

# Water Quality and Chemical Evolution of Ground Water in the Long Pine Creek Area, Brown and Rock Counties, Nebraska, 1993–94

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96–4095

Prepared in cooperation with the  
NEBRASKA DEPARTMENT OF ENVIRONMENTAL QUALITY



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By A.D. Druliner

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Lincoln, Nebraska  
1997



**U.S. DEPARTMENT OF THE INTERIOR**  
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**For additional information write to:**

**District Chief  
U.S. Geological Survey  
Room 406, Federal Building  
100 Centennial Mall North  
Lincoln, NE 68508**

**Copies of this report can be purchased  
from:**

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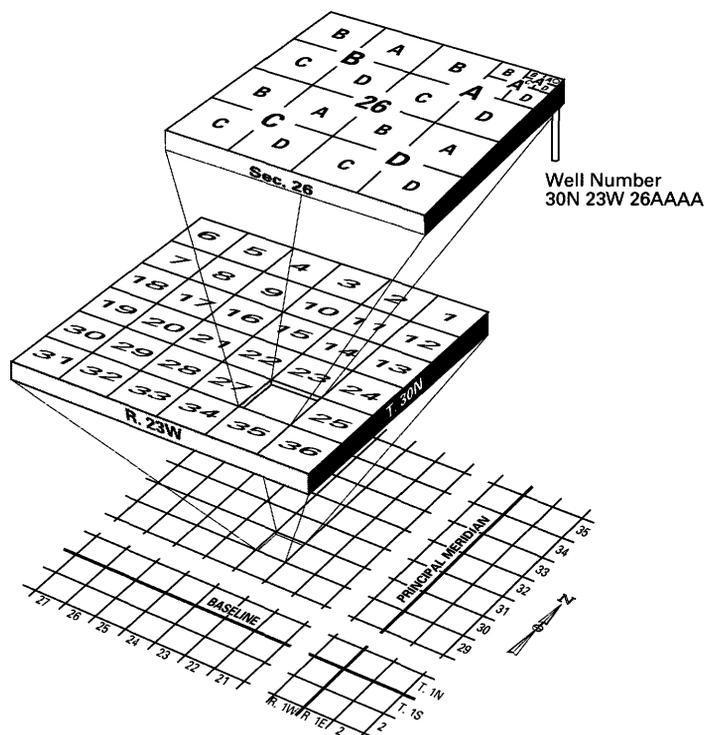
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**VERTICAL DATUM**

**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 “Mean Sea Level of 1929.”

**WELL NUMBERING SYSTEM**



# Water Quality and Chemical Evolution of Ground Water in the Long Pine Creek Area, Brown and Rock Counties, Nebraska, 1993–94

By A.D. Druliner

## Abstract

In 1981, the Long Pine Creek Drainage Basin, which occupies 500 square miles in north-central Nebraska, was selected for inclusion in the U.S. Department of Agriculture's Rural Clean Water Program to control agricultural nonpoint-source contamination of Long Pine Creek, its tributaries, and local ground-water supplies. Twenty-one ground-water observation wells were installed in the Long Pine Creek study area to monitor ground-water quality. Water-level data and water-quality samples were collected from these wells four times during August, November, and December 1993 and June 1994. Field properties were measured and samples were analyzed for major ions, nutrients, and selected herbicides by the National Water-Quality Laboratory of the U.S. Geological Survey in Arvada, Colorado. Water samples from 12 wells also were analyzed for tritium.

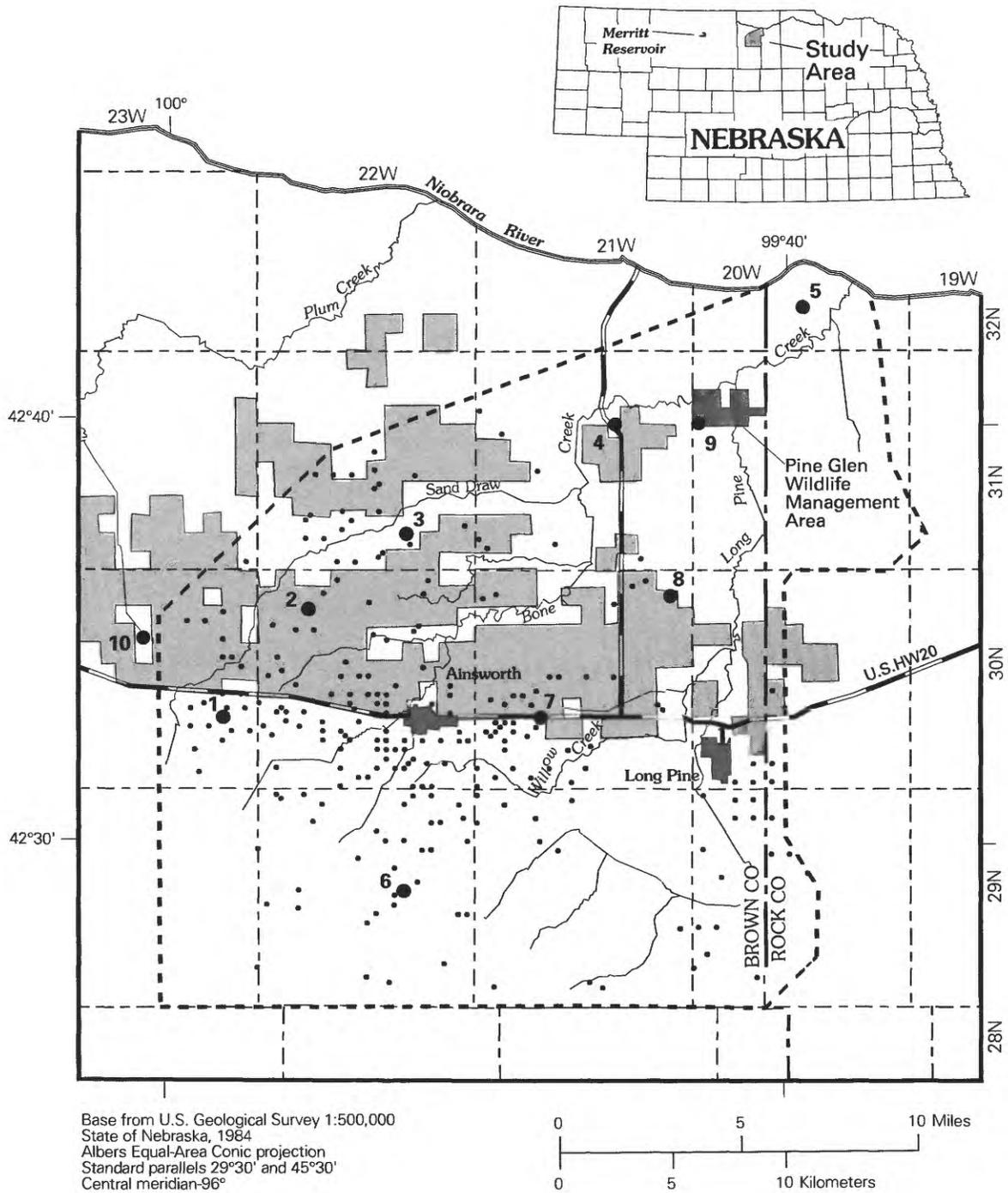
Analyses indicated that the ground water is a well-oxygenated, calcium carbonate type with a very small dissolved-solids content in which silica is the dominant constituent. Nitrate concentrations in ground-water samples ranged from 0.5 to 32 milligrams per liter. Larger concentrations of sulfate, chloride, and nitrate were found in shallow observation wells in areas of irrigated agriculture compared to areas of nonirrigated agriculture. Seasonal variation in nitrate concentrations ranging from 0.08 to 6.6 milligrams per liter were present in water samples collected from shallow observation wells in areas of irrigated agriculture, whereas little variation was observed in nitrate concentrations in water samples from nonirrigated areas.

Water samples from 4 of the 19 observation wells that were analyzed for triazine herbicides contained trace amounts of atrazine or its metabolites. Atrazine and its metabolites were detected only in water samples from shallow observation wells in areas of irrigated agriculture where nitrate concentrations in ground water were more than 10 milligrams per liter.

Estimated ages of the ground-water samples based on tritium concentrations and water-level and water-quality data are consistent with the concept that ground water moves along deep flow paths from the Sand Hills northward toward the Niobrara River. Good quality ground water flowing north from the Sand Hills discharges seasonally in the northern part of the study area to produce wet meadows. Local row-crop agriculture and seasonal recharge from the Ainsworth Irrigation Project strongly influence the quality of the shallow ground water in the central portion of the study area, but have no effect on the quality of ground water following the deeper flow paths. Ground water near the bottom of the Long Pine Creek Drainage Basin is a mixture of very old water from deep flow paths with young water from recharge of local precipitation.

## INTRODUCTION

The Long Pine Creek study area contains most of the Long Pine Creek Drainage Basin, which is located in Brown and Rock Counties, Nebraska (fig. 1). The study area was used principally for ranchland and limited amounts of dryland farming until 1964, when the construction of the Merritt



**Figure 1.** Locations of the Long Pine Creek study area, land irrigated by the Ainsworth Irrigation Project, registered irrigation wells, and ground-water observation well sites, north-central Nebraska.

Reservoir and the Ainsworth Irrigation Project canal system was completed, permitting surface-water irrigation of about 35,000 acres in the drainage basin. The extensive use of agricultural chemicals on these newly irrigated and cropped fields soon resulted in the contamination of surface and ground water at concentrations often in excess of the U.S. Environmental Protection Agency's drinking-water regulations (Hermsmeyer, 1991). Also, sediment from erosion and runoff on irrigated croplands has partially filled several area creeks and seriously degraded trout habitat in Long Pine Creek, which is one of only a few self-sustaining trout streams in the State (Hermsmeyer, 1991).

In 1981, the Long Pine Creek Drainage Basin was selected for inclusion in the Rural Clean Water Program (RCWP), a U.S. Department of Agriculture sponsored program designed to control agricultural nonpoint-source contamination in rural drainage basins through implementation of best-management practices (BMPs). The RCWP continued in the Long Pine Drainage Basin through 1991 and included pre-implementation, implementation, and post-implementation surface- and ground-water-quality monitoring conducted by the Nebraska Department of Environmental Quality (NDEQ).

The original ground-water-quality monitoring plan required the identification and annual collection of water samples from 30 irrigation wells within the drainage basin. The monitoring was to identify trends in ground-water quality with respect to agriculture chemicals as BMPs were implemented and continued. Unfortunately, many of these wells were not available for water-sample collection from year to year due to changing agricultural practices, and substitute wells were used. Consequently, water samples were collected from 67 wells from 1982 to 1991, with samples collected from most wells fewer than five times and only once from many of the wells. These factors made it difficult to statistically compare ground-water quality within the drainage basin from the pre-BMP implementation period through the end of the monitoring. Water-quality data for groups of sites with samples collected for 5 or more years showed considerable variation with no apparent systematic trends.

To better define ground-water quality in the Long Pine Creek Drainage Basin, a more complete understanding of the local ground-water hydrology was necessary. Because of the difficulty in collecting

annual water samples from available irrigation wells in the study area, a network of ground-water observation wells at strategic locations in the drainage basin was needed to permit the systematic and long-term monitoring of trends in ground-water quality. To address these needs, the U.S. Geological Survey entered into an agreement with the Nebraska Department of Environmental Quality to conduct a study in the Long Pine Creek Drainage Basin. The objectives of the study were: (1) to establish a network of observation wells in the drainage basin for long-term monitoring of nitrate and other agricultural compounds and to determine the current water quality in the drainage basin; (2) to determine the seasonal variability of nitrate concentrations in ground water in the drainage basin and identify optimal sampling times; and (3) to determine the relative age of ground water at different depths in the study area and describe the general flow paths and chemical evolution of ground water as it moves through the drainage basin.

## **Purpose and Scope**

The purpose of this report is to describe the results of the ground-water-quality study conducted in the Long Pine Creek Drainage Basin during 1993–94. The report describes the location and installation of 21 ground-water observation wells; ground-water-quality sampling protocols; and the results of major ion, nutrients, and selected pesticide analyses. An interpretation of the general flow paths and chemical evolution of ground water and a discussion of the seasonal variation of nitrate concentrations in ground water are included.

## **Acknowledgments**

I thank the land owners and managers who permitted us to install observation wells on their property and to access those wells on a regular basis. Staff members of the Ground-Water Section of the Nebraska Department of Environmental Quality provided much assistance in the geologic characterization of the study area and in the installation of the observation wells. I also thank Elmer Lentz of the Middle Niobrara Natural Resources District for his help in identifying land owners and in selecting alternate drilling sites.

## DESCRIPTION OF THE STUDY AREA

The study area generally conforms to the Long Pine Creek Drainage Basin, which encompasses about 500 square miles in northeastern Brown and northwestern Rock Counties. The drainage basin is in the High Plains section of the Great Plains physiographic province (Fenneman, 1946) and borders the northeastern edge of the Nebraska Sand Hills. The study area is bounded by the Sand Hills to the south, the Plum Creek Basin to the west and northwest, the Niobrara River to the north, and the Elkhorn River Drainage Basin to the east. The southern edge of the Long Pine Creek Drainage Basin contains stabilized sand dunes and interdunal areas with commonly more than 100 feet of difference in elevation. The remainder of the basin is nearly flat to gently rolling tableland with several narrow, deep canyons cut by streams.

Long Pine Creek, the principal stream in the drainage area, flows from south to north along the eastern part of the study area and flows into the Niobrara River. The principal tributaries of Long Pine Creek include Bone Creek, which flows south to north through the central portion of the study area and Sand Draw, which drains the northwestern part of the study area and joins Bone Creek about 6 miles upstream from Bone Creek's confluence with Long Pine Creek

(fig. 1). Long Pine Creek is perennial and is the longest self-sustaining trout stream in Nebraska. Sand Draw also is perennial, but was ephemeral prior to the delivery of irrigation water through the Ainsworth Irrigation Project.

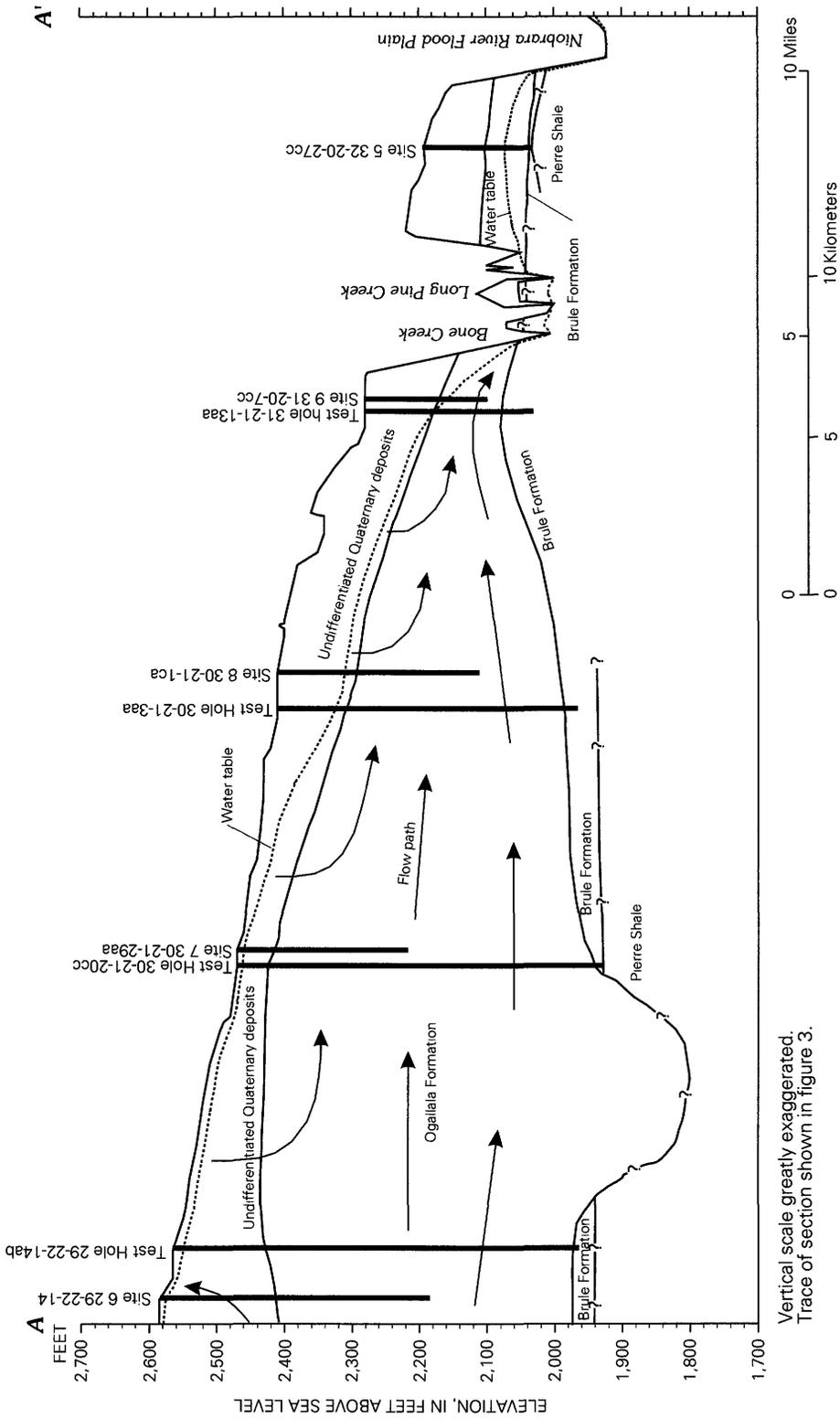
## Hydrogeology

The primary geologic units in the study area are the Pierre Shale of Cretaceous age, the Brule Formation and the Ogallala Formation, both of Tertiary age, and an assortment of clayey silt, sand, and gravel deposits of Quaternary age (table 1) (fig. 2). The Pierre Shale is a relatively impermeable dark brown to black marine shale that underlies the entire study area. Its thickness is estimated to be several hundred feet, and it is not considered to be a source of water supply in the area.

The Brule Formation unconformably overlies the Pierre Shale throughout much of the study area. The Brule Formation generally appears as a pinkish sandy silt with clay of relatively low permeability. The thickness of the Brule Formation is estimated to be from zero to nearly 100 feet, and this unit is not considered to be a source of water supply in the study area.

Table 1. Summary of hydrogeologic units in the Long Pine Creek study area, Brown and Rock Counties, Nebraska

System and series	Geologic unit	Character and distribution	Hydrogeologic unit	Water-bearing properties
Quaternary: Holocene Pleistocene	Undifferentiated deposits	Fluvial clays, sands, and gravels, and eolian silts and fine sands. Underlies most of the study area.	High Plains aquifer (upper)	Good source of water supply in the southern half of the study area where these deposits are saturated.
Tertiary: Pliocene	Ogallala Formation	Silt, sand, gravel, and sandstone, with layers cemented with calcium carbonate. Underlies most of the study area.	(lower)	Relatively high permeability. A principal source of water supply.
Tertiary: Oligocene	Brule Formation	Pinkish, very fine sandy silt with varying amounts of clay. Underlies most of the study area.	None	Relatively impermeable. Not a source of water supply.
Cretaceous: Late Cretaceous	Pierre Shale	Dark, fissile, marine shale. Underlies most of the study area.	None	Relatively impermeable. Not a source of water supply.



**Figure 2. Generalized geologic cross section of the Long Pine Creek study area and probable ground-water flow paths in north-central Nebraska.**

The Ogallala Formation overlies the Brule Formation. The Ogallala Formation extends from South Dakota to Texas and underlies part of eight Midwestern States. The Ogallala Formation in the study area consists of loosely to poorly cemented silt, fine- to medium-textured quartz sand, and fine gravel mixed with layers of sandstone and occasional calcium carbonate-cemented sandstone. The Ogallala Formation varies in thickness from about 500 feet in the central part of the study area to less than 100 feet in the northern part of the study area, where the land surface drops toward the Niobrara River (Cronin and others, 1956). Permeable lenses of gravel and coarser sand in the Ogallala Formation make it a suitable source of water supply for domestic, stock, and irrigation use.

Overlying an erosion unconformity at the top of the Ogallala Formation are clay, sand, and gravel deposits of Pleistocene age. These fluvial deposits range in thickness from about 50 to 150 feet in the study area and locally have been referred to as the Keim and Long Pine Formations by Skinner and Hibbard (1972). These deposits commonly are composed of about 10 to 50 feet of silty clay overlain by about 20 to 100 feet of reddish-brown sand and gravel composed of quartz and some feldspar minerals. The sand and gravel deposits are a commercial source of aggregate for road surfacing and construction. The deposits also are a source of water supply in the central and southern parts of the study area where the deposits are saturated.

Deposits of Holocene age overlie the Pleistocene-age sediments throughout much of the study area. These deposits consist principally of a thin mantle of fluvial sand and gravel, and eolian silt and occasional dune sand. The thickness of these deposits seldom exceeds 50 feet. In the extreme southern end of the study area the relatively thick, partially saturated deposits of dune sand are a local source of water supply.

Water-bearing deposits of the Quaternary System and the Ogallala Formation compose the High Plains aquifer in the study area. Although some locally confining clay and silty clay lenses are present, the aquifer is generally considered to be unconfined. The saturated thickness of the High Plains aquifer in the study area varies from 35 feet near the confluence of Long Pine Creek with the Niobrara River at the northern end of the study area to over 500 feet in the central and southern parts of the study area.

An aquifer test conducted by Cronin and others (1956) in the southern part of the study area yielded a transmissivity of about 10,300 ft<sup>3</sup> per day per foot, which is considered to be representative of much of the High Plains aquifer in the study area. This translates to an average hydraulic conductivity of about 150 feet per day and indicates that the aquifer is moderately permeable.

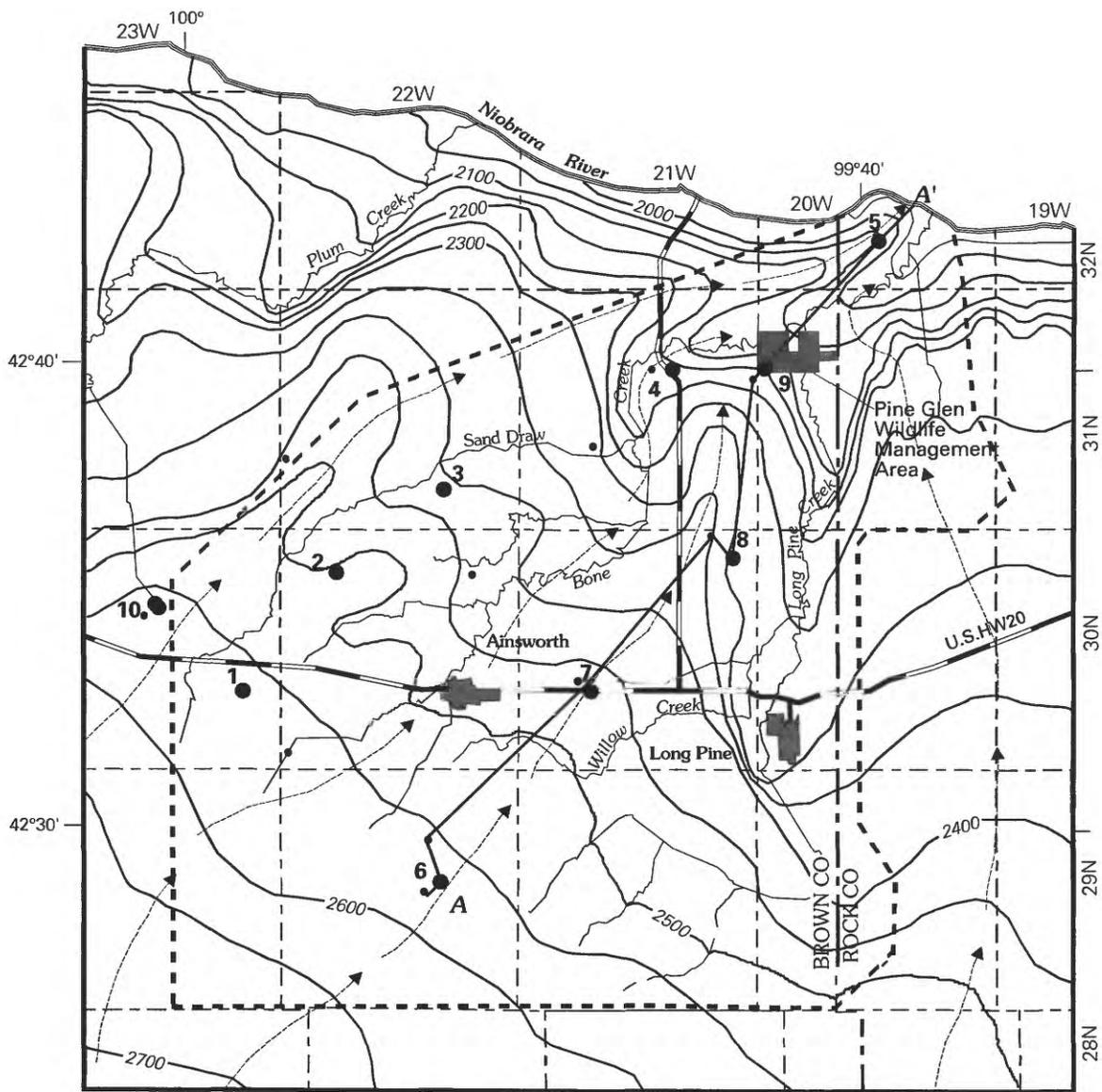
The direction of ground-water flow within the High Plains aquifer in the study area is generally from the southwest to the northeast (Cronin and others, 1956). Although the water table has risen and its slope has become steeper in some areas since the delivery of irrigation water began in 1964 through the Ainsworth Irrigation Project, little change in the direction of ground-water flow has been observed (Conservation and Survey Division, 1980) (fig. 3).

The High Plains aquifer in the study area receives recharge water from local precipitation, lateral ground-water flow from south of the area, and seasonally from seepage from the Ainsworth Irrigation Project and excess irrigation water. Discharge from the aquifer occurs principally through local streams in the area, to a lesser extent through evaporation and transpiration in areas where the water table is close to the land surface (in the southern part of the area), and through irrigation-well pumpage. During May through September each year, enough water recharges the aquifer from the system of canals to allow the aquifer to discharge water to the tributaries of Long Pine Creek during the rest of the year.

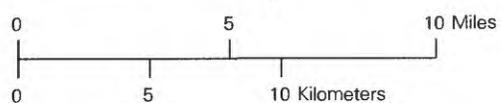
## **Land Use and Agricultural Chemical Use**

The population of the study area is estimated to be about 2,500. The chief population centers (1990) are Ainsworth, population 1,900, and Long Pine, population 400.

Nearly all of the land in the study area is used for crop and livestock production, with a minor amount used for lumber production. About 35,000 acres of cropland are irrigated by the Ainsworth Irrigation Project in the study area. As of 1991, 224 registered irrigation wells were located in and adjacent to the surface-water irrigated lands. Although the exact numbers are not available, many of the registered irrigation wells in the southern portion of the study area have not been used for crop production during the last few years. Corn is the dominant



Base from U.S. Geological Survey 1:500,000  
 State of Nebraska, 1984  
 Albers Equal-Area Conic projection  
 Standard parallels 29°30' and 45°30'  
 Central meridian-96°



**EXPLANATION**

- 2700- Lines of equal water-table elevation, in feet above sea level. Contour interval 50 feet.
- - - Boundary of the Long Pine Rural Clean Water Program and Long Pine study area
- ↗ Generalized ground-water flow path
- 8 Ground-water observation well site and number
- Geologic test hole

**Figure 3. Generalized potentiometric surface of the High Plains aquifer and ground-water flow paths in the Long Pine Creek study area, spring 1979 and 1994.**

irrigated crop, although some alfalfa is grown in sprinkler-irrigated fields north of the surface-irrigated farmland and native hay is grown in areas where the water table is near the land surface, in the southern part of the study area.

Relatively large amounts of fertilizer and pesticide are applied to irrigated corn fields annually to maintain crop yields. In the 1970's an estimated 180–220 pounds of nitrogen, 30–35 pounds of phosphate, and 50–60 pounds of potassium and a variety of pesticides were applied per acre in most irrigated cropland used to produce corn (Hermsmeyer, 1991). Although the total number of irrigated acres for Brown County has declined slightly from about 67,000 acres in 1987 to about 64,000 acres in 1991, the number of acres planted to corn increased slightly from 43,000 to 45,000 acres during that period (Nebraska Department of Agriculture, 1992). Thus, the total amount of fertilizers and pesticides being applied to cropland in the study area has probably been relatively constant during the past decade. Corn herbicides such as atrazine are among the more commonly used pesticides in the area.

## APPROACH

### Location and Installation of Ground-Water Observation Wells

To accomplish the objectives of this study, two transects of ground-water observation wells and nests of observation wells were installed, which trend from the southwest to the northeast through the study area, approximately parallel to generalized ground-water flow paths (Cronin and others, 1956; Conservation and Survey Division, 1980) (fig. 3). The two transects are composed of four sites each and they converge into a fifth site at the extreme northern end of the study area about 1.5 miles south of the Niobrara River. A description of well-completion data is presented in table 2. Geologic logs for each of the observation well sites are located in table 7 (at the back of the report).

The northwestern transect starts with site 1 (fig. 1) about 8 miles west of Ainsworth and just south of U.S. Highway 20 in an area characterized by a shallow water table and intensively irrigated crop production. The land use is generally consistent through the third site in the transect, although the

depth to water continues to increase northeastward along the transect. The fourth site (site 4) in the transect is bordering on the irrigated cropland area and has a much greater depth to water. The fifth site in the transect is located about 1.5 miles south of the Niobrara River in a rangeland area with a depth to water of about 130 feet.

The fourth and fifth sites are most likely not part of the same physical ground-water flow path as the first three sites because Sand Draw probably intercepts the shallower ground-water flow between sites 3 and 4. Nonetheless, sites 4 and 5 are considered to be representative of ground water in these portions of the basin and also are thought to represent the deeper ground-water flow paths through the study area.

The southeastern transect starts with site 6 (figs. 1, 2, and 3) on the edge of the Sand Hills about 6 miles south of the town of Ainsworth. This area consists of rolling, grass-covered hills with wet hay meadows in the lower areas. Depth to water at the site is 10 feet or less, and the land is used mainly for pasturing cattle and for hay production. The ground-water quality at this site is believed to represent relatively pristine water as it flows into the study area from a similar land-use area in the south.

The next two sites along the southeastern transect are in areas of intensively irrigated crop production with depths to water of about 10 feet at site 7 and about 130 feet at site 8. The fourth site, site 9, is located in the Pine Glen Wildlife Management Area, which is in an area of grass-covered rangeland and has a depth to water of about 135 feet (figs. 1 and 3). Much of the ground-water flow leaving site 8 is probably intercepted by Long Pine Creek rather than reaching site 9. Nonetheless, site 8 should be representative of ground water about 1 mile west that flows along the divide between Bone Creek and Long Pine Creek to reach site 9. Downgradient from site 9, Long Pine and Bone Creeks cut through the base of the Ogallala Formation and intercept most of the ground-water flow from that formation.

The sites were spaced about 3.5 to 6 miles apart and were composed of 1 to 3 ground-water observation wells of varying depths. All of the ground-water observation sites were located a minimum of 0.5 mile from the nearest surface-water irrigation canal. This was done to minimize the likelihood of collecting water samples that were influenced by canal-water chemistry.

**Table 2.** Location, depth, screened interval, median depth to water, and dominant land use for ground-water observation wells in the Long Pine area, north-central Nebraska, 1993 and 1994

[D, deep; M, medium; S, shallow; Cropland, irrigated; Rangeland, nonirrigated]

Well location		Well depth (feet)	Screened interval below land surface (feet)	Median depth to water (feet) <sup>1</sup>	Dominant land use near well
Identification number	Township, range, section, and quarter section				
1D	30N 23W 26 NE 1/4	350	230–350	10.11	Cropland
1M	30N 23W 26 NE 1/4	150	130–150	10.03	Cropland
1S	30N 23W 26 NE 1/4	40	30–40	9.74	Cropland
2D	30N 22W 8 NW 1/4	250	230–250	32.00	Cropland
2S	30N 22W 8 NW 1/4	70	50–70	29.36	Cropland
3D	31N 22W 35 NW 1/4	352	332–352	45.85	Cropland
3S	31N 22W 35 NW 1/4	130	110–130	45.24	Cropland
4D	31N 21W 10 SE 1/4	255	225–245	158.32	Cropland
4S	31N 21W 10 SE 1/4	187	167–187	158.52	Cropland
5	32N 20W 27 SW 1/4	155	145–155	126.06	Rangeland
6D	29N 22W 14 SW 1/4	400	380–400	8.24	Rangeland
6M	29N 22W 14 SW 1/4	200	180–200	6.89	Rangeland
6S	29N 22W 14 SW 1/4	50	40–50	6.67	Rangeland
7D	30N 21W 29 NE 1/4	250	230–250	12.05	Cropland
7S	30N 21W 29 NE 1/4	50	30–50	9.54	Cropland
8D	30N 21W 1 SW 1/4	295	175–295	126.47	Cropland
8M	30N 21W 1 SW 1/4	203	183–203	126.06	Cropland
8S	30N 21W 1 SW 1/4	150	130–150	126.68	Cropland
9	31N 20W 7SW 1/4	180	160–180	134.63	Rangeland
10D	30N 23W 9 SE 1/4	200	160–180	14.74	Cropland
10S	30N 23W 9 SE 1/4	65	45–65	14.68	Cropland

<sup>1</sup>Based on four measurements during 1993–94.

A tenth site is located about 11 miles west of Ainsworth, and is just outside of the Long Pine Creek RCWP boundaries. This site was included in the study to serve as a control by which changes in ground-water quality at the other sites within the RCWP can be measured over time. The location for site 10 was selected because it was adjacent to the RCWP project boundaries and had similar land-use and hydrologic characteristics, was not subjected to BMP implementation, and was drained by a different stream system.

The wells were drilled with a mud rotary rig, cased with 3-inch-diameter, flush-joint threaded PVC casing with 20-foot-long, 0.0125-inch slotted PVC screens at the bottom. Selected wells were screened with 10-foot-long, 0.0125-inch slotted PVC screens. A gravel pack was installed around the screened interval from the bottom of the screened interval to about 5 feet above it. The annular space above the

gravel pack was sealed with bentonite pellets. The remaining annular space was backfilled with a mixture of bentonite and drill cuttings to within 3 feet of the land surface. A cement grout, 3 feet deep and 2 feet wide, was installed around each well at the land surface. The wells were developed with compressed air until the discharge was reasonably clear. A submersible pump was used to further develop the wells prior to sample collection.

### Water-Quality Sample Collection

Ground-water-quality samples were collected four times from each of the ground-water observation wells from August 1993 through June 1994. The depth to water was measured and recorded for each well prior to water-sample collection. Water samples were collected through a stainless-steel and

polytetrafluoroethylene (PTFE) submersible pump with PTFE-lined polypropylene discharge tubing. The wells were pumped a sufficient length of time to withdraw a minimum of three casing volumes of water prior to the collection of water samples to assure that the samples were representative of the aquifer. Additionally, field measurements of specific conductance, pH, temperature, and dissolved-oxygen concentration of the ground water were monitored using a flowthrough chamber every 3–5 minutes during the pumping of the wells. When the field measurements were consistent for two measurement intervals after the minimum of three casing volumes of water had been removed from the well, water samples were collected for analyses.

Unfiltered water samples, used for laboratory determinations of pH, specific conductance, and alkalinity, were collected directly from the PTFE-lined tubing connected to the submersible pump. Filtered samples were collected in a 6-liter polypropylene churn splitter and pumped through the appropriately sized filter with a peristaltic pump with tygon tubing. The churn splitter was washed with a laboratory-grade detergent in the laboratory and rinsed with distilled water prior to use in the field. After the first use in the field, the churn splitter was rinsed 10 times with discharge water from the well from which the next water samples were to be collected. Water samples collected for nutrient analyses (nitrite, nitrate, ammonium, and phosphorus) were filtered through a 0.45-micrometer membrane filter, preserved with 0.5 mL (milliliter) of mercuric chloride and hydrochloric acid, and immediately chilled to about 4 degrees Celsius. Water samples collected for major cations, iron, and manganese analyses were filtered with 0.45-micrometer membrane filters and adjusted to a pH of 2 or less with 1 mL of nitric acid. Water samples were collected and analyzed for triazine and related herbicide analyses twice—once in August 1993 and again in June 1994. These water samples were filtered through a 1.0-micrometer glass filter into a 1-liter, baked, glass pesticide bottle with a PTFE-lined cap and immediately chilled to about 4 degrees Celsius. Water samples collected for anion analysis were filtered with a 0.45-micrometer membrane filter and stored at ambient temperature without preservation. Water samples were usually collected within a 3–4 day period and were sent to the U.S. Geological Survey's National Water-Quality

Laboratory (NWQL) in Arvada, Colorado, within 1 week of sample collection.

## Analytical Methods

The analyses for concentrations of all inorganic species, with the exception of tritium, were performed in the NWQL using methods described by Fishman and Friedman (1989). All nitrogen and phosphorus compounds were analyzed by colorimetric methods. The cadmium-reduction method was used to analyze nitrate and nitrite. Atomic absorption and emission spectrometric methods were used to analyze the metals. Inductively coupled plasma methods were used to analyze silica and chloride. A turbidimetric method was used to analyze sulfate and an ion-selective electrode method was used for fluoride.

Water samples intended for tritium analysis were sent to the NWQL and were then forwarded to the University of Miami. The University of Miami uses an electrolytic enrichment gas counting method for the analysis of tritium.

Prior to sending the water samples to the NWQL, an aliquot from each of the pesticide samples was screened for the presence of triazine herbicides using an enzyme-linked immunosorbent assay procedure (ELISA) (Pomes and others, 1991). When the results of the triazine screening test indicated total triazine concentrations of 0.1 microgram per liter ( $\mu\text{g/L}$ ) or more, the rest of the 1-liter sample was forwarded to the NWQL for gas chromatography-mass spectrometry (GC/MS) analyses. About 10 percent of the water samples with negative ELISA results also were submitted to the NWQL for GC/MS analysis. The GC/MS analytical method is described by Sandstrom and others (1991) and involves the solid-phase extraction of water samples, elution with hexaneisopropanol, and analysis by capillary-column GC/MS with selected-ion monitoring.

## Quality Control and Quality Assurance

A variety of quality-control techniques are a part of every analysis that is performed at the NWQL. The following is a brief overview of some of the techniques used by the NWQL to ensure reliable, precise, and accurate analytical data (Jones, 1987).

Bottles used for sample collection, the chemicals used for sample preservation, and the field filters are subject to quality control by the NWQL. The NWQL adheres to standard, analytical methodologies and maintains strict protocols in handling both samples and analytical results. The NWQL maintains a series of checks and balances on analytical production such as the systematic inclusion of laboratory blanks and standards of known concentrations with each batch of field samples that are analyzed.

The water-quality assurance program of the NWQL includes a laboratory blind-sample program in which blind quality-assurance samples are intermixed with field samples on a daily schedule to verify the precision and accuracy of inorganic constituents. The NWQL participates in an external blind-sample program through the U.S. Geological Survey's Branch of Quality Assurance, which submits blind samples for most inorganic analyses on a daily basis. Additionally, the NWQL participates in the U.S. Geological Survey and U.S. Environmental Protection Agency interlaboratory evaluation programs in which laboratories throughout the Nation receive and analyze blind samples.

Another quality-assurance check for major ions is the anion-cation balance. Because water is essentially neutrally charged, the sum of the positive charges should equal the sum of the negative charges for any given water sample. If the ionic charges do not balance within a 5-percent difference, the major anions and cations are reanalyzed by the NWQL.

In the field, in addition to standard sampling and processing protocols, quality-assurance samples are submitted for most analyses. About 5 percent of all samples submitted to the NWQL for analysis were replicate samples for one or more sites. The analyses of these samples provide an external check of the precision of the laboratory analyses. Repetitive sampling of the same sites over many months also makes it possible to compare new analyses with earlier ones as a means of identifying potentially nonrepresentative analyses (Kruskal and Wallis, 1952).

## Statistical Analyses

Statistical analyses were performed on the water-quality data to describe the distributions of individual variables, to identify relations between different variables, and to test the significance of

relations between subsets of variables. Robust statistics such as minimum, maximum, and percentiles were used to describe variable distributions. Spearman's rho (Spearman, 1904; Conover, 1971), a correlation method using ranked values, was used to identify increasing or decreasing relations between pairs of variables. The Mann-Whitney test (Mann and Whitney, 1947; Conover, 1971), a nonparametric or distribution-free method, was used to test hypotheses that median values of separate populations of variables were the same or different. The Kruskal-Wallis test (Kruskal and Wallis, 1952; Conover, 1971) was used to determine if median values were different when variables were divided into more than two groups. A 95-percent confidence level was used to identify the difference in medians as being either statistically significant or not significant. P-values also are presented with the results of the Mann-Whitney tests as a measure of test's reliability. A p-value is the probability of getting a test statistic equal to or more extreme than the value computed from the same data when the medians of the two populations being tested are the same. More simply, p-values of 0.05 or smaller indicate that the medians of the populations being considered are different. The smaller the p-value, the greater is the confidence in that difference. Conversely, the larger the p-value is above 0.05, the greater is the confidence that there is no difference between the medians of the two populations.

## GROUND-WATER QUALITY RESULTS

Results of the water-quality analyses are presented in table 8 (at the back of the report). These results show that the ground water in the study area is generally a well-oxygenated, calcium carbonate water with very limited mineralization. In areas directly influenced by irrigated agricultural activities, the water tends to be more mineralized and contains elevated concentrations of potassium, sulfate, and nitrate. Traces of herbicides and/or herbicide-degradation products were found in four ground-water samples that were collected at 4 of the 10 sites in August 1993.

## Field Measurements

Specific conductance is a measure of the electrical conductivity of water that relates directly

to the concentrations of dissociated major ions. Specific-conductance values for ground-water samples collected during this study ranged from 94 to 859  $\mu\text{S}/\text{cm}$  (microsiemens per centimeter) at 25°C (degrees Celsius) (table 3). The median value of 176  $\mu\text{S}/\text{cm}$  was relatively small compared to median values of 555 and 440  $\mu\text{S}/\text{cm}$  for ground-water samples from deposits of Quaternary age (upper portion of the High Plains aquifer) and the Ogallala Formation (lower portion of the High Plains aquifer), respectively, as determined by Engberg (1984) for the entire State. Water samples collected from wells screened in the shallower deposits of Quaternary age in the study area were more heavily mineralized than water samples from wells completed in the underlying Ogallala Formation. The median specific conductance was 249  $\mu\text{S}/\text{cm}$  in water samples from the four wells (1S, 2S, 6S, and 7S) screened in deposits of Quaternary age, and 162  $\mu\text{S}/\text{cm}$  in water samples from the 15 wells (excluding the control site) screened in the Ogallala Formation. Also, specific conductance of ground-water samples from areas of irrigated agriculture (sites 1, 2, 3, 4, 7, and 8) were significantly larger than for ground-water samples from areas of nonirrigated agriculture and rangeland (sites 5, 6, and 9) (Mann-Whitney test,  $p$ -value = 0.0003).

The pH of the water samples, which is the negative log of the hydrogen ion activity, ranged from 6.5 to 8.2 (table 3). Values of pH increased with well depth in the study area (Spearman's  $\rho$  = 0.63), probably because the shallow ground water is influenced by carbon dioxide from the unsaturated zone and the deeper waters by calcium carbonate cement common in the Ogallala Formation.

Temperatures ranged from 10.5 to 17.5 degrees Celsius among all of the water samples (table 3) and varied somewhat seasonally. Temperatures generally increased slightly with increased well depth (Spearman's  $\rho$  = 0.61) and tended to fluctuate with the air temperature seasonally.

Concentrations of dissolved oxygen in water samples ranged from 1.8 to 11.1 mg/L (milligrams per liter) (table 3). Concentrations of dissolved oxygen in water samples from a given nest of observation wells frequently decreased from shallow to deeper wells as would be expected because water from deeper flow paths has had exposure to oxygen-consuming chemical processes. Concentrations of dissolved oxygen in water samples from individual wells tended to fluctuate with seasonal changes in air temperature.

Alkalinity is a measure of the water's ability to neutralize acid. Alkalinity in the ground-water samples collected from different wells was highly variable and ranged from 24 to 357 mg/L as calcium carbonate (table 3). The largest alkalinities were observed in water samples from well 2S (table 8). Variations in alkalinity showed no relation to well depth; however, there appears to be a weak positive association (Spearman's  $\rho$  = 0.56) between alkalinity and depth to water. The alkalinity of ground water from the Ogallala Formation tended to be larger than the alkalinity of water from deposits of Quaternary age.

## Major Ions

Most of the ground-water samples were a calcium bicarbonate type (fig. 4), with a few calcium sodium bicarbonate water types and a few calcium bicarbonate nitrate water types in areas where the nitrate concentrations were large. The concentrations of major ions in ground water tended to be larger in water from deposits of Quaternary age than from the Ogallala Formation, which is consistent with Engberg's (1984) statewide statistical comparison of ground-water samples from these geologic units.

Median concentrations of the major ions exceeded 10 mg/L only for calcium (median concentration of 23 mg/L) and silica (median concentration of 59 mg/L) (table 3) within the study area. Concentrations in ground water of all major ions except fluoride and silica decreased with increasing well depth. Similarly, the concentrations of all of the major ions except silica were larger in water samples collected from deposits of Quaternary age than in water samples collected from the Ogallala Formation (Mann-Whitney test,  $p$ -value range <0.0001 to 0.05). The trace element manganese also showed the same relation with depth and geologic unit. The median concentrations of iron in ground-water samples from the Ogallala Formation were larger than those from the deposits of Quaternary age; however, the difference was not statistically significant (Mann-Whitney test,  $p$ -value = 0.07).

Calcium was the principal cation in nearly all of the water samples. Calcium concentrations ranged from 10 to 98 mg/L (table 3). The largest concentrations of calcium were found in water from well 2S (table 8). Calcium concentrations in the water

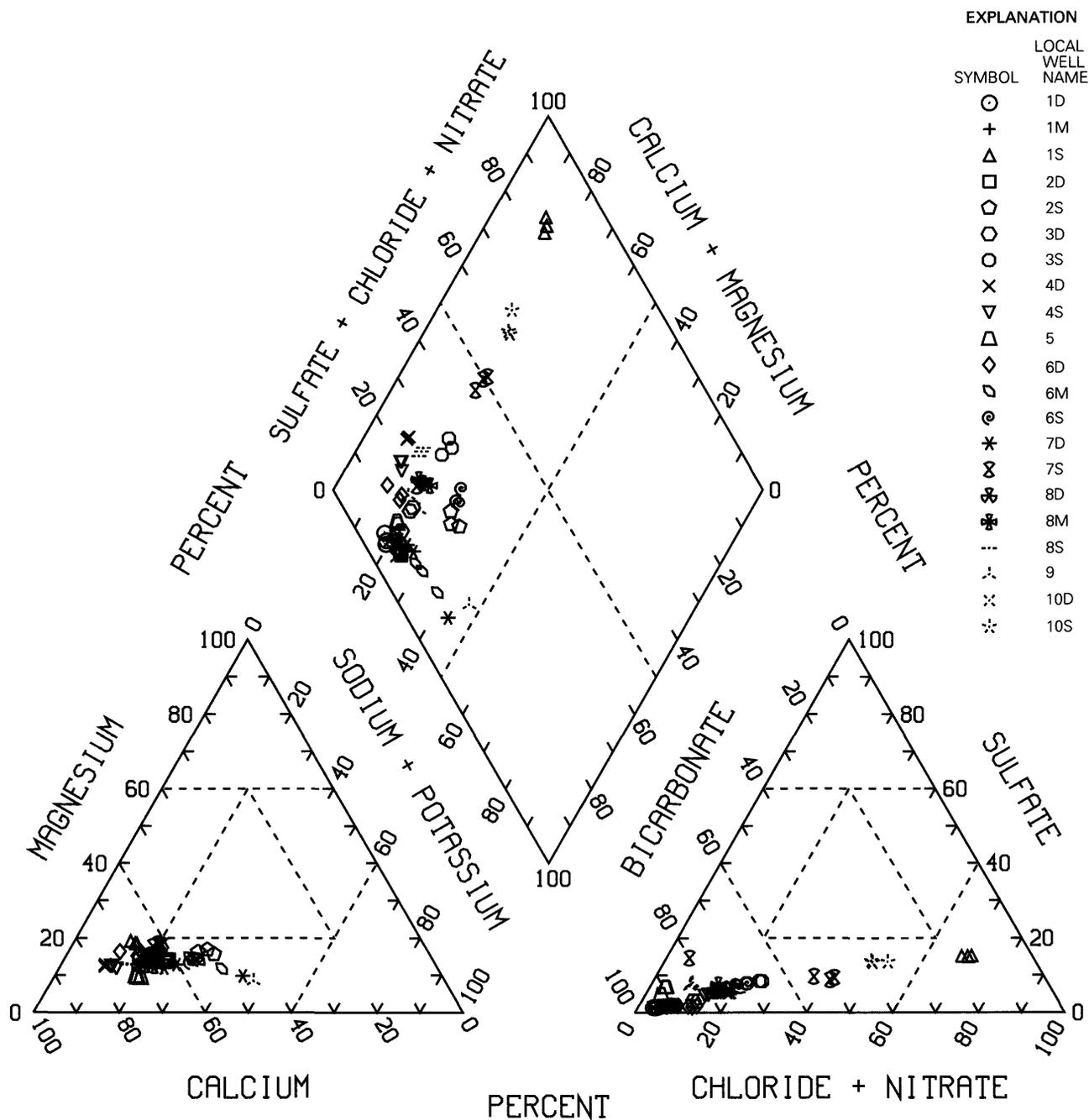
**Table 3. Summary of field measurements and chemical analyses for major ions, nutrients, and trace elements for ground-water samples collected in the Long Pine Creek study area from August 1993 through June 1994**

[Upper values represent data from 19 observation wells collected within the Long Pine Creek Rural Clean Water Program (RCWP) area. Lower values represent data from two wells at site 10, outside of the RCWP area. Concentrations in milligrams per liter (mg/L) unless listed. All concentrations are dissolved. USEPA, U.S. Environmental Protection Agency;  $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius;  $\mu\text{g}/\text{L}$ , micrograms per liter; NA, not applicable; <, less than]

Constituent	Number of water samples analyzed	USEPA drinking-water regulation <sup>1</sup>	Number of water samples exceeding regulation	Concentration or value				
				Minimum	25th percentile	Median	75th percentile	Maximum
Specific conductance ( $\mu\text{S}/\text{cm}$ )	74	NA	NA	94	128	176	342	859
	8			180	182	300	436	474
pH, lab (standard units)	79	6.5–8.5*	0	6.5	7.3	7.6	7.7	8.2
	8			6.7	6.8	7.4	7.8	8.0
Temperature (degrees Celsius)	78	NA	NA	10.5	12.0	13.0	14.0	17.5
	8			11.0	11.1	12.2	12.9	13.5
Dissolved oxygen	77	NA	NA	1.8	3.7	6.2	7.9	11.1
	8			1.0	1.1	3.4	7.9	9.3
Alkalinity as $\text{CaCO}_3$	79	NA	NA	24	56	69	145	357
	8			71	72	82	90	95
Calcium	79	NA	NA	10	16	23	50	98
	8			23	24	36	53	59
Magnesium	79	NA	NA	1.4	2.0	3.1	5.8	18
	8			3.2	3.3	5.4	7.6	8.1
Sodium	79	NA	NA	3.4	4.5	5.3	8.4	61
	8			5.6	5.9	10	13	14
Potassium	79	NA	NA	.4	3.9	5.0	6.3	16
	8			4.3	4.5	6.2	6.3	6.9
Sulfate	79	250*	0	.8	1.2	4.9	11	28
	8			1.5	1.6	13.4	27	29
Chloride	79	250*	0	.2	.5	.8	2.2	9.0
	8			.4	.5	4.7	9.6	11
Fluoride	79	4*	0	<.1	.2	.2	.3	.5
	8			<.1	.1	.2	.2	.3
Silica	79	NA	NA	30	52	59	62	73
	8			38	39	48	65	66
Iron ( $\mu\text{g}/\text{L}$ )	78	300*	0	<3	<3	4.0	6	32
	8			<3	<3	5	7	10
Manganese ( $\mu\text{g}/\text{L}$ )	79	50*	0	<1	<1	<1	2	20
	8			<1	<1	<1	3	4
Dissolved solids	79	500*	4	107	132	161	253	570
	8			161	163	227	309	330
Nitrite as N	78	1	0	<.01	<.01	<.01	<.01	.01
	8			<.01	<.01	<.01	<.01	<.01
Nitrite plus nitrate as N	78	10	<sup>2</sup> 15	.5	.9	2.3	9.2	32
	8			.5	.6	11.8	24	27
Ammonium as N	78	NA	NA	<.01	.02	.02	.03	.07
	8			.01	.02	.02	.03	.03
Orthophosphate as P	79	NA	NA	<.01	.05	.11	.19	.47
	8			.03	.03	.10	.17	.18

<sup>1</sup>U.S. Environmental Protection Agency (1994) primary drinking-water regulations unless noted with an asterisk, in which case the value is a secondary drinking-water regulation.

<sup>2</sup>Includes water samples from four of the nine sites within the study area.



**Figure 4.** Ionic composition of ground-water samples from the Long Pine Creek study area, north-central Nebraska, 1993-94.

collected throughout the study area tended to decrease with well depth and were larger in deposits of Quaternary age than in the Ogallala Formation.

Magnesium, sodium, and potassium in ground water within the study area, with median concentrations of 3.1, 5.3, and 5.0 mg/L, respectively (table 3) were considerably less than calcium. These ions followed the same relations relative to vertical distribution and geologic unit as calcium.

The concentrations of sulfate, chloride, and fluoride within the study area also were small with median values of 4.9, 0.8, and 0.2 mg/L, respectively (table 3). The concentrations of these constituents were larger in water from shallow wells screened in deposits of Quaternary age than in the underlying Ogallala Formation. Also, median concentrations of chloride were larger in ground-water samples from areas of irrigated agriculture than in ground-water samples from nonirrigated areas (table 2 and fig. 5) (Mann-Whitney test,  $p$ -value =  $<0.0001$ ). Concentrations of sulfate also were larger in ground-water samples from irrigated areas than in ground-water samples from nonirrigated areas, but the median concentrations were not statistically significant (Mann-Whitney test,  $p$ -value = 0.086).

Concentrations of silica in water samples range from 30 to 73 mg/L with a median of 59 mg/L (table 3). Unlike the major ions, concentrations of silica in water samples tend to be larger (more than 55 mg/L) in the deep wells than in shallow wells (Spearman's  $\rho$  = 0.69). Similarly, concentrations of fluoride, which ranged from  $<0.1$  to 0.5 mg/L (table 3), also increased with the depth of the well (Spearman's  $\rho$  = 0.47). Water from the deep wells followed much longer flow paths than the water from the shallower wells, and this water is in contact with aquifer materials, principally quartz, for long periods of time. This longer exposure time has enabled the water to dissolve larger concentrations of silica and fluoride than younger water found in most of the shallower wells.

Concentrations of dissolved solids in the ground water range from 107 to 570 mg/L with a median of 161 mg/L (table 3). Concentrations of dissolved solids show the same relations to well depth and geologic unit as did most of the major ions. All water samples collected from well 2S exceeded the secondary drinking-water regulation of 500 mg/L (U.S. Environmental Protection Agency, 1994) for dissolved solids (table 8). Dissolved-solids concentra-

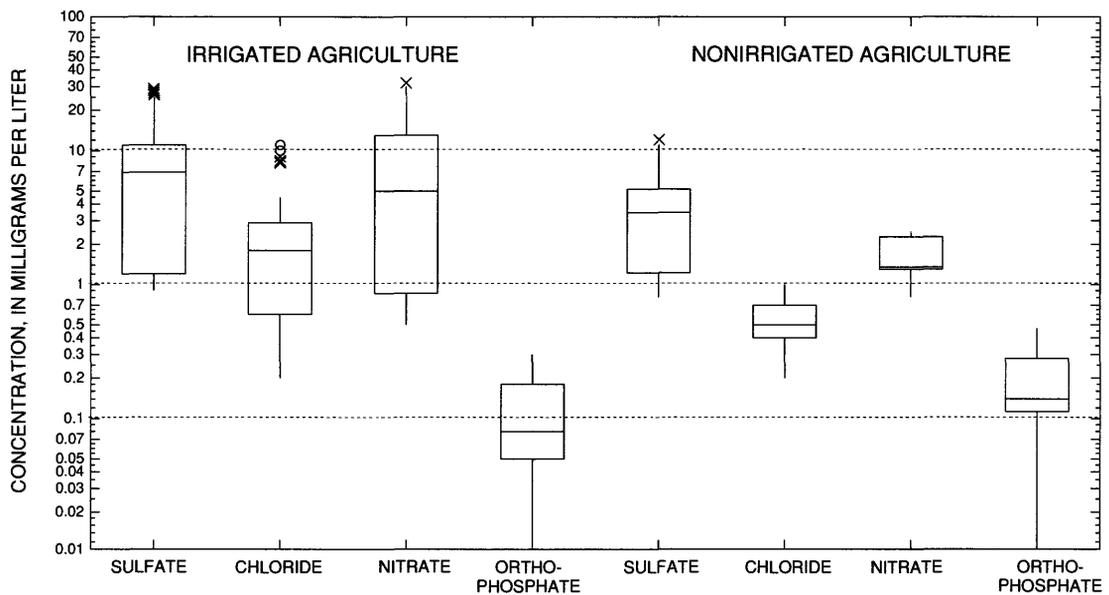
tions in water from most of the other wells ranged from 100 to 350 mg/L. Dissolved-solids concentrations in most water samples from well depths of 200 feet or greater were below 150 mg/L. This pattern of larger ion concentrations in water samples from shallower wells than from deeper wells can be explained by the larger abundance of more easily dissolved materials such as feldspar minerals in the shallower aquifer material. The application of agricultural fertilizer in row-cropped areas also is a likely source of elevated dissolved-solids concentrations in water from the shallow wells.

### Nutrients and Seasonal Variability in Nitrate Concentrations

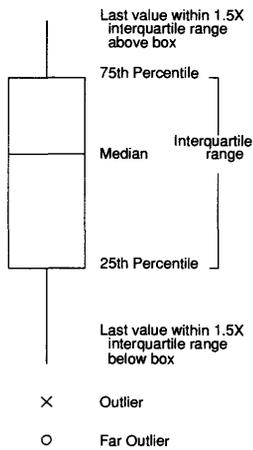
Nutrients detected in ground-water samples consisted principally of nitrate ( $\text{NO}_3$ ). Nitrite ( $\text{NO}_2$ ), which is formed from the chemical reduction of nitrate, was present in one water sample from well 6S at the detection limit of 0.01 mg/L (as N) (table 8 at back of report). The lack of detectable concentrations of nitrite, even in the deep wells, in conjunction with the presence of dissolved oxygen suggests the prevalence of oxidizing conditions and thermodynamically does not support the presence of nitrite.

Nitrite plus nitrate concentrations (hereinafter referred to as nitrate) in ground-water samples from the wells ranged from 0.05 to 32 mg/L (as N). The median concentration of nitrate for 78 samples was 2.3 mg/L (table 3). Nitrate concentrations exceeded the Maximum Contamination Level (MCL) established by U.S. Environmental Protection Agency (1994) for drinking water of 10 mg/L in 15 ground-water samples. The 15 water samples came from shallow wells at four sites (1S, 2S, 7S, and 8S), all of which are in areas of irrigated agriculture (table 8 at back of report). Concentrations of nitrate also exceeded the MCL in the four water samples collected from the shallow well at site 10 (10S), just outside of the RCWP area.

Nitrate concentrations in ground water were negatively correlated to well depth (Spearman's  $\rho$  =  $-0.53$ ). When nitrate concentrations from observation wells in areas of only irrigated agriculture were considered (well nests 1, 2, 3, 4, 7, and 8), the negative correlation with well depth improved (Spearman's  $\rho$  =  $-0.68$ ). These relations suggest that the nitrate concentrations are most likely the result



**EXPLANATION**

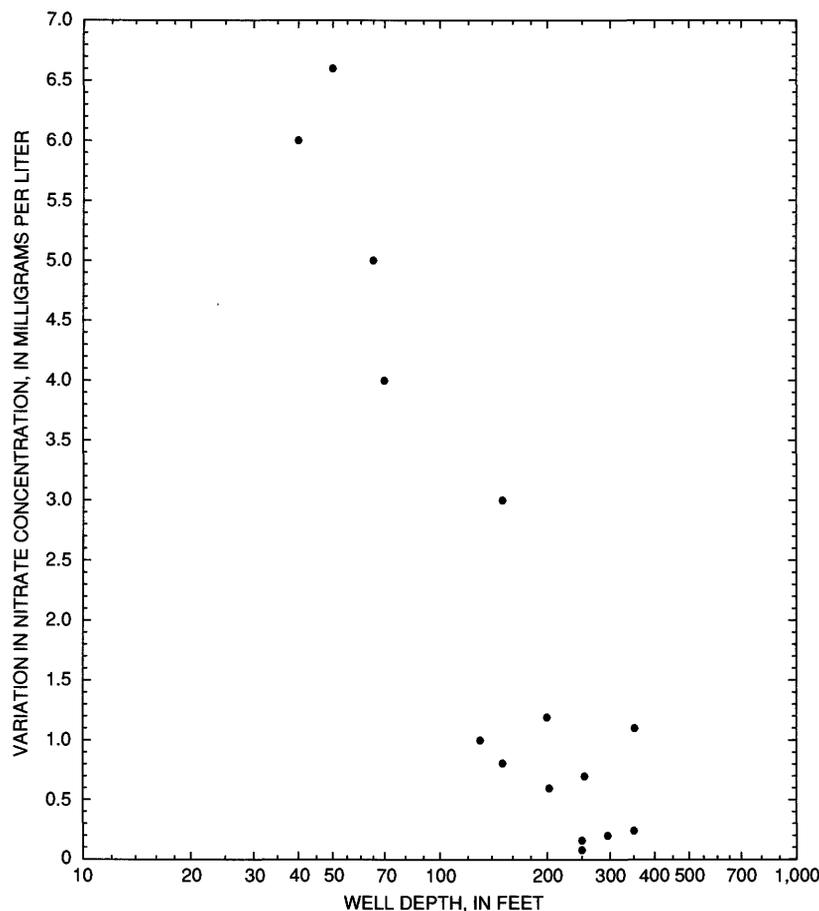


**Figure 5.** Distributions of sulfate, chloride, nitrate, and orthophosphate concentrations in ground water from areas of irrigated and nonirrigated agriculture in the Long Pine Creek study area, north-central Nebraska, 1993–94.

of agricultural fertilizer application associated with irrigated crop production in the area. Further support to this interpretation is provided by the close correlation of nitrate concentrations with sulfate and chloride concentrations (Spearman's rho = 0.88 and 0.80, respectively), which are frequently components in commercial and/or animal fertilizers (Sittig, 1974). No apparent associations were found between concentrations of nitrate and well depth, sulfate, and chloride concentrations in ground-water samples from observation wells in areas of nonirrigated agriculture (well nests 5, 6, and 9) (Spearman's rho = 0.08, 0.03, and -0.20, respectively). Concentrations of nitrate in ground water also were correlated with specific conductance measurements (Spearman's rho = 0.75).

Seasonal variation was apparent in nitrate concentrations in ground-water samples from the observation wells in areas of irrigated agriculture.

Nitrate concentrations in water samples from individual wells varied from 0.08 to 6.6 mg/L, seasonally. The amount of this variation in areas of irrigated agriculture is negatively correlated to the log of well depth (Spearman's rho = -0.76) (fig. 6). No relation was observed between variations in nitrate concentration in ground-water samples and well depth for observation wells that were in areas of nonirrigated agriculture (Spearman's rho = 0.10). No single sampling period showed significantly larger concentrations of nitrate in water samples than any other period (Kruskal-Wallis test, p-value = 0.94). This was true both when all sites were grouped together and when only sites from areas of irrigated agriculture were considered. However, about two-thirds of the largest concentrations of nitrate from all water samples were collected during the first and second sample-collection trips in August and in early



**Figure 6.** Relation of variations in nitrate concentrations in ground water to well depth in areas of irrigated agriculture in the Long Pine Creek study area in north-central Nebraska, 1993–94.

November. Therefore, late summer to fall might be a time to observe relatively large concentrations of nitrate in ground water.

Ammonium (NH<sub>4</sub>) concentrations in ground-water samples were quite low as would be expected in water containing detectable amounts of molecular oxygen (O<sub>2</sub>). Ammonium concentrations ranged from less than 0.01 to 0.07 mg/L as N and had a median concentration of 0.02 mg/L (table 3). Ammonium concentrations in ground-water samples were not correlated to observation well depth and were only weakly correlated to depth to water (Spearman's rho = -0.04 and 0.22, respectively). Also, there was no clear distinction between concentrations of ammonium and variations in concentrations of ammonium in observation wells located in areas of irrigated agriculture and in areas of nonirrigated agriculture (Mann-Whitney test, p-value = 0.10 and p-value = 0.26, respectively).

Concentrations of orthophosphate from ground-water samples ranged from less than 0.01 to 0.47 mg/L (as phosphorus), with a median concentration of 0.11 mg/L (table 3). Median concentrations of orthophosphate for water samples collected in areas of irrigated agriculture and for water samples from areas of nonirrigated agriculture, which includes rangeland, were 0.08 and 0.14 mg/L, respectively, and were significantly different (Mann-Whitney test, p-value = 0.02). The larger concentrations of orthophosphate observed in samples of ground water in nonirrigated areas may be the result of livestock manure. Orthophosphate concentrations in ground water also were negatively correlated with well depth (Spearman's rho = -0.64), which is reasonable given that phosphate tends to partition to sediment rather than water and is not very mobile.

## Herbicides

Water samples from the 21 observation wells were collected in August of 1993 and screened for triazine herbicides using ELISA (Pomes and others, 1991). The ELISA results were inconclusive for most samples, so water samples from all but two wells (7D and 8D) were analyzed by the NWQL using GC/MS methodology. Herbicides analyzed using this method included alachlor, ametryn, atrazine, cyanazine, deethylatrazine, deisopropylatrazine, metolachlor, metribuzin, prometon, prometryn, and propazine. Additional GC/MS analyses were performed on ground-water samples from selected observation wells in June 1994. The results of GC/MS analyses from both sampling periods are shown in table 8 at the back of this report, and a summary of the results is presented in table 4.

Water samples from 4 of the 19 observation wells that were analyzed for triazine herbicides contained trace amounts of atrazine or its metabolites during the two sampling periods (table 8). Atrazine, a broadleaf herbicide used in corn and sorghum fields, was detected in water samples from two observation wells (1S and 2S). Deethylatrazine, a relatively long-lived metabolite of atrazine, was detected in the same water samples containing atrazine and in water samples from two additional observation wells (7S and 10S). Deisopropylatrazine, a relatively short-lived metabolite of atrazine, was detected in one of the water samples also containing a trace amount of atrazine (1S) (table 8). Atrazine, deethylatrazine, and deisopropylatrazine were found only in shallow observation wells (less than 100 feet deep) in areas of irrigated, row-crop agriculture. Concentrations of nitrate exceeding 10 mg/L were present in all water samples containing atrazine or its metabolites.

**Table 4.** Summary of herbicide analyses of ground-water samples collected in August 1993 and June 1994

[Concentrations in micrograms per liter (µg/L). USEPA, U.S. Environmental Protection Agency; <, less than; NA, not applicable. The following herbicides also were analyzed but were not detected at or above the reporting limits of 0.05 µg/L: alachlor, ametryn, cyanazine, metolachlor, metribuzin, prometon, prometryn, and propazine]

Constituent	Number of water samples analyzed	USEPA primary drinking-water regulation <sup>1</sup>	Number of water samples with concentrations at or above the reporting limit	Concentrations	
				Minimum	Maximum
Atrazine	26	3.0	2	<0.05	0.8
Deethylatrazine	26	NA	4	<.05	1.4
Deisopropylatrazine	26	NA	1	<.05	.13

<sup>1</sup>U.S. Environmental Protection Agency, 1994.

## Quality-Assurance Results

Replicate water samples for all inorganic analyses were collected from randomly selected wells—2D, 7S, and 8D—during three of the four sample-collection periods. Replicate samples were collected, processed, and submitted for analysis in the same manner as the regular samples.

Generally, little analytical variation was found when comparing the original sample results with the replicate sample results (table 5). Most sample pairs showed less than a 3-percent variation in concentration. Concentrations of sulfate and iron showed the largest percentage of variation between the original samples and the replicate samples with an average percent variation for the three paired samples of 22 percent for both constituents. The percent variation for replicate samples of these constituents is a bit misleading because the water samples contained only small concentrations, and minor differences of only 0.1 to 2 mg/L produced large percent differences.

## CHEMICAL EVOLUTION OF GROUND WATER

The chemistry of ground water in the Long Pine Creek study area is the product of the natural interaction of the ground water with aquifer materials as the water moves along flow paths and the accumulation of anthropogenic chemicals from both recent and past land-use activities that has accompanied recharge to the aquifer. This section discusses the impact of current land-management practices on ground-water quality in the study area, trends in water quality associated with increased agricultural activities over time, and the age of selected ground-water samples collected during this study. These aspects are combined with hydrologic and chemical data to describe the general chemical evolution of ground water as it moves beneath the study area.

**Table 5.** Results of replicate ground-water sample analyses for major ions, nutrients, and trace elements in the Long Pine Creek study area, 1993–94

[ $\mu\text{S/cm}$ , microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter;  $\mu\text{g/L}$ , micrograms per liter]

Constituent	Average percent difference in concentration of three paired samples	Maximum variation in concentration of paired samples
Specific conductance, laboratory ( $\mu\text{S/cm}$ )	0.5	2
Alkalinity, as $\text{CaCO}_3$ (mg/L)	7.6	15
Ammonium, as N (mg/L)	.6	.3
Nitrite, as N (mg/L)	0	0
Nitrate, as N (mg/L)	3.4	.01
Orthophosphate as P (mg/L)	3.7	.01
Calcium (mg/L)	0	0
Magnesium (mg/L)	1.7	.1
Sodium (mg/L)	2.2	.1
Potassium (mg/L)	7.8	1.0
Chloride (mg/L)	12	.2
Sulfate (mg/L)	22	2.0
Fluoride (mg/L)	0	0
Silica (mg/L)	.6	1
Iron ( $\mu\text{g/L}$ )	22	1
Manganese ( $\mu\text{g/L}$ )	0	0
Dissolved solids (mg/L)	1.6	7

## Comparison of Ground-Water Quality of the Long Pine Creek Rural Clean Water Program with Control Site

Site 10, located just west of the Long Pine Creek RCWP area in the Plum Creek Basin, was selected as a control with which to compare changes in ground-water quality in the Long Pine Creek RCWP area, where BMPs were encouraged, to nonproject areas in which there were no special efforts to establish the use of BMPs. No data were available prior to the implementation of the Long Pine RCWP for comparison of initial water-quality conditions at site 10 with other sites within the RCWP area. Thus it is unknown if currently observed differences in ground-water quality between site 10 and sites within the RCWP area are the result of initial conditions or are the direct result of different land-management practices. Furthermore, it is not known if sufficient time has passed for the ground-water quality to reflect changes in land-management practices.

Based on data from four sample-collection periods, the water quality of the deep observation well at site 10 did not appear to differ appreciably from the quality of water samples collected from deep wells at other sites in the area of irrigated agriculture (sites 1, 2, 3, 4, 7, and 8). Median concentrations of sulfate, chloride, and nitrate in water from the shallow well at site 10, which is more susceptible to contamination from agricultural chemicals than the deep well, were significantly larger than median concentrations from other shallow observation wells in areas of irrigated agriculture located in the study area (Mann-Whitney test, p-values = 0.019, 0.008, and 0.0013, respectively). The largest concentrations of sulfate and chloride observed during the study were found in water samples from the shallow well at site 10. These results suggest that the effects of agricultural activities on the quality of shallow ground water may be more pronounced near site 10 than at sites within the Long Pine Creek RCWP area. A more detailed analysis of water-quality data would be required from 5 to 10 wells both inside and outside of the Long Pine Creek RCWP area to determine conclusively if BMPs are having a significant impact on ground-water quality relative to areas outside of the RCWP boundaries.

## Comparison of Current and Historical Ground-Water-Quality Data

The earliest available data on ground-water quality in the study area were collected by Cronin and others (1956), from five wells near the towns of Ainsworth and Long Pine from 1949 through 1952. These wells ranged in depth from 65 to 70 feet and were located in areas with shallow water tables and intensive row-crop agriculture. The locations of these wells were close to sites 7 and 8 and similar in depth to water and land use to site 10; therefore, the historical water-quality data were compared to current water-quality data from wells 7S, 8S, and 10S.

Generally, the quality of the shallow ground water at these sites was better in the early 1950's than it is currently. Specific conductance and concentrations of calcium, sulfate, and nitrate were significantly larger in recent water samples than in the historical data (Mann-Whitney test, p-values = 0.0008, 0.0008, 0.0007, and 0.0009, respectively). Concentrations of chloride were not significantly different in water samples from wells 7S, 8S, and 10S than from the historic water samples (Mann-Whitney test, p-value = 0.08). These tests were repeated without data for well 10S, which contained the largest concentrations of many constituents analyzed during the study and yielded the same results (Mann-Whitney test, p-values = 0.0017, 0.0016, 0.0014, and 0.0019, respectively). Median concentrations for specific conductance, calcium, sulfate, chloride, and nitrate for historical and recent analyses are presented in table 6. It appears that the concentrations of specific conductance, calcium,

**Table 6.** Median concentrations of specific conductance, calcium, sulfate, chloride, and nitrate in water samples from wells 7S, 8S, and 10S from 1993–94 and from five wells sampled from 1949–52

[ $\mu\text{S}/\text{cm}$ , microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter]

Constituent	Median	
	Historical data	Recent data
Specific conductance ( $\mu\text{S}/\text{cm}$ )	137	400
Calcium (mg/L)	3.6	48
Sulfate (mg/L)	3.0	13
Chloride (mg/L)	2.5	2.9
Nitrate as N (mg/L)	0.75	14.0

sulfate, and nitrate were about 3 to 18 times larger in 1993–94 than in 1949–52. These apparent changes in the water chemistry are most likely the result of both the long-term application of mineral fertilizers over the last 40 years and the accelerated leaching of these chemicals through surface- and ground-water irrigation into the shallow ground water.

### **Tritium Analyses and Ages of Selected Ground-Water Samples**

Tritium is a radioactive isotope of hydrogen with a half-life (the time required for half of the nuclide to decay to another form) of 12.43 years. Among other applications, tritium can be used to estimate the relative age of water in an aquifer from about 100 years ago to the present. Small amounts of tritium are constantly being produced when neutrons released by the bombardment of nitrogen gas ( $N_2$ ) with cosmic radiation in the Earth's upper atmosphere are captured by hydrogen atoms and fall to the Earth as precipitation. In 1952, above-ground testing of thermonuclear devices began releasing large pulses of tritium into the atmosphere of the northern hemisphere in concentrations up to three orders of magnitude larger than natural background levels. This artificial release of tritium to the atmosphere was mostly discontinued about 1973.

These large pulses of tritium entering the hydrologic cycle for a known period of time and the subsequent decay of these elevated tritium concentrations provide the basis for a method of relative age-dating of ground water. Tritium concentrations in precipitation prior to atmospheric nuclear testing were estimated by Thatcher (1962) to be between 6 and 26 picocuries per liter (pCi/L). Plummer and others (1993) estimated that the maximum range of tritium concentrations in the 1990's for water derived exclusively from precipitation prior to atmospheric nuclear testing would be 0.6 to 2.6 pCi/L. Therefore, this range of values can be used to identify pre-1952 recharge water as well as water representing a mixture of pre-1952 and more recent water.

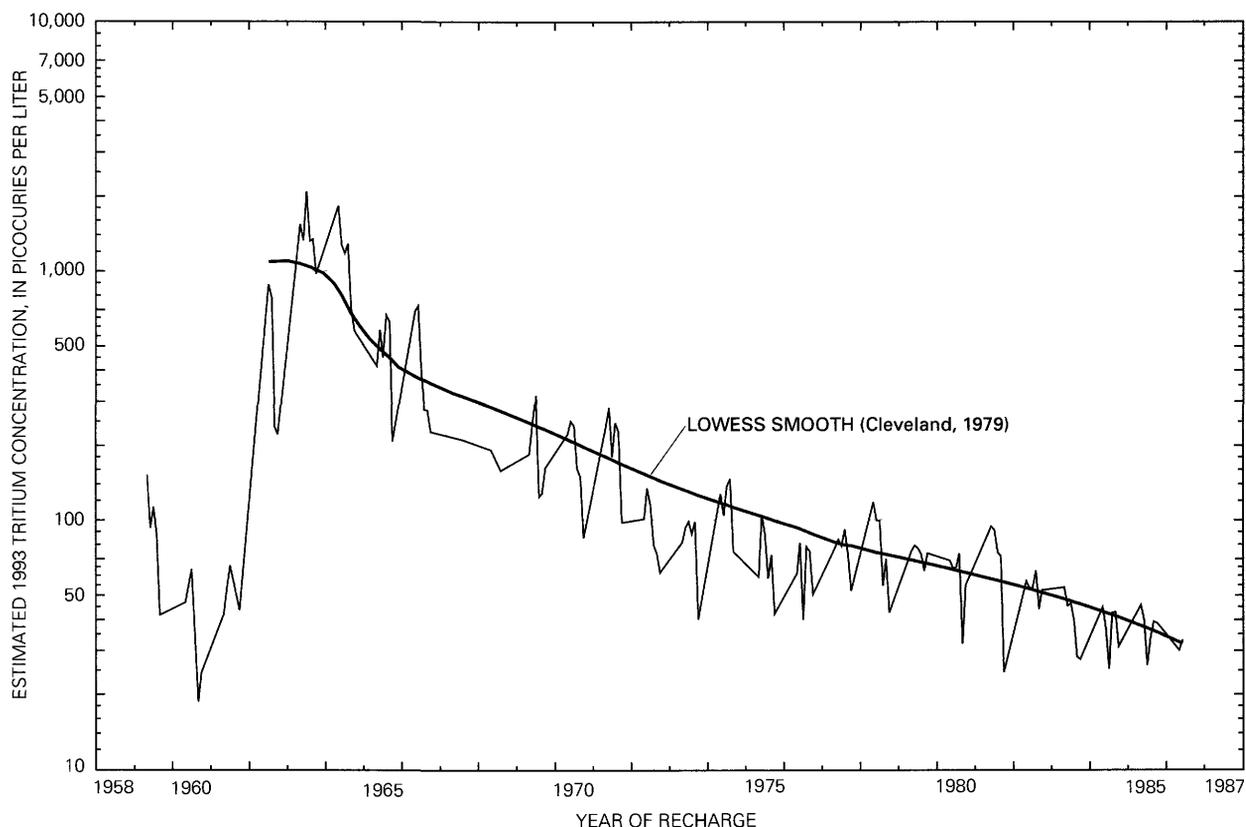
Ground-water samples from 12 observation wells at 6 sites were collected and analyzed for tritium concentrations in November 1993. Water samples from all of the observation wells in the southeastern transect (sites 6, 7, 8, 9, and 5), and from observation wells at site 4, were analyzed for tritium. The results

of these analyses are shown in table 8. Using the criteria described above, water samples from wells 6D, 6M, 6S, 7D, 8D, and 9 represent water that most likely recharged the aquifer prior to 1952. Water samples from wells 4D, 4S, 7S, 8M, 8S, and 5 contained tritium concentrations of 15 to 77 pCi/L and represent water that is probably either a mixture of pre-1952 and younger water or mostly younger water.

Monthly precipitation samples were collected and analyzed for tritium by the U.S. Geological Survey at Lincoln, Nebraska, from 1959 through 1986 as reported by Plummer and others (1993). Using the decay constant for tritium ( $\lambda = 0.0558$ ), these concentrations were used to estimate concentrations that would be expected if the precipitation recharged a local aquifer each month and underwent radioactive decay until 1993 (fig. 7), the year water samples from the Long Pine Creek study area were collected and analyzed for tritium. Comparison of observed concentrations of tritium in ground-water samples from the Long Pine Creek study area with the calculated concentrations made it possible to more closely approximate the age of recharge of some of the water samples from the Long Pine Creek study area. These approximations assume that most of the recharge to the aquifer occurred during the spring and early summer months, commonly the case in Nebraska, and that subsequent mixing of the ground water did not occur.

Based on these results, it appears that site 6 is in a ground-water discharge area. Concentrations of tritium in water samples from these wells were less than 1 pCi/L, which suggests the water is pre-1952 and was not recharged locally. This is consistent with water-level measurements made in August and December 1993 (table 8), which show the hydraulic head to be generally higher in the deep wells than in the shallow well. The location of site 6 in a wet meadow just downgradient from the northern edge of the Sand Hills also suggests that ground-water discharge may prevail in this area.

The water sample from well 7D contained no detectable tritium concentration ( $<0.3$  pCi/L), which suggests that pre-1952 water lies along a relatively deep flow path. The tritium concentration in water from well 7S was 77 pCi/L, the largest concentration measured (table 8). Comparison of concentrations of tritium in water from well 7S with the estimated decay of observed tritium concentrations in precipitation at Lincoln as described above suggested that the water



**Figure 7.** Estimated concentrations of tritium from spring and summer recharge corrected for radioactive decay to 1993 in monthly precipitation samples from Lincoln, Nebraska, from 1959 through 1986.

from well 7S was recharged to the aquifer either between 1959 and 1962 or between 1978 and 1981. The concentrations of nitrate and sulfate in water samples from well 7S were more than 10 mg/L for both constituents, suggesting that the water was recharged locally during the latter period.

The water from well 8D contained no detectable concentration of tritium ( $<0.3$  pCi/L), which suggests that it was recharged prior to 1952 and has traveled along a deep flow path. This suggestion is further supported by low concentrations of nitrate and sulfate. The tritium concentration in water from well 8M was 15 pCi/L (table 8), and appears to be a mixture of post-1952 water with older water. Concentrations of nitrate and sulfate of 5 and 8 mg/L, respectively, in water samples from well 8M also suggest that water from well 8M is a mixture of relatively young water with older, more pristine water. The concentration of tritium in water from well 8S was 60 pCi/L (table 8). Comparison of the concentration of tritium in this

water sample with the estimated decay of observed tritium concentrations in precipitation at Lincoln suggests that this water was recharged either between 1960 and 1962 or between 1974 and 1982. The large concentration of tritium and concentrations of nitrate and sulfate that exceed 10 mg/L in water from well 8S indicate that this water probably was recharged to the aquifer during the latter period and probably originated from local recharge that leached agricultural chemicals into the top of the aquifer.

The concentration of tritium in water from well 9 was 2.6 pCi/L (table 8 at back of report) and probably represents mostly recharge water that entered the aquifer at least prior to 1959 and more probably before 1952. Water from well 9 is considered to be younger than the water from wells 6D, 7D, and 8D because the tritium concentrations in water from the latter wells had decayed below the detection limit of the method used.

The concentration of tritium in water from well 5 was 19 pCi/L (table 8) and was most likely recharged prior to 1959 as determined through comparison with decay estimates of the tritium data from Lincoln, Nebraska. As this water contains concentrations of calcium, sulfate, and dissolved solids that are similar to young water from Quaternary-age deposits, water collected from this well may be a mixture of some older pre-1952 water with more recent water.

Concentrations of tritium in water samples from wells 4D and 4S were 54 and 31 pCi/L, respectively. Water from both wells is post-1952 and was recharged either between 1959 and 1962 or between 1982 and 1983 for 4D, and either between 1959 and 1962 or between 1985 and 1986 for 4S, as determined by comparison with the estimated decay of observed tritium concentrations in precipitation at Lincoln. Comparison of concentrations of nitrate (8 to 9 mg/L) and sulfate (9 to 10 mg/L) in water samples from both wells suggests that the latter recharge dates are more probable and that the water was locally recharged (table 8).

## Changes in Ground-Water Chemistry Along Selected Flow Paths

Based on the tritium analyses and general water-quality characteristics, the vertical extent to which agricultural chemicals entered the aquifer in the study area is highly variable and is a function of the basin's hydrologic and land-use characteristics. Although the correlation between the concentration of tritium and the median concentrations of nitrate in ground-water samples is high (Spearman's  $\rho = 0.83$ ), both concentrations of tritium and median concentrations of nitrate were not strongly correlated with either well depth (Spearman's  $\rho = -0.60$  and  $-0.40$ , respectively) or the saturated thickness of the aquifer from which the samples were collected (Spearman's  $\rho = -0.50$  and  $0.36$ , respectively). Water samples with post-1952 concentrations of tritium young enough to have been contaminated with agricultural chemicals were collected from wells ranging in depth from 50 to 255 feet and with saturated thicknesses ranging from 10 to 97 feet. Therefore, to identify areas in the Long Pine Drainage Basin that are susceptible to ground-water contamination with agricultural chemicals, the general ground-water flow paths (figs. 2 and 3) and

chemical evolution of the ground water must be considered.

The chemical evolution of ground water beneath the study area appears to be relatively simple. Based on the water-quality data previously described, relatively dilute ground water flows northward from the edge of the Sand Hills. Dissolved silica is the dominant constituent found in this water. Silica was dissolved over very long periods of time from the quartz sands comprising most of the Sand Hills. As this water flows beneath the southern portion of the study area, the hydraulic head is large enough to cause seasonal discharge of water to produce the wet meadows observed south of Ainsworth. This process also limits the amount of local recharge to the aquifer in this area, keeping the quality of the water relatively unchanged. This is consistent with the low tritium concentrations in the water (site 6). It is unlikely that anything other than limited contamination of the shallow ground water with agricultural chemicals would occur in this area.

As the ground water flows beneath areas of row-crop agriculture beginning just south of U.S. Highway 20, the chemical composition of the shallow aquifer changes (sites 1, 2, 3, and 7). Here large increases in concentrations of calcium, sulfate, chloride, and nitrate are observed. This is likely the result of percolation of irrigation water, leakage from the unlined canals, and the increased use of mineral fertilizers associated with row-crop agriculture. The mounding of the ground water from canal leakage reduces the distance that the contaminants must travel to reach the ground water, and application of irrigation water helps speed their transport into the ground water. The smallest concentrations of sulfate, chloride, and nitrate in water from a shallow well in this area were found in well 3S, which is considerably deeper than the other shallow wells. Local recharge and the leaching of agricultural chemicals in this portion of the study area probably extend from the water table to below 70 feet (well 2S) and possibly to below 130 feet (well 3S).

Farther downgradient along the northern edge of the irrigated areas of row-crop agriculture and some distance from the irrigation canals (sites 4 and 8), the water table is about 150 to 160 feet below the land surface. Most of the water near the top of the water table is pre-1952 and is recharged through irrigated agricultural lands above. The larger depth to water appears to moderate the agricultural impact on

ground-water quality. Deeper ground-water flow paths are intercepted by wells 8D and 8M. Water-quality samples from well 8D (295 feet deep) show old (pre-1952), relatively pristine water that is unaffected by local recharge from above. Water-quality samples from well 8M (203 feet deep) show a mixture of older, high-silica water with younger water from above containing larger concentrations of calcium, sulfate, and nitrate. Water-quality samples from well 8S (150 feet deep) indicate that water is post-1952 and contains large concentrations of calcium, sulfate, and nitrate.

Continuing along the ground-water flow path to site 9 (180 feet deep), the saturated thickness of the Ogallala Formation steadily decreases to less than 100 feet (fig. 2). Much of the ground water flowing from site 8 recharges Long Pine Creek to the east. Site 9 receives ground water from deep flow paths passing west of site 8. The ground water at site 9 appears to be mostly from very deep flow paths and was probably recharged prior to 1952. Typically this water has low concentrations of major ions and nitrate and has the largest concentration of silica detected during the study. Concentrations of sulfate in water samples from site 9 are larger than in water samples from most deep wells, and the relative concentrations of major ions in water samples from site 9 are quite similar to those in water samples from wells 1M, 2D, 6M, and 7D.

At site 5, near the bottom of the Long Pine Creek Drainage Basin a few miles from the confluence of Long Pine Creek with the Niobrara River, the saturated thickness of the Ogallala Formation is reduced to about 25 feet and the depth to water is about 150 feet (fig. 2). The water is probably a mixture of recharge from local precipitation and very old water from deep flow paths that were not captured by Long Pine and Bone Creeks. Concentrations of calcium, sodium, and sulfate were more similar to concentrations from shallow wells in irrigated agricultural areas (2S, 4S, 7S, and 8S) than from deep wells. The more mineralized nature of the water is likely caused by the proximity of the underlying Brule Formation and the Pierre Shale.

## SUMMARY

Twenty-one ground-water observation wells were installed in nests in two transects in the Long

Pine Creek study area. Water-quality samples were collected from these wells four times from August 1993 through June 1994 and were analyzed for field measurements, major ions, nutrients, two trace elements, and selected herbicides. Water samples from 12 wells also were analyzed for tritium.

These analyses indicate that the ground water is generally a well-oxygenated, calcium bicarbonate type with a small dissolved-solids content (median = 161 mg/L). Silica was the dominant constituent in most water samples with a median concentration of 59 mg/L. Water samples from shallow observation wells, which were mostly screened in deposits of Quaternary age, contained significantly larger concentrations of all major ions except silica than did water samples from the Ogallala Formation.

Nitrate concentrations ranged from 0.5 to 32 mg/L with larger nitrate concentrations found in shallow observation wells in areas of irrigated agriculture compared to areas of nonirrigated agriculture. A similar pattern was observed in concentrations of chloride and sulfate. Water samples from five of these observation wells consistently exceeded the 10-mg/L drinking-water regulation for nitrate established by the U.S. Environmental Protection Agency. Variation in concentrations of nitrate showed a negative correlation with well depth. Considerable seasonal variation in nitrate concentrations (0.08 to 6.6 mg/L) was present in water samples from shallow observation wells collected in areas of irrigated agriculture, whereas little variation was observed in nitrate concentrations in water samples from nonirrigated areas. The largest concentrations of nitrate in many of the shallow observation wells were observed during the late summer and fall. Ammonium concentrations were near the detection limit of 0.01 mg/L in most water samples. Orthophosphate concentrations in ground-water samples ranged from less than 0.01 to 0.47 mg/L as P and were significantly larger at the 95-percent confidence level in areas of nonirrigated agriculture.

Water samples from 4 of the 19 observation wells that were analyzed for triazine herbicides contained trace amounts of atrazine or its metabolites during the two sampling periods. Atrazine and its metabolites were detected only in water samples from shallow observation wells in areas of irrigated agriculture with nitrate concentrations of more than 10 mg/L. No other herbicides or their metabolites were detected.

The actual effectiveness of BMP promotion within the Long Pine Creek RCWP area relative to

nonproject areas could not be determined with data from only one nonproject site. However, the water-quality data from the shallow observation well at site 10, which is outside of the project area, had significantly larger concentrations of chloride, sulfate, and nitrate than did water samples from shallow observation wells in areas of irrigated agriculture within the RCWP area.

Comparisons of the current quality of the ground water to historical data from 1949 to 1952 near the towns of Ainsworth and Long Pine suggest that calcium, sulfate, and nitrate concentrations have increased significantly. Although the data are limited, they suggest that concentrations of these constituents in these areas are about 3 to 18 times larger today than in 1956.

Tritium concentrations in ground-water samples from 12 wells ranged from less than 0.3 to 77 pCi/L. When compared to tritium concentrations in precipitation samples collected in Lincoln, Nebraska, from 1959 to 1986 that were adjusted for tritium decay to 1993, the ages of ground-water samples analyzed for tritium ranged from pre-1952 to about 1982.

Estimated ages of the ground-water samples and water-level and water-quality data support the concept that ground water moves along deep flow paths from the Sand Hills northward toward the Niobrara River. Good-quality ground water flowing north from the Sand Hills discharges seasonally in the southern part of the study area to produce wet meadows. Local row-crop agriculture and seasonal recharge from the Ainsworth Irrigation Project strongly influence the quality of the shallow ground water in the central portion of the study area but have had no apparent effect on the current quality of ground water following the deeper flow paths. Much of the recharge water from the Ainsworth Irrigation Project and of the ground water following the deeper flow paths from the Sand Hills discharges to Long Pine Creek and its tributaries before reaching the bottom of the Long Pine Creek Drainage Basin. Ground water just above the Niobrara River near the bottom of the Long Pine Creek Drainage Basin is a mixture of very old water from deep flow paths with young water from recharge of local precipitation.

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**GEOLOGIC LOGS AND WATER-QUALITY DATA**

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**Table 7. Geologic logs of observation wells drilled in the Long Pine Creek Study area, north-central Nebraska, 1993**

Observation Well Site #1		
Legal Location: 30N 23W 26AAAA      Latitude and Longitude: 423256 0995807		
Depth (feet)	Thickness (feet)	Description
<b>Quaternary System:</b>		
<b>Pleistocene Series, undifferentiated:</b>		
11	11	Sand, medium to coarse, moderately sorted
56	45	Sand, fine to gravel, medium, poorly sorted, brownish-red
60	4	Sand, fine to coarse, poorly sorted, some very silty clay, tan
76	16	Sand, fine to gravel, fine, moderately sorted, brownish-red
81	5	Sand, medium to coarse, some fine, some medium gravel and clay, poorly sorted
86	5	No sample
95	9	Sand, fine to medium, well sorted, reddish-brown
<b>Tertiary System:</b>		
<b>Pliocene Series—Ogallala Formation:</b>		
114	19	Sand, fine to medium, well sorted, some sandstone, brown
119	5	Clay, silty, blocky, light tan
130	11	Sand, fine, well sorted
136	6	Silt, clayey, light tan
141	5	Sand, fine, well sorted, light tan
161	20	Sand, fine to coarse, poorly sorted, light tan, some silt and clay, calcareous cement
172	11	Sand, fine to very fine, well sorted, some silt and clay, light tan
176	4	Sand, fine to medium, sandstone, some silt and clay, light tan to brown
181	5	Sand, fine to medium, well sorted, brown to light tan
186	5	Sand, medium to coarse, well sorted, some gravel, fine, light brown to tan
190	4	Sand, fine to coarse, moderately to poorly sorted, sandstone, some calcareous cement, light brown to tan
196	6	Sand, fine to coarse, poorly sorted, calcareous cement, some clay and silty
201	5	Clay, silty, blocky, light tan-white
206	5	Sand, fine to medium, some clay and silt, light tan, poorly sorted, some calcareous cement
263	57	Sand, fine to coarse, some sandstone, poorly sorted, light brown, calcareous cement, some silt
273	10	Sandstone, fine to medium, brown
282	9	Sand and sandstone, some calcareous cement, slightly clayey, little gravel, brown
297	15	Sand, fine to medium, some clayey siltstone, poorly sorted, some calcareous cement, light brown to tan
302	5	Sand, fine, some siltstone, yellowish-tan, clayey, sandstone, tan
321	19	Sand, fine to medium and silt, moderately sorted, clayey, light brown
331	10	Sand, fine, well sorted, light brown to tan
340	9	Sand, fine, well sorted, some sandstone, light brown
350	10	Sand, fine, very well sorted, light brown

**Table 7. Geologic logs of observation wells drilled in the Long Pine Creek Study area, north-central Nebraska, 1993—Continued**

<b>Observation Well Site #2</b>		
	<b>Legal Location: 30N 23W 26BBBC</b>	<b>Latitude and Longitude: 423531 0995523</b>
<b>Depth (feet)</b>	<b>Thickness (feet)</b>	<b>Description</b>
<b>Quaternary System:</b>		
1	1	Soil, clayey, dark brown Pleistocene series
<b>Pleistocene Series:</b>		
15	14	Sand, medium to fine gravel, moderately sorted, brown
55	40	Sand, medium to medium gravel, moderately sorted, brown
70	15	Sand, medium to coarse, well sorted, some clay, brown
85	15	Silt and clay, sandy, some gravel, light gray
<b>Tertiary System:</b>		
<b>Pliocene Series—Ogallala Formation:</b>		
95	10	Sand, fine to medium, some gravel, medium, poorly sorted, some clay, tan
100	5	Sand, medium, clayey, poorly sorted, some sandstone, tan
125	25	Sand, fine to medium, well sorted, weakly cemented sandstone, some clay and silt, some calcareous cement
155	30	Sand, fine to medium, clayey, some silt, poorly sorted, some weakly cemented sandstone, tan
165	10	Sand, fine to medium, moderately sorted, some silt and clay, brown
175	10	Sand, fine to medium, well sorted, clayey, brown
180	5	Sand, fine to medium, some sandstone, moderately sorted, brown
185	5	Sand, fine to medium, very clayey and silty, tan
195	10	Sand, fine, well sorted, slightly clayey
210	15	Sand, fine to medium, poorly sorted, clayey, tan, light brown
220	10	Sand, medium, well sorted, brown
230	10	Sand, medium to coarse, moderately to well sorted, some sandstone, poorly cemented, some clay
245	15	Sand, fine, well sorted, some sandstone, poorly cemented, very slightly clayey
250	5	Sand, fine with some clayey silty, light tan

**Table 7.** Geologic logs of observation wells drilled in the Long Pine Creek Study area, north-central Nebraska, 1993—Continued

<b>Observation Well Site #3</b>		
<b>Legal Location: 31N 22W 35BBBB</b>		<b>Latitude and Longitude: 423720 0995214</b>
<b>Depth (feet)</b>	<b>Thickness (feet)</b>	<b>Description</b>
<b>Quaternary System:</b>		
<b>Holocene Series:</b>		
1	1	Soil
<b>Pleistocene Series, undifferentiated:</b>		
5	4	Sand, medium, well sorted, brown
14	9	Sand, medium to coarse, well sorted, dark brown
24	10	Sand, coarse to fine gravel, moderately sorted, reddish-brown
30	6	Sand, fine to gravel, fine, poorly sorted, brown
46	16	Sand, fine to medium, some fine gravel, very clayey and silty
61	15	Clay and silt, sandy, tan
65	4	Sand, fine, slightly clayey, poorly sorted
71	6	Sand, medium, well sorted, some gravel, medium, brown, tan
81	10	Sand, fine to medium, some gravel, well sorted, clay, tan
85	4	Sand, fine to coarse, some fine gravel, some clayey silt, brown to tan
112	27	Silt, very clayey, blocky, red to tan
121	9	Sand, fine to gravel, fine, poorly sorted, white calcareous cement, tan to light tan
<b>Tertiary System:</b>		
<b>Pliocene Series—Ogallala Formation:</b>		
126	5	Sand, fine to coarse, some calcareous cement, poorly sorted, light tan to light gray
134	8	Silt, very clayey, some sand, light tan
154	20	Sand, fine to medium, light tan, some silt, clayey, sandstone, fine to medium, some gravel, tan
185	31	Sand, fine to coarse, moderately to poorly sorted, clayey, some calcareous cement, light tan, sandstone pebbles, brown
189	4	Sand, medium to fine gravel, silt, very clayey, calcareous cement, light tan to light tan
204	15	Sand, fine to medium, moderately to well sorted, clayey, light brown
247	43	Sand, fine to medium, well sorted, some sandstone, weakly cemented, light brown
252	5	Sand, fine to medium, well sorted, some silt and clay
268	16	Sand, fine to medium, well sorted, some sandstone, light brown
273	5	Sand, fine to medium, well sorted, slightly clayey, light brown
284	11	Sand, fine to medium, some coarse, and sandstone, light brown
294	10	Sand, fine to medium, moderately, some calcareous cement, brown
299	5	Sand, fine to medium, moderately to poorly sorted, some clay, light brown
325	26	Sand, fine to coarse, sandstone, moderately to well sorted, calcareous cement, some clay, brown
329	4	Sand, fine to medium, some clay, moderately to poorly sorted, brown
335	6	Sand, medium to coarse, sandstone, calcareous cement, very clayey, tan
350	15	Sand, fine, some coarse, clayey, moderately to poorly sorted brown

**Table 7. Geologic logs of observation wells drilled in the Long Pine Creek Study area, north-central Nebraska, 1993—Continued**

<b>Observation Well Site #4</b>		
<b>Legal Location: 31N 21W 10DDCC</b>		<b>Latitude and Longitude: 423958 0994530</b>
<b>Depth (feet)</b>	<b>Thickness (feet)</b>	<b>Description</b>
<b>Quaternary System:</b>		
<b>Holocene Series:</b>		
1	1	Soil, black
<b>Pleistocene Series—undifferentiated:</b>		
15	14	Sand, fine to medium, calcareous cement, clayey, dark brown
29	14	Sand, very fine to medium, calcareous cement, some clay, brown to light tan
39	10	Sand, fine to medium, very clayey, calcareous cement, light tan
44	5	Sand, medium, poorly sorted, some calcareous cement, brown
50	6	Missing
54	4	Silt with gravel, very clayey, brown
75	21	Sand, fine to fine gravel, clayey, poorly sorted, calcareous cement, light brown
<b>Tertiary System:</b>		
<b>Pliocene Series—Ogallala Formation:</b>		
95	20	Sand, fine to coarse, moderately to poorly sorted, clayey, sandstone, light brown
106	11	Sand, fine silty, moderately sorted, brown
141	35	Sand, fine, some coarse, moderately sorted, slightly clayey, brown
148	7	Sand, fine, well sorted, brown
228	80	Sand, fine, some sandstone, dark brown
251	23	Sand, fine, some sandstone, slightly clayey, dark brown
256	5	Sand, fine, some siltstone and sandstone Oligocene series-Brule formation:
260	4	Clay, silt and siltstone, reddish-brown changing to light gray-green

**Table 7. Geologic logs of observation wells drilled in the Long Pine Creek Study area, north-central Nebraska, 1993—Continued**

<b>Observation Well Site #5</b>		
<b>Legal Location: 32N 20W 27DDBB      Latitude and Longitude: 424246 0993926</b>		
<b>Depth (feet)</b>	<b>Thickness (feet)</b>	<b>Description</b>
<b>Quaternary System:</b>		
4	4	No sample
<b>Pleistocene Series, undifferentiated:</b>		
9	5	Sand, fine, well sorted, dark brown
15	6	Sand, fine to medium, moderately sorted, dark brown
21	6	Sand, medium to coarse, some fine, some gravel, medium, well-sorted, brown
35	14	Sand, medium, well sorted, brown
39	4	Sand, medium, some coarse, some gravel, fine, well sorted, brown
52	13	Sand, medium, well sorted, some calcareous cement,
57	5	Sand, fine to medium, moderately sorted, brown, some calcareous cement
73	16	Sand, fine to medium, some coarse, well sorted, brown
88	15	Sand, fine to medium, well sorted, some calcareous cement, brown
<b>Tertiary System:</b>		
<b>Pliocene Series—Ogallala Formation:</b>		
94	6	Sand, fine to medium, well sorted, light tan, some weakly cemented sandstone
99	5	Sand, fine to medium, sandstone, moderately well sorted, some calcareous cement, tan to brown
105	6	Sand, fine to medium, some gravel, fine, poor to moderately sorted, some calcareous cement, tan
115	10	Sand, fine to medium, poor to moderately sorted
119	4	Sand, fine to medium, moderately well sorted, some calcareous cement, tan
139	20	Sand, fine to coarse, some gravel, fine to medium, poorly sorted, calcareous cement, brown
150	11	Sand, fine some medium, moderately well sorted, some calcareous cement, brown
<b>Tertiary System:</b>		
<b>Oligocene Series—Brule Formation:</b>		
155	5	Siltstone, orange-yellow to brown, sand, fine to medium, some gravel, calcareous cement
<b>Cretaceous System:</b>		
<b>Pierre Shale</b>		
160	5	Shale, black to dark gray, mixed with some fine gravel

**Table 7. Geologic logs of observation wells drilled in the Long Pine Creek Study area, north-central Nebraska, 1993—Continued**

<b>Observation Well Site #6</b>		
	<b>Legal Location: 29N 22W 14CCBB</b>	<b>Latitude and Longitude: 422849 0995215</b>
<b>Depth (feet)</b>	<b>Thickness (feet)</b>	<b>Description</b>
<b>Quaternary System:</b>		
<b>Pleistocene Series, undifferentiated:</b>		
10	10	Sand, fine to medium, silty, red-brown
35	25	Clay, blocky, silty, some sand, tan-brown
46	11	Sand, fine to medium, clay (carry over), reddish
54	8	Sand, medium to coarse, poorly sorted, red-brown
69	15	Sand, fine, gravel, medium, poorly sorted, slightly clayey, red-brown
74	5	Sand, medium, some fine to coarse, moderately sorted, red-brown
80	6	Sand, medium, some gravel, coarse, reddish-brown
89	9	Sand, fine to coarse, some silt and gravel, poorly sorted
119	30	Sand, medium to gravel, medium, moderately sorted, red-brown
125	6	Sand, fine to medium, well sorted, red-brown
135	10	Sand, medium to coarse, some gravel, moderately sorted, red brown
139	4	Sand, medium to fine, some clay, tan, topping clay, red-brown
161	22	Sand and silty clay, fine to medium sand with some gravel, blocky clay, reddish-tan
166	5	Sand, fine to medium, well sorted, some cobbles, silt, light tan
171	5	Sand, fine, tan, slightly clayey, silt and clay, red, some cobbles
177	6	Sand, fine to medium, clayey, brown, some silty clay, blocky, light tan
<b>Tertiary System:</b>		
<b>Pliocene Series—Ogallala Formation:</b>		
190	13	Sand, fine to medium, sandstone, tan, well sorted
195	5	Sand, fine to medium, some coarse, sandstone, poorly sorted, brown
201	6	Sand, fine to medium, silt and clay, light tan, sandstone, tan
216	15	Sand, coarse to gravel, fine, sandstone, fine to medium, brown
220	4	Sand, fine to medium, some coarse, sandstone, fine to medium, some calcareous cement, tan
230	10	Sand, fine to medium, some gravel, fine, sandstone, brown
236	6	Sand, medium, gravel, fine, clayey, sandstone
245	9	Sand, fine to coarse, brown, some silty clay, light brown, some sandstone
250	5	Silt and sand, fine, light brown to tan
254	4	Sand, fine to medium, some gravel, fine to medium, clayey silt, brown, light tan
259	5	Sandstone, fine to medium, brown, some calcareous cement, light tan
265	6	Sand, fine to coarse, brown, moderately clayey, some calcareous cement
275	10	Sand, fine to coarse, some gravel, fine, poorly sorted, silty clay, light tan, some calcareous cement
298	23	Silt, light tan, sandy, some clay, calcareous cement
308	10	Sand, fine and silt, clayey, light tan, some sandstone, calcareous cement
334	26	Sand, fine to medium, and silt, clayey, light tan, sandstone, fine to medium, brown
339	5	Sand, fine to medium, well sorted, brown
353	14	Sand, fine to medium, well sorted, brown, some calcareous cement
358	5	Sand, fine to medium, sandstone, well sorted, brown
378	20	Sand, fine, sandstone, light brown, well sorted, some calcareous cement, some clay, light tan
400	22	Sand, fine to medium, sandstone, fine to medium, well sorted, brown

**Table 7. Geologic logs of observation wells drilled in the Long Pine Creek Study area, north-central Nebraska, 1993—Continued**

<b>Observation Well Site #7</b>		
<b>Legal Location: 30N 21W 29AABB      Latitude and Longitude: 423259 0994751</b>		
<b>Depth (feet)</b>	<b>Thickness (feet)</b>	<b>Description</b>
<b>Quaternary System:</b>		
<b>Holocene Series:</b>		
1	1	Topsoil, thin, dark
<b>Pleistocene Series, undifferentiated</b>		
15	14	Sand, fine to gravel, fine, clayey, poorly sorted, red-brown
34	19	Sand, medium to gravel, fine, well sorted, red-brown
44	10	Sand, fine to gravel, fine, some coarse, poorly sorted, red-brown
58	14	Silt, clayey, some medium sand to coarse gravel, light tan
<b>Tertiary System:</b>		
<b>Pliocene Series—Ogallala Formation:</b>		
73	15	Sandstone, fine to medium, brown
79	6	Sandstone, fine to medium, brown, abundant calcareous cement
84	5	Sand, medium, some sandstone, well sorted, brown,
100	16	Silt, clayey, blocky, light tan, calcareous cement
122	22	Sand, fine to coarse, poorly sorted, tan-brown, silt and clay, blocky, light tan
127	5	Sand, fine, clayey, brown, tan
136	11	Sand, fine, well sorted, brown, tan
141	5	Sand, fine, moderately sorted, brown
147	6	Sand, fine, moderately sorted, brown-tan, some calcareous cements, some sandstone, some silt
157	10	Sand, fine, well sorted, brown, tan
171	14	Sand, fine, well sorted, some sandstone, brown
176	5	Sand, fine, well sorted, some calcareous cement, brown-tan
192	16	Sand, fine, well sorted, light brown, tan, some sandstone, fine-grained, some calcareous cement
196	4	Sand, fine to medium, some sandstone, some calcareous cement, brown-tan
210	14	Sand, fine to medium, some coarse, very clayey, some sandstone, tan-brown
215	5	Sand, fine to medium, well sorted, some sandstone, brown
219	4	Sand, fine to medium to coarse, moderately sorted, brown
234	15	Sand, fine, well sorted, very clayey, light tan, brown
241	7	Sand, fine to medium, moderately sorted, some sandstone, slightly clayey, brown
247	6	Sandstone, fine, brown, moderately well cemented, brown
250	3	Sand and sandstone, with clayey silt, very poorly sorted

**Table 7. Geologic logs of observation wells drilled in the Long Pine Creek Study area, north-central Nebraska, 1993—Continued**

<b>Observation Well Site #8</b>		
	<b>Legal Location: 30N 21W 1CACC</b>	<b>Latitude and Longitude: 423553 0994341</b>
Depth (feet)	Thickness (feet)	Description
<b>Quaternary System:</b>		
<b>Holocene Series:</b>		
1	1	Soil
<b>Pleistocene Series, undifferentiated:</b>		
36	21	Sand, medium to coarse gravel, poorly sorted, cobbles near bottom
45	9	Silt and clay, light tan with quartz cobbles up to 2-cm diameter
57	12	Silty clay and sand, medium, light tan to reddish-tan
72	15	Sand, fine to medium, well sorted, light tan
91	19	Clay, very silty, quartz cobbles near bottom
<b>Tertiary System:</b>		
<b>Pliocene Series—Ogallala Formation:</b>		
111	20	Sand, fine to medium, moderately to well sorted, with silt and clay, light tan
127	16	Sandstone, silty, fine to clay, with white calcareous cement
146	19	Sand, fine, very silty to clayey, some fine gravel, calcareous cement
171	25	Sand, medium, brown with clay and some silt, light tan
185	14	Clay with calcareous and quartz pebbles, some sandstone pebbles, light tan
211	26	Sand, fine to medium, some medium gravel, very clayey
251	40	Sand, fine to medium, very clayey, light brown
270	19	Sand, medium, well sorted, little to no clay
300	30	Sand, medium, well sorted, some clay, brown to dark brown

**Table 7. Geologic logs of observation wells drilled in the Long Pine Creek Study area, north-central Nebraska, 1993—Continued**

<b>Observation Well Site #9</b>		
<b>Legal Location: 31N 20W 7C CCC</b>		<b>Latitude and Longitude: 424000 0994247</b>
<b>Depth (feet)</b>	<b>Thickness (feet)</b>	<b>Description</b>
<b>Quaternary System:</b>		
<b>Pleistocene Series, undifferentiated:</b>		
18	18	Sand, very fine, well sorted, brown
28	10	Sand, fine, some coarse, well sorted, tan, brown
34	6	Sand, fine, some coarse, well sorted, slightly clayey, tan-brown
39	5	Sand, fine to medium, some gravel, moderately sorted, tan
61	22	Sand, fine to medium, some gravel, fine, moderately to well sorted, brown-tan
65	4	Sand, fine, well sorted, tan
86	21	Sand, fine to medium, some gravel, fine, moderately to well sorted, some calcareous cement, tan-brown
<b>Tertiary System:</b>		
<b>Pliocene Series—Ogallala Formation:</b>		
91	5	Sand, fine to medium, some gravel, poorly sorted, sandstone, olive-tan, calcareous cement
97	6	Sand, fine to gravel, fine, poor to moderately sorted, tan
101	4	Sandstone, fine to medium, calcareous cement, tan to olive-tan
121	20	Sand, fine to medium, moderately sorted, tan, sandstone, tan to olive, calcareous cement
138	17	Sand, medium, some fine, moderately sorted, some calcareous chips, tan
143	5	Sand, medium to coarse, some fine, clean, moderately sorted, abundant calcareous cement, fine gravel texture
147	4	Sand, fine to coarse, poorly to moderately sorted, tan, sandstone, limestone
157	10	Sand, fine to medium, well sorted, tan, some calcareous chips
162	5	Sand, very fine to fine, very well sorted, some sandstone, fine, slightly clayey, tan
167	5	Sand, fine to medium, and sandstone, fine to medium, calcareous cement, tan
171	4	Sand, very fine to fine, moderately sorted, tan
176	5	Sand, fine, and sandstone, fine, clayey, calcareous cement, tan
180	4	Sand, very fine to fine, very well sorted, some silt and clay, tan

**Table 7. Geologic logs of observation wells drilled in the Long Pine Creek Study area, north-central Nebraska, 1993—Continued**

<b>Observation Well Site #10</b>		
<b>Legal Location: 30N 23W 9DDDC</b>		<b>Latitude and Longitude: 423443 1000037</b>
<b>Depth (feet)</b>	<b>Thickness (feet)</b>	<b>Description</b>
<b>Quaternary System:</b>		
<b>Holocene Series:</b>		
4	4	Soil, clay, dark brown
<b>Pleistocene Series, undifferentiated:</b>		
9	5	Sand, medium to coarse, clay, soil, poorly sorted, dark brown, reddish
15	6	Clay, silty, very blocky, some coarse sand, tan
20	5	Sand, medium to medium gravel, poor to moderately sorted, reddish-brown
39	19	Sand, medium to coarse, some fine, moderately sorted, brown
55	16	Sand, fine to coarse, moderately clayey, moderately sorted, brownish-red
59	4	Sand, medium to coarse, some fine gravel, moderately sorted, reddish-brown
62	3	Sand, fine to medium, some coarse, some silty clay, blocky, some mafics, large gravel-sized, brown, sand has reddish color due to underlying silt
78	16	Clay, silty, blocky, red
95	17	Sand, fine to medium, poorly sorted, clayey, red silt
<b>Tertiary System:</b>		
<b>Pliocene Series—Ogallala Formation:</b>		
101	6	Sand, fine to medium, sandstone, clayey, brown
107	6	Sand, medium, moderately sorted, some calcareous cement, fine gravel texture, brown
111	4	Sand, medium to fine, moderately sorted, some calcareous, cement, brown
147	36	Sand, fine to medium and sandstone, medium to coarse, some calcareous cement, brown
157	10	Sand, fine to gravel, fine, red, sandstone, some coarse sandstone better sorted than sand, brown
166	9	Sand, fine to medium, some coarse sand and fine gravel, sandstone, some calcareous cement, poorly sorted, little clay, brown
171	5	Sand, fine to medium, moderately sorted, brown
180	9	Sand, fine to medium, moderately clayey, some calcareous cement, light tan
190	10	Sand, fine to medium, moderately sorted, some calcareous cement, some sandstone, brown
194	4	Sand, fine to medium, some calcareous cement, some coarse, tan-green
200	6	Sandstone, fine to medium sand, some silt and clay, brown, some calcareous cement, green-gray

**Table 8. Physical properties and analytical results of water samples collected from observation wells in the Long Pine Creek study area, north-central Nebraska, 1993–94**

[121OGLL, Ogallala Formation; 112SDGV, Undifferentiated Quaternary deposits;  $\mu\text{S/cm}$ , microsiemens per centimeter at 25 degrees Celsius; Deg C, degrees Celsius; mg/L, milligrams per liter;  $\mu\text{g/L}$ , micrograms per liter; pCi/L, picocuries per liter; --, not analyzed; <, less than]

Station number	Date	Geologic unit	Depth of well, total (feet)	Depth to water <sup>1</sup> (feet)	Specific conductance ( $\mu\text{S/cm}$ )	pH, whole lab (standard units)	Temperature water (Deg C)	Oxygen, dissolved (mg/L)	Alkalinity lab (mg/L as $\text{CaCO}_3$ )
423256099580701 (1D)	08-18-93	121OGLL	350	10.5	--	8.1	14.5	--	85
	11-02-93	121OGLL	350	8.7	175	7.5	13.5	3.6	86
	11-30-93	121OGLL	350	9.7	174	7.8	13.5	4.6	87
	06-28-94	121OGLL	350	10.7	170	7.7	14.5	3.2	85
423256099580702 (1M)	08-18-93	121OGLL	150	10.1	107	8.2	13.0	2.7	60
	11-02-93	121OGLL	150	9.9	128	7.7	11.5	5.8	60
	11-30-93	121OGLL	150	10.0	133	7.8	12.0	7.7	--
	06-28-94	121OGLL	150	10.4	130	7.7	12.5	5.2	60
423256099580703 (1S)	08-18-93	112SDGV	40	9.4	309	7.0	11.5	3.0	25
	11-02-93	112SDGV	40	9.7	373	6.9	11.0	6.2	24
	11-30-93	112SDGV	40	9.8	363	6.5	11.5	7.9	25
	06-28-94	112SDGV	40	9.9	394	6.5	11.5	5.4	25
423531099552301 (2D)	08-20-93	121OGLL	250	28.4	127	7.7	13.0	2.3	59
	11-02-93	121OGLL	250	31.9	120	7.4	12.5	5.6	58
	11-30-93	121OGLL	250	32.0	120	7.3	12.0	6.8	60
	11-30-93	121OGLL	250	32.0	120	7.4	12.0	6.8	58
	06-29-94	121OGLL	250	33.1	120	7.3	13.5	4.6	57
423531099552302 (2S)	08-20-93	112SDGV	70	32.9	842	7.5	12.5	4.0	343
	11-02-93	112SDGV	70	28.3	859	7.3	11.5	8.2	356
	11-30-93	112SDGV	70	28.3	847	7.4	10.5	10.8	357
	06-29-94	112SDGV	70	30.4	814	7.4	12.5	6.5	353
423720099521401 (3D)	08-20-93	121OGLL	352	46.7	176	8.0	14.5	1.8	82
	11-03-93	121OGLL	352	45.0	185	7.4	13.5	5.3	80
	12-01-93	121OGLL	352	44.8	186	7.6	14.0	6.6	83
	06-29-94	121OGLL	352	49.2	176	7.6	15.0	4.1	81
423720099521402 (3S)	08-20-93	121OGLL	130	46.1	--	7.6	13.0	3.6	56
	11-03-93	121OGLL	130	44.4	176	7.4	12.0	8.2	56
	12-01-93	121OGLL	130	43.5	172	7.3	12.0	10.4	64
	06-29-94	121OGLL	130	48.5	162	7.2	13.5	6.6	55
423958099453001 (4D)	08-19-93	121OGLL	255	159.8	311	7.8	15.5	3.7	145
	11-02-93	121OGLL	255	158.4	379	7.6	14.0	8.2	150
	12-01-93	121OGLL	255	158.2	381	7.6	14.0	10.9	150
	06-29-94	121OGLL	255	157.6	386	7.9	17.5	4.8	146
423958099453002 (4S)	08-19-93	121OGLL	187	159.4	340	7.9	17.0	2.8	164
	11-02-93	121OGLL	187	--	403	7.5	12.0	--	171
	12-01-93	121OGLL	187	158.4	411	7.6	15.0	8.6	172
	06-29-94	121OGLL	187	158.5	404	7.6	15.5	6.4	163

**Table 8. Physical properties and analytical results of water samples collected from observation wells in the Long Pine Creek Study area, north-central Nebraska, 1993–94—Continued**

Local identification	Date	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO <sub>4</sub> )	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO <sub>2</sub> )	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)
(1D)	08-18-93	26	3.3	5.0	4.7	1.3	0.4	0.4	66	<3	<1
	11-02-93	24	3.3	4.9	5.3	1.2	.6	.4	65	<3	<1
	11-30-93	23	3.3	4.9	5.1	1.2	.2	.4	67	<3	<1
	06-28-94	24	3.3	4.5	4.6	1.1	.4	.4	65	<3	<1
(1M)	08-18-93	16	1.8	4.8	3.5	1.0	.5	.2	62	7	2
	11-02-93	17	2.0	4.5	3.5	1.2	.6	.2	62	6	2
	11-30-93	17	2.1	4.4	3.7	1.8	.4	.2	63	6	1
	06-28-94	17	2.0	4.2	3.7	1.4	.7	.2	59	<3	<1
(1S)	08-18-93	49	8.4	7.9	5.0	26	8.2	<.1	30	<3	1
	11-02-93	43	7.2	7.7	4.9	23	8.1	.1	33	4	<1
	11-30-93	41	6.9	7.4	5.2	22	8.1	<.1	32	<3	1
	06-28-94	46	7.5	7.9	4.7	24	9.0	.1	32	<3	<1
(2D)	08-20-93	16	2.1	4.7	3.9	1.1	.6	.2	63	4	2
	11-02-93	15	2.1	4.5	4.0	.90	.6	.2	65	6	<1
	11-30-93	15	2.0	4.4	4.0	1.1	.6	.2	65	<3	<1
	11-30-93	15	2.1	4.3	4.0	1.0	.8	.2	65	4	<1
	06-29-94	15	2.0	4.3	3.7	1.0	.7	.2	59	<3	<1
(2S)	08-20-93	98	18	56	12	28	4.3	.4	41	<3	<1
	11-02-93	90	17	61	16	28	4.5	.4	42	<3	<1
	11-30-93	90	18	57	13	27	4.0	.3	40	<3	<1
	06-29-94	90	17	58	13	26	3.4	.4	42	<3	<1
(3D)	08-20-93	24	3.1	6.1	5.0	1.6	.5	.4	66	--	2
	11-03-93	24	3.3	5.3	6.1	2.8	1.0	.4	66	9	1
	12-01-93	24	3.3	5.1	6.3	2.9	.7	.4	67	4	<1
	06-29-94	23	3.1	5.1	5.6	2.0	.7	.4	63	7	<1
(3S)	08-20-93	22	2.9	5.8	4.8	6.8	1.7	.3	60	5	<1
	11-03-93	22	3.0	4.6	5.3	6.8	1.9	.2	61	3	<1
	12-01-93	21	2.9	4.4	5.5	6.9	1.5	.2	60	16	2
	06-29-94	20	2.8	4.4	5.2	6.9	1.5	.2	58	<3	<1
(4D)	08-19-93	60	5.8	5.8	6.0	9.8	2.7	.1	60	<3	<1
	11-02-93	59	6.0	5.4	6.2	10	2.5	.2	60	4	<1
	12-01-93	59	5.9	5.3	6.4	10	3.2	.1	62	3	<1
	06-29-94	61	6.0	5.5	5.9	10	3.0	.2	59	6	<1
(4S)	08-19-93	61	5.8	8.5	6.8	8.8	1.9	.1	56	8	11
	11-02-93	63	6.3	7.3	6.7	9.3	1.8	.2	55	5	6
	12-01-93	63	6.2	7.4	7.1	10	1.8	.1	52	11	20
	06-29-94	64	5.8	7.5	6.3	9.8	2.2	.1	60	6	6

**Table 8.** Physical properties and analytical results of water samples collected from observation wells in the Long Pine Creek Study area, north-central Nebraska, 1993–94—Continued

Local identification	Date	Solids, sum of constituent, dissolved (mg/L)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> , dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Tritium, total (pCi/L)	Alachlor, water, dissolved, recoverable, (µg/L)	Ametryn, water, dissolved, recoverable, (µg/L)	Atrazine, water, dissolved, recoverable (µg/L)
(1D)	08-18-93	161	<0.01	0.74	0.01	0.02	--	<0.05	<0.05	<0.05
	11-02-93	159	<.01	.55	.02	.03	--	--	--	--
	11-30-93	160	<.01	.55	.02	.02	--	--	--	--
	06-28-94	157	<.01	.50	.03	<.01	--	<.05	<.05	<.05
(1M)	08-18-93	129	<.01	.59	.01	.24	--	<.05	<.05	<.05
	11-02-93	132	<.01	.91	.01	.25	--	--	--	--
	11-30-93	--	<.01	1.40	.01	.26	--	--	--	--
	06-28-94	130	<.01	1.20	.03	.23	--	--	--	--
(1S)	08-18-93	291	<.01	32.0	.02	.08	--	<.05	<.05	.80
	11-02-93	266	<.01	28.0	.02	.12	--	--	--	--
	11-30-93	253	<.01	26.0	.02	.11	--	--	--	--
	06-28-94	279	<.01	30.0	.03	.10	--	--	--	--
(2D)	08-20-93	130	<.01	.55	.02	.10	--	<.05	<.05	<.05
	11-02-93	130	<.01	.56	.01	.10	--	--	--	--
	11-30-93	131	<.01	.62	.01	.09	--	--	--	--
	11-30-93	130	<.01	.63	.01	.10	--	--	--	--
	06-29-94	123	<.01	.61	.02	.08	--	--	--	--
(2S)	08-20-93	557	<.01	21.0	.03	.20	--	<.05	<.05	.65
	11-02-93	570	<.01	22.0	.02	.19	--	--	--	--
	11-30-93	553	<.01	20.0	.07	.19	--	--	--	--
	06-29-94	542	<.01	18.0	.03	.18	--	--	--	--
(3D)	08-20-93	164	<.01	1.70	.02	.03	--	<.05	<.05	<.05
	11-03-93	170	<.01	2.80	.02	.11	--	--	--	--
	12-01-93	172	<.01	2.70	.02	.08	--	--	--	--
	06-29-94	160	<.01	1.90	.03	.05	--	--	--	--
(3S)	08-20-93	161	<.01	4.90	.03	.29	--	<.05	<.05	<.05
	11-03-93	162	<.01	5.10	.02	.28	--	--	--	--
	12-01-93	163	<.01	4.90	.02	.25	--	--	--	--
	06-29-94	151	<.01	4.10	.01	.30	--	--	--	--
(4D)	08-19-93	278	<.01	9.30	.02	.05	--	<.05	<.05	<.05
	11-02-93	280	<.01	9.10	.02	.05	54	--	--	--
	12-01-93	283	<.01	9.30	.03	.05	--	--	--	--
	06-29-94	282	<.01	9.80	.03	.04	--	--	--	--
(4S)	08-19-93	279	<.01	7.00	.04	.07	--	<.05	<.05	<.05
	11-02-93	287	<.01	7.90	.02	.07	31	--	--	--
	12-01-93	286	<.01	8.00	.03	.08	--	--	--	--
	06-29-94	295	<.01	9.30	.04	.05	--	--	--	--

**Table 8.** Physical properties and analytical results of water samples collected from observation wells in the Long Pine Creek Study area, north-central Nebraska, 1993–94—Continued

Local identification	Date	Cyanazine, water, dissolved, recoverable (µg/L)	Deethylatrazine, water, dissolved, recoverable (µg/L)	Deiso-propyl-atrazine, water, dissolved, recoverable (µg/L)	Metolachlor, water, dissolved (µg/L)	Metribuzin sencor, water dissolved (µg/L)	Prometon, water, dissolved, recoverable (µg/L)	Prometryn, water, dissolved, recoverable (µg/L)	Propazine, water, dissolved, recoverable (µg/L)	Simazine, water, dissolved, recoverable (µg/L)
(1D)	08-18-93	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	--
	11-02-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
	06-28-94	<.20	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
(1M)	08-18-93	<.20	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	11-02-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
	06-28-94	--	--	--	--	--	--	--	--	--
(1S)	08-18-93	<.20	1.4	.13	<.05	<.05	<.05	<.05	<.05	<.05
	11-02-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
	06-28-94	--	--	--	--	--	--	--	--	--
(2D)	08-20-93	<.20	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	11-02-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
	06-29-94	--	--	--	--	--	--	--	--	--
(2S)	08-20-93	<.20	.62	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	11-02-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
	06-29-94	--	--	--	--	--	--	--	--	--
(3D)	08-20-93	<.20	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	11-03-93	--	--	--	--	--	--	--	--	--
	12-01-93	--	--	--	--	--	--	--	--	--
	06-29-94	--	--	--	--	--	--	--	--	--
(3S)	08-20-93	<.20	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	11-03-93	--	--	--	--	--	--	--	--	--
	12-01-93	--	--	--	--	--	--	--	--	--
	06-29-94	--	--	--	--	--	--	--	--	--
(4D)	08-19-93	<.20	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	11-02-93	--	--	--	--	--	--	--	--	--
	12-01-93	--	--	--	--	--	--	--	--	--
	06-29-94	--	--	--	--	--	--	--	--	--
(4S)	08-19-93	<.20	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
	11-02-93	--	--	--	--	--	--	--	--	--
	12-01-93	--	--	--	--	--	--	--	--	--
	06-29-94	--	--	--	--	--	--	--	--	--

**Table 8. Physical properties and analytical results of water samples collected from observation wells in the Long Pine Creek Study area, north-central Nebraska, 1993–94—Continued**

Station number (local identification)	Date	Geologic unit	Depth of well, total (feet)	Depth to water <sup>1</sup> (feet)	Specific conduc- tance ( $\mu\text{S}/\text{cm}$ )	pH, whole lab (standard units)	Tempera- ture, water (Deg C)	Oxygen, dissolved (mg/L)	Alkalinity lab (mg/L as ( $\text{CaCO}_3$ ))
42304609939260 (5)	08-20-93	121OGLL	155	126.8	348	7.9	14.0	2.0	161
	11-03-93	121OGLL	155	126.3	337	7.4	14.0	3.8	163
	12-01-93	121OGLL	155	125.8	338	7.6	13.5	4.6	164
	06-30-94	121OGLL	155	125.0	322	7.6	17.0	2.6	163
422849099521501 (6D)	08-17-93	121OGLL	400	8.4	131	8.2	13.5	4.0	68
	11-01-93	121OGLL	400	8.0	154	7.7	13.5	7.8	69
	11-30-93	121OGLL	400	7.7	159	7.9	13.5	8.9	69
	06-28-94	121OGLL	400	8.5	153	7.8	13.5	6.2	69
422849099521502 (6M)	08-18-93	121OGLL	200	7.0	113	7.8	13.0	3.4	51
	11-01-93	121OGLL	200	6.8	108	7.6	12.5	7.9	50
	11-30-93	121OGLL	200	6.5	105	7.5	12.0	8.8	49
	06-28-94	121OGLL	200	7.3	103	7.5	15.0	5.9	48
422849099521503 (6S)	08-18-93	112SDGV	50	7.2	100	7.3	12.5	3.7	32
	11-01-93	112SDGV	50	6.0	95	7.3	11.5	9.4	34
	11-30-93	112SDGV	50	6.6	94	7.1	11.0	10.6	34
	06-28-94	112SDGV	50	6.7	96	7.0	12.5	7.1	33
423259099475101 (7D)	08-20-93	121OGLL	250	13.0	119	7.5	12.5	2.8	53
	11-01-93	121OGLL	250	10.1	116	7.4	11.5	7.2	54
	12-01-93	121OGLL	250	11.1	114	7.4	12.0	9.6	54
	06-30-94	121OGLL	250	14.7	116	7.2	13.0	6.5	54
423259099475102 (7S)	08-20-93	112SDGV	50	9.3	276	7.1	11.0	3.2	63
	11-01-93	112SDGV	50	10.4	266	7.1	10.5	7.6	75
	11-01-93	112SDGV	50	10.4	266	6.8	10.5	7.6	60
	12-01-93	121OGLL	50	9.5	283	6.9	10.5	9.5	66
	06-30-94	112SDGV	50	9.5	294	6.8	11.5	5.7	68
423553099434101 (8D)	08-19-93	121OGLL	295	126.4	--	7.9	14.0	2.8	70
	11-02-93	121OGLL	295	--	146	7.7	13.5	7.0	71
	12-02-93	121OGLL	295	127.4	146	7.7	13.0	8.5	70
	06-30-94	121OGLL	295	127.4	136	7.6	15.5	5.6	70
	06-30-94	121OGLL	295	126.5	137	7.6	16.0	5.6	70
423553099434102 (8M)	08-19-93	121OGLL	203	126.4	--	8.0	14.0	3.5	116
	11-02-93	121OGLL	203	--	293	7.7	13.0	8.5	118
	12-02-93	121OGLL	203	126.9	294	7.7	12.5	10.4	118
	06-30-94	121OGLL	203	125.7	279	7.7	16.0	3.7	117
423553099434103 (8S)	08-19-93	121OGLL	150	126.5	390	7.8	--	3.5	185
	11-02-93	121OGLL	150	127.4	486	7.4	13.0	9.9	193
	12-02-93	121OGLL	150	126.9	500	7.6	12.5	11.1	195
	06-30-94	121OGLL	150	125.6	430	7.7	15.5	6.4	180

**Table 8. Physical properties and analytical results of water samples collected from observation wells in the Long Pine Creek Study area, north-central Nebraska, 1993–94—Continued**

Local identification	Date	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO <sub>4</sub> )	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO <sub>2</sub> )	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)
(5)	08-20-93	52	4.3	12	6.5	12	0.9	0.2	48	3	4
	11-03-93	50	4.0	12	7.7	8.6	.8	.2	49	<3	<1
	12-01-93	51	4.1	12	6.7	12	1.0	.2	47	10	4
	06-30-94	52	4.0	11	6.5	11	1.0	.2	48	<3	<1
(6D)	08-17-93	23	3.1	4.0	4.1	1.4	.4	.5	61	4	<1
	11-01-93	21	3.1	3.5	4.3	1.2	.4	.5	62	5	<1
	11-30-93	21	2.9	3.6	.7	1.3	.2	.4	62	<3	<1
	06-28-94	21	3.0	3.4	4.2	1.1	.4	.4	58	<3	<1
(6M)	08-18-93	12	1.7	8.3	3.5	1.3	.4	.3	60	32	3
	11-01-93	12	1.9	5.8	3.7	1.1	.4	.3	60	16	3
	11-30-93	12	1.9	4.9	3.7	1.0	.2	.3	62	5	4
	06-28-94	12	2.0	4.2	3.5	.8	.4	.3	59	4	2
(6S)	08-18-93	11	1.6	4.6	3.4	3.5	.5	.2	53	5	<1
	11-01-93	10	1.6	4.4	3.7	3.3	.6	.2	55	7	<1
	11-30-93	10	1.6	4.2	3.5	3.4	.6	.2	52	7	1
	06-28-94	10	1.5	4.4	3.4	4.1	.7	.1	52	4	<1
(7D)	08-20-93	11	1.4	10	3.2	1.1	.5	.3	59	5	<1
	11-01-93	14	1.8	4.8	4.0	1.3	.6	.2	61	6	<1
	12-01-93	15	1.7	4.3	3.9	1.2	.5	.2	63	4	<1
	06-30-94	14	1.7	4.4	3.9	1.1	.5	.2	57	<3	<1
(7S)	08-20-93	33	5.6	8.0	5.6	11	2.8	.1	48	3	<1
	11-01-93	31	5.6	8.1	5.5	13	3.1	.2	49	<3	<1
	11-01-93	31	5.6	8.3	6.5	11	3.0	.2	50	<3	<1
	12-01-93	32	5.8	8.4	6.1	11	2.5	.1	48	<3	<1
	06-30-94	35	6.1	7.9	5.8	10	2.9	.1	47	<3	<1
(8D)	08-19-93	20	2.5	5.1	3.9	1.1	.7	.2	60	4	<1
	11-02-93	20	2.6	5.1	4.6	1.2	.8	.2	64	5	<1
	12-02-93	19	2.6	5.3	4.3	1.1	.4	.2	59	3	<1
	06-30-94	19	2.6	4.8	3.9	1.9	.8	.2	60	<3	<1
	06-30-94	19	2.6	4.9	3.7	1.1	.8	.3	60	14	<1
(8M)	08-19-93	42	4.6	9.6	5.6	8.2	2.1	.1	59	<3	<1
	11-02-93	39	4.5	11	6.7	11	2.2	.2	59	<3	<1
	12-02-93	40	4.6	10	6.1	8.4	2.5	.2	57	<3	<1
	06-30-94	41	4.6	9.2	6.0	8.6	2.1	.2	58	<3	<1
(8S)	08-19-93	73	7.9	13	8.1	13	1.8	.3	54	3	6
	11-02-93	72	7.9	13	7.8	12	1.8	.3	54	4	1
	12-02-93	73	8.0	13	8.3	13	2.0	.3	53	<3	5
	06-30-94	66	7.1	12	7.7	11	1.8	.3	54	<3	<1

**Table 8.** Physical properties and analytical results of water samples collected from observation wells in the Long Pine Creek Study area, north-central Nebraska, 1993–94—Continued

Local identification	Date	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> , dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Tritium, total (PCI/L)	Alachlor, water, dissolved, recoverable (µg/L)	Ametryn, water, dissolved, recoverable (µg/L)	Atrazine, water, dissolved, recoverable (µg/L)
(5)	08-20-93	239	<0.01	1.40	0.02	0.12	--	<0.05	<0.05	<0.05
	11-03-93	236	<.01	1.30	.02	.12	19	--	--	--
	12-01-93	238	<.01	1.30	.02	.12	--	--	--	--
	06-30-94	238	<.01	1.30	.03	.11	--	<.05	<.05	<.05
(6D)	08-17-93	149	<.01	2.50	.01	.02	--	<.05	<.05	<.05
	11-01-93	148	<.01	2.30	.02	.02	<.3	--	--	--
	11-30-93	143	<.01	2.20	.03	.04	--	--	--	--
(6D)	06-28-94	143	<.01	2.20	.02	.01	--	<.05	<.05	<.05
(6M)	08-18-93	123	<.01	.93	.02	.17	--	<.05	<.05	<.05
	11-01-93	119	<.01	.83	.02	.14	.3	--	--	--
	11-30-93	119	<.01	.82	.02	.14	--	--	--	--
	06-28-94	115	<.01	.81	.02	.13	--	<.05	<.05	<.05
(6S)	08-18-93	109	.01	2.50	.02	.27	--	<.05	<.05	<.05
	11-01-93	110	<.01	2.30	<.01	.28	.9	--	--	--
	11-30-93	107	<.01	2.20	.02	.28	--	--	--	--
	06-28-94	107	<.01	2.40	.01	.28	--	<.05	<.05	<.05
(7D)	08-20-93	123	<.01	.83	.02	.22	--	--	--	--
	11-01-93	125	<.01	.99	.02	.19	<.3	--	--	--
	12-01-93	127	<.01	.94	.02	.19	--	--	--	--
	06-30-94	120	<.01	.91	.03	.17	--	--	--	--
(7S)	08-20-93	152	--	--	--	.15	--	<.05	<.05	<.05
	11-01-93	219	<.01	13.0	.02	.18	77	--	--	--
	11-01-93	210	<.01	13.0	<.01	.18	--	--	--	--
	12-01-93	216	<.01	14.0	.02	.17	--	--	--	--
	06-30-94	189	<.01	7.40	.04	.16	--	--	--	--
(8D)	08-19-93	139	<.01	.78	.02	.07	--	--	--	--
	11-02-93	146	<.01	1.00	<.01	.07	<.3	--	--	--
	12-02-93	138	<.01	.96	.02	.06	--	--	--	--
	06-30-94	139	<.01	.80	.03	.05	--	--	--	--
	06-30-94	138	<.01	.87	.02	.05	--	--	--	--
(8M)	08-19-93	225	<.01	5.50	.02	.05	--	<.05	<.05	<.05
	11-02-93	230	<.01	5.70	.01	.05	15	--	--	--
	12-02-93	224	<.01	5.60	.02	.04	--	--	--	--
	06-30-94	223	<.01	5.10	.03	.04	--	<.05	<.05	<.05
(8S)	08-19-93	344	<.01	14.0	.02	.05	--	<.05	<.05	<.05
	11-02-93	342	<.01	13.0	.02	.06	60	--	--	--
	12-02-93	350	<.01	14.0	.02	.05	--	--	--	--
	06-30-94	317	<.01	11.0	.03	.03	--	--	--	--

**Table 8.** Physical properties and analytical results of water samples collected from observation wells in the Long Pine Creek Study area, north-central Nebraska, 1993–94—Continued

Local identification	Date	Cyanazine, water, dissolved, recoverable (µg/L)	Deethylatrazine, water, dissolved, recoverable (µg/L)	Deisopropylatrazine, water, dissolved, recoverable (µg/L)	Metolachlor, water, dissolved (µg/L)	Metribuzin sencor, water, dissolved (µg/L)	Prometon, water, dissolved, recoverable (µg/L)	Prometryn, water, dissolved, recoverable (µg/L)	Propazine, water, dissolved, recoverable (µg/L)	Simazine, water, dissolved, recoverable (µg/L)
(5)	08-20-93	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	--
	11-03-93	--	--	--	--	--	--	--	--	--
	12-01-93	--	--	--	--	--	--	--	--	--
	06-30-94	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
(6D)	08-17-93	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	--
	11-01-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
(6D)	06-28-94	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
(6M)	08-18-93	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	--
	11-01-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
	06-28-94	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
(6S)	08-18-93	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	11-01-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
	06-28-94	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	--
(7D)	08-20-93	--	--	--	--	--	--	--	--	--
	11-01-93	--	--	--	--	--	--	--	--	--
	12-01-93	--	--	--	--	--	--	--	--	--
	06-30-94	--	--	--	--	--	--	--	--	--
(7S)	08-20-93	<0.20	.23	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	11-01-93	--	--	--	--	--	--	--	--	--
	11-01-93	--	--	--	--	--	--	--	--	--
	12-01-93	--	--	--	--	--	--	--	--	--
	06-30-94	--	--	--	--	--	--	--	--	--
(8D)	08-19-93	--	--	--	--	--	--	--	--	--
	11-02-93	--	--	--	--	--	--	--	--	--
	12-02-93	--	--	--	--	--	--	--	--	--
	06-30-94	--	--	--	--	--	--	--	--	--
	06-30-94	--	--	--	--	--	--	--	--	--
(8M)	08-19-93	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	--
	11-02-93	--	--	--	--	--	--	--	--	--
	12-02-93	--	--	--	--	--	--	--	--	--
	06-30-94	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	--
(8S)	08-19-93	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	11-02-93	--	--	--	--	--	--	--	--	--
	12-02-93	--	--	--	--	--	--	--	--	--
	06-30-94	--	--	--	--	--	--	--	--	--

**Table 8.** Physical properties and analytical results of water samples collected from observation wells in the Long Pine Creek Study area, north-central Nebraska, 1993–94—Continued

Station number (local identification)	Date	Geologic unit	Depth of well, total (feet)	Depth to water <sup>1</sup> (feet)	Specific conduc- tance ( $\mu$ S/cm)	pH, whole lab (standard units)	Temperature water (Deg C)	Oxygen, dissolved (mg/L)	Alkalinity lab (mg/L as CaCO <sub>3</sub> )
424000099424701 (9)	08-19-93	121OGLL	180	134.5	--	7.6	15.0	2.4	60
	11-03-93	121OGLL	180	134.6	131	7.3	14.0	6.6	56
	12-01-93	121OGLL	180	134.7	130	7.1	13.5	8.0	54
	06-30-94	121OGLL	180	136.0	128	7.0	16.5	6.5	54
423443100003701 (10D)	08-20-93	121OGLL	200	14.8	180	8.0	13.0	--	88
	11-02-93	121OGLL	200	14.5	181	7.8	12.5	1.0	89
	11-30-93	121OGLL	200	14.7	185	7.8	12.0	1.1	90
	06-29-94	121OGLL	200	16.2	201	7.7	13.5	1.1	95
423443100003702 (10S)	08-20-93	112SDGV	65	14.8	474	7.0	11.5	--	74
	11-02-93	112SDGV	65	14.4	410	6.8	11.0	7.4	72
	11-30-93	112SDGV	65	14.6	400	6.7	11.0	9.3	71
	06-29-94	112SDGV	65	16.1	445	6.8	12.5	5.6	75

Local identifica- tion	Date	Calcium, dissolved (mg/L as Ca)	Mag- nesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potas- sium, dissolved (mg/L as K)	Sulfate, dissolved (mg/L as SO <sub>4</sub> )	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO <sub>2</sub> )	Iron, dissolved ( $\mu$ g/L as Fe)	Man- ganese, dissolved ( $\mu$ g/L ss Mn)
(9)	08-19-93	13	1.5	4.4	4.6	4.9	0.5	0.2	69	28	4
	11-03-93	17	1.9	4.9	--	4.9	.7	.2	71	<3	1
	12-01-93	17	2.0	3.9	5.0	5.0	.7	.2	73	10	3
	06-30-94	16	2.0	3.9	4.7	5.2	.5	.2	69	14	1
(10D)	08-20-93	26	3.3	5.6	4.4	1.5	.4	.2	64	3	3
	11-02-93	23	3.2	7.1	4.8	1.6	.5	.3	66	4	3
	11-30-93	24	3.3	5.8	4.3	1.7	.6	.2	66	7	4
	06-29-94	26	4.0	6.3	6.3	2.7	1.0	.2	57	<3	2
(10S)	08-20-93	59	8.1	14	6.3	28	11	<.1	39	10	<1
	11-02-93	47	6.9	13	6.9	25	8.4	.2	40	7	<1
	11-30-93	48	6.9	13	6.1	24	8.4	.1	38	7	<1
	06-29-94	55	7.8	13	6.3	29	10	.2	39	<3	<1

**Table 8.** Physical properties and analytical results of water samples collected from observation wells in the Long Pine Creek Study area, north-central Nebraska, 1993–94—Continued

Local identification	Date	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, NO <sub>2</sub> +NO <sub>3</sub> , dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Tritium, total (PCI/L)	Alachlor, water, dissolved, recoverable (µg/L)	Ametryn water, dissolved, recoverable (µg/L)	Atrazine, water, dissolved, recoverable (µg/L)
(9)	08-19-93	142	<0.01	1.50	0.05	0.47	--	<0.05	<0.05	<0.05
	11-03-93	--	<0.01	1.30	<0.01	.44	2.6	--	--	--
	12-01-93	146	<0.01	1.30	.02	.43	--	--	--	--
	06-30-94	141	<0.01	1.30	.01	.42	--	<0.05	<0.05	<0.05
(10D)	08-20-93	161	<0.01	.51	.02	.03	--	<0.05	<0.05	<0.05
	11-02-93	163	<0.01	.58	.01	.03	--	--	--	--
	11-30-93	163	<0.01	.70	.02	.03	--	--	--	--
	06-29-94	168	<0.01	1.70	.03	.03	--	--	--	--
(10S)	08-20-93	330	<0.01	27.0	.02	.16	--	<0.05	<0.05	<0.05
	11-02-93	289	<0.01	22.0	.02	.17	--	--	--	--
	11-30-93	285	<0.01	22.0	.02	.18	--	--	--	--
	06-29-94	316	<0.01	25.0	.03	.16	--	--	--	--

Local identification	Date	Cysnazine, water, dissolved, recoverable (µg/L)	Deethylatrazine, water, dissolved, recoverable (µg/L)	Delso-propyl-atrazine, water, dissolved, recoverable (µg/L)	Metolachlor, water, dissolved (µg/L)	Metribuzin sencor, water, dissolved (µg/L)	Prometon, water, dissolved, recoverable (µg/L)	Prometryn, water, dissolved, recoverable (µg/L)	Propazine water, dissolved, recoverable (µg/L)	Simazine, water, dissolved, recoverable (µg/L)
(9)	08-19-93	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	--
	11-03-93	--	--	--	--	--	--	--	--	--
	12-01-93	--	--	--	--	--	--	--	--	--
	06-30-94	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	--
(10D)	08-20-93	<0.20	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	11-02-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
	06-29-94	--	--	--	--	--	--	--	--	--
(10S)	08-20-93	<0.20	.50	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	11-02-93	--	--	--	--	--	--	--	--	--
	11-30-93	--	--	--	--	--	--	--	--	--
	06-29-94	--	--	--	--	--	--	--	--	--

<sup>1</sup>Note that depth to water values for a given nest of wells were made from the same datum and are directly comparable.