19-94	10	10	0	13	30
		01-23-95	12	8.7	-28	13	8.3
		07-18-95	13	13	0	13	0
		09-05-95	12	13	8.3	13	8.3
401655100583203	Beverly Shallow	09-23-93	12	11	-8.3	13	8.3
		01-12-94	8.3	8.3	0	8.3	0
		10-25-94	12	12	0	13	8.3
		12-19-94	8.7	8.9	2.3	10	15
		01-23-95	8.5	12	41	9.1	7.1
		07-18-95	7.7	7.8	1.3	7.8	1.3
		09-05-95	12	12	0	13	8.3
401412100364201	McCook North Deep	08-11-93	3.4	3.5	2.9	ND	--
		03-21-94	3.2	3.3	3.1	3.6	12
		09-19-94	3.6	3.6	0	3.6	0
		03-29-95	3.5	3.4	-2.9	3.6	2.9

Table 8. Quality assurance and quality control results of analysis for nitrate concentrations in water samples from the monitor wells in the study area, southwest Nebraska, 1993–95--Continued

USGS station identification number	Name	Date	Olsen's Agricultural Laboratory (original)	Olsen's Agricultural Laboratory replicate	Difference between original and Olsen's replicate (%)	NWQL replicate	Difference between Olsen's original and NWQL replicate (%)
401412100364202	McCook North	03-21-94	8.8	8.1	-8.0	8.5	-3.4
	Medium-depth	09-19-94	10	11	10	10	0
		03-29-95	10	9.8	-2.0	10	0
401412100364203	McCook North Shallow	08-11-93	22	22	0	ND	--
		03-21-94	22	22	0	22	0
		09-19-94	24	24	0	22	-8.3
		03-29-95	24	24	0	24	0
		06-20-95	30	30	0	28	-6.7
401016100391801	McCook South Deep	10-20-93	21	21	0	20	-4.8
		02-16-94	27	ND	--	27	0
		06-20-94	23	19	-17	22	-4.3
		11-21-94	23	23	0	23	0
		02-22-95	27	27	0	27	0
		05-22-95	24	24	0	ND	--
401016100391802	McCook South	10-20-93	18	18	0	19	5.6
	Medium-depth	02-16-94	20	ND	--	20	0
		06-20-94	20	20	0	20	0
		11-21-94	19	19	0	20	5.3
		02-22-95	19	19	0	20	5.3
		05-22-95	17	17	0	20	18
401016100391803	McCook South Shallow	10-20-93	12	12	0	12	0
		02-16-94	10	ND	--	9.6	-4
		06-20-94	10	10	0	10	0
		11-21-94	8.7	8.8	1.1	9.2	5.7
		02-22-95	10	10	0	11	10
		05-22-95	7.8	7.7	-1.3	9.2	18
400357100135201	Shippee Deep	11-22-93	<.10	.18	--	.05	--
		04-14-94	.15	ND	--	<.05	--
		07-19-94	.01	.01	0	.20	1,900
		04-25-95	<.01	.04	--	.06	--

Table 8. Quality assurance and quality control results of analysis for nitrate concentrations in water samples from the monitor wells in the study area, southwest Nebraska, 1993–95--Continued

USGS station identification number	Name	Date	Olsen's Agricultural Laboratory (original)	Olsen's Agricultural Laboratory replicate	Difference between original and Olsen's replicate (%)	NWQL replicate	Difference between Olsen's original and NWQL replicate (%)
400357100135202	Shippee Shallow	11-22-93	2.0	2.3	15	2.0	0
		04-14-94	1.6	1.4	-12	1.4	-12
		08-16-94	15	15	0	16	6.7
		04-25-95	8.7	8.9	2.3	10	15
400818101124001	Stratton Deep	05-23-94	16	15	-6.2	14	-12
		07-18-94	14	14	0	14	0
400818101124002	Stratton Shallow	05-23-94	19	19	0	18	-5.3
		07-18-94	19	19	0	19	0
Median difference for all samples					0		0

Table 9. Concentrations of nitrate in blind reference samples

[All data expressed in milligrams per liter, except where noted; %, percent; USGS, U.S. Geological Survey; NWQL, National Water Quality Laboratory]

Date	Blind Reference	Olsen's Agricultural Laboratory	Variation (%)	USGS NWQL	Variation (%)
6-20-95	6.36	5.80	8.8	6.40	0.6
		5.71	10.2	6.40	.6
8-15-95	6.36	6.30	.9	6.20	2.5
		6.20	2.5	6.20	2.5

Table 10. Summary statistics for all surface-water, monitor well, and irrigation well field measurements in the study area, southwest Nebraska, 1993-95

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius]

Water type	Property	Number of samples	Minimum	Percentile 25th	50th (Median)	75th	Maximum
Surface water	Specific conductance, µS/cm	12	383	396	580	707	927
	pH, standard units	12	7.8	8.1	8.1	8.2	8.6
	Temperature, °C	12	18.0	25.0	28.5	30.0	32.0
Ground water	Specific conductance, µS/cm	482	110	653	1,030	1,270	2,230
	pH, standard units	482	6.4	7.2	7.4	7.5	9.0
	Temperature, °C	480	12.0	13.5	14.0	15.0	20.0

Specific conductance is the measure of the electrical conductivity of water and is determined by the species and concentrations of dissolved solids found in the water. During this study, specific conductance values in the surface water ranged from 383 to 927 µS/cm (microsiemens per centimeter) at 25 °C, with a median value of 580 µS/cm (table 10). The range of specific conductance values in the ground water was much larger, 110 to 2,230 µS/cm, with a median value (1,030 µS/cm) almost twice the surface-water value (table 10). Specific conductance values generally were largest in the shallow and medium-depth monitor wells (both with a median of 1,160 µS/cm) and smaller in the deep monitor wells (median of 974 µS/cm) (fig. 16).

The specific conductance of water collected from the deep and medium-depth monitor wells was significantly smaller than in water collected from the shallow monitor wells (fig. 16) based on the Mann-Whitney test. The p-value from comparison of specific conductance of water collected from the deep and shallow monitor wells was 0.000; from comparison of water from the medium-depth and shallow monitor wells, the p-value was 0.005. However, a significant difference in specific conductance was not indicated between water from the deep and medium-depth wells (p-value = 0.22). For irrigation wells, the Mann-Whitney test showed a significant difference in specific conductance between wells deeper or shallower than 75 ft (p-value = 0.000).

Some of the differences in specific conductance values between water collected from the deep and shallow monitor wells and from the medium-depth and shallow monitor wells can be attributed to the amount of leaching of minerals by water used for irrigation. Irrigation water applied to fields can dissolve minerals as it percolates downward through the unsaturated zone, thus increasing the specific conductance of the shallow aquifer system. In addition, feldspathic minerals, such as those found in this area (Waite and others, 1944), are generally more soluble than quartz. Quartz appears to be the dominant mineral in the lower part of the aquifer in this area. Quartz is not highly soluble in water and ground water from this part of the aquifer tends to have smaller specific conductance values than the upper part of the aquifer.

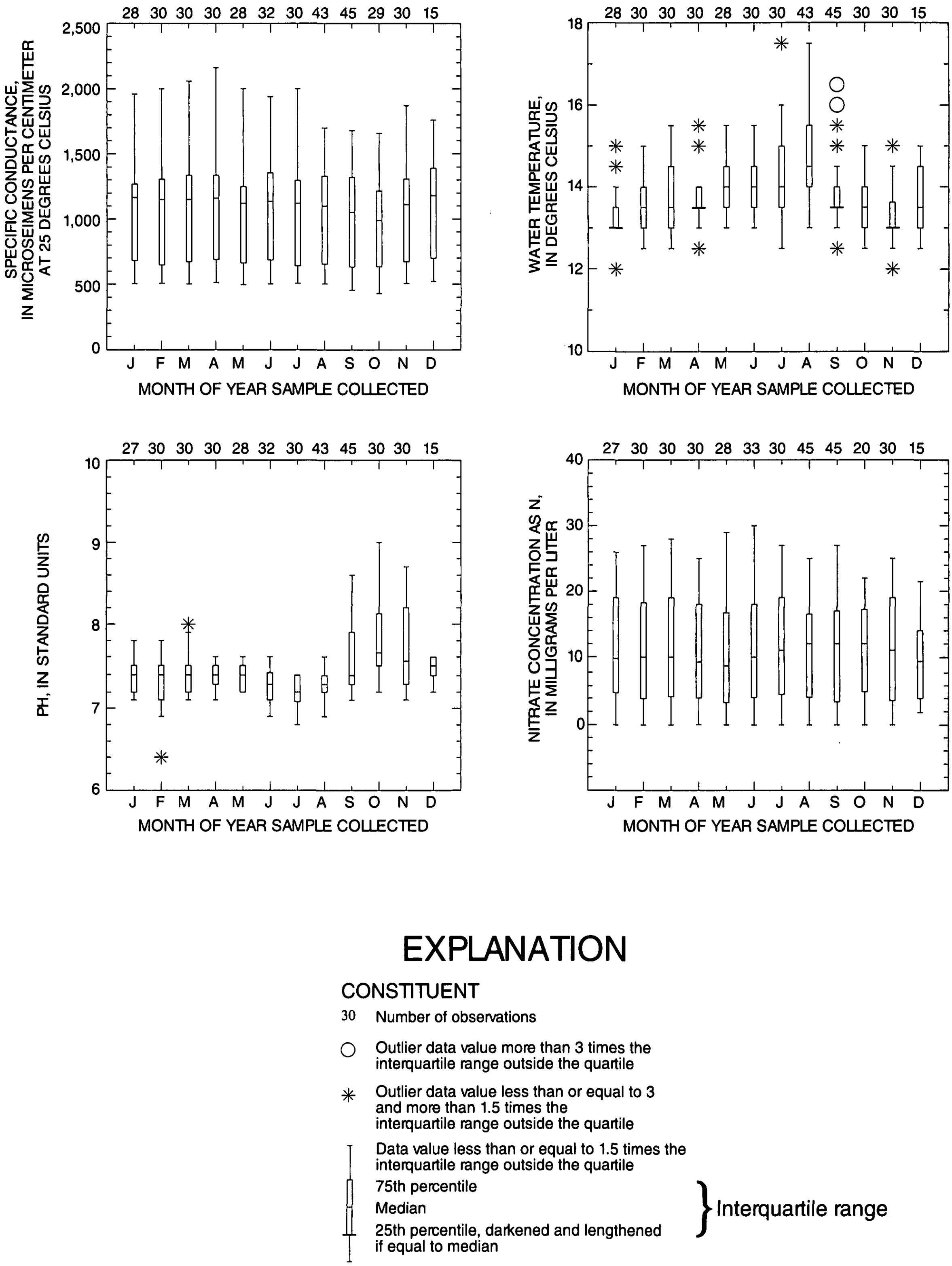


Figure 15. Field measurements and nitrate concentrations by month in water samples from monitor wells in the study area, southwest Nebraska, 1993-95.

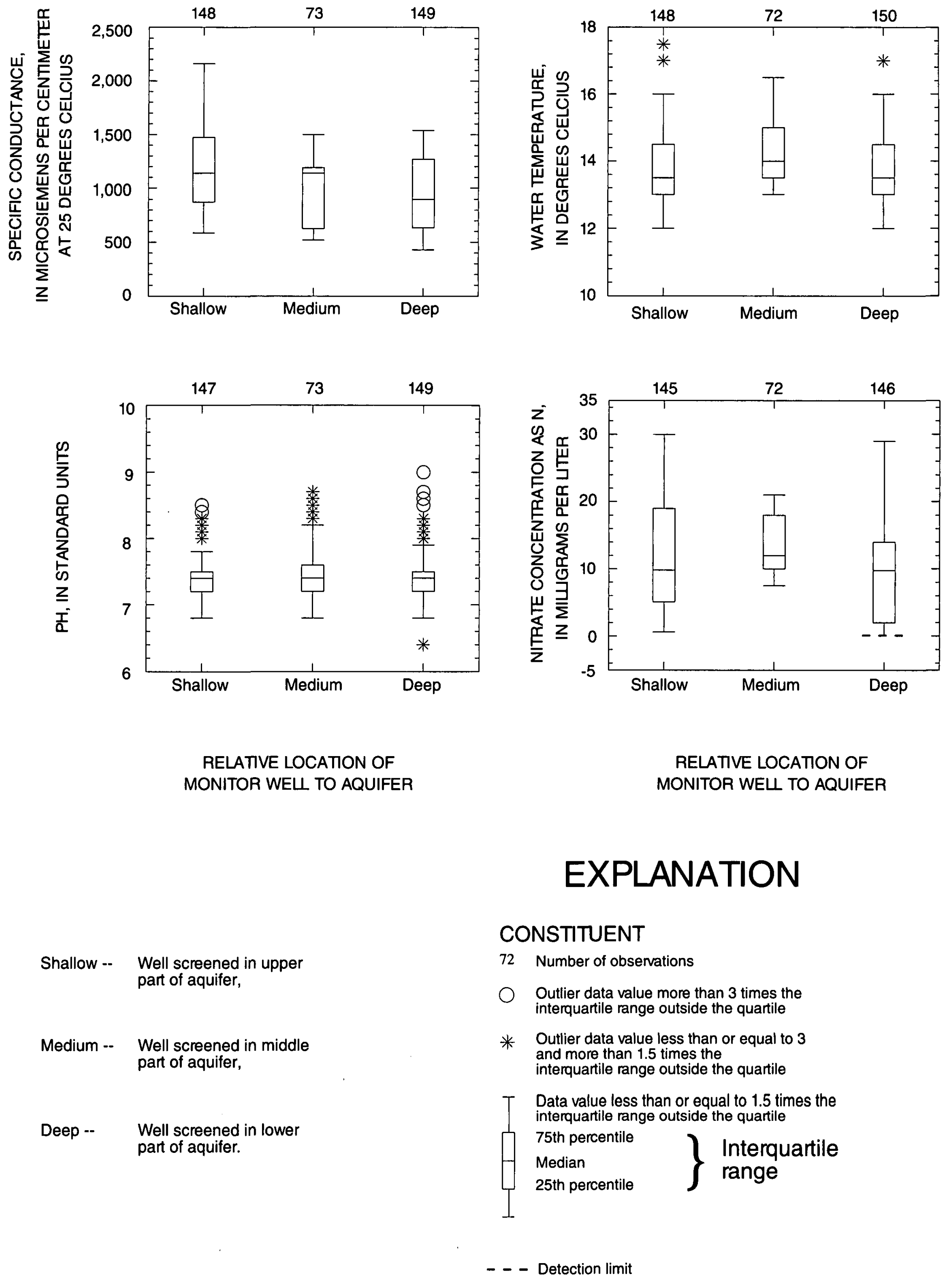


Figure 16. Field measurements and nitrate concentrations by depth of monitor well in the study area, southwest Nebraska, 1993-95.

pH is a measurement of the hydrogen-ion concentration or activity. The pH represents the negative base-10 logarithm of the hydrogen activity in moles per liter (Hem, 1985). For this study, pH ranged from 7.8 to 8.6 standard units, with a median of 8.1 standard units in surface-water samples. Analysis of ground-water samples in monitor and irrigation wells indicated the pH ranged from 6.4 to 9.0 standard units, with a median of 7.4 standard units (table 10).

Water temperature values of surface-water samples varied from 18 to 32 °C, with a median of 28.5 °C. Temperatures of water samples from wells varied from 12 to 20 °C, with a median of 14 °C.

Major Ions, Dissolved Solids, and Selected Trace Elements

Surface-water samples collected in July 1994 and August 1995 consisted of predominantly a calcium magnesium bicarbonate type (fig. 17). Ground-water samples collected in April and October 1994, and March 1995 varied between a calcium magnesium bicarbonate type and a calcium magnesium sulfate bicarbonate type.

In the surface-water systems of the study area, the predominant chemical species was sulfate with a median concentration of 57 mg/L (table 11). Sulfate was followed by, in decreasing order of median concentration: calcium, silica, sodium, magnesium, potassium, chloride, fluoride, manganese, and iron.

Concentrations in the surface water of the study area varied slightly during the two sampling periods. In August 1995 concentrations of alkalinity, calcium, magnesium, sodium, and sulfate (excluding Colbertson Extension Canal) species in the surface-water samples at all three sites were larger than in July 1994 (table 12).

Concentrations of dissolved solids in surface water were largest at the two natural sites, Republican River at McCook and Frenchman Creek near Culbertson, and smallest at the Culbertson Extension Canal north of McCook (table 12). The mean concentrations of dissolved solids at the Republican River at McCook (403 mg/L) and Frenchman Creek near Culbertson

Table 11. Summary statistics for concentrations of dissolved solids, alkalinity, major ions, and selected trace elements in water from monitor wells and surface water of the study area, southwest Nebraska, 1994-95

[$CaCO_3$, calcium carbonate; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than]

Constituent	Surface water: Number of samples	Surface water: Minimum	Surface water: Median	Surface water: Maximum	Ground water: Number of samples	Ground water: Minimum	Ground water: Median	Ground water: Maximum
Dissolved solids, mg/L	6	231	336	497	45	318	676	1,520
Alkalinity, mg/L of $CaCO_3$	6	160	200	300	45	180	310	450
Calcium, mg/L	6	37	47	78	45	55	120	230
Magnesium, mg/L	6	11	17	25	45	16	28	72
Sodium, mg/L	6	14	31	55	45	19	57	140
Potassium, mg/L	6	13	16	19	45	9.0	20	29
Sulfate, mg/L	6	22	57	100	45	18	150	670
Chloride, mg/L	6	4.1	9.0	20	45	7.2	30	73
Fluoride, mg/L	6	.8	1.0	1.2	45	.4	.6	1.4
Silica, mg/L	6	18	33	55	45	27	55	64
Iron, µg/L	6	<3.0	2.8	40	45	<3.0	23	790
Manganese, µg/L	6	<1.0	3.0	23	45	<1.0	69	550

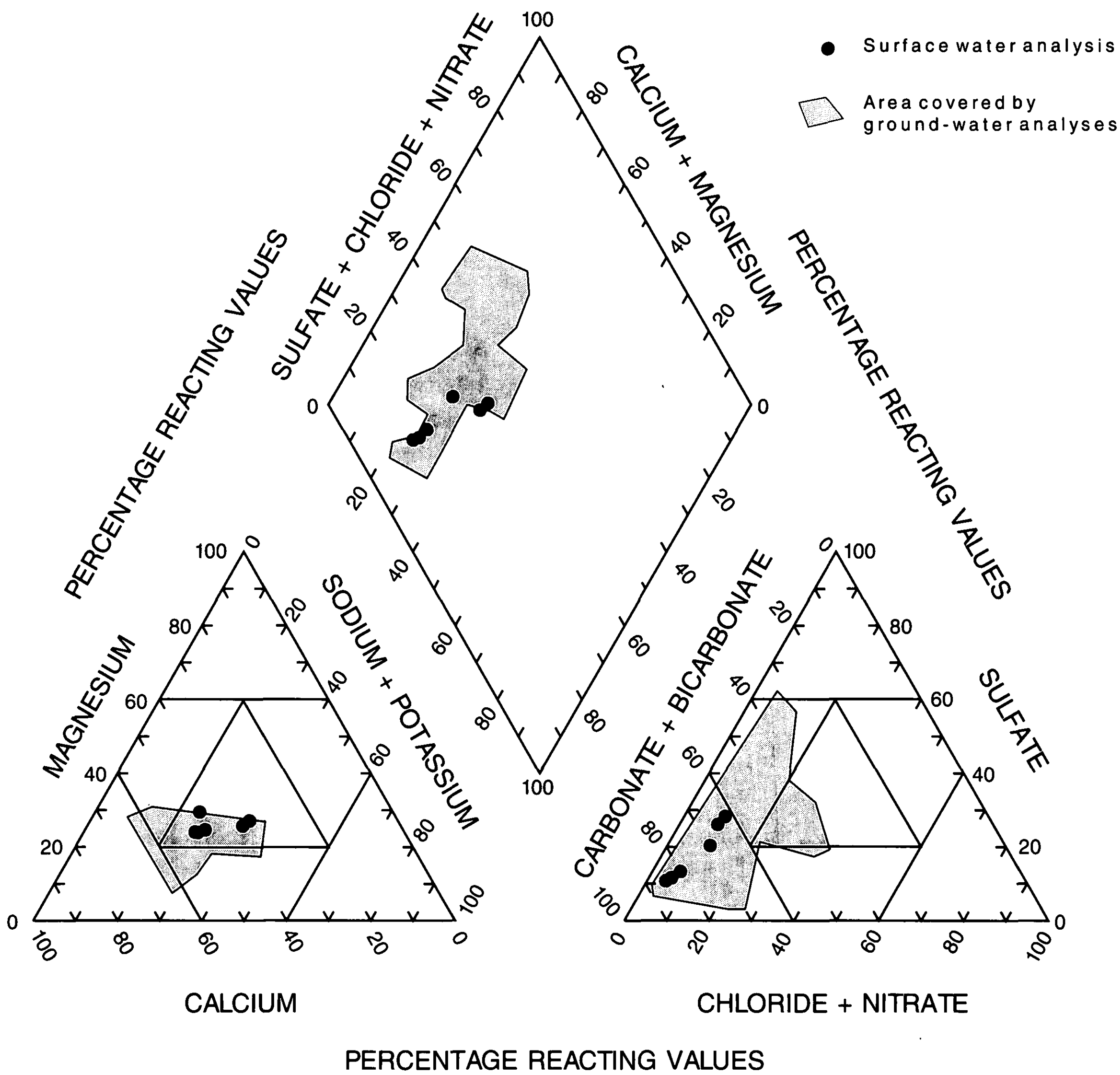


Figure 17. Chemical composition of surface water and ground water in the study area, southwest Nebraska, 1994-95.

Table 12. Results of water-quality analysis for dissolved solids, alkalinity, major ions, and selected ions in surface-water and monitor-well samples of the study area, southwest Nebraska, 1994–95

[USGS, U.S. Geological Survey; in milligrams per liter, unless otherwise noted; µg/L, micrograms per liter; <, less than; NA, not applicable]

USGS station identification number	Local identifier	Name	Date	Time	Dissolved solids	Alkalinity	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride	Fluoride	Silica	Iron (µg/L)	Manganese (µg/L)
					Surface-Water Sites											
06835500	NA	Frenchman Creek at Culbertson	07-18-94	14:25	295	198	47	14	19	18	32	5.9	0.8	40	4	3
			08-14-95	13:20	497	300	78	25	44	17	85	12	1.1	55	<3	23
06835040	NA	Culbertson Extension Canal at County Road, 3 miles north of McCook	07-18-94	15:40	231	162	37	11	14	14	22	4.6	.8	30	43	3
			08-14-95	15:15	252	177	38	15	16	13	22	4.1	.9	36	<3	<1
06837000	NA	Republican River at McCook	07-18-94	16:40	378	213	48	20	43	19	82	17	1.0	20	7	3
			08-14-95	16:15	429	230	52	24	55	15	100	20	1.2	18	<3	5
					Monitor-Well (Ground-Water) Sites											
401454100215401	3N 27W 9AAAA1	Bartley Deep	04-14-94	14:00	426	246	73	17	32	18	64	19	.6	55	<3	<1
			10-25-94	09:20	415	256	69	17	32	19	51	17	.6	56	<3	<1
			03-30-95	09:35	373	210	73	20	19	12	41	20	.7	61	<3	<1
401454100215402	3N 27W 9AAAA2	Bartley Shallow	04-14-94	14:15	406	246	72	16	32	18	50	16	.6	54	6	<1
			10-25-94	09:35	401	259	68	16	33	20	38	15	.6	55	<3	<1
			03-30-95	09:55	1,300	386	200	60	120	24	540	57	.7	63	11	36
401655100583201	4N 32W30DCBB1	Beverly Deep	04-13-94	09:45	839	311	130	40	76	18	300	25	.7	63	<3	<1
			10-25-94	15:10	913	327	130	42	85	19	300	27	.6	64	<3	<1
			03-29-95	09:05	813	371	160	33	62	24	250	32	.6	28	85	89

Table 12. Results of water-quality analysis for dissolved solids, alkalinity, major ions, and selected ions in surface-water and monitor-well samples of the study area, southwest Nebraska, 1994–95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Dissolved solids	Alkalinity	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride	Fluoride	Silica	Iron (µg/L)	Manganese (µg/L)
Monitor-Well (Ground-Water) Sites--Continued																
401655100583202	4N 32W30DCBB2	Beverly Medium-depth	04-13-94	10:10	773	274	120	35	78	20	270	24	0.8	61	<3	<1
			10-25-94	15:45	993	345	140	43	96	20	340	30	.7	63	<3	<1
			03-29-95	09:25	403	253	67	16	31	20	46	15	.6	56	<3	<1
401655100583203	4N 32W30DCBB3	Beverly Shallow	04-13-94	10:30	1,520	424	230	72	140	23	670	73	.7	61	<3	2
			10-25-94	16:00	668	286	110	30	57	19	140	40	.6	46	<3	1
			03-29-95	10:00	472	185	100	28	19	13	90	50	.6	60	<3	<1
401016100391801	2N 30W 1ACDD1	McCook South Deep	04-14-94	09:15	676	260	130	33	56	20	180	56	.6	44	<3	<1
			10-24-94	16:00	1,120	306	170	54	110	24	470	45	.7	62	<3	1
			03-29-95	15:50	912	454	130	42	130	28	220	45	1.3	43	<3	210
401016100391802	2N 30W 1ACDD2	McCook South Medium-depth	04-14-94	09:45	685	333	140	25	61	25	160	38	.5	35	<3	28
			10-24-94	16:20	661	339	130	25	61	22	150	32	.5	37	<3	34
			03-29-95	16:10	960	337	150	44	97	22	350	30	.7	64	<3	<1
401016100391803	2N 30W 1ACDD3	McCook South Shallow	04-14-94	10:00	709	388	140	20	72	16	150	39	.4	39	<3	<1
			10-24-94	16:35	716	426	140	21	78	89	140	32	.4	40	<3	2
			03-29-95	16:25	671	258	130	33	57	21	170	59	.6	45	<3	<1
401412100364201	3N 29W 8DDBA1	McCook North Deep	04-13-94	14:40	325	229	56	16	21	11	19	7.3	.7	57	<3	<1
			10-24-94	14:20	318	218	55	17	20	10	18	7.4	.7	59	8	1
			03-29-95	14:10	834	321	130	40	82	20	280	25	.6	64	<3	<1
401412100364202	3N 29W 8DDBA2	McCook North Medium-depth	04-13-94	15:00	355	216	67	18	20	11	35	17	.7	57	<3	<1
			10-24-94	14:45	371	213	69	20	20	12	41	21	.7	59	<3	<1
			03-29-95	14:30	678	327	140	25	61	23	150	44	.5	38	<3	15

Table 12. Results of water-quality analysis for dissolved solids, alkalinity, major ions, and selected ions in surface-water and monitor-well samples of the study area, southwest Nebraska, 1994–95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Dissolved solids	Alkalinity	Calcium	Magnesium	Sodium	Potassium	Sulfate	Chloride	Fluoride	Silica	Iron (µg/L)	Manganese (µg/L)
Monitor-Well (Ground-Water) Sites--Continued																
401412100364203	3N 29W 8DDBA3	McCook North Shallow	04-13-94	15:15	462	183	100	27	19	12	89	46	0.7	58	<3	<1
			10-24-94	15:05	465	176	100	28	19	12	92	47	.6	60	<3	<1
			03-29-95	14:50	462	335	87	20	40	12	39	16	.6	46	13	130
400357100135201	1N 26W11CBBB1	Shippee Deep	04-14-94	11:30	447	330	84	19	39	12	36	15	.7	43	5	190
			10-25-94	10:30	437	296	82	20	41	12	43	17	.6	44	6	130
			03-30-95	10:55	409	269	68	16	36	21	37	14	.6	55	<3	<1
400357100135202	1N 26W11CBBB2	Shippee Shallow	04-14-94	12:00	717	385	140	29	53	23	180	26	.6	27	790	160
			10-25-94	10:50	683	316	130	29	57	24	200	26	.6	27	68	87
			03-30-95	11:25	830	426	120	39	110	26	190	47	1.2	41	<3	550
400818101124001	2N 35W13AAAD1	Stratton Deep	04-13-94	11:45	818	413	120	37	110	22	190	50	1.2	39	<3	530
			10-25-94	13:55	877	420	110	40	110	23	190	47	1.1	41	<3	530
			03-29-95	11:10	328	228	56	17	20	10	20	7.2	.7	60	<3	<1
400818101124002	2N 35W13AAAD2	Stratton Shallow	04-13-94	12:10	868	448	110	39	130	25	210	44	1.4	40	<3	160
			10-25-94	14:10	930	358	120	43	130	29	220	45	1.3	42	<3	200
			03-29-95	11:30	327	228	56	17	20	11	19	7.2	.7	59	<3	<1

(396 mg/L) were nearly double that at the Culbertson Extension Canal north of McCook (241 mg/L) (where the mean concentration was used instead of median because two samples were collected per site). Alkalinity values show a similar relation. This, along with the ground-water data discussed next, suggests that, at least during July and August, much of the water in the Republican River and Frenchman Creek was likely derived from baseflow and was quite different from the water in the Culbertson Extension Canal.

Dominant chemical species, alkalinity, sulfate, and calcium in ground-water samples are the same as those in the surface water (fig. 17 and tables 11 and 12). Link (1991) also reported large concentrations of calcium bicarbonate and sulfate in ground-water samples from domestic and irrigation wells. The soil in the study area commonly contains substantial amounts of calcium carbonate (table 7) and likely is one of the sources of the large concentrations of alkalinity. The large concentrations of sulfate probably originate from the oxidation of pyrite in areas where the ground water is near Cretaceous-age bedrock. Bradley and Johnson (1957) report common thin layers of iron pyrite in many horizons of the Pierre Shale.

Ground-water chemistry can change significantly as water flowing through the aquifer or percolating down through the soil horizons of the unsaturated zone dissolves soluble minerals. If ground-water flow paths are long enough and enough soluble material exists in the saturated deposits, concentrations of dissolved solids can increase with age of the water. In addition, dissolved-solids concentrations tend to increase in the ground water if irrigation water leaches minerals from the surface soil and into the ground-water system. If this occurs, the shallower part of the aquifer would tend to have higher concentrations of dissolved solids than the deeper part of the aquifer. The latter explanation seems to be the case for this study area, because concentrations of dissolved solids in the deeper monitor wells are smaller than in the shallow or medium-depth monitor wells (table 13).

Dissolved-solids concentrations in water samples collected from the monitor wells ranged from

Table 13. Summary statistics for concentrations of dissolved solids, alkalinity, major ions, and selected trace elements, by monitor-well depth, in the ground water of the study area, southwest Nebraska, 1994-95

[in milligrams per liter unless otherwise noted; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; <, less than]

Constituent	Shallow well			Medium-depth well			Deep well		
	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
Dissolved solids	327	677	1,520	355	678	993	318	562	1,120
Alkalinity, $CaCO_3$	176	326	448	213	327	345	210	301	454
Calcium	56	115	230	67	130	150	55	97	170
Magnesium	16	28.5	72	16	25	44	16	26.5	54
Sodium	19	57	140	20	61	97	19	48.5	130
Potassium	8.9	19.5	29	11	20	25	10	19	28
Sulfate	19	145	670	35	150	350	18	122	470
Chloride	7.2	42	73	15	30	44	7.2	22.5	56
Fluoride	.4	.6	1.4	.5	.7	.8	.6	.7	1.0
Silica	27	46	63	35	57	64	28	55.5	64
Iron, µg/L	<3.0	<3.0	790	<3.0	<3.0	<3.0	<3.0	<3.0	85
Manganese, µg/L	<1.0	1.5	550	<1.0	<1.0	34	<1.0	<1.0	530

318 mg/L at the McCook North Deep well to 1,520 mg/L at the Beverly Shallow well (table 12). The McCook South Deep well had the largest median concentration of dissolved solids per monitor well, 912 mg/L. Median concentrations of dissolved solids in the ground water of the Republican River valley gradually decreased from west to east.

Large dissolved-solids concentrations at the Beverly, McCook South, and Stratton sites could be the result of infiltration of water applied for irrigation and the dissolving of minerals as the water percolates down through the unsaturated zone. This process is likely the same reason larger specific conductance values were reported in water from some of the shallow wells as opposed to the deeper wells (Field Measurements section).

Herbicides

To determine concentrations of ten triazine herbicides and two atrazine metabolites in the study area, water samples were collected from all monitor wells in September 1995. Water samples for herbicide analysis were collected concurrently with the final monthly sampling for nitrate analysis. Samples were analyzed for the following herbicides: alachlor, ametryn, atrazine, cyanazine, metolachlor, metribuzin, prometryn, prometon, propazine, simazine, and the two atrazine metabolites, deisopropylatrazine and deethylatrazine.

Herbicides, often used to cultivate corn, soybeans, and sorghum, are used to control weeds and grasses. Agriculture accounts for more than 80 percent of the total herbicide usage in the United States (U.S. Department of Agriculture, 1992). In the upper midwestern United States, which includes Nebraska, atrazine, a triazine herbicide widely used to control broadleaf and grassy weeds, was the most frequently detected and most persistent of the major herbicides (Goolsby and others, 1991).

Burkart and Kolpin (1993) reported seasonal variations, preplanting as opposed to postplanting, of herbicide detections in near-surface aquifers of the midcontinental United States. These aquifers, which included the Republican River valley, reportedly had a 7.3-percent increase in detections of all herbicides from samples collected after planting (postplanting), compared to preplanting detections (Mann-Whitney p-value = 0.04). With respect to atrazine, Burkart and Kolpin (1993) reported about a 6-percent increase in detections from postplanting as compared to preplanting detections. However, because ground-water flow path data were not available it could not determined if the seasonal frequency in herbicide detections was caused by herbicides that were applied between the pre- and postplanting sampling.

Atrazine and its metabolite, deethylatrazine, were the only two targeted compounds detected in water samples. Atrazine was detected in 40 percent (6 of 15) of the samples, but all concentrations were less than the MCL of 3.0 μg/L (U.S. Environmental Protection Agency, 1996) (table 14). Atrazine was detected in water samples at sites where the water is shallow (Bartley and Stratton) in the Republican River valley, and where the water is deep (McCook North) in the uplands areas.

Deethylatrazine was detected in 53 percent (8 of 15) of the samples (table 14). Deethylatrazine also can be a by-product of propazine. However, deethylatrazine is thought to represent degradation of atrazine in this study, because in most samples in which atrazine was detected, deethylatrazine also was detected, but propazine was not.

Atrazine was detected in water samples from both monitor wells at Bartley and Stratton, from the McCook North Medium-depth well, and from the Shippee Deep well. Deethylatrazine was detected in water samples collected from both monitor wells at the Bartley, Shippee, and Stratton sites, and from the medium-depth and shallow wells at McCook South.

Atrazine data indicate that the minimum and the 25^{th} and 50^{th} percentiles all were less than 0.05 μg/L (the reporting limit), but the 75^{th} percentile was 0.15 μg/L and the maximum concentration was 0.45 μg/L. For deethylatrazine, the minimum concentration and the 25^{th} percentile were less than the reporting limit of 0.05 μg/L, whereas the 50^{th} percentile was 0.05 μg/L, the 75^{th} percentile was 0.07 μg/L, and the maximum concentration was 0.18 μg/L. Deethylatrazine-to-atrazine ratio (DAR) was computed for the five samples that contained a measurable amount of atrazine and deethylatrazine (table 14). DAR is the dimensionless ratio of deethylatrazine concentration to atrazine concentration and provides a possible indicator of point-source as opposed to nonpoint-source contamination by atrazine (Adams and Thurman, 1991). DAR values greater than 0.7 indicate the possibility that atrazine is being transported slowly into the ground-water system and that deethylation of the atrazine by soil microorganisms has occurred (consistent with nonpoint-source contamination). DAR values

Table 14. Concentrations of atrazine and deethylatrazine in water from monitor wells of the study area, southwest Nebraska, September 1995

[Units are in micrograms per liter; DAR, deethylatrazine-to-atrazine ratio; <, less than; --, no ratio]

Local identifier	Name	Atrazine	Deethylatrazine	DAR value
3N 27W 9AAAA1	Bartley Deep	0.15	0.07	0.46
3N 27W 9AAAA2	Bartley Shallow	.15	.05	.33
4N 32W30DCBB1	Beverly Deep	<.05	<.05	--
4N 32W30DCBB2	Beverly Medium-depth	<.05	<.05	--
4N 32W30DCBB3	Beverly Shallow	<.05	<.05	--
3N 29W 8DDBA1	McCook North Deep	<.05	<.05	--
3N 29W 8DDBA2	McCook North Medium-depth	.08	<.05	--
3N 29W 8DDBA3	McCook North Shallow	<.05	<.05	--
2N 30W 1ACDD1	McCook South Deep	<.05	<.05	--
2N 30W 1ACDD2	McCook South Medium-depth	<.05	.08	--
2N 30W 1ACDD3	McCook South Shallow	<.05	.07	--
1N 26W11CBBB1	Shippee Deep	.16	.05	.31
1N 26W11CBBB2	Shippee Shallow	<.05	.05	--
2N 35W13AAAD1	Stratton Deep	.34	.11	.32
2N 35W13AAAD2	Stratton Shallow	.45	.18	.40

of 0.2 to 0.3 may indicate rapid entry into the ground-water system (point-source contamination) without deethylation of the atrazine compound (E. Michael Thurman, U.S. Geological Survey, oral commun., 1996). DAR values between 0.3 and 0.7 generally cannot be interpreted to indicate nonpoint-source or point-source contamination definitely.

DAR values indicate that atrazine occurrence in the study area can not be clearly associated with either nonpoint-source or point-source contamination. All DAR values were greater than 0.3 and less than 0.7. Although no clear interpretation of the data can be made, three of the five DAR values were within 10 percent of 0.3.

CONTRIBUTION OF SURFACE WATER TO NITRATE CONCENTRATIONS IN GROUND WATER

This study focused on the nitrate concentrations in the ground water and was not designed to describe the interaction of the surface water and ground water of the SPA quantitatively. However, to help understand the processes influencing the quality of the ground water, it is useful to consider the quality of the surface-water system and how these two systems interact.

Statistical evaluation of the surface-water and ground-water data collected during this study suggests that median nitrate concentrations in the surface water are significantly smaller than those in the ground water (Mann-Whitney rank-sum p-value = 0.000). As discussed in earlier sections, the smaller nitrate concentrations in the surface water generally dilute nitrate concentrations in the ground water when the two waters interact. These effects are illustrated by seasonal fluctuations in nitrate concentrations in water from monitor wells (fig. 8). Nitrate concentrations in the nearby ground-water system increased seasonally when influx of surface water used for irrigation and leakage from irrigation canals was minimal, and decreased in response to an increased influx of those sources (fig. 8). Likewise, evidence of changes in the water quality, such as nitrate concentrations in Frenchman Creek, occurred seasonally.

The potential contribution of irrigation-canal and other surface water to nitrate concentrations in the ground water was not definitive. In areas containing canals and where depths to ground water are shallow (less than 30 ft), the leakage from the canals or influx of water from surface-water irrigation diluted nitrate concentrations in the ground water. In areas where most of the water used for irrigation was diverted from streams, a decrease in surface-water flow because of diversions preceded an increase in nitrate concentrations in water samples from nearby wells. Likewise, an increase in surface-water flow, following the end of diversions, preceded a decrease of nitrate concentrations in water from the shallow monitor well. In areas where depths to ground water exceed 100 ft, nitrate concentrations seem to be less affected by the influx of infiltrating surface water. However, in these areas (depths greater than 100 ft) sufficient data does not exist to draw any conclusions about surface-water and ground-water quality interaction.

The relative chemistry of the surface water was similar to that of the ground water in the study area. However, not enough chemical data are available to quantify fully the interaction between the surface-water and ground-water systems. During times when the ground water discharges to the surface-water system, the dissolved solids and nitrate concentrations of the surface water will increase. Likewise, when the surface-water system loses water to the aquifer, dissolved solids and nitrate concentrations in the ground water tend to be diluted.

SUMMARY AND CONCLUSIONS

Local officials have become concerned about elevated concentrations of nitrate in the ground water of Red Willow and Hitchcock Counties, Nebraska. In 1991, the NDEQ evaluated and recommended the formation of an SPA in two areas in Red Willow and Hitchcock Counties in southwest Nebraska. In 1992, the USGS entered into a 4-year cooperative study with the MRNRD to design and operate a ground-water quality monitoring network in the SPA. The objectives of the study were to (1) monitor spatial, temporal, and vertical variations of nitrate concentrations, (2) determine nitrogen content of the unsaturated zone at selected sites, (3) determine the potential contribution of surface water (including irrigation-canal water and irrigation runoff) to nitrate concentrations in the ground water, and (4) document the general chemistry of the surface water and ground water and concentrations of herbicides in the ground water.

To meet the objectives of the study, 15 monitor wells were installed at 6 sites to monitor the spatial and temporal variations of the concentrations of nitrate as N in the ground water of the SPA. Water samples from the monitor wells were collected monthly to determine nitrate concentrations and three times for major-ion analysis. Samples for herbicide analysis were collected once in September 1995.

In July 1994 and August 1995, samples for nitrate analysis were collected from 61 irrigation wells and 6 surface-water sites. Samples for major-ion analysis also were collected at three of the six surface-water sites.

Most nitrate concentrations in surface-water samples were less than or equal to 1.6 mg/L as N. Nitrate concentrations in ground-water samples varied from less than the reporting limit of the analytical method (0.01 mg/L) to 30 mg/L. The median nitrate concentration in water from the monitor wells was 10 mg/L.

Ground-water samples from the Republican River valley contained the two largest median nitrate concentrations—McCook South (17 mg/L) and Stratton (17 mg/L). McCook North (12 mg/L) and Beverly (11 mg/L) were the other two sites with large median nitrate concentrations in ground-water samples. These sites are in areas where the predominant crops are row crops, surface water and ground water are used extensively for irrigation, depths to water are shallow (except at McCook North), the soil is well drained, and commercial fertilizers are used in the cultivation of row crops. The other two monitor-well sites had median nitrate concentrations below the USEPA MCL.

Vertical variations of median nitrate concentrations in samples from monitor wells indicated that the largest concentration was in the medium-depth monitor wells (12 mg/L), intermediate in the shallow monitor wells (11 mg/L), and the smallest in the deep monitor wells (10 mg/L). However, the Beverly and McCook South monitor-well sites had larger nitrate concentrations in the deepest monitor well, during part of the year, than in the medium-depth or shallow monitor wells.

Nitrate concentrations in water samples from monitor wells were smallest in the spring months and largest from May to August. Reasons for the larger nitrate concentrations include: (1) detection generally followed application of commercial fertilizers, and (2) irrigation generally was sufficiently active to cause nitrates to leach through the unsaturated zone and into the aquifer.

In 1994, nitrate concentrations in water samples from 59 irrigation wells ranged from 0.01 to 22 mg/L, with a median value of 8.4 mg/L. In 1995, nitrate concentrations in water samples from 54 irrigation wells (including 2 alternates not sampled in 1994, thus totaling 61 wells for both years) ranged from 0.40 to 20 mg/L, with a median value of 6.8 mg/L.

The average core-interval nitrogen content in soil samples ranged from 122 to 570 lb/acre. Stratton contained the largest average core-interval total nitrogen content, 570 lb/acre. The other four sites contained substantially smaller average core-interval total nitrogen concentrations in the soils of the unsaturated zone, ranging from 122 to 220 lb/acre.

Field measurements included specific conductance, pH, and water temperature, and were collected on site. Specific conductance values in the surface water ranged from 383 to 927 µS/cm at 25 °C, with a median value of 580 µS/cm. In the ground water, the range in specific conductance was much larger, 110 to 2,230 µS/cm, and the median value was 1,030 µS/cm. pH in surface-water samples ranged from 7.8 to 8.6 standard units, with a median of 8.1 standard units. pH in water samples from monitor and irrigation wells ranged from 6.4 to 9.0 standard units; with a median of 7.4 standard units. Water temperature for the surface-water sites ranged from 18 to 32 °C, with a median of 28.5 °C, and for ground water from 12 to 20 °C, with a median of 14 °C.

The surface water was predominantly a calcium magnesium bicarbonate type. Sulfate, with median concentration of 57 mg/L, was the predominant chemical species in surface-water samples. The ground water in the study area varied between a calcium magnesium bicarbonate type and a calcium magnesium sulfate bicarbonate type. The predominant species in the ground-water samples was sulfate and calcium.

Tests for 10 herbicide constituents in ground-water samples detected only 2 of the 10 herbicides. Atrazine was detected in 40 percent (6 of 15) of the water samples, with all concentrations less than the MCL of 3.0 mg/L. The atrazine metabolite, deethylatrazine, was detected in 53 percent (8 of 15) of the water samples.

Examination of the data indicated that nitrate concentrations in the surface water were significantly smaller than those in the ground water. The potential contribution from surface water used for irrigation to nitrate concentrations in the ground water was not definitive. Nitrate concentrations in the ground water were larger in areas where there was no influx of surface water than in areas where there was an influx of surface water. The data showed increases in total dissolved solids and nitrate concentrations in Frenchman Creek existed seasonally, but were inconclusive in the other surface-water systems.

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SUPPLEMENTAL DATA

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95

[USGS, U.S. Geological Survey; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; --, no data; <, less than]

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
401454100215401	3N 27W 9AAAA1	Bartley Deep	08-11-93	1230	679	7.4	14.0	1.7
401454100215401	3N 27W 9AAAA1	Bartley Deep	09-24-93	1335	605	7.4	13.0	1.7
401454100215401	3N 27W 9AAAA1	Bartley Deep	10-21-93	1000	630	7.4	13.0	1.8
401454100215401	3N 27W 9AAAA1	Bartley Deep	11-22-93	1740	673	7.6	13.0	2.2
401454100215401	3N 27W 9AAAA1	Bartley Deep	01-12-94	1620	677	7.4	13.5	3.6
401454100215401	3N 27W 9AAAA1	Bartley Deep	02-17-94	0940	603	7.1	13.0	2.0
401454100215401	3N 27W 9AAAA1	Bartley Deep	03-22-94	0940	664	7.6	13.5	1.8
401454100215401	3N 27W 9AAAA1	Bartley Deep	04-14-94	1355	671	7.6	14.0	2.0
401454100215401	3N 27W 9AAAA1	Bartley Deep	05-24-94	0925	666	7.5	13.5	2.0
401454100215401	3N 27W 9AAAA1	Bartley Deep	06-21-94	1000	653	7.1	13.5	2.0
401454100215401	3N 27W 9AAAA1	Bartley Deep	07-19-94	0930	657	7.4	13.5	1.9
401454100215401	3N 27W 9AAAA1	Bartley Deep	08-16-94	0950	648	7.3	13.5	2.0
401454100215401	3N 27W 9AAAA1	Bartley Deep	09-20-94	1005	602	7.5	13.5	2.0
401454100215401	3N 27W 9AAAA1	Bartley Deep	10-25-94	0920	638	8.1	13.0	--
401454100215401	3N 27W 9AAAA1	Bartley Deep	11-22-94	0950	637	7.3	13.0	2.3
401454100215401	3N 27W 9AAAA1	Bartley Deep	12-20-94	1155	640	7.6	14.0	1.9
401454100215401	3N 27W 9AAAA1	Bartley Deep	01-24-95	1055	618	7.7	13.0	1.6
401454100215401	3N 27W 9AAAA1	Bartley Deep	02-23-95	0910	630	7.4	13.0	1.6
401454100215401	3N 27W 9AAAA1	Bartley Deep	03-30-95	0930	640	7.4	13.0	1.7
401454100215401	3N 27W 9AAAA1	Bartley Deep	04-25-95	0925	643	7.4	13.5	1.6
401454100215401	3N 27W 9AAAA1	Bartley Deep	05-31-95	1130	615	7.4	13.5	1.8
401454100215401	3N 27W 9AAAA1	Bartley Deep	06-20-95	1140	618	7.5	14.0	1.9
401454100215401	3N 27W 9AAAA1	Bartley Deep	07-19-95	0940	565	7.4	14.5	2.2
401454100215401	3N 27W 9AAAA1	Bartley Deep	08-16-95	1300	625	7.5	14.5	2.2
401454100215401	3N 27W 9AAAA1	Bartley Deep	09-06-95	0935	613	7.4	13.5	2.1
401454100215402	3N 27W 9AAAA2	Bartley Shallow	08-11-93	1253	653	7.4	14.0	2.2
401454100215402	3N 27W 9AAAA2	Bartley Shallow	09-24-93	1355	587	7.4	13.0	2.8
401454100215402	3N 27W 9AAAA2	Bartley Shallow	10-21-93	1015	613	7.4	13.0	2.7

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
401454100215402	3N 27W 9AAAA2	Bartley Shallow	11-22-93	1755	670	7.5	13.0	3.7
401454100215402	3N 27W 9AAAA2	Bartley Shallow	01-12-94	1640	684	7.2	13.5	4.9
401454100215402	3N 27W 9AAAA2	Bartley Shallow	02-17-94	0950	627	7.0	13.0	6.3
401454100215402	3N 27W 9AAAA2	Bartley Shallow	03-22-94	0950	661	7.5	13.5	4.7
401454100215402	3N 27W 9AAAA2	Bartley Shallow	04-14-94	1410	657	7.6	13.5	4.2
401454100215402	3N 27W 9AAAA2	Bartley Shallow	05-24-94	0940	658	7.5	13.5	4.4
401454100215402	3N 27W 9AAAA2	Bartley Shallow	06-21-94	1015	636	7.1	13.5	4.6
401454100215402	3N 27W 9AAAA2	Bartley Shallow	07-19-94	0945	643	7.4	13.0	4.9
401454100215402	3N 27W 9AAAA2	Bartley Shallow	08-16-94	1025	638	7.3	13.5	4.5
401454100215402	3N 27W 9AAAA2	Bartley Shallow	09-20-94	1015	596	7.4	13.5	3.7
401454100215402	3N 27W 9AAAA2	Bartley Shallow	10-25-94	0935	629	8.2	13.0	--
401454100215402	3N 27W 9AAAA2	Bartley Shallow	11-22-94	1005	632	7.3	12.5	4.6
401454100215402	3N 27W 9AAAA2	Bartley Shallow	12-20-94	1215	701	7.6	14.0	6.7
401454100215402	3N 27W 9AAAA2	Bartley Shallow	01-24-95	1110	654	7.7	13.0	4.5
401454100215402	3N 27W 9AAAA2	Bartley Shallow	02-23-95	0920	653	7.4	13.5	4.1
401454100215402	3N 27W 9AAAA2	Bartley Shallow	03-30-95	0950	675	7.4	13.0	4.5
401454100215402	3N 27W 9AAAA2	Bartley Shallow	04-25-95	0940	694	7.4	13.5	5.3
401454100215402	3N 27W 9AAAA2	Bartley Shallow	05-31-95	1145	661	7.4	14.0	4.5
401454100215402	3N 27W 9AAAA2	Bartley Shallow	06-20-95	1155	676	7.5	14.0	6.0
401454100215402	3N 27W 9AAAA2	Bartley Shallow	07-19-95	1000	611	7.4	16.0	5.6
401454100215402	3N 27W 9AAAA2	Bartley Shallow	08-16-95	1315	655	7.5	16.0	5.2
401454100215402	3N 27W 9AAAA2	Bartley Shallow	09-06-95	0950	626	7.4	13.5	4.3
401655100583201	4N 32W30DCBB1	Beverly Deep	08-10-93	0920	1,280	7.2	14.0	12
401655100583201	4N 32W30DCBB1	Beverly Deep	09-23-93	1230	1,300	7.2	13.5	12
401655100583201	4N 32W30DCBB1	Beverly Deep	10-20-93	0955	1,060	7.3	13.5	12
401655100583201	4N 32W30DCBB1	Beverly Deep	11-22-93	0920	1,270	7.3	13.0	11
401655100583201	4N 32W30DCBB1	Beverly Deep	01-12-94	0935	1,280	7.1	13.0	11
401655100583201	4N 32W30DCBB1	Beverly Deep	02-16-94	0855	1,280	7.1	13.0	11

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
401655100583201	4N 32W30DCBB1	Beverly Deep	03-21-94	0930	1,250	7.3	13.5	11
401655100583201	4N 32W30DCBB1	Beverly Deep	04-13-94	0940	1,270	7.3	13.5	12
401655100583201	4N 32W30DCBB1	Beverly Deep	05-23-94	0935	1,250	7.2	14.0	12
401655100583201	4N 32W30DCBB1	Beverly Deep	06-20-94	0900	1,190	7.2	14.0	10
401655100583201	4N 32W30DCBB1	Beverly Deep	07-18-94	1000	1,210	7.0	13.5	11
401655100583201	4N 32W30DCBB1	Beverly Deep	08-15-94	1030	1,270	7.3	14.0	11
401655100583201	4N 32W30DCBB1	Beverly Deep	09-19-94	1005	1,230	8.3	13.5	12
401655100583201	4N 32W30DCBB1	Beverly Deep	10-25-94	1510	1,290	7.9	13.5	11
401655100583201	4N 32W30DCBB1	Beverly Deep	11-21-94	0940	1,300	8.5	13.0	12
401655100583201	4N 32W30DCBB1	Beverly Deep	12-19-94	1020	1,330	7.3	13.0	9.5
401655100583201	4N 32W30DCBB1	Beverly Deep	01-23-95	1300	1,310	7.4	13.5	11
401655100583201	4N 32W30DCBB1	Beverly Deep	02-22-95	1155	1,290	7.4	14.0	11
401655100583201	4N 32W30DCBB1	Beverly Deep	03-29-95	0900	1,330	7.2	13.0	11
401655100583201	4N 32W30DCBB1	Beverly Deep	04-24-95	0940	1,320	7.2	13.5	10
401655100583201	4N 32W30DCBB1	Beverly Deep	05-30-95	1000	1,270	7.2	13.5	10
401655100583201	4N 32W30DCBB1	Beverly Deep	06-19-95	1415	1,290	7.2	14.0	11
401655100583201	4N 32W30DCBB1	Beverly Deep	07-18-95	0925	1,280	7.3	13.5	11
401655100583201	4N 32W30DCBB1	Beverly Deep	08-16-95	1510	1,260	7.3	14.0	11
401655100583201	4N 32W30DCBB1	Beverly Deep	09-05-95	1220	1,240	7.3	14.0	11
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	08-10-93	1100	1,270	7.2	15.5	12
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	09-23-93	1300	1,350	7.3	13.5	12
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	10-20-93	1010	974	7.3	13.0	12
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	11-22-93	0940	1,140	7.4	13.0	11
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	01-12-94	1000	1,150	7.2	13.5	11
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	02-16-94	0915	1,160	7.2	13.0	11
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	03-21-94	0950	1,170	7.3	13.5	11
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	04-13-94	1005	1,180	7.3	13.5	11
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	05-23-94	1005	1,130	7.3	14.0	11

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	06-20-94	0915	1,050	7.3	14.0	10
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	07-18-94	1015	1,180	7.0	13.5	11
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	08-15-94	1045	1,350	7.3	14.0	12
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	09-19-94	1020	1,340	8.3	13.5	13
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	10-25-94	1545	1,390	7.7	13.5	12
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	11-21-94	0955	1,400	8.4	13.0	13
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	12-19-94	1045	1,450	7.2	13.0	10
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	02-22-95	1205	1,440	7.4	14.0	13
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	03-29-95	0920	1,500	7.2	13.0	13
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	04-24-95	0955	1,500	7.2	13.5	12
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	05-30-95	1010	1,440	7.2	13.5	12
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	06-19-95	1430	1,460	7.1	14.0	14
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	07-18-95	0950	1,400	7.3	13.5	13
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	08-16-95	1525	1,360	7.4	14.5	12
401655100583202	4N 32W30DCBB1	Beverly Medium-Depth	09-05-95	1245	1,370	7.2	14.0	12
401655100583203	4N 32W30DCBB1	Beverly Shallow	08-10-93	1145	1,660	7.2	14.5	12
401655100583203	4N 32W30DCBB1	Beverly Shallow	09-23-93	1330	1,650	7.2	13.0	12
401655100583203	4N 32W30DCBB1	Beverly Shallow	10-20-93	1025	1,540	7.2	13.0	9.3
401655100583203	4N 32W30DCBB1	Beverly Shallow	11-22-93	1005	1,870	7.2	13.0	8.4
401655100583203	4N 32W30DCBB1	Beverly Shallow	01-12-94	1100	1,960	7.1	13.0	8.3
401655100583203	4N 32W30DCBB1	Beverly Shallow	02-16-94	0935	2,000	7.1	12.5	7.4
401655100583203	4N 32W30DCBB1	Beverly Shallow	03-21-94	1010	2,060	7.1	13.0	7.3
401655100583203	4N 32W30DCBB1	Beverly Shallow	04-13-94	1025	2,160	7.1	13.0	7.6
401655100583203	4N 32W30DCBB1	Beverly Shallow	05-23-94	1025	2,000	7.2	13.0	8.8
401655100583203	4N 32W30DCBB1	Beverly Shallow	06-20-94	0940	1,780	7.1	13.5	8.5
401655100583203	4N 32W30DCBB1	Beverly Shallow	07-18-94	1030	1,610	7.0	13.0	11
401655100583203	4N 32W30DCBB1	Beverly Shallow	08-15-94	1105	1,640	7.2	14.0	12
401655100583203	4N 32W30DCBB1	Beverly Shallow	09-19-94	1040	1,600	8.2	13.5	14

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
401655100583203	4N 32W30DCBB1	Beverly Shallow	10-25-94	1600	1,660	7.6	13.0	12
401655100583203	4N 32W30DCBB1	Beverly Shallow	11-21-94	1010	1,700	8.2	13.0	12
401655100583203	4N 32W30DCBB1	Beverly Shallow	12-19-94	1100	1,760	7.2	13.5	8.7
401655100583203	4N 32W30DCBB1	Beverly Shallow	02-22-95	1225	1,800	7.4	14.0	9.1
401655100583203	4N 32W30DCBB1	Beverly Shallow	03-29-95	0955	1,920	7.1	12.5	8.5
401655100583203	4N 32W30DCBB1	Beverly Shallow	04-24-95	1010	1,970	7.2	13.0	7.9
401655100583203	4N 32W30DCBB1	Beverly Shallow	05-30-95	1025	1,930	7.2	13.0	7.3
401655100583203	4N 32W30DCBB1	Beverly Shallow	06-19-95	1440	1,940	7.1	13.5	8.3
401655100583203	4N 32W30DCBB1	Beverly Shallow	07-18-95	1020	2,000	7.2	15.0	7.7
401655100583203	4N 32W30DCBB1	Beverly Shallow	08-16-95	1535	1,700	7.5	15.5	11
401655100583203	4N 32W30DCBB1	Beverly Shallow	09-05-95	1305	1,680	7.2	14.0	12
401412100364201	3N 29W 8DDBA1	McCook North Deep	08-11-93	0930	517	7.5	15.0	3.4
401412100364201	3N 29W 8DDBA1	McCook North Deep	09-27-93	1050	454	7.5	16.0	3.4
401412100364201	3N 29W 8DDBA1	McCook North Deep	10-20-93	1600	429	7.8	15.0	3.6
401412100364201	3N 29W 8DDBA1	McCook North Deep	11-22-93	1320	505	7.5	15.0	3.8
401412100364201	3N 29W 8DDBA1	McCook North Deep	01-12-94	1320	513	7.2	15.0	--
401412100364201	3N 29W 8DDBA1	McCook North Deep	02-16-94	1420	513	7.4	15.0	3.6
401412100364201	3N 29W 8DDBA1	McCook North Deep	03-21-94	1330	503	7.5	15.5	3.2
401412100364201	3N 29W 8DDBA1	McCook North Deep	04-13-94	1435	511	7.6	15.5	3.6
401412100364201	3N 29W 8DDBA1	McCook North Deep	05-23-94	1530	495	7.6	15.5	3.9
401412100364201	3N 29W 8DDBA1	McCook North Deep	06-20-94	1545	503	7.5	15.5	3.6
401412100364201	3N 29W 8DDBA1	McCook North Deep	07-18-94	1635	505	7.1	15.5	3.6
401412100364201	3N 29W 8DDBA1	McCook North Deep	08-16-94	1400	504	7.4	17.0	3.6
401412100364201	3N 29W 8DDBA1	McCook North Deep	09-19-94	1605	481	8.6	15.5	3.6
401412100364201	3N 29W 8DDBA1	McCook North Deep	10-24-94	1420	510	9.0	15.0	--
401412100364201	3N 29W 8DDBA1	McCook North Deep	11-21-94	1515	511	8.7	15.0	3.6
401412100364201	3N 29W 8DDBA1	McCook North Deep	12-20-94	1015	521	7.5	15.0	3.9
401412100364201	3N 29W 8DDBA1	McCook North Deep	01-24-95	0935	504	7.5	15.0	3.3

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
401412100364201	3N 29W 8DDBA1	McCook North Deep	02-22-95	1530	505	7.5	15.0	3.5
401412100364201	3N 29W 8DDBA1	McCook North Deep	03-29-95	1400	524	7.4	15.0	3.5
401412100364201	3N 29W 8DDBA1	McCook North Deep	04-24-95	1515	526	7.6	15.0	3.1
401412100364201	3N 29W 8DDBA1	McCook North Deep	05-31-95	0950	507	7.5	15.0	3.1
401412100364201	3N 29W 8DDBA1	McCook North Deep	06-20-95	1000	506	7.6	15.0	2.9
401412100364201	3N 29W 8DDBA1	McCook North Deep	07-18-95	1510	518	7.4	15.5	3.6
401412100364201	3N 29W 8DDBA1	McCook North Deep	08-15-95	1100	514	7.2	16.0	3.8
401412100364201	3N 29W 8DDBA1	McCook North Deep	09-05-95	1015	503	7.6	15.0	3.9
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	08-11-93	1010	587	7.5	15.0	7.5
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	09-27-93	1205	527	7.6	16.5	8.8
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	10-20-93	1620	520	7.6	15.0	9.3
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	11-22-93	1345	597	7.6	15.0	9.0
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	01-12-94	1340	609	7.5	15.0	8.9
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	02-16-94	1440	592	7.6	15.0	8.3
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	03-21-94	1350	585	7.5	15.0	8.8
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	04-13-94	1455	598	7.6	15.0	8.9
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	05-23-94	1555	597	7.6	15.5	8.9
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	06-20-94	1605	605	7.5	15.5	9.4
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	07-18-94	1655	608	7.1	15.0	9.9
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	08-16-94	1430	612	7.6	16.5	10
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	09-19-94	1635	587	8.6	15.0	10
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	10-24-94	1445	626	8.7	15.0	--
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	11-21-94	1535	625	8.5	14.5	10
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	12-20-94	1045	642	7.5	15.0	11
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	01-24-95	0955	622	7.5	--	9.5
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	02-22-95	1550	617	7.5	15.0	9.6
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	03-29-95	1425	645	7.4	15.0	10
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	04-24-95	1535	645	7.6	15.0	8.4

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	05-31-95	1010	619	7.5	15.0	8.4
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	06-20-95	1025	604	7.6	15.0	8.7
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	07-18-95	1530	635	7.4	15.5	10
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	08-15-95	1120	633	7.2	15.5	9.9
401412100364202	3N 29W 8DDBA1	McCook North Medium-Depth	09-05-95	1040	641	7.5	15.0	12
401412100364203	3N 29W 8DDBA1	McCook North Shallow	08-11-93	1040	907	7.4	15.0	22
401412100364203	3N 29W 8DDBA1	McCook North Shallow	09-27-93	1230	780	7.5	16.0	21
401412100364203	3N 29W 8DDBA1	McCook North Shallow	10-20-93	1635	746	7.7	14.5	22
401412100364203	3N 29W 8DDBA1	McCook North Shallow	11-22-93	1410	877	7.6	14.5	22
401412100364203	3N 29W 8DDBA1	McCook North Shallow	01-12-94	1400	881	7.4	14.5	22
401412100364203	3N 29W 8DDBA1	McCook North Shallow	02-16-94	1500	881	7.5	14.5	23
401412100364203	3N 29W 8DDBA1	McCook North Shallow	03-21-94	1410	849	7.4	15.0	22
401412100364203	3N 29W 8DDBA1	McCook North Shallow	04-13-94	1510	814	7.5	15.0	24
401412100364203	3N 29W 8DDBA1	McCook North Shallow	05-23-94	1615	866	7.5	15.5	26
401412100364203	3N 29W 8DDBA1	McCook North Shallow	06-20-94	1625	867	7.4	15.5	25
401412100364203	3N 29W 8DDBA1	McCook North Shallow	07-18-94	1710	857	7.0	15.0	22
401412100364203	3N 29W 8DDBA1	McCook North Shallow	08-16-94	1500	860	7.3	17.5	23
401412100364203	3N 29W 8DDBA1	McCook North Shallow	09-19-94	1700	826	8.4	15.0	24
401412100364203	3N 29W 8DDBA1	McCook North Shallow	10-24-94	1505	874	8.5	15.0	--
401412100364203	3N 29W 8DDBA1	McCook North Shallow	11-21-94	1550	878	8.3	14.5	25
401412100364203	3N 29W 8DDBA1	McCook North Shallow	12-20-94	1055	893	7.6	15.0	21
401412100364203	3N 29W 8DDBA1	McCook North Shallow	01-24-95	1010	869	7.5	14.0	22
401412100364203	3N 29W 8DDBA1	McCook North Shallow	02-22-95	1605	875	7.4	15.0	24
401412100364203	3N 29W 8DDBA1	McCook North Shallow	03-29-95	1445	895	7.4	14.5	24
401412100364203	3N 29W 8DDBA1	McCook North Shallow	04-24-95	1555	921	7.5	15.0	25
401412100364203	3N 29W 8DDBA1	McCook North Shallow	05-31-95	1025	922	7.4	15.0	24
401412100364203	3N 29W 8DDBA1	McCook North Shallow	06-20-95	1040	931	7.5	15.0	30
401412100364203	3N 29W 8DDBA1	McCook North Shallow	07-18-95	1555	944	7.3	15.5	27

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
401412100364203	3N 29W 8DDBA1	McCook North Shallow	08-15-95	1145	--	--	--	25
401412100364203	3N 29W 8DDBA1	McCook North Shallow	09-05-95	1100	912	7.5	15.0	27
401016100391801	2N 30W 1ACDD1	McCook South Deep	08-10-93	1500	1,030	7.1	15.5	20
401016100391801	2N 30W 1ACDD1	McCook South Deep	09-24-93	0910	900	7.2	13.5	17
401016100391801	2N 30W 1ACDD1	McCook South Deep	10-20-93	1325	926	7.6	14.0	21
401016100391801	2N 30W 1ACDD1	McCook South Deep	11-22-93	1455	1,110	7.3	13.5	23
401016100391801	2N 30W 1ACDD1	McCook South Deep	01-13-94	0935	1,180	7.2	13.0	26
401016100391801	2N 30W 1ACDD1	McCook South Deep	02-16-94	1200	1,210	7.3	13.5	27
401016100391801	2N 30W 1ACDD1	McCook South Deep	03-21-94	1450	1,200	7.2	14.5	28
401016100391801	2N 30W 1ACDD1	McCook South Deep	04-14-94	0910	1,210	7.4	13.5	25
401016100391801	2N 30W 1ACDD1	McCook South Deep	05-23-94	1400	1,240	7.3	14.5	29
401016100391801	2N 30W 1ACDD1	McCook South Deep	06-20-94	1400	1,090	--	14.5	23
401016100391801	2N 30W 1ACDD1	McCook South Deep	07-18-94	1455	1,040	6.8	14.0	19
401016100391801	2N 30W 1ACDD1	McCook South Deep	08-15-94	1435	1,010	7.2	14.5	17
401016100391801	2N 30W 1ACDD1	McCook South Deep	09-19-94	1420	974	8.2	14.0	18
401016100391801	2N 30W 1ACDD1	McCook South Deep	10-24-94	1600	1,070	8.3	14.0	--
401016100391801	2N 30W 1ACDD1	McCook South Deep	11-21-94	1335	1,110	8.2	13.5	23
401016100391801	2N 30W 1ACDD1	McCook South Deep	12-19-94	1440	1,190	7.4	13.0	21
401016100391801	2N 30W 1ACDD1	McCook South Deep	01-23-95	0935	1,230	7.4	13.0	26
401016100391801	2N 30W 1ACDD1	McCook South Deep	02-22-95	0955	1,180	7.8	13.5	27
401016100391801	2N 30W 1ACDD1	McCook South Deep	03-29-95	1545	1,220	7.2	13.5	26
401016100391801	2N 30W 1ACDD1	McCook South Deep	04-24-95	1340	1,210	7.2	14.0	24
401016100391801	2N 30W 1ACDD1	McCook South Deep	05-22-95	1145	1,170	7.2	13.5	24
401016100391801	2N 30W 1ACDD1	McCook South Deep	06-19-95	1025	1,180	7.3	14.0	28
401016100391801	2N 30W 1ACDD1	McCook South Deep	07-18-95	1350	1,160	7.2	14.0	24
401016100391801	2N 30W 1ACDD1	McCook South Deep	08-15-95	1420	1,100	7.1	15.0	18
401016100391801	2N 30W 1ACDD1	McCook South Deep	09-05-95	1605	1,120	7.1	14.0	22
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	08-10-93	1520	1,090	7.2	16.5	18

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	09-24-93	0935	971	7.3	13.5	17
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	10-20-93	1345	957	7.5	13.5	18
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	11-22-93	1515	1,100	7.3	13.5	19
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	01-13-94	0950	1,160	7.1	13.0	20
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	02-16-94	1225	1,160	7.2	13.5	20
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	03-21-94	1505	1,140	7.2	14.0	20
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	04-14-94	0940	1,160	7.4	13.5	20
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	05-23-94	1420	1,190	7.3	14.5	21
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	06-20-94	1420	1,140	6.9	14.5	20
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	07-18-94	1510	1,130	6.8	14.0	19
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	08-15-94	1455	--	--	--	18
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	09-19-94	1435	1,070	8.1	14.0	19
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	10-24-94	1620	1,130	8.2	13.5	--
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	11-21-94	1355	1,140	8.2	14.0	19
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	12-19-94	1500	1,180	7.4	13.0	15
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	01-23-95	0955	1,190	7.3	13.0	18
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	02-22-95	1015	1,150	7.6	13.5	19
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	03-29-95	1605	1,200	7.9	13.0	19
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	04-24-95	1355	1,210	7.4	13.5	18
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	05-22-95	1200	1,160	7.2	13.5	17
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	06-19-95	1045	1,170	7.3	14.0	20
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	07-18-95	1410	1,180	7.1	14.5	19
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	08-15-95	1440	1,160	7.0	15.0	16
401016100391802	2N 30W 1ACDD1	McCook South Medium-Depth	09-05-95	1625	1,120	7.1	14.0	17
401016100391803	2N 30W 1ACDD1	McCook South Shallow	08-10-93	1550	1,160	7.2	17.0	12
401016100391803	2N 30W 1ACDD1	McCook South Shallow	09-24-93	1005	1,050	7.2	13.5	12
401016100391803	2N 30W 1ACDD1	McCook South Shallow	10-20-93	1400	1,030	7.5	13.5	12
401016100391803	2N 30W 1ACDD1	McCook South Shallow	11-22-93	1530	1,160	7.3	13.5	11

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
401016100391803	2N 30W 1ACDD1	McCook South Shallow	01-13-94	1005	1,170	7.1	13.0	9.8
401016100391803	2N 30W 1ACDD1	McCook South Shallow	02-16-94	1245	1,150	7.1	13.5	10
401016100391803	2N 30W 1ACDD1	McCook South Shallow	03-21-94	1520	1,130	7.2	14.5	10
401016100391803	2N 30W 1ACDD1	McCook South Shallow	04-14-94	0955	1,160	7.4	14.0	9.8
401016100391803	2N 30W 1ACDD1	McCook South Shallow	05-23-94	1435	1,160	7.3	14.5	10
401016100391803	2N 30W 1ACDD1	McCook South Shallow	06-20-94	1445	1,150	--	14.0	10
401016100391803	2N 30W 1ACDD1	McCook South Shallow	07-18-94	1525	1,200	6.8	14.0	13
401016100391803	2N 30W 1ACDD1	McCook South Shallow	08-15-94	1520	1,190	7.3	15.0	13
401016100391803	2N 30W 1ACDD1	McCook South Shallow	09-19-94	1450	1,130	8.1	14.0	12
401016100391803	2N 30W 1ACDD1	McCook South Shallow	10-24-94	1635	1,180	8.2	13.5	--
401016100391803	2N 30W 1ACDD1	McCook South Shallow	11-21-94	1410	1,160	8.1	13.0	8.7
401016100391803	2N 30W 1ACDD1	McCook South Shallow	12-19-94	1515	1,180	7.4	13.0	7.3
401016100391803	2N 30W 1ACDD1	McCook South Shallow	01-23-95	1006	1,170	7.3	13.0	8.8
401016100391803	2N 30W 1ACDD1	McCook South Shallow	02-22-95	1030	1,130	7.1	13.5	10
401016100391803	2N 30W 1ACDD1	McCook South Shallow	03-29-95	1620	1,160	8.0	13.0	9.3
401016100391803	2N 30W 1ACDD1	McCook South Shallow	04-24-95	1410	1,160	7.4	14.0	8.2
401016100391803	2N 30W 1ACDD1	McCook South Shallow	05-22-95	1215	1,110	7.2	14.0	7.8
401016100391803	2N 30W 1ACDD1	McCook South Shallow	06-19-95	1100	1,130	7.3	14.5	7.8
401016100391803	2N 30W 1ACDD1	McCook South Shallow	07-18-95	1425	1,110	7.1	15.0	6.8
401016100391803	2N 30W 1ACDD1	McCook South Shallow	08-15-95	1505	1,100	6.9	15.0	7.7
401016100391803	2N 30W 1ACDD1	McCook South Shallow	09-05-95	1650	1,080	7.1	14.0	9.3
400357100135201	1N 26W11CBBB1	Shippee Deep	08-11-93	1405	748	7.3	14.0	.10
400357100135201	1N 26W11CBBB1	Shippee Deep	09-24-93	1505	657	7.6	13.5	.01
400357100135201	1N 26W11CBBB1	Shippee Deep	10-21-93	1110	693	7.5	13.5	.01
400357100135201	1N 26W11CBBB1	Shippee Deep	11-22-93	1630	729	7.4	13.5	<.01
400357100135201	1N 26W11CBBB1	Shippee Deep	01-12-94	1510	733	7.4	13.5	.01
400357100135201	1N 26W11CBBB1	Shippee Deep	02-17-94	1050	653	6.4	13.5	<.01
400357100135201	1N 26W11CBBB1	Shippee Deep	03-22-94	1055	712	7.4	13.5	.01

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
400357100135201	1N 26W11CBBB1	Shippee Deep	04-14-94	1125	722	7.4	13.5	0.15
400357100135201	1N 26W11CBBB1	Shippee Deep	05-24-94	1045	730	7.4	14.0	.01
400357100135201	1N 26W11CBBB1	Shippee Deep	06-21-94	1115	710	7.1	13.5	.50
400357100135201	1N 26W11CBBB1	Shippee Deep	07-19-94	1350	704	7.2	14.5	.01
400357100135201	1N 26W11CBBB1	Shippee Deep	08-16-94	1135	700	7.2	14.0	.01
400357100135201	1N 26W11CBBB1	Shippee Deep	09-20-94	1110	686	7.2	14.0	.01
400357100135201	1N 26W11CBBB1	Shippee Deep	11-22-94	1105	741	7.1	13.0	.01
400357100135201	1N 26W11CBBB1	Shippee Deep	12-20-94	1440	758	7.6	14.5	3.5
400357100135201	1N 26W11CBBB1	Shippee Deep	01-24-95	1335	730	7.4	13.0	.01
400357100135201	1N 26W11CBBB1	Shippee Deep	02-23-95	1050	740	7.5	13.5	<.01
400357100135201	1N 26W11CBBB1	Shippee Deep	03-30-95	1050	752	7.3	13.0	<.01
400357100135201	1N 26W11CBBB1	Shippee Deep	04-25-95	1045	750	7.3	13.5	.04
400357100135201	1N 26W11CBBB1	Shippee Deep	05-31-95	1330	717	7.3	13.5	.02
400357100135201	1N 26W11CBBB1	Shippee Deep	06-20-95	1330	706	7.3	14.5	<.01
400357100135201	1N 26W11CBBB1	Shippee Deep	07-19-95	1100	630	7.2	15.0	.10
400357100135201	1N 26W11CBBB1	Shippee Deep	08-15-95	1630	739	7.2	15.0	.10
400357100135201	1N 26W11CBBB1	Shippee Deep	09-06-95	1100	734	7.3	14.5	.01
400357100135202	1N 26W11CBBB1	Shippee Shallow	08-11-93	1440	1,120	7.4	14.0	4.9
400357100135202	1N 26W11CBBB1	Shippee Shallow	09-24-93	1525	965	7.7	13.0	2.2
400357100135202	1N 26W11CBBB1	Shippee Shallow	10-21-93	1130	988	7.6	13.0	1.7
400357100135202	1N 26W11CBBB1	Shippee Shallow	11-22-93	1645	1,070	7.6	13.0	2.0
400357100135202	1N 26W11CBBB1	Shippee Shallow	01-12-94	1530	1,180	7.5	13.0	5.0
400357100135202	1N 26W11CBBB1	Shippee Shallow	02-17-94	1105	1,030	6.9	13.0	3.0
400357100135202	1N 26W11CBBB1	Shippee Shallow	03-22-94	1110	1,100	7.5	14.0	1.7
400357100135202	1N 26W11CBBB1	Shippee Shallow	04-14-94	1155	1,110	7.5	14.0	1.6
400357100135202	1N 26W11CBBB1	Shippee Shallow	05-24-94	1105	1,190	7.6	14.0	3.2
400357100135202	1N 26W11CBBB1	Shippee Shallow	06-21-94	1130	1,150	7.2	13.5	3.1
400357100135202	1N 26W11CBBB1	Shippee Shallow	07-19-94	1405	1,270	7.4	14.0	7.3

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
400357100135202	1N 26W11CBBB1	Shippee Shallow	08-16-94	1150	1,460	7.3	14.0	15
400357100135202	1N 26W11CBBB1	Shippee Shallow	09-20-94	1125	1,140	7.4	13.5	3.2
400357100135202	1N 26W11CBBB1	Shippee Shallow	10-25-94	1050	1,120	7.2	12.5	--
400357100135202	1N 26W11CBBB1	Shippee Shallow	11-22-94	1120	1,130	7.3	12.0	2.6
400357100135202	1N 26W11CBBB1	Shippee Shallow	12-20-94	1445	1,140	7.6	13.5	4.0
400357100135202	1N 26W11CBBB1	Shippee Shallow	01-24-95	1410	1,180	7.8	13.0	5.3
400357100135202	1N 26W11CBBB1	Shippee Shallow	02-23-95	1110	1,280	7.6	13.0	7.9
400357100135202	1N 26W11CBBB1	Shippee Shallow	03-30-95	1120	1,350	7.4	13.0	10
400357100135202	1N 26W11CBBB1	Shippee Shallow	04-25-95	1105	1,330	7.4	14.0	8.7
400357100135202	1N 26W11CBBB1	Shippee Shallow	05-31-95	1345	1,080	7.4	13.5	2.2
400357100135202	1N 26W11CBBB1	Shippee Shallow	06-20-95	1345	1,030	7.4	14.5	0.6
400357100135202	1N 26W11CBBB1	Shippee Shallow	07-19-95	1115	1,020	7.3	17.5	3.6
400357100135202	1N 26W11CBBB1	Shippee Shallow	08-15-95	1655	1,070	7.2	15.0	1.1
400357100135202	1N 26W11CBBB1	Shippee Shallow	09-06-95	1120	1,050	7.4	13.5	1.2
400818101124001	2N 35W13AAAD1	Stratton Deep	08-10-93	1245	1,320	7.4	14.0	15
400818101124001	2N 35W13AAAD1	Stratton Deep	09-23-93	1430	1,340	7.4	13.0	14
400818101124001	2N 35W13AAAD1	Stratton Deep	10-20-93	1125	1,120	7.6	12.5	15
400818101124001	2N 35W13AAAD1	Stratton Deep	11-22-93	1105	1,330	7.4	12.5	14
400818101124001	2N 35W13AAAD1	Stratton Deep	01-13-94	1110	1,360	7.3	13.0	15
400818101124001	2N 35W13AAAD1	Stratton Deep	02-16-94	1030	1,360	7.3	12.5	14
400818101124001	2N 35W13AAAD1	Stratton Deep	03-21-94	1110	1,330	7.5	13.0	15
400818101124001	2N 35W13AAAD1	Stratton Deep	04-13-94	1140	1,350	7.4	13.0	15
400818101124001	2N 35W13AAAD1	Stratton Deep	05-23-94	1125	1,350	7.5	13.5	16
400818101124001	2N 35W13AAAD1	Stratton Deep	06-20-94	1035	1,330	7.1	13.0	14
400818101124001	2N 35W13AAAD1	Stratton Deep	07-18-94	1130	1,340	7.1	13.0	14
400818101124001	2N 35W13AAAD1	Stratton Deep	08-15-94	1120	1,330	7.4	13.5	14
400818101124001	2N 35W13AAAD1	Stratton Deep	09-19-94	1135	1,270	8.3	13.0	15
400818101124001	2N 35W13AAAD1	Stratton Deep	10-25-94	1355	1,340	8.0	13.0	14

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (µS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
400818101124001	2N 35W13AAAD1	Stratton Deep	11-21-94	1055	1,360	8.3	12.5	15
400818101124001	2N 35W13AAAD1	Stratton Deep	12-19-94	1215	1,390	7.6	12.5	12
400818101124001	2N 35W13AAAD1	Stratton Deep	01-23-95	1115	1,400	7.5	12.0	14
400818101124001	2N 35W13AAAD1	Stratton Deep	02-22-95	1350	1,350	7.4	13.0	14
400818101124001	2N 35W13AAAD1	Stratton Deep	03-29-95	1105	1,410	7.4	12.5	14
400818101124001	2N 35W13AAAD1	Stratton Deep	04-24-95	1100	1,410	7.4	12.5	13
400818101124001	2N 35W13AAAD1	Stratton Deep	06-02-95	1200	1,360	7.3	13.0	13
400818101124001	2N 35W13AAAD1	Stratton Deep	06-19-95	1320	1,390	7.3	13.5	15
400818101124001	2N 35W13AAAD1	Stratton Deep	07-18-95	1110	1,390	7.4	13.0	14
400818101124001	2N 35W13AAAD1	Stratton Deep	08-16-95	1415	1,370	7.4	13.5	13
400818101124001	2N 35W13AAAD1	Stratton Deep	09-05-95	1420	1,350	7.5	13.5	14
400818101124002	2N 35W13AAAD1	Stratton Shallow	08-10-93	1320	1,490	7.3	14.0	21
400818101124002	2N 35W13AAAD1	Stratton Shallow	09-23-93	1500	1,450	7.4	12.5	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	10-20-93	1140	1,250	7.5	12.5	20
400818101124002	2N 35W13AAAD1	Stratton Shallow	11-22-93	1125	1,460	7.4	12.5	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	01-13-94	1125	1,480	7.2	13.0	20
400818101124002	2N 35W13AAAD1	Stratton Shallow	02-16-94	1045	1,450	7.4	12.5	18
400818101124002	2N 35W13AAAD1	Stratton Shallow	03-21-94	1125	1,430	7.4	13.0	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	04-13-94	1205	1,450	7.4	13.5	18
400818101124002	2N 35W13AAAD1	Stratton Shallow	05-23-94	1140	1,440	7.4	13.0	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	06-20-94	1050	1,420	7.2	13.0	17
400818101124002	2N 35W13AAAD1	Stratton Shallow	07-18-94	1145	1,490	7.1	12.5	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	08-15-94	1235	1,480	7.3	13.0	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	09-19-94	1150	1,410	8.2	13.0	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	10-25-94	1410	1,460	8.0	13.0	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	11-21-94	1110	1,450	8.2	12.5	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	12-19-94	1230	1,480	7.5	12.5	14
400818101124002	2N 35W13AAAD1	Stratton Shallow	01-23-95	1130	1,550	7.4	12.0	19

Table 15. Results of monitor-well water-quality analyses for field measurements and nitrate concentrations in the study area, southwest Nebraska, 1993-95--Continued

USGS station identification number	Local identifier	Name	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Water temperature (°C)	Nitrate as N (mg/L)
400818101124002	2N 35W13AAAD1	Stratton Shallow	02-22-95	1400	1,490	7.3	13.0	20
400818101124002	2N 35W13AAAD1	Stratton Shallow	03-29-95	1125	1,530	7.3	12.5	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	04-24-95	1115	1,530	7.3	12.5	18
400818101124002	2N 35W13AAAD1	Stratton Shallow	06-02-95	1220	1,500	7.3	13.0	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	06-19-95	1305	1,540	7.3	13.0	22
400818101124002	2N 35W13AAAD1	Stratton Shallow	07-18-95	1130	1,540	7.3	13.0	20
400818101124002	2N 35W13AAAD1	Stratton Shallow	08-16-95	1425	1,500	7.4	14.5	19
400818101124002	2N 35W13AAAD1	Stratton Shallow	09-05-95	1445	1,580	7.4	13.0	23

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