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Extent, Magnitude, and Sources of Nitrate in the Flaxville and Underlying Aquifers, Fort Peck Indian Reservation, Northeastern Montana

Water-Resources Investigations Report 98-4079

U.S. Department of the Interior
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By David A. Nimick and Joanna N. Thamke

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In cooperation with the
OFFICE OF ENVIRONMENTAL PROTECTION of the FORT PECK TRIBES

U.S. Department of the Interior

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June 1998

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Multiply	By	To obtain
acre	4,047	square meter
foot (ft)	0.3048	meter
gallon (gal)	3.785	liter
gallon per acre (gal/acre)	9.352	liters per hectare
gallon per minute (gpm)	0.06309	liter per second
inch (in.)	25,400	micrometer (micron)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer
pound per acre (lb/acre)	1.121	kilogram per hectare
pound per cubic foot	0.01602	gram per cubic centimeter (g/cm^3)
square mile (mi^2)	2.59	square kilometer

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:

$$°F = 9/5(°C)+32$$

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

Abbreviated water-quality units and symbols used in this report:

g/cm^3	gram per cubic centimeter
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
‰	permil
<	less than

Acronyms used in this report:

CFC	chlorofluorocarbon
CRP	Conservation Reserve Program
MCL	maximum contaminant level
PVC	polyvinyl chloride

EXTENT, MAGNITUDE, AND SOURCES OF NITRATE IN THE FLAXVILLE AND UNDERLYING AQUIFERS, FORT PECK INDIAN RESERVATION, NORTHEASTERN MONTANA

By David A. Nimick and Joanna N. Thamke

Abstract

Information on soils, land use, pore- and ground-water chemistry, ground-water age, and stable isotopes was collected to examine the relation between extensive dryland agriculture and elevated concentrations of nitrate (NO_3) in water in the Flaxville and two underlying aquifers in the Fort Peck Indian Reservation, northeastern Montana. Concentrations of NO_3 equaled or exceeded 10 milligrams per liter NO_3 as nitrogen (N) in water from 84 percent of the wells completed in the Flaxville aquifer and 51 percent of all wells sampled in the study area. On the basis of $\delta^{15}N_{NO3}$ values for ground water, mineralization of soil organic N derived from wheat stubble in crop-fallow farmland is the dominant source of NO_3. Livestock wastes locally are a point source of NO_3. Fertilizer was not a direct NO_3 source. Median NO_3 concentrations in soil samples collected from pits 10-feet deep in dryland cropland were higher in fertilized areas than in non-fertilized areas. This apparent increase in NO_3 loading from fertilized cropland probably results from the larger amount of soil organic N, which is induced by fertilization and then mineralized during the fallow season. $\delta^{15}N_{NO3}$ values in pore water extracted from cropland soil confirmed that soil organic N is the primary NO_3 source. Ground-water ages determined from concentrations of chlorofluorocarbons generally were 6-30 years, indicating that NO_3 concentrations in ground water sampled during this study were affected by land-use conditions during the previous 30 years. Reductions in NO_3 concentrations probably could be achieved through a variety of land-management strategies.

INTRODUCTION

High NO_3 concentrations in ground water commonly are related to land use in overlying areas. In most areas, agricultural activities are the primary source of NO_3 to ground water, particularly where row crops are intensively irrigated and fertilized (Mueller and Helsel, 1996). However, agricultural activities can affect NO_3 concentrations in ground water in non-irrigated areas and where use of fertilizer is limited. This potential effect is of particular interest in the semi-arid Great Plains, where dryland production of small grains using crop-fallow rotation is common. The potential for NO_3 leaching from crop-fallow systems is great because NO_3 is mobilized by mineralization of organic matter at the same time that excess soil moisture is available for deep leaching (Power, 1970; Cassel and others, 1971). NO_3 can be derived from decomposition of the original native sod in the first years of farming after initial ground breaking (Doughty and others, 1954; Reinhorn and Avnimelech, 1974; Kreitler and Jones, 1975; Custer, 1976; Lamb and others, 1985) or from crop residue left after harvest (Cassel and others, 1971; Power, 1972).

In northeastern Montana, crop-fallow farming is widespread and many wells completed in shallow aquifers produce water having NO_3 concentrations that exceed 10 mg/L NO_3-N (Donovan and Bergantino, 1987; Thamke, 1991), the maximum contaminant level (MCL) specified by primary drinking-water regulations established by the U.S. Environmental Protection Agency (1991). The relation between crop-fallow farming and high NO_3 concentrations in ground water was suggested by Bauder and others (1993), who used a multiple-regression analysis to link the relatively high NO_3 concentrations in ground water in counties of northeastern Montana to specific soil types and physiographic conditions commonly associated with crop-fallow farming.

In the northern Great Plains, high NO_3 concentrations occur in fine-grained aquifers having slow flow rates as well as more transmissive, coarse-grained aquifers. Fine-grained aquifers, such as ones composed of glacial till, have been studied extensively in Montana because of widespread saline-seep development (Miller and Bergantino, 1983). Saline seeps develop where recharge is increased by crop-fallow farming and salts, including NO_3, are mobilized (Miller, 1971; Custer, 1976; Doering and Sandoval, 1981). The increased salinity and NO_3 concentrations are related to pre-farming conditions--accumulated salts in the soil and organic-rich native sod (Custer, 1976; Doering and Sandoval, 1981). In contrast, the high NO_3 concentrations in coarse-grained, shallow aquifers in northeastern Montana have been recognized (Donovan and Bergantino, 1987; Thamke, 1991; Bauder and others, 1993), but the NO_3 source has not been conclusively determined.

In the Fort Peck Indian Reservation, the Tertiary Flaxville Formation caps plateaus and topographic benches that provide ample land for dryland wheat farms and residential development. High NO_3 concentrations have been observed in water samples from the Flaxville and underlying aquifers, which are important sources of ground water on the reservation (Donovan and Bergantino, 1987; Thamke, 1991). No studies have been conducted to determine the source of NO_3 in the Flaxville and underlying aquifers or the hydrogeochemical processes that affect the mobilization and transport of the NO_3. The sand and gravel deposits of the Flaxville Formation provide a natural laboratory for examining potential relations between non-irrigated agriculture and NO_3 concentrations in a coarse-grained, shallow aquifer.

PURPOSE AND SCOPE

This report examines the extent, magnitude, and sources of NO_3 concentrations in the Flaxville and underlying aquifers in the Fort Peck Indian Reservation, northeastern Montana (fig. 1). Extent and magnitude were determined through sampling of 5 test wells and 107 domestic and stock wells throughout the study area. Possible human-induced and natural sources of NO_3 were examined using a variety of methods including analysis of stable isotopes, comparison of past and present land uses to NO_3 concentrations in ground water, age-dating of ground water using chlorofluorocarbons (CFCs), and chemical analysis of soils from areas of different land use. Interpretations presented here are based on data collected from August 1994 through April 1996 for this study (tables 2-8, at back of report), previously published data, and unpublished data retrieved from the Ground Water Information Center at the Montana Bureau of Mines and Geology in Butte, Mont.

The study area is in the Fort Peck Indian Reservation and is delineated by the boundary of the Flaxville Formation (fig. 2); it includes about 720 mi^2 in parts of Daniels, Roosevelt, Sheridan, and Valley Counties. Underlying aquifers included in this study were the Fort Union aquifer of Paleocene age and the Fox Hills-lower Hell Creek aquifer of Late Cretaceous age.

METHODS OF DATA COLLECTION

Farmland and native rangeland were mapped from 1:50,000 composite images derived from Landsat satellite imagery obtained in August 1993. Owing to the scale of the Landsat images, these land uses were mapped as large blocks of land and included thin strips of land used for roads and areas used for homes and farm headquarters. Farmland was defined as land that currently (1993) was being farmed or previously had been farmed based on visible signs (on the 1993 Landsat images) of farm strips typical of crop-fallow rotations. Farmland enrolled in the Conservation Reserve Program (CRP) was delineated on the Landsat images by transferring the boundaries of CRP land from large-scale maps and aerial photographs on file in county offices of the Natural Resources Conservation Service. Land enrolled in the CRP is rotated for 10 years or more from farmland to perennial vegetation under contract with the Federal government. Hayfields and pasture were mapped together with rangeland because these three land uses were difficult to distinguish on the Landsat images and because NO_3 loading from these land uses was expected to be similar and uniformly low.

Agricultural statistics were obtained for the four counties in the study area from information published annually or biannually by the Montana Department of Agriculture or about every 5 years by the U.S. Department of Commerce. Data were compiled by county because data were not available for just the study area or the reservation. Farm operations in the study area are similar to dryland operations outside the reservation and, therefore, the county statistics were assumed to be representative of the study area. Fertilized cropland includes all crops, irrigated and non-irrigated; however, the vast majority of cropland in the four counties is used for dryland wheat so the fertilized cropland statistics were assumed to be representative of non-irrigated cropland.

In August-October 1994, 162 domestic and stock wells throughout the study area were inventoried. Initial water-quality data, information on land-use practices that potentially could affect NO_3 in ground water, and well-construction information were obtained during the inventory.

Test wells were installed in July 1995 with an air-rotary drill rig. Casing material was 6-in. diameter steel or 4-in. diameter polyvinyl chloride (PVC).

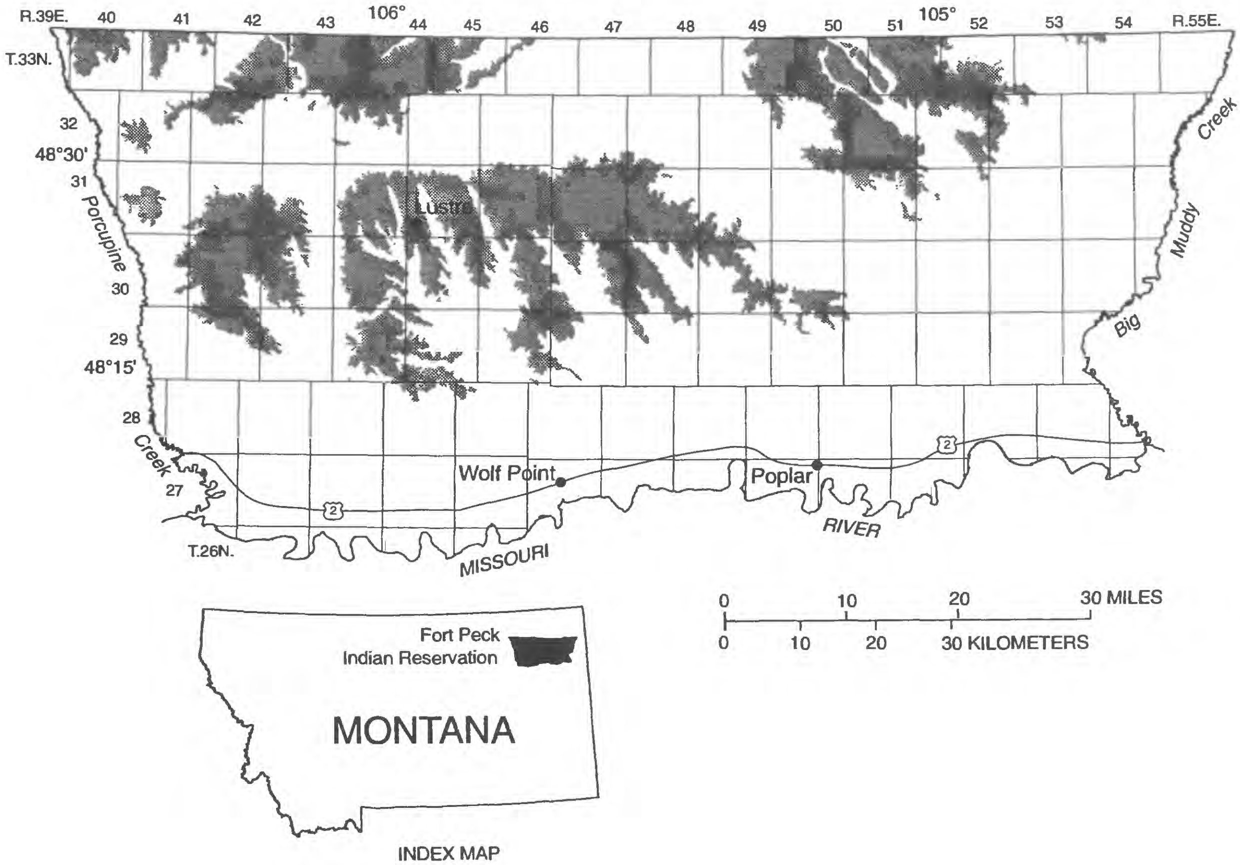

Figure 1. Location of Fort Peck Indian Reservation and study area (shaded) in Montana. The study area is the area underlain by the Flaxville Formation.

Perforations were cut with a torch in steel casing, which was driven to the desired depth. PVC-cased wells had a factory-slotted screen, and the annulus adjacent to the screen was filled with silica sand; bentonite pellets or chips were placed on top of the sand pack to form a seal 1-2-ft thick. Test wells were developed with air and then by pumping until clear water was produced.

Ground-water samples were collected from domestic and stock wells using the existing pumps and from test wells using a portable stainless-steel submersible pump. All wells were purged until at least three well volumes of water were removed and field parameters (temperature, pH, dissolved oxygen, and specific conductance) had stabilized (Knapton, 1985). Quality-control data were provided by replicate and field-blank samples, which comprised about 10 percent of the total number of samples analyzed (Knapton and Nimick, 1991). Samples were collected from 112 wells for NO_3 analysis; samples from 45 of these wells were also analyzed for major ions. $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ values and CFC concentrations were determined in samples from 33, 18, and 23 of the 45 wells, respectively.

Chemical analyses were performed by the U.S. Geological Survey National Water Quality Laboratory, Arvada, Colo., using methods described by Fishman and Friedman (1989) and Fishman (1993). NO_3 concentrations are reported as mg/L NO_3 as N. Concentrations of CFCs and associated dissolved gases used to estimate ground-water recharge dates were analyzed by the U.S. Geological Survey, Reston, Va., using methods described in Busenberg and Plummer (1992). Stable isotope ratios of O and N in NO_3 in water were

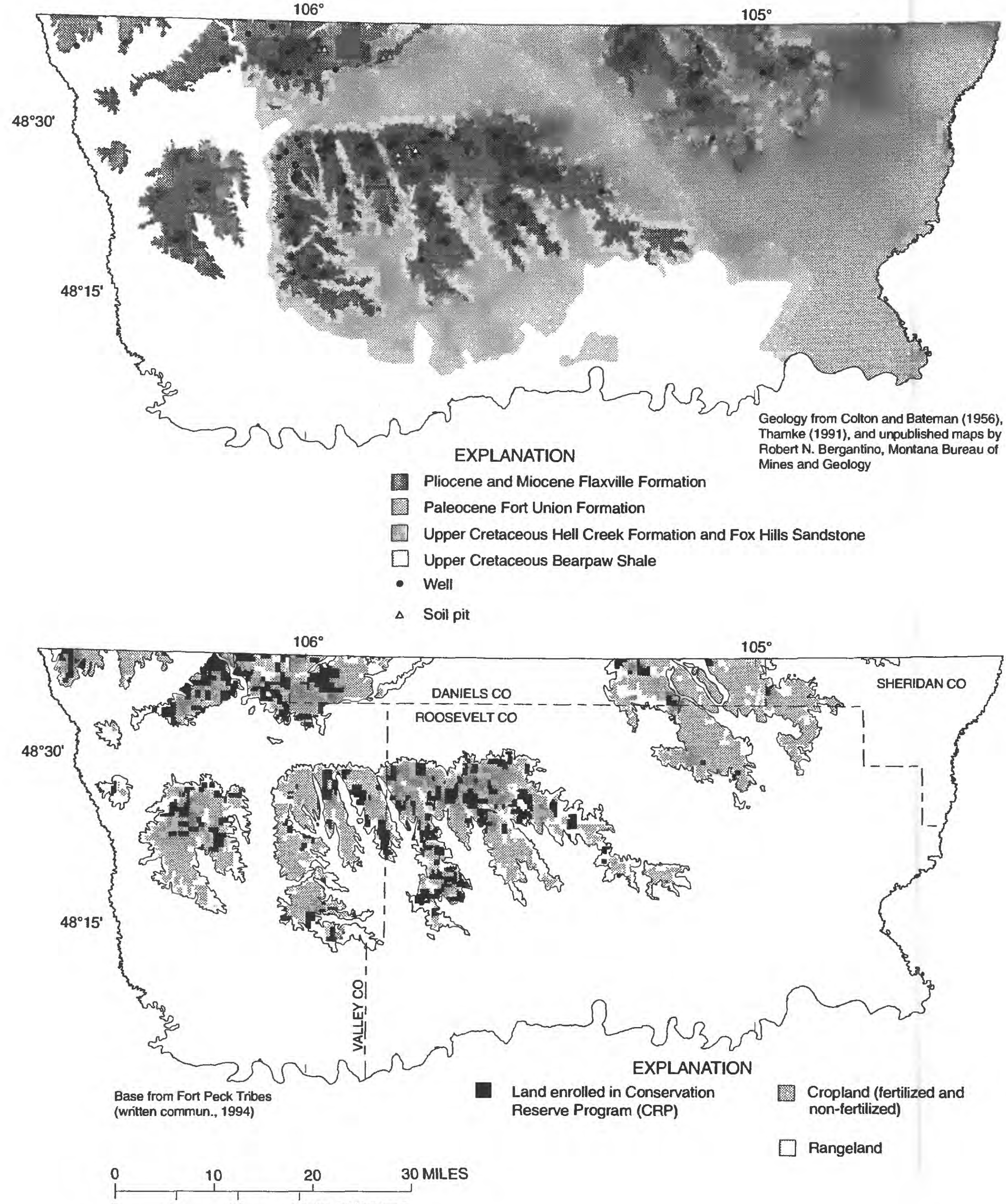

Figure 2. Generalized geology of the Fort Peck Indian Reservation and sampling-site locations (top) and land use in 1993 in the study area (areas underlain by the Flaxville Formation) (bottom).

determined by the U.S. Geological Survey, Menlo Park, Calif., from NO_3 concentrated on anion exchange resin columns within 24 hours of sample collection (Kendall and Grim,1990; Kendall and others, 1996).

Soil samples were collected in June 1995 from soil pits (fig. 2). Bulk samples generally were collected from seven intervals (typically 0-1, 1-2, 2-3, 3-4, 4-6, 6-8, and 8-10 ft) in each pit. Samples were cooled in the field and kept frozen until analyses were performed. In the laboratory, clasts larger than 2 mm were removed by sieving. Physical and chemical analyses were performed on the finer fraction. Soil NO_3 was extracted with KCl (Page, 1982). $\delta^{15}N_{NO3}$ was determined in 1:10 (soil:deionized water by weight) extracts. Deionized water was used in the extracts for $\delta^{15}N_{NO3}$ determinations instead of KCl so that only mobile NO_3 would be extracted (Herbel and Spalding, 1993). Except for $\delta^{15}N_{NO3}$ determinations by the U.S. Geological Survey, all soil analyses were performed by the Soil Analytical Laboratory, Montana State University, Bozeman, Mont.

AGRICULTURAL LAND USE

Farming Methods

Cropland for production of small grains is the primary land use in the study area, with most of the cropland devoted to growing wheat using crop-fallow rotation. Smaller amounts of oats and barley are grown. Typically, half the farmland in a rotation is left uncropped and weed-free with a crop-stubble cover for one growing season. Use of recrop (rotation using about two-thirds crop, one-third fallow) and continuous cropping (rotation using fallow once every 3-5 years) is increasing. Small grains are planted in the spring because winter wheat generally will not survive the winter.

Fallowing of soil is a moisture-storage technique commonly used in northeastern Montana since the 1930's. Moisture is stored in the soil below the surficial evaporation zone during the fallow period, but the proportion of rainfall stored is low--about 15-30 percent (Mathews and Army, 1960; Haas and Willis, 1962; Greb and others, 1970; Olson, 1984). However, sufficient moisture is stored to complement the cropping-season rainfall (Olson, 1984). Reduced and no-tillage farming systems increase moisture-storage efficiency to as much as 40-50 percent (Fenster and Peterson, 1979).

Fallowing not only stores moisture but also promotes NO_3 accumulation in the soil because organic N is mineralized during the fallow period (Cassel and others, 1971; Kreitler and Jones, 1975; Olson, 1984). This conversion of organic N to NO_3 provides valuable crop nutrients and is one of the main reasons to summer fallow. The combination of excess soil moisture that percolates to ground water and excess NO_3 available at times when deep percolation is occurring results in deep leaching of NO_3 and NO_3 loading to ground water. The amount of NO_3 loading is dependent on a variety of factors, including the timing and magnitude of precipitation, soil texture and structure, and amount of crop residue after harvest (Swenson and others, 1979).

Land-Use Distribution and Temporal Trends

On the basis of mapping from 1993 Landsat imagery (fig. 2), 55 percent of the study area was cropland and 15 percent was former cropland enrolled in the CRP. Rangeland, which accounts for 30 percent of the study area, is located in areas generally not suitable for farming and primarily near the perimeter of areas underlain by the Flaxville Formation. The amount of land planted in wheat in the four counties has not changed as much as cattle numbers have during the past 50 years (fig. 3). Since 1960, the land area planted in wheat has been about 1,000,000 acres, but has fluctuated by up to 40 percent. The largest sustained fluctuation occurred during the 1970's and early 1980's, when land speculation led to extensive sod busting. Land area planted in wheat probably did not increase in the study area during the 1970's nearly as much as the county statistics suggest because relatively little rangeland was available to convert to cropland. The dramatic decline in cropland area during the early 1980's was a response to drought conditions. The gradual decrease in cropland area in 1986-95 probably was a result of participation in the CRP (Debi Madison, Fort Peck Tribes, oral commun., 1997).

The ratio of land farmed by continuous cropping compared to crop-fallow rotation changed significantly in 1989-95. Prior to 1989, less than 10 percent of the land planted in wheat was in continuous crop. By 1995, the proportion was 23 percent.

The use of fertilizer increased dramatically during 1954-92 (fig. 3). Virtually no fertilizer was used prior to 1954. In 1987, about 47 percent of the land planted in wheat was fertilized. Although the amount of fertilized land decreased between 1987 and 1992 because of drought conditions (Terry Angvick, Montana State University Extension Service, Plentywood, Mont., oral commun., 1995), reports gathered from

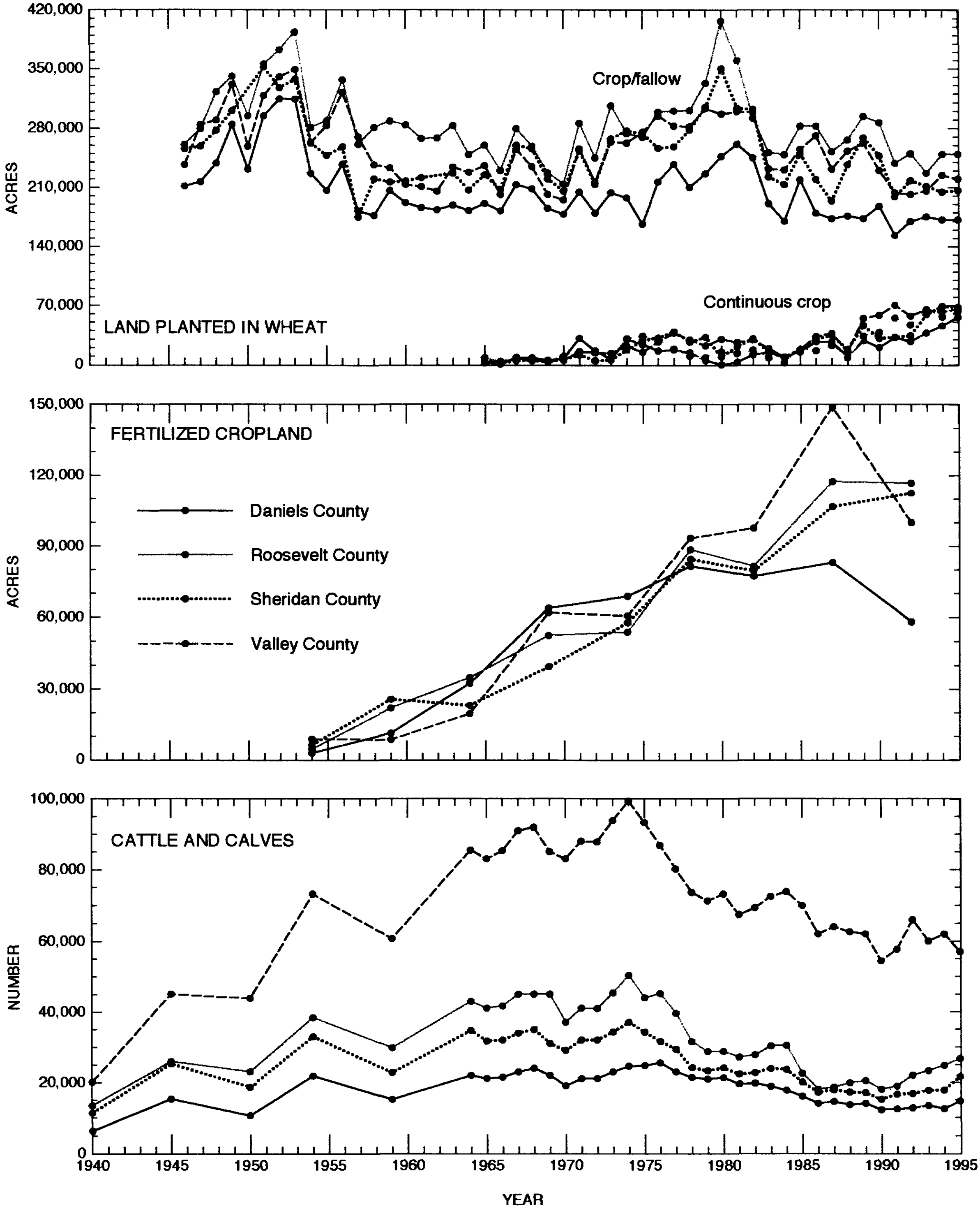

Figure 3. Agricultural statistics for the four counties in the Fort Peck Indian Reservation, northeastern Montana. Data for fertilized cropland and for cattle and calves prior to 1965 from U.S. Department of Commerce (issued periodically). Data for land planted in wheat and for cattle and calves after 1964 from Montana Department of Agriculture (issued annually or biannually).

local operators and fertilizer distributors during this study indicate that the use of fertilizer on crop-fallow farmland is widespread in the study area. Fertilizer use also has increased as land has been converted to continuous crop, which requires higher rates of fertilization and fertilization of entire fields rather than parts of fields. Fertilizer is applied to crop-fallow fields in the spring (March-May) at rates of 5-20 lb/acre N. Somewhat more fertilizer is used on recrop or continuous crop. Currently, ammonium-based fertilizers are used almost exclusively.

Livestock Distribution and Temporal Trends

Many farm operators raise cattle or, in a few circumstances, hogs. Cattle typically are kept in confined areas near farm headquarters for much of the year, both to keep them out of cropland and to make feeding easier in the winter. On the basis of livestock information compiled by Debi Madison (Fort Peck Tribes, written commun., 1996) for the central part of the study area, about 55 percent of the farm operators raise livestock. Herd sizes typically range from 30 to 100 cattle, but several herds are larger.

The number of cattle and calves raised in the four counties has fluctuated over the past 55 years (fig. 3). The number of cattle and calves more than quadrupled between 1940 and 1974 but then decreased by about half by 1990. Numbers have increased slightly since 1990. Livestock trends in the study area are assumed to be similar to the trends in the four counties.

SITE-NUMBERING SYSTEM

Ground-water sites are assigned location numbers according to their geographic position within the rectangular grid system used for the subdivision of public lands (fig. 4). The location number consists of as many as 14 characters. The first three characters specify the township and its position north (N) of the Montana Base Line. The next three characters specify the range and its position east (E) of the Montana Principal Meridan. The next two characters are the section number. The next two to four characters designate the quarter section (160-acre tract), the quarter-quarter section (40-acre tract), the quarter-quarter-quarter section (10-acre tract), and the quarter-quarter-quarter-quarter section (2.5-acre tract), respectively, in which the well is located. These four subdivisions of the section are designated A,B,C, and D in a counter-clockwise direction, beginning in the northeast quadrant. The last two

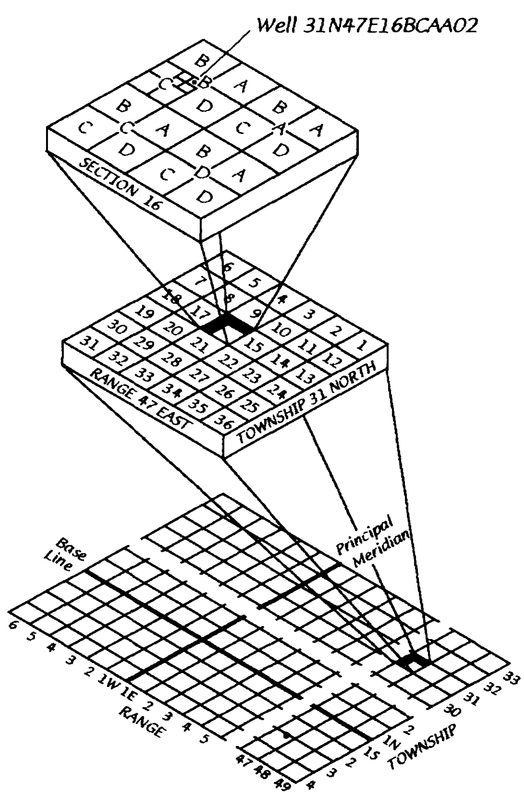

Figure 4. Numbering system for soil and ground-water sites in the Fort Peck Indian Reservation, northeastern Montana.

numeric characters specify a sequence number, based on the order of inventory, to distinguish between multiple wells at a single location. For example, as shown in figure 4, well 31N47E16BCAA02 is the second well inventoried in the NE 1/4 NE 1/4 SW1/4 NW1/4 sec. 16, T. 31 N., R. 47 E.

ACKNOWLEDGMENTS

This study was conducted in cooperation with the Fort Peck Tribes. The authors thank the Office of Environmental Protection and the Water Resources Office of the Fort Peck Tribes for supplying hydrologic and digital data. We also thank individual landowners for their cooperation in allowing access to their lands and for many valuable discussions about farming and water resources. Mary Manydeeds and Tom Stafne assisted with data-collection efforts. Detailed unpublished maps of the Flaxville Formation were provided by Robert N. Bergantino, Montana Bureau of Mines and Geology. Valuable comments on the manuscript were provided by J.W. Bauder, A.D. Druliner, Jane Holzer, and S.R. Silva.

HYDROGEOLOGY OF THE FLAXVILLE AND UNDERLYING AQUIFERS

GEOLOGY

Primary geologic units that contain water used for drinking supply in the study area, in ascending order, are the Upper Cretaceous Fox Hills Sandstone and Hell Creek Formation, the Paleocene Fort Union Formation, and the Miocene and Pliocene Flaxville Formation (fig. 2). The Fox Hills Sandstone consists of an upper sandstone unit and a lower marine shale. The overlying Hell Creek Formation consists dominantly of shale, siltstone, and sandstone. Together, these units form the Fox Hills-lower Hell Creek aquifer. The Fort Union Formation consists primarily of clay, silt, sandstone, and sand irregularly interbedded with carbonaceous seams and thin, discontinuous lignite beds (Witkind, 1959). The Flaxville Formation consists of fluvial sand and gravel (Witkind, 1959). The gravels cap plateaus and benches, which are dissected by many streams. A thin layer (generally 15 feet thick) of till and outwash locally covers part of the study area.

GROUND-WATER OCCURRENCE AND QUALITY

Water in the Flaxville aquifer is unconfined and generally flows toward the many streams that intersect the aquifer (Thamke, 1991). Depths of inventoried wells completed in the aquifer were 18-95 ft below land surface, with a median of 40 ft (table 1). Depth to water ranged from about 1-54 ft below land surface. The aquifer is recharged by precipitation and discharges primarily to springs that are common in the lower part of the aquifer near stream channels and through leakage to underlying aquifers. Owing to the dissected nature of this formation, flow paths are assumed to be relatively short (<12 mi) and the

Table 1. Statistical summary of well depth and nitrate concentration for the Flaxville and underlying aquifers, Fort Peck Indian Reservation, northeastern Montana

[Abbreviations: mg/L, milligrams per liter. Symbol: <, less than]

	Statistic	Flaxville aquifer	Fort Union aquifer	Fox Hills - lower Hell Creek aquifer
Well depth (feet)	number	58	41	45
	mean	45	108	148
	median	40	94	135
	minimum	18	40	65
	maximum	95	303	440
Nitrate concentration (mg/L NO_3-N)	number	44	24	44
	mean[1]	20	7.3	9.0
	median	18	2.8	4.3
	minimum	.19	<.05	<.05
	maximum	82	27	83

[1]Concentrations less than the minimum reporting level of 0.05 mg/L were set to 0.025 mg/L for calculating the mean.

recharge area for any specific well is assumed to have limited areal extent. The Fort Union aquifer underlies the Flaxville aquifer in the eastern half of the study area. The Fox Hills-lower Hell Creek aquifer underlies the Fort Union aquifer in the eastern half and directly underlies the Flaxville in the western half of the study area. The lack of water in parts of the Flaxville aquifer likely occurs where the lithology of the underlying formation is sandstone or a similar permeable unit.

Water in the Fort Union aquifer is confined to semi-confined and generally flows eastward (Thamke, 1991). Depths of inventoried wells completed in the aquifer were 40-303 ft, with a median of 94 ft. Depth to water ranged from about 9 to 177 ft. The aquifer is recharged by precipitation on outcrops and by leakage from the overlying Flaxville aquifer and discharges through leakage to other aquifers.

Water in the Fox Hills-lower Hell Creek aquifer is generally confined and generally flows eastward (Thamke, 1991). Depths of inventoried wells completed in the aquifer were 65-440 ft, with a median of 135 ft. Depths to water ranged from 10 to 367 ft. The aquifer is recharged by precipitation on outcrops and by leakage from overlying aquifers.

On the basis of samples from 45 wells (table 4), water in the Flaxville and underlying aquifers generally is a mixed cation bicarbonate type water with dissolved-solids concentrations between 220 and 823 mg/L. Samples from two wells had high dissolved-solids concentrations (869 and 1,220 mg/L), partly owing to high NO_3 concentrations (82-83 mg/L). Ground water generally is oxic in all aquifers. Concentrations of dissolved oxygen were higher than 5 mg/L in samples from more than 64 percent of the wells and 1-5 mg/L in another 18 percent. In samples from the remaining wells, either dissolved-oxygen concentrations were <1 mg/L or no data were collected. Fewer samples from wells completed in the Fort Union aquifer were oxic; as many as 38 percent of the samples had dissolved-oxygen concentrations <1 mg/L or had no data. The greater depth, presence of carbonaceous material, and presence of fine-grained units in the Fort Union aquifer compared to the Flaxville and Fox Hills-lower Hell Creek aquifers probably explain this result.

GROUND-WATER AGES

Because NO_3 concentrations in shallow ground water commonly are associated with overlying land use and because agricultural land uses change in response to economics and other factors, understanding the relation between specific land uses and time of ground-water recharge can provide useful information for analyzing current conditions and for managing ground-water resources. The recent development of a technique using chlorofluorocarbons (CFCs or Freons) (Plummer and others, 1993) to estimate the recharge date of ground water less than about 50 years old allows comparison of land use and recharge dates.

The stability of CFCs in the hydrosphere has led to their effective use as conservative tracers to estimate the date that ground water has been recharged during the past 50 years (Plummer and others, 1993). CFCs are synthetic compounds whose atmospheric concentrations have steadily increased since they were first manufactured in the 1930's and are stable under aerobic conditions, but subject to degradation processes under anaerobic conditions. Detectable concentrations are present in post-1940 ground water or mixtures of older ground water and post-1940 water. CFC concentrations in recharge water are dependent on the atmospheric concentration of CFCs and the temperature at the base of the unsaturated zone during recharge. Recharge temperature can be determined from mean annual air temperature and concentrations of dissolved argon and nitrogen. The estimated age of ground water, as estimated by the CFC method, is the time since the water became isolated from the unsaturated-zone atmosphere (and entered the aquifer) to the time when the CFC sample was collected.

Ground-water ages were estimated for 23 samples collected in May-August 1995. All samples had detectable concentrations of CFCs. Most wells produced water with CFC-determined recharge dates between 1965 and 1989. In general, ground-water age increased with depth (fig. 5). Wells having depths less than about 60 ft typically produced water recharged after 1970, whereas wells having depths greater than about 60 ft generally produced water recharged prior to 1975. The estimated recharge dates for seven samples from the Flaxville aquifer ranged from 1971 to 1989, indicating that ground water was 6-24 years old at the time of sampling. Seven samples from the Fort Union aquifer had estimated recharge dates between 1966 and 1987, indicating that ground water was 8-29 years old. Nine samples from the Fox Hills-lower Hell Creek aquifer had estimated recharge dates between 1947 and 1977, indicating that the ground water was 18-48 years old.

EXTENT AND MAGNITUDE OF NITRATE IN GROUND WATER

Developing a unified data set to describe NO_3 concentrations in ground water was complicated because some wells had data for 1981-85 or 1989 from

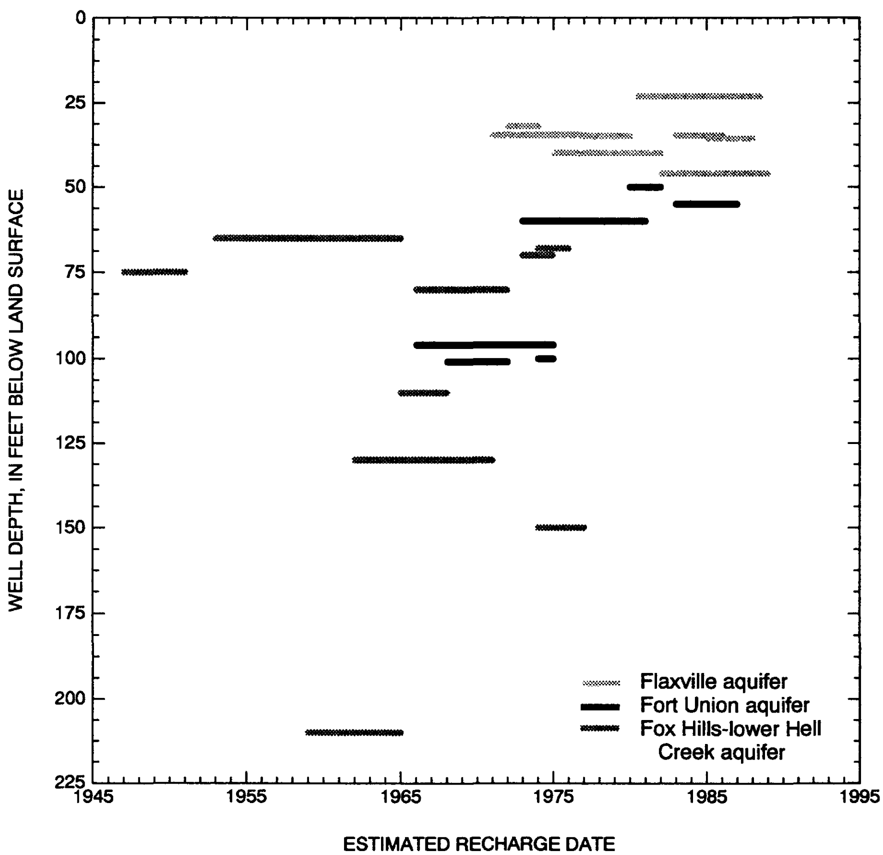

Figure 5. Relation of well depth to aquifer and date of ground-water recharge estimated from CFC concentrations in areas underlain by the Flaxville Formation in the Fort Peck Indian Reservation, northeastern Montana.

earlier investigations and some wells had data from as many as three samples collected in 21 months in 1994-96 during this study. To describe the spatial distribution of NO_3 in the study area for wells with multiple samples, only the concentration from the most recently collected sample was used.

NO_3 concentrations ranged from <0.05 to 34 mg/L in samples from all but 2 of the 112 wells in the Flaxville and underlying aquifers. NO_3 concentrations in samples from the 2 wells were 82 and 83 mg/L. Samples from 51 percent of the 112 wells equaled or exceeded the MCL of 10 mg/L. NO_3 concentrations were higher in the Flaxville aquifer than in the underlying Fort Union and Fox Hills-lower Hell Creek aquifers.

NO_3 concentrations in samples from 44 wells completed in the Flaxville aquifer ranged from 0.19 to 82 mg/L, with a median of 18 mg/L (table 1). Concentrations in samples from all but 2 wells ranged from 5.2 to 34 mg/L. The MCL of 10 mg/L was equaled or exceeded in 84 percent of the samples. The spatial distribution of NO_3 concentrations appears uniform throughout the study area, indicating that all parts of the aquifer have been affected by high NO_3 concentrations and that the NO_3 likely is derived from nonpoint sources. Although no data exist to define the vertical distribution of NO_3 in the aquifer, NO_3 is assumed to be distributed uniformly because the aquifer is generally less than 50 feet thick, the horizontal NO_3 distribution is relatively uniform, and NO_3 appears to be stable under the predominant geochemical conditions in the aquifer.

In aquifers underlying the Flaxville aquifer, NO_3 concentrations are lower than those in the Flaxville aquifer, ranging from <0.05 to 27 mg/L (median of 2.8 mg/L) in 24 samples from the Fort Union aquifer and <0.05 to 83 mg/L (median of 4.3 mg/L) in 44 samples from the Fox Hills-lower Hell Creek aquifer (table 1). The MCL of 10 mg/L was exceeded in 29 percent of the samples from the Fort Union aquifer and in 30 per-

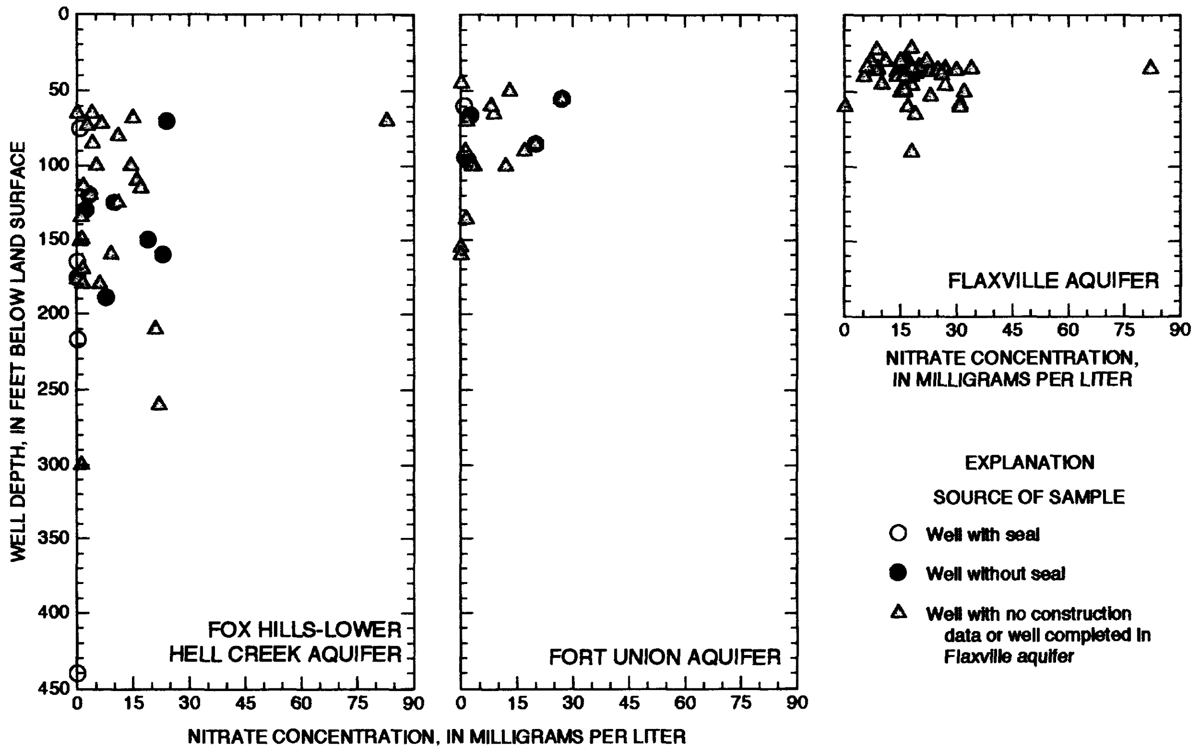

Figure 6. Relation of well depth and aquifer to nitrate concentration in ground-water samples collected in 1994-96 in the Fort Peck Indian Reservation, northeastern Montana. Nitrate concentrations less than the minimum reporting level (0.05 mg/L) are plotted as 0.025 mg/L.

cent of the samples from the Fox Hills-lower Hell Creek aquifer. A vertical pattern in NO_3 concentrations in these aquifers is apparent based on well depth. In the Fort Union aquifer, NO_3 concentrations are low at depth, not exceeding 1.5 mg/L in samples from wells greater than about 100 ft deep (fig. 6). Clay-rich zones in the Fort Union Formation probably are barriers in some places to downward movement of NO_3-rich water from the Flaxville aquifer. In addition, denitrification probably decreases NO_3 concentrations in the parts of the aquifer where reducing conditions prevail. In the Fox Hills-lower Hell Creek aquifer, which lacks the clay-rich zones of the Fort Union Formation, NO_3 concentrations are as high as 22 mg/L at a depth of 260 ft.

LONG-TERM TRENDS IN NITRATE CONCENTRATIONS

Data to examine long-term trends in NO_3 concentrations and possible relations to land use were available from 22 wells sampled once in 1981-85 or 1989 and again during this study. The difference in NO_3 concentrations between years by geologic unit was determined. The number of positive and negative differences in NO_3 concentrations between years was nearly the same, indicating no significant long-term trends in NO_3 concentrations. Averages of percent differences in NO_3 concentrations through time also indicate no significant trends in long-term data.

POTENTIAL EFFECTS OF WELL CONSTRUCTION ON NITRATE CONCENTRATIONS

Many domestic wells in the study area are old; some date from the homestead years of the late 1910's. Almost all sampled wells were located at farm headquarters. Many older wells, particularly hand-dug wells completed in the Flaxville aquifer, probably have no surface seal. Any well with an inadequate seal potentially could be affected by nitrogen-enriched surface runoff if livestock-confinement areas are nearby. The high NO_3 concentrations in samples from some wells completed in the Fort Union or Fox Hills-lower Hell Creek aquifers also could be caused by vertical well-bore leakage, either from the surface or from the overlying Flaxville aquifers. Leakage may be possible because an adequate borehole seal was never installed or because the seal is no longer effective. Few data are available to evaluate this hypothesis. Only four wells completed in the Fort Union or Fox Hills-lower Hell Creek aquifer had adequate information from drillers' logs to indicate that a seal was emplaced (fig. 6). NO_3 concentrations in samples from these four wells were low, ranging from <0.05 to 0.9 mg/L. Twelve wells completed in these aquifers had adequate information from drillers' logs to indicate that no seal was emplaced. NO_3 concentrations in samples from 10 of these wells were higher than 1 mg/L, ranging from 1.1 to 27 mg/L. Although few records of well sealing are available, visual observations of surface conditions at most drilled wells did not indicate gaps in the annular space between the well casing and undisturbed ground.

SOURCES OF NITRATE IN GROUND WATER

Ground-water samples with NO_3 concentrations that exceed the MCL are distributed geographically throughout the Flaxville and underlying aquifers, indicating that nonpoint sources are the likely cause of the high NO_3 concentrations. Potential nonpoint sources of NO_3 include atmospheric, geologic, and biologic N fixation, although these sources generally have little effect on ground water (Power, 1972), and agricultural sources. Potential agricultural nonpoint sources of NO_3 are nitrogen fertilizer, which is applied to farmland in the reservation, and natural soil organic N, either from native prairie or crop stubble. Physical and chemical properties of study-area soils were investigated to determine if agricultural activities affect nitrate in ground water.

NITRATE IN SOIL

Because a likely source of NO_3 in ground water is areal recharge through dryland cropland and because soil has a large renewable N reservoir, soils were sampled and analyzed to determine the chemical attributes of recharge water and the amount of N available for leaching. Two soil pits were excavated in June 1995 in the Flaxville Formation in each of the four major land-use categories: fertilized cropland, non-fertilized cropland, land enrolled in the CRP, and native rangeland (fig. 2). Wheat has been grown using crop-fallow rotation at the fertilized and non-fertilized cropland sites and, prior to 1987, at the CRP site. Pits at cropland sites were in areas that were fallow in 1995. Fields at the fertilized cropland site have been fertilized annually since at least 1968 (when the current landowner acquired the property) except during 4-5 drought years in the mid-1980's. Liquid fertilizer (11 percent N, 46 percent P, 0 percent K) was applied at about 5 gal/acre prior to 1983. Since 1983, granular fertilizer (35-18-0) has been applied at 40-80 lb/acre, depending on soil-moisture conditions. At the non-fertilized cropland site, one field (site W-S, fig. 7) has never been fertilized. The other field (site W-N) had been fertilized annually in 1960-77 with a variety of fertilizers (primarily 11-48-0 or 18-46-0) but has not been fertilized subsequently. The CRP site was planted with crested wheatgrass (*Agropyron cristatum*), pubescent wheatgrass (*Elytrigia intermedia ssp. crichophorum*), and alfalfa (*Medicago sativa*) in the fall of 1987 and has not been farmed or fertilized subsequently. Prior to 1987, the CRP land was crop-fallow farmland fertilized with urea (46-0-0). The rangeland site has never been farmed and is vegetated with native forbs and grasses.

Study area soils generally have formed on alluvial or eolian deposits and are deep, well-drained, and medium to coarse textured. The Flaxville Formation is a heterogeneous fluvial deposit; therefore, soil textures are variable, ranging from gravel to clay. About half of the samples were sandy loam to gravel and a quarter were loam or sandy clay loam.

Soil-moisture data (fig. 7) indicate that recharge from cropland likely is greater than from land in CRP or rangeland, because soil-moisture content is greatest under cropland. Soil moisture ranged from 3.5 to 21.6 percent, with a mean of 10.8 percent, in 30 samples from the four cropland soil pits. In contrast, soil moisture ranged from 2.7 to 13.8 percent, with a mean of 7.3 percent, in 28 samples from the four CRP and rangeland soil pits. Using a Wilcoxon nonparametric test, these differences are significant ($p < 0.01$).

NO_3-concentration profiles (fig. 7) were distinctly different at cropland sites compared to profiles at CRP and rangeland sites. Concentrations were higher at the cropland sites (0.2-8.3 mg/kg) than at the CRP and rangeland sites (<0.1-1.6 mg/kg). Within the cropland sites, concentrations were higher at the fertilized sites (median of 2.1 mg/kg) than at the non-fertilized sites (median of 1.0 mg/kg). Concentrations were higher at the CRP sites (median of 0.40 mg/kg) than at the rangeland sites (median of 0.25 mg/kg). At the cropland sites, NO_3 concentrations >0.1 mg/kg (the minimum reporting level) persisted throughout the profile, whereas concentrations generally were <0.1 mg/kg at depths greater than 3-6 ft at the CRP and rangeland sites. Concentrations below depths of 3-6 ft are important because these depths generally are below the root zone, particularly beneath cropland, and pore water that reaches these depths is presumed to flow to the water table. These concentration patterns were expected because NO_3 is efficiently utilized in the root zone of native grasslands of the Great Plains (Power,

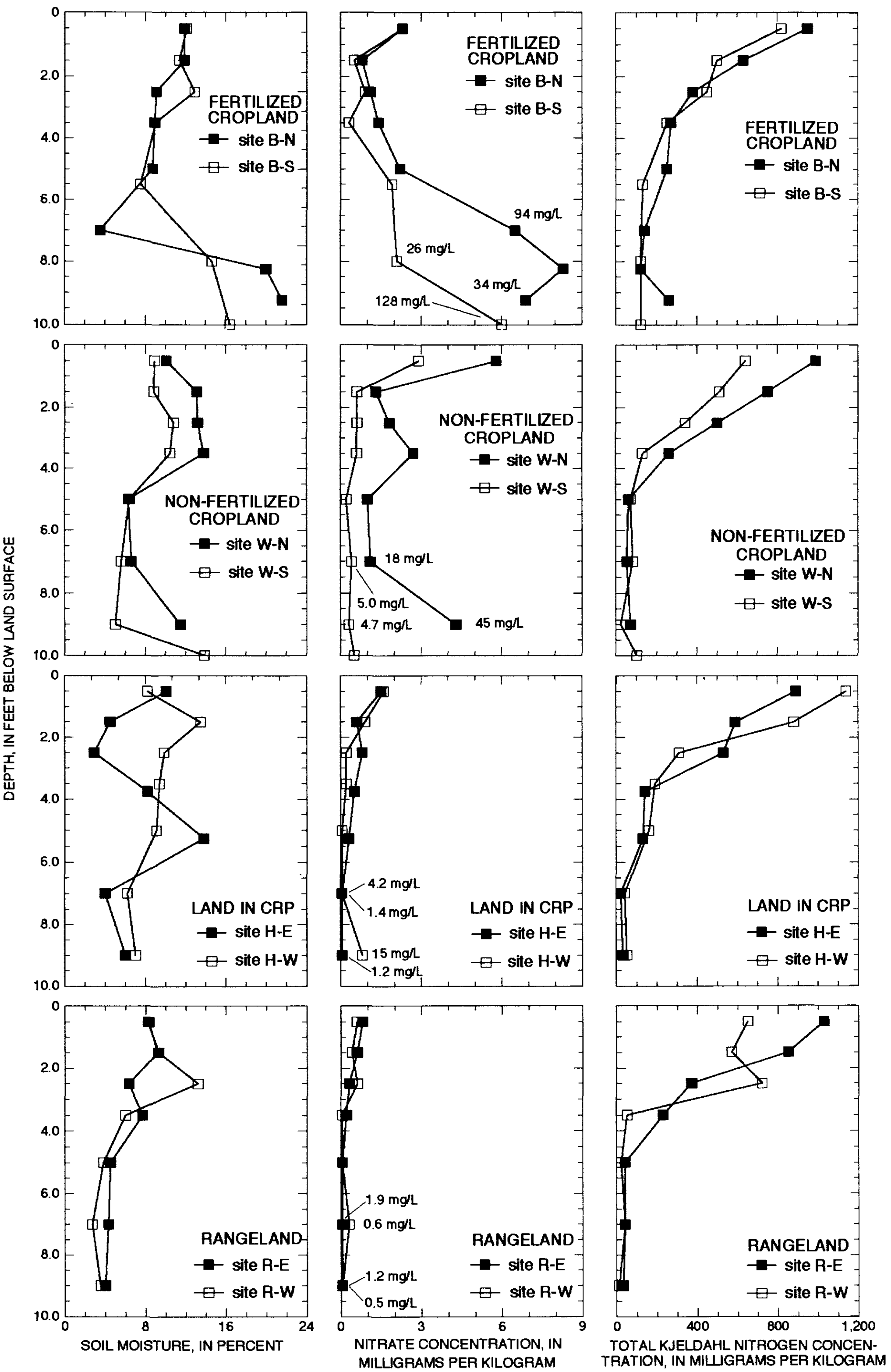

Figure 7. Nitrate concentrations, total Kjeldahl N concentrations, and soil moisture in the <2mm-size fraction of soil samples collected in June 1995 in the Fort Peck Indian Reservation, northeastern Montana. Nitrate concentrations less than the minimum reporting level (0.1 mg/kg) are plotted as 0.05 mg/kg. Nitrate concentrations (in mg/L) in saturated paste extracts of selected samples are shown in middle graphs.

1972) and presumably by well-established vegetation of CRP land. The greater amount of NO_3 in the soil profile under crop-fallow fields can be attributed to increased mineralization and mobilization of soil organic N induced by crop-fallow farming (Doughty and others, 1954; Reinhorn and Avnimelech, 1974; Kreitler and Jones, 1975; Custer, 1976; Lamb and others, 1985).

Pore-water chemistry was determined from saturated-paste extracts of two deep (generally 6-8 and 8-10 ft) samples from each pit. NO_3 concentrations in the saturated-paste extracts (fig. 7) differed between sites but exhibited similar patterns as NO_3 concentrations in soil. Concentrations in samples from fertilized (26-128 mg/L; median of 34 mg/L) and non-fertilized (4.7-45 mg/L; median of 12 mg/L) cropland were relatively high. Concentrations in samples from CRP land (1.2-15 mg/L; median of 2.8 mg/L) and rangeland (0.5-1.9 mg/L; median of 0.9 mg/L) were lower.

Total Kjeldahl (organic and ammonia) N profiles (fig. 7) in all pits have the same general pattern of high concentrations in the root zone in the upper 3 ft and low concentrations below 4 ft. The important difference in total Kjeldahl N profiles is the higher concentrations (20-140 mg/kg) below 6 ft at the cropland sites, particularly the fertilized cropland site, compared to the concentrations (10-50 mg/kg) at the CRP and rangeland sites. These higher concentrations reflect the downward movement of soil organic N in crop-fallow farmland.

The distribution of NO_3 in soil indicates that cropland is a source of NO_3 to ground water but that CRP land and rangeland probably are not. In addition, fertilized cropland, assuming equal vertical water movement in fertilized and non-fertilized sites, is a larger NO_3 source to ground water than non-fertilized cropland. However, fertilizer probably is not the primary direct source of any increased NO_3 loading from fertilized cropland because the amount of soil organic N, which can be mineralized to form NO_3, is far greater in the soil profile than the NO_3 introduced by fertilizer application. The amount of total Kjeldahl N currently (1995) in the top 4 ft of each cropland soil profile, assuming a soil density of 1.5 g/cm^3, ranges from 7,460 to 11,520 lb/acre. If 1-2 percent of this organic N is mineralized in a year, the NO_3 released would be about 4-12 times the maximum NO_3 available from fertilizer, assuming an application rate of 20 lb/acre. The apparent increase in NO_3 loading from fertilized cropland probably results not from direct deep leaching of the fertilizer but rather from the greater fertilizer-induced biomass in the wheat crop. Mineralization during the fallow season of the larger N pool contained in this stubble and root mass releases more NO_3 than is released from the smaller amount of crop residue in non-fertilized cropland.

$\delta 15N_{NO3}$ AND $\delta 18O_{NO3}$ IN SOIL MOISTURE AND GROUND WATER

The ratios of stable isotopes of N ($^{15}N/^{14}N$) and O ($^{18}O/^{16}O$) in NO_3 can be used in many circumstances to determine the source of NO_3 in ground or pore water (for example, Kreitler, 1975; Gormly and Spalding, 1979; Flipse and Bonner, 1985; Bottcher and others, 1990; and Wassenaar, 1995, among many others). Interpretation of NO_3 sources requires caution because the isotope ratios of different sources may overlap and because original ratios can be altered by isotope fractionation mainly during denitrification and ammonia volatilization. Variations in the relative abundance of the isotopes commonly are expressed as deviations from a standard [atmospheric N_2 and an arbitrary standard known as SMOW (standard mean ocean water) (Craig, 1961)] using this equation:

$$\delta\chi\ (‰) = \left(\frac{R_\chi}{R_{standard}} - 1\right) \times 1000$$

where R_χ and $R_{standard}$ are the $^{15}N/^{14}N$ or $^{18}O/^{16}O$ atomic ratios of the sample and standard, respectively. The symbols $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ are used here to indicate that the $\delta^{15}N$ and $\delta^{18}O$ values are for the N and O, respectively, in NO_3.

Animal and human wastes generally have a $\delta^{15}N_{NO3}$ value between +9 and +22‰ (Kreitler, 1975; Gormly and Spalding, 1979; Lindau and Spalding, 1984; Heaton, 1986). $\delta^{15}N_{NO3}$ values in inorganic fertilizers range from about -7 to +7‰ (Spalding and others, 1982), although most fertilizers have values less than +4‰ (Heaton, 1986; Wilson and others, 1994). In particular, urea and ammonium-based fertilizers have values that typically range from -4 to +2‰; NO_3 fertilizers have higher values, typically ranging from 0 to +6‰ (Spalding and others, 1982). Nitrate derived from ammonium fertilizer retains the original $\delta^{15}N_{NO3}$ value if little or no volatilization of $\delta^{15}N_{NO3}$-depleted ammonia occurs. Alkaline conditions promote volatilization and can result in $\delta^{15}N_{NO3}$ enrichment of 2 to 5‰ (Fenn and Kissel, 1973; Feigin and others, 1974; Kreitler, 1975). $\delta^{15}N_{NO3}$ values in NO_3 derived from mineralization or oxidation of organic N in soil typically are between +4 and +9‰ (Boyce and others, 1976; Gormly and Spalding, 1979; Wolterink and others, 1979; Heaton, 1986), and their range is typically small, often within ±1‰, when derived from soil of uniform type (Heaton, 1986).

Direct comparison of $\delta^{15}N_{NO3}$ values in NO_3 sources to $\delta^{15}N_{NO3}$ values in soil moisture or ground water can be made only if the isotopic composition of the NO_3 has remained unchanged along the flow path. Denitrification is the most likely process to affect $\delta^{15}N_{NO3}$ values. Typically, denitrification is not significant in shallow, transmissive aquifers, like the Flaxville aquifer, with oxic water, low concentrations of organic carbon, and a water table at least 6.5-10 ft below land surface (Gillham and Cherry, 1978; Gormly and Spalding, 1979; Starr and Gillham, 1993). Occurrence of denitrification can be detected by analysis of $\delta^{18}O_{NO3}$ and $\delta^{15}N_{NO3}$ (Amberger and Schmidt, 1987; Bottcher and others, 1990; Voerkelius and Schmidt, 1990). In the study area, $\delta^{18}O_{NO3}$ values would be about -3‰ when the NO_3 is derived from ammonium fertilizer, soil organic N, or animal or human wastes. This value is computed by assuming two oxygen atoms are derived from local water ($\delta^{18}O$ of about -16‰) and one oxygen atom from dissolved O_2 ($\delta^{18}O$ = 23‰) (Amberger and Schmidt, 1987). If denitrification occurs, $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ values would increase in the residual NO_3 in a ratio of about 2:1 (Amberger and Schmidt, 1987; Bottcher and others, 1990; Voerkelius and Schmidt, 1990).

$\delta^{18}O_{NO3}$ was determined in 18 of the 34 ground-water samples having $\delta^{15}N_{NO3}$ data. $\delta^{18}O_{NO3}$ values ranged from -4.20 to +4.74‰ (fig. 8). All but two samples had values between -4.20‰ and -1.69‰, close to the -3‰ value expected for NO_3 derived from ammonium fertilizer, soil organic N, or animal or human wastes; therefore, denitrification presumably is not significant in ground water at most sites and $\delta^{15}N_{NO3}$ data can be used to identify NO_3 sources. Two samples had high $\delta^{18}O_{NO3}$ (+1.80‰ and +4.74‰), indicating active denitrification, and high $\delta^{15}N_{NO3}$ (14.64‰ and 26.69‰) values. These samples had detectable NO_2 concentrations (0.02 and 0.03 mg/L), a condition which is consistent with denitrification. The NO_3 source cannot be determined as definitively for these two samples because the original $\delta^{15}N_{NO3}$ value of the NO_3 source likely was altered by denitrification.

$\delta^{15}N_{NO3}$ values for ground water and pore water as well as typical ranges for various NO_3 sources are shown in figure 9. Nineteen of 33 samples had $\delta^{15}N_{NO3}$

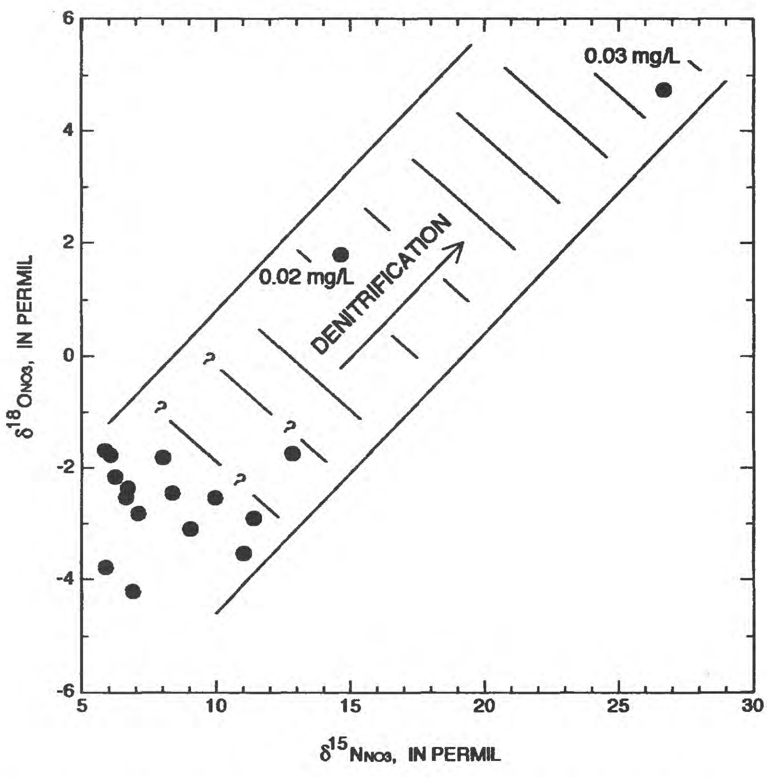

Figure 8. Relation of $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ in ground-water samples collected in 1994-96, Fort Peck Indian Reservation, northeastern Montana. The nitrite concentration was less than or equal to the minimum reporting level of 0.01 mg/L in all samples except as indicated. The expected range of $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ for denitrified samples is indicated.

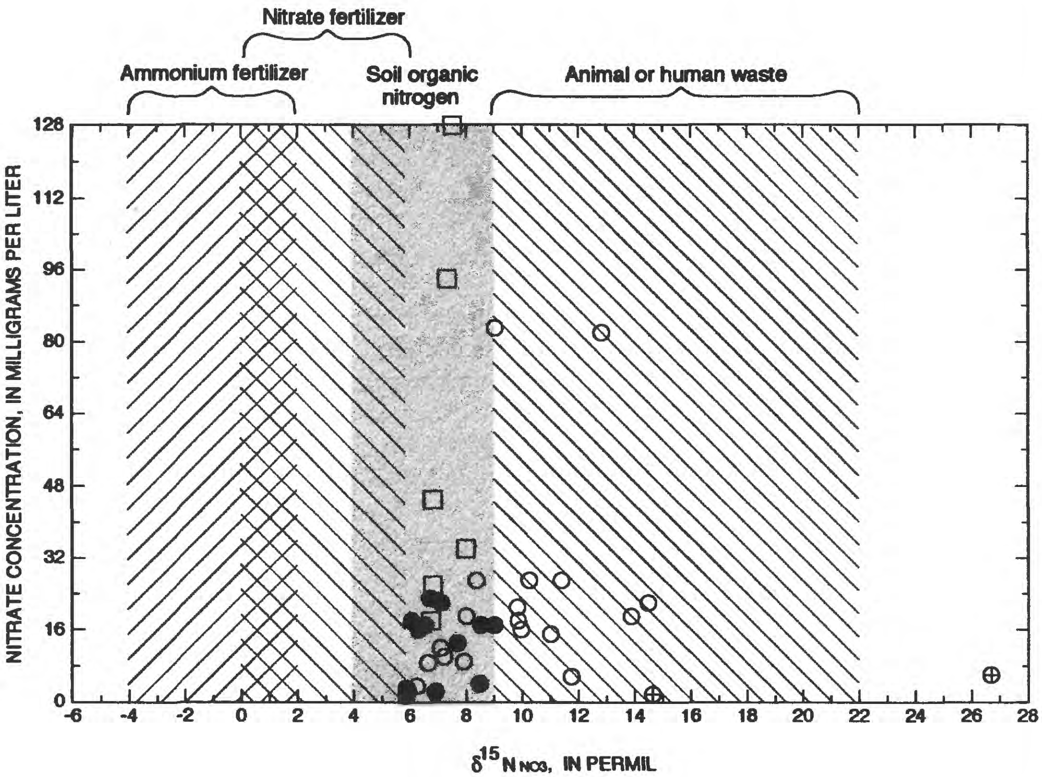

Figure 9. $\delta^{15}N_{NO3}$ values for ground water (circles) and water extracts of cropland soils (squares) in areas underlain by the Flaxville Formation, Fort Peck Indian Reservation, northeastern Montana. Solid circles indicate wells greater than 1,000 ft from a corral. Open circles indicate wells within 1,000 ft of a corral. Cross in circle indicates ground water was affected by denitrification (see fig. 8). Background patterns indicate typical ranges of $\delta^{15}N_{NO3}$ values in various NO_3 sources.

values of +5.85 to +8.52‰ (mean of +7.02‰, standard deviation of 0.89‰), within the common $\delta^{15}N_{NO3}$ range of +4 to +9‰ expected for NO_3 derived from the decomposition of soil organic N. For comparison, the mean $\delta^{15}N_{NO3}$ values in pore-water extracts of six deep (6-11 ft) samples from three soil pits excavated in fertilized and non-fertilized cropland ranged from +6.74 to +7.99‰ (mean of +7.20‰; standard deviation of 0.50‰) (fig. 9). The similarity in these $\delta^{15}N_{NO3}$ values for pore water and ground water support the conclusion drawn from soil data that NO_3 in ground water is derived from overlying wheat fields. Water from all sampled wells located away from corrals or other livestock-congregation areas had $\delta^{15}N_{NO3}$ values in this group. The proportion of samples with $\delta^{15}N_{NO3}$ values between +4 and +9‰ were similar for each aquifer: 60 percent for the Flaxville aquifer, 63 percent for the Fort Union aquifer, and 50 percent for the Fox Hills-lower Hell Creek aquifer. The NO_3 source for these samples of ground and pore water possibly could be ammonium fertilizer if sufficient ammonia had volatilized as the fertilizer was nitrified. However, ammonium fertilizer is not a likely NO_3 source because no $\delta^{15}N_{NO3}$ values were in the common range (-4 to +2‰) for nitrified ammonium fertilizer and because $\delta^{15}N_{NO3}$ values in pore water were virtually identical in samples from fertilized and non-fertilized cropland.

Fourteen ground-water samples had $\delta^{15}N_{NO3}$ values higher than +9‰. Ignoring the two samples affected by denitrification based on $\delta^{18}O_{NO3}$ values (fig. 8), these $\delta^{15}N_{NO3}$ values (mean of +11.10‰, standard deviation of 1.82‰) were within the range of +9 to +22‰ expected for NO_3 derived from animal or human wastes. All but one of these samples were collected from wells in or near (<1,000 ft) a corral or barnyard where livestock are (or were) confined for a significant part of the year.

Dissolved-oxygen concentrations in ground water support the conclusions drawn from $\delta^{15}N_{NO3}$ data that NO_3 in some ground-water samples was derived from livestock wastes. In ground-water samples with $\delta^{15}N_{NO3}$ and dissolved-oxygen data, all samples with dissolved-oxygen concentrations of 4 mg/L or less were collected from wells where livestock are presumed to be the NO_3 source, on the basis of $\delta^{15}N_{NO_3}$ values greater than +9‰. Livestock wastes probably contribute significant amounts of dissolved organic carbon (DOC) to the otherwise carbon-depleted Flaxville aquifer. The DOC could promote the growth of microbes that consume dissolved oxygen. Dissolved-oxygen concentrations were higher than 4 mg/L in all ground-water samples with $\delta^{15}N_{NO_3}$ values less than +9‰, perhaps because decomposition of soil organic matter provides little DOC to stimulate microbe growth.

The difference in NO_3 concentrations in ground-water samples affected by soil organic N and livestock wastes can be determined by comparing samples with $\delta^{15}N_{NO_3}$ values less than and greater than 9. NO_3 concentrations were significantly higher ($p = 0.009$ using Wilcoxon rank-sum test) in the 12 samples affected by livestock wastes (median of 20 mg/L) compared to the 19 samples affected by soil organic N (median of 12 mg/L). These results make sense because ground water throughout the study area is affected by NO_3 from crop-fallow farmland, whereas ground water near farm headquarters with livestock operations would have additional NO_3 loading from infiltration or borehole leakage of livestock wastes.

NITRATE SOURCES

$\delta^{15}N_{NO_3}$ values indicate that NO_3 fertilizer is not a significant direct source of NO_3 to ground water. This conclusion is reasonable for the study area because relatively little fertilizer is applied and because nitrogen fertilizer typically is applied just before crops utilize it. Nutrient demand by dryland crops is small compared to irrigated crops, and NO_3 from mineralization of organic N in the soil supplies much of the needed NO_3.

Cultivation of native prairie and subsequent crop-fallow farming lead to rapid mineralization of the large reservoir of biomass found in prairie soils (Power, 1972; Reinhorn and Avnimelech, 1974) and the potential for subsequent increases in NO_3 in underlying ground water. Although large NO_3 reservoirs found in soil profiles and ground water in the Great Plains have been associated with initial sod busting (Custer, 1976; Lamb and others, 1985), relatively young ground-water ages indicate that NO_3 in the Flaxville aquifer is not from initial sod busting, which occurred in the early part of this century.

Crop-fallow farming appears to be the most important NO_3 source in the study area. About 70 percent of the land is current or former cropland. $\delta^{15}N_{NO_3}$ values in 58 percent of the ground-water samples are within the range (+4 to +9‰) expected for mineralization of soil organic N, and these samples are distributed about equally in the three aquifers. $\delta^{15}N_{NO_3}$ values in extracts of soil samples collected below the root zone beneath cropland are within this range and have a similar range and mean value as these ground-water samples.

Common point sources of NO_3 in ground water are infiltration from barnyards and feedlots and effluent from septic tanks and cesspools. Considering the large number of livestock in this rural area, livestock wastes probably are a much more significant source than human wastes. Ground water near farm headquarters with livestock operations has elevated NO_3 concentrations from the regional, or non-point source, loading from crop-fallow farmland. Livestock waste is an additional NO_3 source that results in even higher NO_3 concentrations locally. Although animal wastes are a significant source of the NO_3 produced in water from many domestic wells in the study area, these wastes probably are not a significant source of widespread NO_3 contamination because farm headquarters are widely spaced in the study area. The common collocation of domestic wells and livestock-use areas make livestock appear to be a more significant and widespread source of NO_3 than probably is the case.

FUTURE CONDITIONS

NO_3 concentrations in ground water presumably reflect land-use practices current at the time of recharge. Because most ground water generally is 6-30 years old in the study area, future water-quality conditions can be predicted, at least qualitatively, from land-use practices prevalent since at least the 1960's.

The amount of land used for wheat production was fairly constant during 1960-90 (except for the increase in 1972-82) (fig. 3). On the basis of total area of farmland, NO_3 loading presumably would not have changed substantially since 1960. However, as discussed below, farming practices, which affect NO_3 loading, have changed since 1960.

Sod busting is a particularly potent NO_3-loading activity because of the large reservoir of organic N in soil. However, substantial sod busting cannot occur in the study area because a large proportion (70 percent) of the land already has been converted to farmland.

The amount of fertilized cropland in the four counties surrounding the study area has increased fairly steadily since the mid-1950's (fig. 3). (The decrease between 1987 and 1992 likely was a response to the extended drought conditions in the 1980's.) Currently, fertilizer does not appear to directly affect ground water in the study area, although the indirect effect through increased biomass in roots and stubble that can break down during the fallow period probably has caused and will continue to cause steadily increasing NO_3 loading. The magnitude and extent of this increased loading is unknown. If the past is any indication of future trends, the amount of fertilized land probably will continue to increase, potentially causing increased NO_3 loading. Fertilizer application rates have not increased significantly in the past few decades and are not expected to increase in the future because, where fertilizer is applied, it generally is applied at optimum rates, and increased application rates would provide no benefit (Terry Angvick, oral commun., 1995).

Farming practices used on crop-fallow fields have changed in the past and may continue to change in the future (Terry Angvick, oral commun., 1995). These changes potentially could alter NO_3 loading from crop-fallow fields. Use of conservation tillage, which reduces the number of times a field is tilled and leaves more stubble on the surface, has increased significantly over the past 20 years. The effect of conservation tillage on NO_3 loading is not well understood. The practice reduces runoff and, according to some studies, increases the potential for deep percolation and NO_3 leaching (Baker and Johnson, 1983; Fox and Bandel, 1986). However, other studies indicate that NO_3 concentrations in soil moisture are lower in no-till fields than in tilled fields as a result of greater denitrification and immobilization under no-till fields (Doran, 1980; Rice and Smith, 1984; Fox and Bandel, 1986). In addition, stubble left on the surface is less likely to break down during the fallow period and contribute to deep NO_3 leaching.

Continuous cropping reduces water movement and utilizes NO_3 produced by mineralization of organic matter. With continuous cropping, wheat fields are fallow for 18 of 24 months instead of for 21 of 24 months in the crop-fallow system. Plants are active longer so NO_3 is more efficiently consumed before it is completely leached. However, NO_3 loading can still occur because NO_3 can be produced by mineralization when crops are not vigorous enough to utilize all available NO_3. The increased use of continuous cropping (fig. 3) probably will decrease NO_3 loading through reduced leaching below the root zone, and future increases in continuous cropping could continue the benefit.

Livestock numbers were highest in 1965-75, the general recharge period for wells greater than 60 ft deep (fig. 5). Therefore, NO_3 concentrations might be expected to decline in these wells over the next 20 years, reflecting the decreased number of cattle. Shallower ground water (<60 ft) generally was recharged after livestock numbers decreased substantially from their 1965-75 peaks. Consequently, current (1994-96) NO_3 concentrations, for the most part, reflect post-peak livestock numbers. Livestock numbers continued to decline after 1978 but at a much lower rate. Therefore, NO_3 concentrations may decrease somewhat over the next 20 years in shallow wells. Because livestock-derived NO_3 appears to be a local phenomenon, predicting future NO_3 concentrations in a well requires consideration of site information about historical livestock numbers, congregation areas, and well location, construction, and geology.

A large amount of land in the study area has been enrolled in the CRP since 1986, but this widespread land-use change generally occurred too recently to affect ground-water quality in 1994-96. Any potential effects could be expected to appear in the next 20 years. The expected effect of the continuous vegetative cover planted on CRP land is the reduction of both NO_3 availability and the amount of soil moisture that percolates to the water table. The net effect is expected to be a decrease in recharge and a decrease in the NO_3 concentration in ground water.

Various strategies have the potential to reduce NO_3 concentrations in the Flaxville and underlying aquifers or to decrease the potential effect of NO_3 on human health. These strategies are listed but are not prioritized or evaluated because understanding their net effect would require information not collected during this study:

1. Increase land area with intensive crop rotations such as continuous crop and recrop,
2. Increase land area enrolled in the CRP or with perennial vegetative cover,
3. Decrease fertilizer use to reduce the amount of stubble residue,
4. Plant alfalfa or other deep-rooted crops to reduce deep percolation (Miller and others, 1981),
5. Manage livestock to reduce NO_3 loading to ground water,
6. Plug or seal unsealed or poorly sealed wells,
7. Ensure new wells have adequate surface seals, and
8. Install treatment systems on domestic wells.

Regional improvements in water quality in the Flaxville aquifer would require land-use changes over large, regional areas. However, local areas could be affected more readily, perhaps by an individual landowner or a small group of landowners with contiguous fields, because ground-water flow paths are short and, therefore, recharge areas are relatively small (2-12 mi^2).

SUMMARY AND CONCLUSIONS

The Flaxville and underlying aquifers in the Fort Peck Indian Reservation are desirable sources of ground water. However, NO_3 concentrations equaled or exceeded 10 mg/L NO_3- N in water from 51 percent of all sampled wells and from 84 percent of the wells completed in the Flaxville aquifer. The generally uniform spatial distribution of NO_3 and the extensive dryland production of small grains indicate that the NO_3 likely is derived from nonpoint agricultural sources. This integrated study of soils, land use, stable isotopes, ground-water chemistry, and ground-water age has demonstrated the connection hypothesized by Bauder and others (1993) between elevated concentrations of NO_3 in ground water and the dominant agricultural land use. Unlike many areas where agricultural practices result in excess NO_3 in ground water, irrigation and deep leaching of fertilizer are not the cause of the high NO_3 concentrations in the study area.

$\delta^{15}N_{NO3}$ values for ground water in the study area indicated that NO_3 is derived primarily from soil organic N and livestock wastes. On the basis of the generally uniform spatial distribution of NO_3 in ground water and the large area of cropland, the predominant nonpoint source of NO_3 in the study area presumably is soil organic N. Livestock wastes appear to be significant point sources of NO_3 locally. Comparison of NO_3 concentrations in soil moisture indicated that NO_3 loading is greater from fertilized cropland than from non-fertilized cropland; however, $\delta^{15}N_{NO3}$ values demonstrated that soil organic N and not fertilizer is the primary NO_3 source. The apparent increase in NO_3 loading from fertilized cropland probably results from the increased amounts of wheat stubble and root mass, which are mineralized during the fallow season. Reductions in NO_3 concentrations in the study area probably could be achieved locally and regionally through a variety of land-management strategies.

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DATA

Table 2. Lithologic logs and completion details for test wells and boreholes drilled in 1995 in the Fort Peck Indian Reservation, northeastern Montana

[Well name, a field-identification number; location number, numbering system described in text; depth, in feet below land surface, except where + indicates feet above land surface. Abbreviations: BLS, below land surface; ft, feet; gpm, gallons per minute; in., inches; PVC, polyvinyl chloride]

Description	Depth (feet)
Well name: B-1	
Location number: 31N46E15CBCC01	
Geologic unit: Flaxville and Fort Union Formations	
Lithology:	
Silt, clayey; little sand and gravel, light-brown; calcareous; slightly damp	0-18
Sand and gravel, brown; sand, medium-grained, fair sorting; gravel, well-rounded; brown; non-calcareous; damp	18-20
Sand and gravel, with very little clay; sand, medium-grained, fair sorting; gravel, well-rounded; brown; non-calcareous; damp	20-22
Gravel, very well-rounded, quartzite; sand, fine- to medium-grained, brown; little clay and silt; matrix slightly calcareous at 22 ft, non-calcareous at 25 ft	22-25
Gravel; clasts to 1 in.; sand, fine- to coarse-grained, poorly sorted; damp	25-35
Gravel, as above; water	35-38
Clay, silty, sandy, light gray-brown, soft, plastic; no water	38-41
Clay, gray; yellowish-brown at 47-48 ft; no water	41-49
Clay, silty, soft; interbedded yellowish-brown and gray brown	49-55
Sand, very fine-grained, yellow brown; little clay at 60 ft; some water	55-60.5
Clay, sandy, silty, soft; interbedded with yellowish-brown and gray sand; non-calcareous; little water	60.5-75
Clay, gray with occasional rust color; soft; non-calcareous; little water	75-85
Clay, brownish-gray, carbonaceous; lignite chips	85-86
Clay, gray	86-93
Clay, sandy, yellowish-brown; sand, very fine-grained	93-108
Clay, gray	108-110
Clay, brownish-gray; shale chips	110-112
Clay, olive green	112-115
Clay, gray; coal chips at 118 ft	115-125
Clay, sandy, gray; sand, very fine-grained	126-130
Completion details:	
Well completion:	
4-in. PVC casing	+1.9-94
4-in. PVC factory-slotted casing (0.020-in. slot size)	94-124
4-in. PVC casing, with open end	124-131
Finish:	
Bentonite grout	0-18
Bentonite grout	57-92
Silica sand pack	92-130
Surface completion:	
6-in. steel casing	+2-60

Remarks: Well drilled using air (and limited water) rotary; completed on July 6, 1995. Site geologist, E. Kendy. PVC casing joined with bolts, not glue. Well bailed dry on 7/13/95 and 7/14/95; made very little water. Well plugged and abandoned on September 10, 1996.

Table 2. Lithologic logs and completion details for test wells and boreholes drilled in 1995 in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Description	Depth (feet)
Well name: B-2	
Location number: 31N46E15CBCC02	
Geologic unit: Flaxville and Fort Union Formations	
Lithology:	
Silt, clayey; light-brown; little sand	0-16
Gravel, some sand	16-37
Clay, silty, dense, medium-gray; some reddish-orange weathered zones	37-44
Clay, silty, soft, gray, damp	44-46
Clay, silty, soft, light-gray and light-brown; little sand	46-49
Clay, silty, dense, brownish-gray	49-55
Sand, fine-grained, silty, clayey, reddish-brown	55-58
Clay, sandy, silty, gray	58-60
Completion details:	
Well completion:	
4-in. PVC casing	+1.5-53
4-in. PVC factory-slotted casing (0.020-in. slot size)	53-58
4-in. PVC casing, with end cap	58-60
Finish:	
Bentonite grout	0-20
Silica sand pack	48-60
Surface completion:	
6-in. steel protective casing	+1.6-49
Remarks: Well drilled using air (and limited water) rotary; completed on July 14, 1995. Site geologist, D.A. Nimick. Developed by air-lift for 25 minutes and pumping for 45 minutes at 0.3 gpm. Well plugged and abandoned on September 10, 1996.	
Well name: B-3	
Location number: 31N46E16DADA01	
Geologic unit: Flaxville Formation	
Lithology:	
Silt, clayey, light-brown; little sand; slightly damp	0-13
Sand and gravel; sand, medium- to coarse-grained, poorly sorted, brown; gravel to 2-in. diameter, well-rounded, quartzite	13-15
Gravel and sand, same as above but more gravel	15-21
Sand and gravel with some silt and clay; gravel same as above	21-26
Gravel, well-rounded quartzite to 2-in. diameter, with fine-grained sand and silty clay	26-32
Gravel with sand, silt, and clay, as above; water	32-34
Gravel and sand, fine- to medium-grained	34-38
Clay, soft to moderately hard, light-gray-brown to yellowish-brown; little silt and very fine grained sand	38-49
Clay, as above, hard, with little dark-gray carbonaceous clay	49-51
Clay, gray, dense, hard	51-57
Clay, mostly hard, gray and yellowish-brown	57-61

Table 2. Lithologic logs and completion details for test wells and boreholes drilled in 1995 in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Description	Depth (feet)
Well name: B-3--continued	
Completion details:	
Well completion:	
6-in. steel casing	+2.0-33
6-in. steel casing, 1-ft by 0.01-ft torch-cut perforations	33-34
6-in. steel casing, with open end	34-34.5
Finish:	
Bentonite grout	0-20
Native backfill	34.5-61
Remarks: Well drilled using air (and limited water) rotary; completed on July 7, 1995. Site geologist, E. Kendy. Developed by airlift for 60 minutes at 12 gpm. Well installed as observation well near well B-4 to be used for aquifer test. Well plugged and abandoned on September 10, 1996.	
Well name: B-4	
Location number: 31N46E16DADA02	
Geologic unit: Flaxville Formation	
Lithology: See description of well B-3	
Completion details:	
Well completion:	
6-in. steel casing	+2-27
6-in. steel casing, 1-ft by 0.01-ft torch-cut perforations	27-37
6-in. steel casing, with open end	37-38
Finish:	
Bentonite grout	0-18
Native backfill or sand pack	none
Remarks: Well drilled using air (and limited water) rotary; completed on July 8, 1995. Site geologist, E. Kendy. Developed by airlift for 25 minutes and pumping for 54 minutes at 14 gpm. Well installed as pumping well for aquifer test.	
Borehole name: WN-1	
Location number: 31N46E17CDCD01	
Geologic units: Flaxville and Hell Creek Formations	
Lithology:	
Topsoil; silt, sandy, medium-brown	0-2.5
Sand, silty, tan	2.5-4
Sand, silty, clayey, poorly sorted, light-brown, damp	4-7
Sand, fine-grained, tan; less fine-grained material than above; damp	7-12
Sand, fine- to medium-grained, damp	12-13
Gravel with sand, silt, and clay; poorly sorted; damp	13-14
Sand, fine- to medium-grained, damp	14-15
Clay, sandy, silty, poorly sorted, brown, damp	15-16
Sand, coarse-grained, with finer sand, silt, and clay; light-brown, damp	16-17
Clay, solid, very dense, light- to medium-brown, calcareous; some horizons softer	17-36

Table 2. Lithologic logs and completion details for test wells and boreholes drilled in 1995 in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Description	Depth (feet)
Borehole name: WN-1--continued	
Clay, sandy, silty, solid, dense, light-brown, calcareous; sand is very fine-grained	36-48
Sand, fine- to medium-grained, reddish-brown	48-55
Gravel, rounded quartzite with 1-2-in. diameter; bottom of Flaxville Formation	55-73
Clay, sandy, light-brownish-gray	73-77
Sand, fine-grained, reddish-brown	77-100
Remarks: Borehole drilled using air (and limited water) rotary; completed on July 14, 1995. Site geologist, D.A. Nimick. Borehole plugged and abandoned because shallow ground water was not encountered.	
Borehole name: WS-1	
Location number: 31N46E20CDDC01	
Geologic units: Flaxville and Hell Creek Formations	
Lithology:	
Topsoil; silt, sandy, dark brown	0-2
Gravel, poorly sorted	2-4
Sand	4-10
Clay, sandy, light-brown, damp	10-15
Silt, clayey, sandy, light-brown, damp	15-18
Sand, fine-grained, well-sorted, brown	18-28
Gravel and sand, well-rounded quartzite with 1-2-in. diameter; bottom of Flaxville Formation	28-43
Clay, light grayish-brown, dry	43-49
Clay, gray	49-52
Clay, sandy, reddish-brown	52-53
Sand, fine-grained, silty, clayey, light-brown, damp	53-65
Sand, fine-grained, alternating reddish-brown and light-brown; fewer fines than above	65-90
Clay, gray, dense	90-109
Sand, fine-grained, reddish-brown	109-120
Remarks: Borehole drilled using air (and limited water) rotary; completed on July 12, 1995. Site geologist, D.A. Nimick. Borehole plugged and abandoned because shallow ground water was not encountered.	
Well name: H-1	
Location number: 33N44E22CDCC01	
Geologic unit: Flaxville and Hell Creek Formations	
Lithology:	
Topsoil, silty, gray-brown, dry	0-3
Silt, gray-brown, calcareous, with little very fine limestone gravel, dry	3-5
Sand, very fine to fine-grained, well-sorted, interbedded light-brown and yellowish-brown, dry; calcareous at 5 ft; non-calcareous at 9 ft	5-10
Sand, fine- to medium-grained, well-sorted, light-brown to brown, slightly calcareous; occasional rounded gravel to 0.5-in. diameter	10-19
Sand, medium-grained, fair sorting, non-calcareous, dry; occasional rounded gravel to 0.5-in. diameter	19-25

Table 2. Lithologic logs and completion details for test wells and boreholes drilled in 1995 in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Description	Depth (feet)
Well name: H-1--continued	
Sand, medium- to coarse-grained, fair sorting, damp, non-calcareous; occasional rounded gravel to 0.5-in. diameter	25-26
Sand, brown, medium- to coarse-grained, fair sorting, brown, non-calcareous, wet; occasional rounded gravel to 0.5-in. diameter	26-26.5
Gravel and sand; quartzite gravel, well-rounded; poorly sorted sand	26.5-34
Gravel, some sand; quartzite gravel to 2-in. diameter, well-rounded; sand poorly sorted and brown	34-36
Clay, dense, medium-hard, dark brown-gray, non-calcareous	36-40
Clay, light-gray and dark-gray, carbonaceous, non-calcareous; light-gray clay is soft; dark gray clay is hard, dense	40-41
Clay, hard, dense, light-gray; possibly some shale	41-57
Clay, sandy, silty, light-brown to light-brown-gray; sand very fine to fine-grained; little water	57-65
Sand, very fine-grained, clayey, light-brown; water	65-70
Sand, brown, generally increasing grain size with depth from fine-grained to medium-grained at 81 ft; water	70-81
Completion details:	
Well completion:	
6-in. steel casing	+2.1-73.5
6-in. steel casing, 1-ft by 0.01-ft torch-cut perforations	73.5-74.5
6-in. steel casing, with open end	74.5-75
Finish:	
Bentonite grout	0-20
Native backfill or sand pack	none
Backfill, caved hole material	75-81
Remarks: Well drilled using air (and limited water) rotary; completed on July 7, 1995. Site geologist, E. Kendy. Developed by pumping for 269 minutes at 15 gpm. Static water level: 24.28 ft BLS. Pumping water level: 43.50 ft BLS. Well plugged and abandoned on September 10, 1996.	
Well name: H-2	
Location number: 33N44E22CDCC02	
Geologic unit: Flaxville Formation	
Lithology: See description of well H-1	
Completion details:	
Well completion:	
6-in. steel casing	+2.0-26
6-in. steel casing, 1-ft by 0.01-ft torch-cut perforations, open end	26-32
Finish:	
Bentonite grout	0-23
Native backfill or sand pack	none
Remarks: Well drilled using air (and limited water) rotary; completed on July 9, 1995. Site geologist, E. Kendy. Developed by airlift for 92 minutes and by pumping for 115 minutes at 1 gpm. Static water level: 22.21 ft BLS. Pumping water level: 27 ft BLS. Well plugged and abandoned on September 10, 1996.	

Table 2. Lithologic logs and completion details for test wells and boreholes drilled in 1995 in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Description	Depth (feet)
Well name: R-1	
Location number: 33N45E26CBAA01	
Geologic unit: Flaxville and Fort Union Formations	
Lithology:	
Topsoil, sandy silt, brown	0-2
Sand, gravely, medium-grained, brown	2-5
Sand, well-sorted, medium-brown, damp	5-11
Gravel and fine- to medium-grained sand, reddish-brown; pebbles up to 2-in. diameter	11-16
Gravel with yellowish-brown and reddish-brown sand	16-24
Clay, medium-gray with yellowish-brown rinds, partially weathered, damp, plastic, minor carbonaceous material	24-32
Sand, fine-grained, light-brown	32-36
Clay, gray, damp, dense, semi-plastic	36-42
Coal, black	42-48
Clay, gray, damp	48-54
Completion details:	
Well completion:	
6-in. steel casing	+2.0-40.5
6-in. steel casing, 1-ft by 0.01-ft torch-cut perforations	40.5-45.5
6-in. steel casing, with open hole at end	45.5-46
Finish:	
Bentonite grout	0-16
Native backfill or sand pack	none
Remarks: Well drilled using air (and limited water) rotary; completed on July 12, 1995. Site geologist, D.A. Nimick. No well development because of insufficient water. Well plugged and abandoned on September 10, 1996.	

Table 3. Physical data for and nitrate concentrations in water samples from private wells, test wells, and springs in areas underlain by the Flaxville Formation in the Fort Peck Indian Reservation, northeastern Montana

[Geologic unit: Qal, Quaternary alluvium; Qt, Quaternary glacial till; Qw, Pleistocene Wiota Gravel; Tf, Miocene and Pliocene Flaxville Formation; Tfu, Paleocene Fort Union Formation; Khc, Upper Cretaceous Hell Creek Formation; Kfh-Khc, Upper Cretaceous Hell Creek Formation and Fox Hills Sandstone. Abbreviations: µS/cm, microsiemens per centimeter at 25 °Celsius; mg/L, milligrams per liter; lab, laboratory. Symbols: <, less than; --, no data]

Location number	Geologic unit	Well depth (feet below land surface)	Date (year, month, day)	Water level (feet below land surface)	Altitude (feet above sea level)	Specific conductance (µS/cm)	Nitrate, field (mg/L as N)	Nitrate plus nitrite, lab (mg/L as N)
29N42E03BCCC01	Qw	63	19940814	59.60	2,700	1,300	5.9	--
29N44E03BBCA01	Khc	120	19891024	51.22	2,679	560	--	--
			19941003	--	--	562	2.5	3.2
29N44E09ACDC01	Khc	80	19940927	--	--	1,040	8.2	11
29N44E14ADAB01	Khc	65	19940927	--	--	737	3.9	4.0
			19950509	--	--	710	3.1	4.0
29N44E16DDDC01	Khc	85	19940927	--	--	594	3.9	4.1
29N44E23BCCA01	Khc	125	19940927	--	--	970	8.2	11
29N44E23BCCD01	Khc	125	19940927	--	--	1,060	9.2	--
29N45E18CCBB01	Khc	110	19940927	--	--	631	10.3	14
			19950502	--	--	626	12.0	16
29N46E02DDAC01	Khc	104	19940813	37	2,643	489	9.8	--
29N46E05DCCD01	Qal	30	19941002	15.47	2,410	858	.7	.40
29N46E08ABBD01	Qal	38	19941002	--	--	885	.2	.20
29N46E10DAAB01	Tfu	100	19890501	75	2,630	510	--	--
			19940811	--	--	500	3.4	--
			19950507	--	--	501	2.7	3.5
29N46E10DAAC01	Tfu	100	19890501	--	--	685	--	--
			19940811	--	--	825	12.1	--
			19950507	--	--	697	9.9	12
29N46E11DDAC01	Khc	200	19940814	--	--	1,120	11.5	--
29N47E06CBCC01	Tf	50	19940814	27.60	2,657	715	16.0	--
30N42E01CDBC01	Tf	22	19890607	12.11	2,728	5,060	--	--
			19890804	13.30	2,727	4,800	--	--
			19940812	--	--	5,780	10.6	16
			19950519	--	--	5,070	11.7	18
30N42E02DDBB01	Tf	24	19940815	18.83	2,716	2,310	3.5	--
30N42E04DCDA01	Tf	--	19940813	--	--	1,970	10.0	--
30N42E33DDDD01	Tf	60	19890514	46.82	2,708	2,240	--	--
			19890804	47.60	2,707	2,000	--	--
			19940812	--	--	2,250	14.0	--
			19950508	--	--	1,970	11.1	17
30N44E09CBAB01	Khc	65	19940929	9.97	2,760	1,760	0	.09
30N44E20ACBA01	Kfh-Khc	68	19941001	49.79	2,745	1,110	11.7	16
			19950503	--	--	1,050	14.1	15
30N44E22BCBC01	Khc	72	19941001	51.45	2,734	662	5.5	6.6
30N44E28DCDB01	Kfh-Khc	--	19941002	--	--	805	1.6	2.3
30N45E04CCAD01	Khc	151	19941001	134.11	2,656	360	.6	.78
30N45E16ACBD01	Khc	177	19940928	125.55	2,619	402	0	<.05
			19950502	--	--	417	.1	<.05

Table 3. Physical data for and nitrate concentrations in water samples from private wells, test wells, and springs in areas underlain by the Flaxville Formation in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Location number	Geologic unit	Well depth (feet below land surface)	Date (year, month, day)	Water level (feet below land surface)	Altitude (feet above sea level)	Specific conductance (μS/cm)	Nitrate, field (mg/L as N)	Nitrate plus nitrite, lab (mg/L as N)
30N45E28BBDA02	Khc	180	19940928	--	--	510	0	--
30N45E28BBDB01	Khc	176	19890608	153.86	2,581	509	--	--
			19940928	158.86	2,576	509	0	<.05
30N46E02BBCD01	Tf	--	19830915	25.60	2,724	670	--	[1]25.5
			19940814	26.00	2,724	875	22.3	--
30N46E10DDDB01	Khc	160	19761010	120	2,605	--	--	--
			19940812	--	--	775	21.1	--
			19960421	--	--	767	--	23
30N46E10DDDB02	Khc	210	19940812	--	--	790	27.3	--
			19950817	--	--	711	17	21
30N46E13CCCC01	Tf	40	19940813	15.38	2,698	568	6.2	--
30N46E14DDAC01	Khc	160	19940813	--	--	700	6.0	--
30N46E14DDDD01	Tf	40	19890501	9.41	2,706	555	--	--
			19890719	9.94	2,705	530	--	11
			19940813	10.91	2,704	893	24.6	--
			19960419	--	--	578	--	14
30N46E26DCBC01	Khc	247	19940812	--	--	485	.7	--
30N47E08DBBA01	Tf	40	19941004	26.75	2,678	539	12.8	18
30N47E12ADCC01	Tf	35	19940924	13.11	2,678	415	7.1	8.9
30N47E24ACDC01	Tf	37	19940923	22.84	2,676	10,300	8.5	14
30N47E24DABA01	Tfu	136	19940923	79.97	2,625	550	1.1	1.5
30N47E31BCBC01	Tf	58	19830901	36	2,669	500	--	[1]17.7
			19940811	40.99	2,664	555	19.6	--
			19960418	--	--	701	21.5	31
30N47E31BCBC02	Tf	--	19940811	39.58	2,665	430	7.5	--
			19960418	--	--	456	--	10
30N47E31BCBC03	Khc	--	19940811	--	--	570	.9	--
			19960418	--	--	552	.2	<.05
30N48E07BAAB01	Tf	38	19940924	9.17	2,673	1,210	11.0	18
			19950521	--	--	744	10.7	19
30N48E07BAAB02	Khc	217	19940924	177.92	2,504	980	0	<.05
			19950521	--	--	977	0	.17
30N48E20DAAB01	Tf	36	19940928	6.45	2,604	3,780	6.3	8.3
30N48E22DDCA01[2]	Tf	--	19830910	--	--	450	--	.32
			19940812	--	--	525	1.3	.44
30N48E32BCBC01	Khc	100	19940925	37.97	2,602	1,320	4.0	5.1
30N49E03ABDD01	Kfh-Khc	440	19941003	367	2,298	923	.3	<.05
31N42E25ABCB01	Qt	32	19940814	24.10	2,866	2,850	8.5	--
31N42E27BABA01	Qt	33	19940814	27.2	2,793	2,960	12.7	--
31N42E28DCDD01	Tf	18	19890607	10.28	2,775	4,030	--	--
			19940812	12.54	2,772	4,760	8.2	--
31N43E20CDDD01	Qt	20	19940815	--	--	905	6.1	--

Table 3. Physical data for and nitrate concentrations in water samples from private wells, test wells, and springs in areas underlain by the Flaxville Formation in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Location number	Geologic unit	Well depth (feet below land surface)	Date (year, month, day)	Water level (feet below land surface)	Altitude (feet above sea level)	Specific conductance (µS/cm)	Nitrate, field (mg/L as N)	Nitrate plus nitrite, lab (mg/L as N)
31N43E20CDDD02	Qt	20	19940815	--	--	1,050	6.1	--
31N43E29BCCB01	Qt	40	19940816	--	--	1,000	15.5	22
			19950508	--	--	929	17.6	22
31N43E29BCCD01	Qt	25	19940816	--	--	764	14.4	--
31N43E30DCAB01	Qt	33	19940815	--	--	1,530	16.8	--
31N44E10BCDC01	Kfh-Khc	180	19940930	--	--	597	1.3	1.5
31N44E12DAAB01	Khc	73	19830912	18.7	2,902	450	--	[3]3.31
			19941003	19.0	2,902	441	3.0	3.1
			19950503	--	--	450	4.0	2.7
31N44E13CABA01	Khc	120	19941003	--	--	914	2.8	3.6
31N44E15BADB01	Kfh-Khc	150	19940930	--	--	514	1.2	1.3
			19950506	--	--	508	1.2	1.3
31N44E17DDAA01	Kfh-Khc	170	19940930	145	2,785	491	1.1	1.5
31N44E20BDBD01	Kfh-Khc	--	19940930	--	--	600	6.0	7.9
31N44E24ADAC01	Kfh-Khc	70	19830913	29.23	2,883	760	--	[1]17.5
			19941003	--	--	662	16.1	24
31N44E27CCCC01	Kfh-Khc	114	19940929	84.26	2,781	656	1.4	1.6
31N44E28AAAB01	Kfh-Khc	--	19940929	--	--	1,250	3.5	4.4
31N44E28AAAC01	Kfh-Khc	125	19940929	103.68	2,791	793	6.9	10
31N44E33DABA01	Kfh-Khc	130	19940929	76.29	2,784	585	2.6	3.2
			19950504	73.33	--	574	1.7	2.3
31N44E33DADA01	Kfh-Khc	--	19940929	--	--	602	5.3	5.6
31N44E34BABA01	Kfh-Khc	180	19940930	77.22	2,773	478	5.1	6.0
31N45E14ABCB01	Tf	45	19941001	15	2,889	552	8.5	10
			19950520	--	--	519	8.4	10
31N45E15ABAA01	Tf	46	19941001	--	--	1,050	15.1	14
			19950520	--	--	1,030	14.4	27
31N45E15DDAB01	Tf	36	19830913	21.08	2,883	960	--	[1]16.9
			19941001	20.80	2,883	1,120	15.9	27
31N45E18ABBA01	Tf	60	19941001	--	--	714	18.3	31
31N45E18BAAA01	Tf	50	19941001	37.25	2,888	802	20.9	32
31N45E18BBBD01	Khc	--	19941004	--	--	1,090	13.9	25
31N45E25CCAB01	Kfh-Khc	260	19940930	--	--	1,130	15.0	21
			19950509	--	--	1,130	17.5	22
31N45E32AAAD01	Tf	53	19940929	43	2,797	775	14.4	23
31N45E32DADB01	Khc	189	19830912	148.11	2,692	680	--	[1]8.07
			19941001	--	--	571	6.0	7.8
31N45E36BCBB01	Khc	100	19941002	42.07	2,780	623	10.1	14
31N46E01CBCA01	Tfu	90	19940816	51.55	2,823	634	13.7	17
31N46E02DDAC01	Tf	30	19960419	--	--	682	--	22
31N46E02DDBD01	Tf	36	19830914	33.64	2,846	670	--	[1]20.8
			19940816	--	--	660	18.8	--

Table 3. Physical data for and nitrate concentrations in water samples from private wells, test wells, and springs in areas underlain by the Flaxville Formation in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Location number	Geologic unit	Well depth (feet below land surface)	Date (year, month, day)	Water level (feet below land surface)	Altitude (feet above sea level)	Specific conductance (μS/cm)	Nitrate, field (mg/L as N)	Nitrate plus nitrite, lab (mg/L as N)
			19960419	--	--	705	--	25
31N46E08CBCC01	Tfu	55	19830913	24.77	2,870	980	--	[1]27.6
			19941003	--	--	862	15.4	23
			19950818	--	--	913	20.4	27
31N46E08CCBA01	Tfu	85	19950818	23.80	2,870	707	11.0	19
			19960419	--	--	686	--	20
31N46E11CBBC01	Tf	35	19940815	--	--	1,490	18.8	--
			19950520	--	--	1,350	20.1	27
31N46E11CBBD01	Tf	35	19940815	--	--	1,740	55.4	--
			19950520	--	--	2,020	54.8	82
31N46E15CBCC01[4]	Tfu	131	19950815	127.48	2,692	--	--	--
31N46E15CBCC02[4]	Tfu	60	19950815	37.02	2,782	724	1.6	.90
			19960420	--	--	610	--	.73
31N46E15CCCB01	Tf	37	19940815	29.47	2,786	1,080	22.3	--
			19950504	--	--	1,070	19.7	23
31N46E16DADA01[4]	Tf	34	19950707	26.98	2,794	1,230	--	--
			19950815	26.86	2,794	854	20	22
			19960420	--	--	1,190	--	20
31N46E16DADA02[4]	Tf	38	19950708	27.05	2,794	1,230	--	22
			19950816	26.92	2,794	1,240	20	21
31N46E18ABBA01	Kfh-Khc	300	19941001	--	--	908	1.5	1.1
31N46E24DCDC01	Tf	49	19811204	39	2,730	747	--	[3]23.0
			19940926	37.22	2,728	655	12.4	16
31N46E24DCDC02	Tf	46	19940927	38.18	2,727	690	12.9	18
31N46E28DDCD01	Khc	150	19940814	90.25	2,660	873	19.5	--
			19950507	--	--	872	24.3	19
31N47E02DADD01	Tf	50	19940927	--	--	795	11.1	16
31N47E06DDDD01	Tfu	55	19830914	27.96	2,842	550	--	[1]10.5
			19890502	30.10	2,840	655	--	--
			19940816	--	--	610	18.3	--
			19960419	--	--	705	--	27
31N47E06DDDD02	Tfu	60	19890502	34.99	2,835	465	--	--
			19890719	38.91	2,831	440	9.0	7.8
			19940816	--	--	540	8.4	--
			19960419	--	--	489	--	8.1
31N47E14AAAC01	Tfu	70	19940928	27.70	2,723	929	.7	1.0
			19950520	--	--	894	1.2	1.6
31N47E16BCAA01	Tfu	100	19940927	41.55	2,770	645	2.9	3.3
			19950521	--	--	637	2.8	3.0
31N47E16BCAA02	Tfu	65	19940927	--	--	555	8.0	10
			19950521	--	--	546	7.4	8.9
31N48E07CBBA01	Tf	30	19830909	12.30	2,740	1,030	--	[1]11.2

Table 3. Physical data for and nitrate concentrations in water samples from private wells, test wells, and springs in areas underlain by the Flaxville Formation in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Location number	Geologic unit	Well depth (feet below land surface)	Date (year, month, day)	Water level (feet below land surface)	Altitude (feet above sea level)	Specific conductance (μS/cm)	Nitrate, field (mg/L as N)	Nitrate plus nitrite, lab (mg/L as N)
			19940928	11.35	2,741	1,230	4.1	7.1
31N48E17ABAA01	Tf	40	19940929	10	2,698	547	3.9	5.2
31N48E18BCBC01	Tf	30	19890429	27	2,715	650	--	--
			19940929	--	--	614	7.2	11
31N48E25BBCB01	Tf	30	19890429	27.82	2,652	2,350	--	--
			19890804	27.87	2,652	1,900	--	--
			19940929	28.93	2,651	2,270	15.3	22
31N48E26BCDA01	Tfu	85	19940929	--	--	2,200	13.7	20
31N48E28BABD01	Tf	40	19890429	32	2,678	670	--	--
			19940929	--	--	807	10.0	16
31N48E28BACB01	Tf	35	19941003	21.37	2,689	947	16.8	34
31N48E30CBCD01	Tfu	66	19670619	30	2,620	--	--	--
			19940926	--	--	355	2.1	2.6
31N48E31DCCC01	Tfu	130	19940926	110	2,510	715	1.1	--
31N51E01ABBB01	Tfu	303	19940812	176.70	2,438	1,100	.9	--
31N51E04AAAD01	Tfu	100	19940814	39.84	2,605	2,550	17.1	--
31N51E04DDAB01	Tfu	90	19940812	52.48	2,537	829	2.3	1.2
32N44E03BDCA01	Khc	70	19850621	62.99	2,878	1,320	--	[3]39.3
			19940928	63.13	2,878	1,490	73.2	90
			19950518	--	--	1,410	70.0	83
32N44E04CBBD01	Khc	115	1963	90	2,832	--	--	--
			19940928	--	--	508	12.6	17
32N44E05DBCC01	Khc	135	19840915	--	--	464	--	[3]5.30
			19940930	--	--	454	1.8	1.1
32N44E06ADDB01	Kfh-Khc	160	19840915	--	--	466	--	[3]7.14
			19940930	--	--	535	6.8	9.1
32N45E05BBCC01	Tf	50	19890515	29.14	2,862	535	--	--
			19890719	34.05	2,857	500	15	16
			19940810	31.45	2,860	532	14.4	--
			19960420	--	--	506	--	15
32N50E12AAAA01	Tfu	176	19940813	--	--	964	.7	--
32N51E04BCBA01	Tfu	55	19940812	39.42	2,491	1,330	.9	--
32N51E05BAAB01	Tfu	124	19940812	9.48	2,526	1,430	4.0	--
32N51E05BAAB02	Tfu	45	19940812	--	--	1,330	1.0	--
			19950516	--	--	1,190	.2	.11
32N51E17DCCC01	Tfu	87	19940812	9.26	2,646	1,440	11.0	--
32N51E20ABBA01	Tfu	--	19940812	--	--	1,170	6.7	--
			19950505	--	--	970	3.8	5.6
32N51E31CCCA01	Tfu	195	19940813	--	--	1,010	0	--
32N52E04BBBB01	Tfu	50	19940813	31.32	2,494	908	4.8	--
			19950516	--	--	599	10.1	13
32N52E04BBBB02	Tfu	50	19940813	--	--	718	5.6	--

Table 3. Physical data for and nitrate concentrations in water samples from private wells, test wells, and springs in areas underlain by the Flaxville Formation in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Location number	Geologic unit	Well depth (feet below land surface)	Date (year, month, day)	Water level (feet below land surface)	Altitude (feet above sea level)	Specific conductance (µS/cm)	Nitrate, field (mg/L as N)	Nitrate plus nitrite, lab (mg/L as N)
33N40E23BBAC01	Tf	62	19940810	17	2,863	1,000	6.3	--
33N40E23BBDA01	Tf	58	19940810	1	2,879	970	4.3	--
33N40E28ABAC01	Tf	23	19940810	5	2,835	1,390	6.1	--
			19950519	--	--	1,160	6.3	8.7
33N41E14BADD01	Tf	75	19890514	53.63	2,831	515	--	--
			19890804	54.10	2,831	445	--	--
			19940809	54.17	2,831	538	5.3	--
33N41E17AADC01	Tf	64	19940811	45	2,835	2,730	9.2	--
33N41E17AADC02	Tf	60	19940811	48.93	2,831	2,590	11.2	--
33N41E20DBBA01	Tf	86	19940810	52	2,828	1,030	1.2	--
33N41E20DBBD01	Tf	36	19940810	33.22	2,847	2,040	12.4	--
			19950517	--	--	2,460	15.4	30
33N42E22BDAD01	Tf	60	19940811	3	2,897	1,270	2.6	--
33N42E22BDDA01	Tf	51	19940811	--	--	817	.7	--
33N42E24ABAC01	Tf	30	19940927	--	--	750	9.3	14
			19950518	--	--	622	12.4	17
33N42E33BCCC01	Tf	95	19890607	30.65	2,899	740	--	--
			19940809	34.76	2,895	823	6.3	--
33N42E33CCBB01	Tf	75	19890607	8.42	2,897	970	--	--
			19940809	15.84	2,889	1,090	3.5	--
33N42E36BAAC01	Tf	39	19940813	29	2,891	626	21.5	--
			19950517	--	--	612	20.5	26
33N43E07CDDD01	Tf	--	19840915	--	--	550	--	[3]13.8
			19940815	--	--	561	9.3	--
33N43E08CDCC01	Tf	--	19940812	--	--	510	14.5	--
33N43E11CDBD01	Tf	30	19940927	15	2,873	546	11.2	15
33N43E17DAAC01	Tf	90	19840915	--	--	520	--	[3]17.5
			19940928	--	--	533	13.6	18
33N43E25ADAD01	Kfh-Khc	165	19840915	--	--	388	--	[3].08
			19890418	30.00	2,875	441	--	--
			19891024	29.59	2,875	440	--	--
			19940928	28.24	2,877	431	.3	<.05
33N44E10BABB01	Kfh-Khc	160	19940810	43.09	2,827	593	19.1	--
33N44E22BBBC01	Tf	35	19940810	--	--	524	17.1	--
			19950518	--	--	508	12.8	18
33N44E22CDCC01[4]	Khc	74	19950708	24.28	2,866	398	--	.97
			19950817	24.16	2,866	388	0	.94
			19960420	--	--	368	--	.76
33N44E22CDCC02[4]	Tf	32	19950709	22.21	2,868	518	--	16
			19950817	22.19	2,868	510	15.1	16
			19960420	--	--	498	--	16
33N44E25CCCC01	Tf	39	19940811	29.25	2,866	531	17.4	--

Table 3. Physical data for and nitrate concentrations in water samples from private wells, test wells, and springs in areas underlain by the Flaxville Formation in the Fort Peck Indian Reservation, northeastern Montana (Continued)

Location number	Geologic unit	Well depth (feet below land surface)	Date (year, month, day)	Water level (feet below land surface)	Altitude (feet above sea level)	Specific conductance (µS/cm)	Nitrate, field (mg/L as N)	Nitrate plus nitrite, lab (mg/L as N)
33N44E30ABBB01	Tf	60	19840915	--	--	423	--	[3].08
			19940928	--	--	451	.9	.19
33N44E33BBAD01	Tf	65	19840915	--	--	389	--	27.7
			19940810	47.09	2,868	584	19.5	--
			19950519	--	--	534	13.4	19
33N45E26CBAA01[4]	Tfu	54	--	--	--	--	--	--
33N45E26DBAD01[2]	Tfu	--	19950502	--	--	667	0	--
33N45E27DADC01[2]	Tfu	--	19950502	--	--	695	0	--
			19950817	--	--	707	--	<.05
			19960419	--	--	710	--	.07
33N45E32ABBD01	Tfu	40	19940811	--	--	609	17.0	--
33N45E32ABBD02	Tfu	70	19940811	--	--	1,000	26.9	--
33N45E33BBCC01	Tfu	40	19940811	--	--	1,350	13.2	--
33N49E24CCDA01	Tfu	94	19940921	53.78	2,658	503	1.8	1.1
33N49E24CCDC01	Tfu	96	19830915	--	--	1,040	--	[1]8.66
			19940921	53.40	2,632	698	3.7	5.7
			19950505	--	--	536	1.6	1.7
			19960418	--	--	535	1.3	1.8
33N49E26DAAA01	Tfu	155	19940921	70.09	2,595	1,150	.7	<.05
33N50E18BCBB01	Tfu	160	19940922	55.58	2,615	530	.3	<.05
33N50E24BDDC01	Tfu	160	19890512	9.59	2,530	1,310	--	--
			19891027	9.41	2,531	1,320	--	--
			19940815	--	--	1,310	.5	--
			19950516	--	--	1,320	.3	<.05
33N50E24DCBB01	Tf	34	19940815	8.67	2,503	1,030	4.4	--
			19950516	--	--	1,050	4.3	6.0
33N51E20DCCC01	Qt	13	19890512	10.50	2,488	1,130	--	--
			19940815	9.65	2,488	1,370	5.4	--
33N51E28BAAC01	Tf	--	19940815	26.27	2,504	869	6.4	--
33N51E35CBCA01	Tfu	100	19850709	54.72	2,485	893	--	[3].09
			19940816	60.10	2,480	941	1.1	--
33N52E27CCBD01	Tfu	214	19940816	83.44	2,557	912	.4	--
33N52E27CCBD02	Tfu	160	19940816	--	--	1,050	1.1	.07
33N53E12DCAD01	Tfu	200	19940809	--	--	1,200	1.5	--
33N54E07CDAB01	Tfu	200	19940809	--	--	1,100	--	--
33N54E18CDDB01	Tfu	82	19940809	55.01	2,235	1,900	.7	--

[1] Data from Donovan and Bergantino (1987).

[2] Spring.

[3] Data retrieved from the Montana Bureau of Mines and Geology Ground Water Information Center data base.

[4] Test well.

Table 4. Ground-water-chemistry data for samples from selected private wells, test wells, and a spring in areas underlain by the Flaxville Formation, 1989, 1995-96, Fort Peck Indian Reservation, northeastern Montana

[Constituents are dissolved, except as indicated. Data collected during 1989 from Thamke (1991). Geologic unit: Qal, Quaternary alluvium; Qt, Quaternary glacial till; Tf, Miocene and Pliocene Flaxville Formation; Tfu, Paleocene Fort Union Formation; Kfh-Khc, Upper Cretaceous Hell Creek Formation and Fox Hills Sandstone. Abbreviations: °C, degrees Celsius; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter. Symbols: --, no data; <, less than.]

Location number	Geologic unit	Depth of well (feet below land surface)	Date	Specific conductance, field (µS/cm)	pH, field (standard units)	Water temperature, field (°C)	Oxygen, dissolved, field (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
29N44E14ADAB01	Kfh-Khc	65	05-09-95	710	7.9	9.0	4.5	15	15	120	2.3	282	62
29N45E18CCBB01	Kfh-Khc	110	05-02-95	626	7.6	9.0	13.8	29	31	51	2.0	212	20
29N46E10DAAB01	Tfu	100	05-07-95	501	7.9	10.0	8.8	23	20	57	2.6	231	20
29N46E10DAAC01	Tfu	100	05-07-95	697	7.9	9.0	9.3	38	54	24	2.0	286	37
30N42E01CDBC01	Tf	22	05-19-95	5,070	7.6	9.0	9.2	130	190	780	6.2	363	1,900
30N42E33DDDD01	Tf	60	05-08-95	1,970	7.8	8.5	8.5	99	77	220	4.1	258	570
30N44E20ACBA01	Kfh-Khc	68	05-03-95	1,050	7.7	8.5	9.5	31	70	77	3.3	243	180
30N45E16ACBD01	Kfh-Khc	177	05-02-95	417	7.2	8.5	.1	28	15	40	1.9	198	20
30N46E10DDDB02	Kfh-Khc	210	08-17-95	711	7.7	9.5	11.5	50	40	30	2.4	236	31
30N46E14DDDD01	Tf	40	07-19-89	555	7.7	11.0	7.0	67	25	11	2.1	227	15
			04-19-96	578	7.5	10.0	5.5	70	23	12	1.3	225	18
30N48E07BAAB01	Tf	38	05-21-95	744	7.5	6.0	4.0	59	31	35	14	252	28
30N48E07BAAB02	Kfh-Khc	217	05-21-95	977	7.5	10.0	.1	54	34	120	3.3	451	94
31N43E29BCCB01	Qt	40	05-08-95	929	7.9	9.0	8.7	57	46	69	2.9	217	150
31N44E12DAAB01	Kfh-Khc	80	05-03-95	450	7.6	8.0	7.5	35	27	19	3.7	227	8.5
31N44E15BADB01	Kfh-Khc	150	05-06-95	508	7.9	8.5	8.0	30	19	50	2.5	190	61
31N44E33DABA01	Kfh-Khc	130	05-04-95	574	7.8	9.0	8.7	28	29	51	2.1	235	44
31N45E14ABCB01	Tf	45	05-20-95	519	7.3	8.0	5.0	35	31	22	3.2	216	19
31N45E15ABAA01	Tf	46	05-20-95	1,030	7.6	8.5	8.1	48	66	83	4.1	363	61
31N45E25CCAB01	Kfh-Khc	260	05-09-95	1,130	7.7	9.0	7.4	63	67	73	9.5	383	77
31N46E08CBCC01	Tfu	55	08-18-95	913	7.8	9.0	9.3	38	63	51	3.9	323	29
31N46E11CBBC01	Tf	35	05-20-95	1,350	7.5	9.0	3.0	49	78	110	3.4	444	51
31N46E11CBBD01	Tf	35	05-20-95	2,020	7.2	7.0	1.2	82	150	87	3.9	494	72
31N46E15CBCC02[1]	Tfu	60	08-15-95	724	7.6	15.0	--	40	42	47	3.9	271	90
31N46E15CCCB01	Tf	37	05-04-95	1,070	7.6	8.5	8.3	56	63	71	4.1	319	130
31N46E16DADA01[1]	Tf	34	08-15-95	854	7.7	15.5	8.3	62	69	88	3.7	334	180
31N46E16DADA02[1]	Tf	37	08-16-95	1,240	7.9	8.5	--	63	69	88	3.8	342	180
31N46E28DDCD01	Kfh-Khc	150	05-07-95	872	7.8	8.5	8.3	70	43	45	3.1	276	80
31N47E14AAAC01	Tfu	70	05-20-95	894	7.0	8.0	1.1	57	65	35	2.2	404	60
31N47E16BCAA01	Tfu	100	05-21-95	637	8.0	9.0	8.7	35	35	50	3.0	296	44
31N47E16BCAA02	Tfu	65	05-21-95	546	8.0	7.5	9.1	25	28	46	2.6	214	23
32N44E03BDCA01	Kfh-Khc	70	05-18-95	1,410	7.3	8.5	9.0	180	48	10	2.9	216	15

Table 4. Ground-water-chemistry data for samples from selected private wells, test wells, and a spring in areas underlain by the Flaxville Formation, 1989, 1995-96, Fort Peck Indian Reservation, northeastern Montana (Continued)

Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Nitrite, dissolved (mg/L as N)	Nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen-15/nitrogen-14 stable isotope ratio in NO_3 (permil)	Oxygen-18/oxygen-16 stable isotope ratio in NO_3 (permil)	Ammonia, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Strontium, dissolved (μg/L as Sr)	Dissolved solids, calculated (mg/L)	Location number
11	1.0	0.12	15	0.01	4.0	8.48	--	<0.015	<0.01	<3	<1	180	428	29N44E14ADAB01
20	.5	.09	17	<.01	16	9.96	-2.54	<.015	<.01	5	<1	310	369	29N45E18CCBB01
2.4	.5	.05	21	<.01	3.5	6.23	-2.16	<.015	<.01	6	<1	310	301	29N46E10DAAB01
11	.3	.08	21	<.01	12	7.09	-2.82	<.015	<.01	7	<1	520	413	29N46E10DAAC01
370	.8	3.0	19	.01	18	9.85	--	<.015	<.01	<9	<3	2,900	3,700	30N42E01CDBC01
110	.3	.53	19	.01	17	8.52	--	<.015	.05	<3	<1	800	1,330	30N42E33DDDD01
49	.5	.35	15	<.01	15	11.01	-3.53	<.015	<.01	4	<1	450	639	30N44E20ACBA01
3.2	.4	.05	16	<.01	<.05	--	--	.04	<.01	540	230	220	245	30N45E16ACBD01
18	.3	.10	17	<.01	21	9.82	--	<.015	<.01	14	<1	570	424	30N46E10DDDB02
5.9	.2	.03	14	--	11	--	--	--	--	13	<1	390	327	30N46E14DDDD01
9.5	.2	.04	14	<.01	14	--	--	--	--	<3	<1	--	345	
26	.4	.07	16	.03	19	13.87	--	.08	.18	42	31	490	446	30N48E07BAAB01
5.8	.2	.12	16	.01	.17	--	--	.97	<.01	650	16	640	601	30N48E07BAAB02
23	.3	.22	16	.01	22	7.10	--	<.015	<.01	<3	<1	570	593	31N43E29BCCB01
3.1	.4	.06	18	<.01	2.7	5.90	-3.79	<.015	<.01	5	<1	450	263	31N44E12DAAB01
5.6	.4	.08	17	<.01	1.3	5.85	--	<.015	<.01	8	3	300	306	31N44E15BADB01
9.0	.4	.10	14	<.01	2.3	6.90	-4.20	.02	.06	<3	<1	340	329	31N44E33DABA01
4.1	.6	.07	15	<.01	10	7.20	--	<.015	.04	<3	<1	440	304	31N45E14ABCB01
23	.7	.18	16	<.01	27	8.36	-2.45	<.015	.12	<3	<1	690	640	31N45E15ABAA01
45	.4	.20	15	<.01	22	14.48	--	<.015	<.01	3	1	940	678	31N45E25CCAB01
22	.6	.09	17	<.01	27	10.25	--	<.015	.03	4	<1	620	539	31N46E08CBCC01
92	1.2	.12	19	<.01	27	11.39	-2.91	<.015	.19	<3	<1	700	791	31N46E11CBBC01
150	1.0	.21	18	.01	82	12.82	-1.74	.02	.01	30	<3	1,200	1,220	31N46E11CBBD01
13	.6	.23	18	.01	.90	--	--	.05	.01	<3	77	530	422	31N46E15CBCC02[1]
25	.7	.35	18	<.01	23	6.70	-2.36	<.015	.02	<3	<1	780	662	31N46E15CCCB01
32	.7	.43	17	<.01	22	7.10	-1.86	.03	.03	70	10	720	752	31N46E16DADA01[1]
33	.7	.44	18	<.01	21	--	--	<.015	.02	18	<1	750	755	31N46E16DADA02[1]
24	.4	.24	15	<.01	19	7.99	-1.81	<.015	.04	13	1	470	531	31N46E28DDCD01
14	.6	.18	19	.01	1.6	--	--	<.015	<.01	49	34	630	503	31N47E14AAAC01
5.2	.3	.08	16	<.01	3.0	5.86	-1.69	<.015	.02	290	4	570	380	31N47E16BCAA01
14	.4	.14	14	<.01	8.9	7.91	--	.02	.02	120	3	460	322	31N47E16BCAA02
100	<.1	.16	15	<.01	83	9.03	-3.10	.03	<.01	7	<1	840	869	32N44E03BDCA01

Table 4. Ground-water-chemistry data for samples from selected private wells, test wells, and a spring in areas underlain by the Flaxville Formation, 1989, 1995-96, Fort Peck Indian Reservation, northeastern Montana (Continued)

Location number	Geo-logic unit	Depth of well (feet below land surface)	Date	Specific conductance, field (μS/cm)	pH, field (standard units)	Water temperature, field (°C)	Oxygen, dissolved, field (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, field (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)
32N45E05BBCC01	Tf	50	07-19-89	680	7.4	--	9.0	62	24	9.9	2.8	191	19
32N51E05BAAB02	Tfu	45	05-16-95	1,190	7.0	8.5	.1	97	81	55	5.3	--	68
32N51E20ABBA01	Tfu	--	05-05-95[2]	970	7.3	8.0	--	67	79	22	3.4	328	130
			05-05-95[2]	970	7.3	8.0	--	65	76	21	3.4	--	130
32N52E04BBBB01	Tfu	50	05-16-95	599	7.6	7.5	7.3	50	42	12	2.1	252	24
33N40E28ABAC01	Tf	23	05-19-95	1,160	7.8	6.0	9.4	62	50	110	5.0	242	290
33N41E20DBBD01	Tf	36	05-17-95	2,460	7.5	7.5	7.2	150	140	190	16	347	700
33N42E24ABAC01	Tf	30	05-18-95	622	7.8	8.0	9.0	48	27	42	3.7	219	33
33N42E36BAAC01	Tf	39	05-17-95	612	7.7	8.0	9.0	47	30	30	3.5	200	25
33N44E22BBBC01	Tf	35	05-18-95	508	7.8	8.5	9.8	55	24	8.8	2.1	172	16
33N44E22CDCC01[1]	Kfh-Khc	75	08-17-95	388	7.8	9.0	1.2	40	21	8.4	2.4	196	6.1
33N44E22CDCC02[1]	Tf	32	08-17-95	510	7.9	9.0	10.5	40	31	11	2.6	178	20
33N44E33BBAD01	Tf	65	05-19-95[2]	534	7.6	8.0	10.6	53	30	8.8	2.3	181	18
			05-19-95[2]	534	7.6	8.0	10.6	51	28	8.7	2.3	--	18
33N45E27DADC01[3]	Tfu	--	08-17-95	707	7.0	--	--	65	39	26	3.8	--	60
33N49E24CCDC01	Tfu	96	05-05-95	536	7.7	8.5	2.5	37	41	15	2.5	261	19
33N50E24BDDC01	Tfu	160	05-16-95	1,320	7.3	8.0	.1	75	58	150	5.7	605	150
33N50E24DCBB01	Tf	34	05-16-95	1,050	7.3	7.0	.2	82	71	42	3.5	401	110

[1]Test well
[2]Replicate analysis
[3]Spring

Table 4. Ground-water-chemistry data for samples from selected private wells, test wells, and a spring in areas underlain by the Flaxville Formation, 1989, 1995-96, Fort Peck Indian Reservation, northeastern Montana (Continued)

Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)	Silica, dissolved (mg/L as SiO_2)	Nitrite, dissolved (mg/L as N)	Nitrite plus nitrate, dissolved (mg/L as N)	Nitrogen-15/nitrogen-14 stable isotope ratio in NO_3 (per-mil)	Oxygen-18/oxygen-16 stable isotope ratio in NO_3 (permil)	Ammonia, dissolved (mg/L as N)	Phosphorus, ortho, dissolved (mg/L as P)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Strontium, dissolved (μg/L as Sr)	Dissolved solids, calculated (mg/L)	Location number
3.4	.2	.04	15	--	16	--	--	--	--	7	<1	440	323	32N45E05BBCC01
5.8	.1	.18	17	<.01	.11	--	--	.62	<.01	1,300	78	1,500	709	32N51E05BAAB02
32	1.0	.40	13	.02	5.6	11.74	--	<.015	<.01	260	110	590	570	32N51E20ABBA01
33	1.0	.41	12	.02	5.6	--	--	<.015	<.01	270	100	570	574	
1.2	.3	.06	17	<.01	13	7.69	--	<.015	<.01	3	<1	300	357	32N52E04BBBB01
39	.3	.33	19	<.01	8.7	6.64	-2.53	<.015	.01	<3	<1	660	760	33N40E28ABAC01
160	.2	.99	21	<.01	30	--	--	.02	.05	30	<3	1,300	1,720	33N41E20DBBD01
7.5	.4	.08	17	<.01	17	9.01	--	<.015	.08	6	<1	400	386	33N42E24ABAC01
4.5	.3	.08	17	<.01	26	--	--	<.015	.01	<3	<1	450	393	33N42E36BAAC01
2.7	.3	.06	17	<.01	18	6.05	-1.77	<.015	.01	3	<1	430	309	33N44E22BBBC01
1.7	.2	.04	17	.02	.94	--	--	.07	<.01	280	120	410	220	33N44E22CDCC01[1]
3.3	.3	.06	16	.01	16	6.30	--	.09	<.01	56	5	500	303	33N44E22CDCC02[1]
3.1	.2	.04	17	<.01	19	6.54	--	<.015	.01	3	<1	540	326	33N44E33BBAD01
3.4	.3	.05	17	<.01	20	--	--	<.015	<.01	<3	<1	510	329	
3.9	.4	.09	15	<.01	<.05	--	--	.08	<.01	130	120	610	412	33N45E27DADC01[3]
5.5	1.2	.08	12	.02	1.7	14.64	1.80	<.015	<.01	<3	18	320	298	33N49E24CCDC01
6.4	<.1	.19	12	.01	<.05	--	--	.70	<.01	610	32	1,700	823	33N50E24BDDC01
39	.5	.26	15	.03	6.0	26.69	4.74	.02	<.01	<3	190	670	631	33N50E24DCBB01

Table 5. Lithologic logs for soil pits excavated in the Flaxville Formation on June 21-22, 1995, Fort Peck Indian Reservation, northeastern Montana

[Soil-pit name, a field-identification number; location number, numbering system described in text. Depth in feet below land surface. Abbreviations: ft, feet; in., inches. Symbol: <, less than]

Description	Depth (feet)
Soil-pit name: B-N	
Location number: 31N46E16ABBA01	
Lithology:	
Topsoil, dark-brown, sandy clay loam, about 5 percent pebbles, non-calcareous	0-1.0
Sand, fine-grained, silty, medium-brown; about 5 percent pebbles; non-calcareous	1.0-4.0
Gravel, clayey, poorly sorted, gray-brown, calcareous	4.0-8.0
Clay, silty, gray interbedded with white calcareous marl; thin oxidized layers in silty clay	8.0-8.5
Clay, silty, dense, massive, gray; few thin orange-brown oxidized layers; non-calcareous	8.5-11.0
Remarks: Boundary between gravel and underlying clay undulates 1-2 ft.	
Soil-pit name: B-S	
Location number: 31N46E15CBBC01	
Lithology:	
Topsoil, dark-brown, sandy clay loam, non-calcareous	0-1.0
Sandy clay loam, medium-brown, non-calcareous	1.0-2.3
Sandy clay loam, tan, lime-rich, calcareous	2.3-3.5
Interbedded 3-9-in.-thick layers of poorly sorted sandy gravel and clayey sandy silt; light brown; calcareous	3.5-7.6
Silt, clayey, massive, tan, calcareous	7.6-11.5
Remarks: Roots extend to 3.3 ft below land surface.	
Soil-pit name: W-N	
Location number: 31N46E20BABB01	
Lithology:	
Topsoil, dark-brown; sandy silt; non-calcareous	0-1.0
Silt, sandy, medium-brown; few pebbles; non-calcareous	1.0-2.6
Silt, clayey, sandy, tan; few pebbles, calcareous	2.6-4.0
Sand, fine- to medium-grained, orange-brown, calcareous	4.0-6.0
Sand, fine- to medium-grained, orange-brown, non-calcareous	6.0-8.0
Silt, clayey, sandy, dense, tan, lime-rich, calcareous	8.0-9.4
Gravel	9.4-9.5
Sand, silty, light-brown, calcareous	9.5-10.4
Gravel; Flaxville Formation	10.4-11.5
Remarks: Roots extend to 3.0 ft below land surface.	

Table 5. Lithologic logs for soil pits excavated in the Flaxville Formation on June 21-22, 1995, Fort Peck Indian Reservation, northeastern Montana (Continued)

Description	Depth (feet)
Soil-pit name: W-S	
Location number: 31N46E20CDCD01	
Lithology:	
Topsoil, dark brown; sandy clay loam; non-calcareous	0-1.0
Silt, sandy, medium brown; <1 percent pebbles; non-calcareous	1.0-2.5
Sand, cemented, lime-rich; about 5 percent pebbles; calcareous	2.5-5.0
Sand, fine- to medium-grained, brown; about 5 percent pebbles; non-calcareous	5.0-6.1
Gravel and sand; pebble diameter is about 0.5-1 in.	6.1-7.0
Sand, fine- to medium-grained; lime-rich layers; calcareous	7.0-10.0
Sand, silty, clayey, tan, lime-rich, calcareous	10-11.5
Remarks: None.	
Soil-pit name: H-E	
Location number: 33N44E22DDCD01	
Lithology:	
Topsoil, medium-brown; sandy loam; non-calcareous	0-1.0
Gravel, orange-brown; matrix of silty fine sand; non-calcareous	1.0-2.3
Gravel, poorly sorted with $CaCO_3$ coating on pebbles; matrix is silty, clayey sand with $CaCO_3$ accumulation; white-tan to orange-brown	2.3-4.5
Sand, massive, gray-tan; faint cross bedding defined by few, thin, iron-stained layers; non-calcareous	4.5-5.5
Clay, silty, massive, gray; discontinuous and undulating horizon	5.5-6.0
Sand, massive, gray-tan; faint cross bedding defined by few, thin, iron-stained layers	6.0-9.5
Sand, massive, gray-tan; faint cross bedding; about 20 percent gravel	9.5-10.0
Remarks: Roots extend to 5.5 ft below land surface.	
Soil-pit name: H-W	
Location number: 33N46E22CDCC01	
Lithology:	
Topsoil, medium- to dark-brown, sandy loam, non-calcareous	0-1.4
Silt, clayey; tan with white specks of $CaCO_3$; lenses of orange sand; very calcareous	1.4-2.6
Sand, fine-grained, well-sorted, orange-brown, with stringers of gray, silty, clayey sand and light-brown sand; calcareous	2.6-3.7
Gravel, poorly sorted, orange, gray, and white; heterogeneous; iron concretions; large caliche chunks; calcareous	3.7-4.9
Sand, fine to very fine, orange-tan, non-calcareous	4.9-10.0
Remarks: Roots extend to 5.5 ft below land surface.	

Table 5. Lithologic logs for soil pits excavated in the Flaxville Formation on June 21-22, 1995, Fort Peck Indian Reservation, northeastern Montana (Continued)

Description	Depth (feet)
Soil-pit name: R-E	
Location number: 33N45E26CBAA02	
Lithology:	
Topsoil, medium- to dark-brown sandy loam; about 10 percent gravel; non-calcareous from 0-2 ft; calcareous from 2-3 ft; bottom of sandy loam undulates from 2-3 ft below land surface	0-3.0
Sand, gravely, silty, tan; about 30 percent gravel; matrix is poorly sorted; lime-rich; very calcareous	3.0-4.0
Sand, massive, tan, non-calcareous	4.0-5.3
Sand, tan; faint cross bedding; non-calcareous	5.3-6.0
Sand, massive, tan; about 1 percent pebbles; non-calcareous	6.0-11.0
Remarks: Roots extend to 4.5 ft below land surface.	
Soil-pit name: R-W	
Location number: 33N45E26CBBD01	
Lithology:	
Topsoil, medium to dark red-brown loam; about 10 percent gravel; somewhat calcareous	0-2.0
Sand and gravel; well-sorted, fine- to medium-grained sand matrix; pebble diameters mostly about 1 in. but range from 0.5-3 in.; $CaCO_3$ accumulation zone; very calcareous	2.0-3.5
Sand and gravel; well-sorted, fine- to medium-grained sand matrix; pebble diameters mostly about 1 in. but range from 0.5-3 in.; little $CaCO_3$ accumulation zone; somewhat calcareous	3.5-8.0
Sand, fine- to medium-grained, massive, very well sorted, tan, non-calcareous	8.0-11.0
Remarks: Top of gravel layer undulates from 1-3 ft below land surface. Roots extend to 4.0 ft below land surface.	

Table 6. Physical characteristics and nitrogen species in soil samples collected from backhoe pits in the Flaxville Formation on June 21-22, 1995, Fort Peck Indian Reservation, northeastern Montana

[Analyses by Soil Analytical Laboratory, Plant and Soil Science Department, Montana State University, Bozeman, Mont. Water content determined on entire sample before gravel removed. Organic matter and nitrogen species determined on sample after gravel removed. Abbreviations: °C, degrees Celsius; exch., exchangeable; mg/kg, milligrams per kilogram. Symbols: <, less than; --, no data]

Soil pit name	Depth (feet below land surface)	Water content at 35°C (percent)	Organic matter (percent)	Total Kjeldahl nitrogen (percent)	Nitrate (mg/kg as N)	Ammonia (mg/kg as N)	Non-exch. ammonia (mg/kg as N)	Gravel (percent)	Sand (percent)	Silt (percent)	Clay (percent)	Texture
B-N	0-1	11.9	1.48	0.095	2.3	1.0	145	--	49	30	21	Loam
	1-2	11.9	.74	.063	.8	1.8	155	--	47	29	24	Loam/sandy clay loam
	2-3	9.1	.35	.038	1.1	.9	122	--	68	15	17	Sandy loam
	3-4	8.9	.13	.027	1.4	1.0	110	--	69	15	16	Sandy loam
	4-6	8.7	.05	.025	2.2	1.2	155	49	14	21	16	Silty clay gravel
	6-8	3.5	<.05	.014	6.5	1.5	106	85	6	5	4	Gravel
	8-8.5	20.0	.15	.012	8.3	.8	124	--	11	59	30	Silty clay loam
	8.5-10	21.6	<.05	.026	6.9	1.2	365	1	2	29	68	Clay
B-S	0-1	12.1	1.17	.082	2.3	1.6	--	--	54	25	21	Sandy clay loam
	1-2	11.4	.54	.050	.5	1.6	--	--	55	24	21	Sandy clay loam
	2-3[1]	12.9	.41	.045	.9	1.3	--	--	41	31	28	Clay loam
	2-3[1]	12.5	.45	.044	.4	1.3	--	--	39	29	32	Clay loam
	3-4	9.0	.13	.025	.3	1.0	--	--	44	31	25	Loam
	4-7	7.5	<.05	.013	1.9	1.3	--	52	21	16	11	Sandy gravel
	7-9	14.6	<.05	.012	2.1	1.2	--	--	35	44	21	Loam
	9-11	16.4	<.05	.012	6.0	1.1	--	--	29	48	23	Loam
W-N	0-1	10.1	1.79	.099	5.8	.6	134	--	52	27	21	Sandy clay loam
	1-2	13.1	.98	.075	1.3	1.4	141	--	44	27	29	Clay loam/sandy clay loam
	2-3	13.2	.56	.050	1.8	1.3	109	--	47	24	29	Sandy clay loam
	3-4	13.8	.17	.026	2.7	1.2	96	--	40	28	32	Clay loam
	4-6	6.3	<.05	.006	1.0	.8	63	--	79	5	16	Sandy loam
	6-8	6.6	<.05	.005	1.1	.9	65	--	73	11	16	Sandy loam
	8-10	11.5	<.05	.007	4.3	.5	70	--	54	19	27	Sandy clay loam
W-S	0-1[1]	8.9	.90	.064	2.9	.9	--	--	61	18	21	Sandy clay loam/sandy loam
	0-1[1]	7.9	.94	.065	2.8	1.2	--	--	63	17	20	Sandy loam/sandy clay loam
	1-2	8.8	.57	.051	.6	1.2	--	--	60	17	23	Sandy clay loam
	2-3	10.8	.28	.034	.6	1.2	--	--	60	17	23	Sandy clay loam
	3-4	10.5	<.05	.013	.6	1.0	--	--	62	15	23	Sandy clay loam
	4-6[1]	6.4	<.05	.007	.2	.6	--	--	80	7	13	Sandy loam
	4-6[1]	6.1	<.05	.006	.3	.8	--	--	82	6	12	Sandy loam/loamy sand
	6-8	5.6	<.05	.008	.4	.9	--	--	87	3	10	Loamy sand
	8-10	5.0	<.05	.002	.3	.4	--	--	87	4	9	Loamy sand
	10-11	13.9	<.05	.010	.5	1.0	--	--	13	43	44	Silty clay
H-E	0-1[1]	10.1	1.48	.089	1.5	1.2	126	--	61	18	21	Sandy clay loam
	0-1[1]	10.5	1.23	.079	.9	1.1	118	--	56	19	25	Sandy clay loam
	1-2	4.5	.72	.059	.6	2.7	116	64	23	5	8	Sandy gravel
	2-3	2.9	.56	.053	.8	2.5	109	79	13	3	5	Sandy gravel
	3-4.5	8.2	<.05	.014	.5	2.2	95	78	14	3	5	Sandy gravel
	4.5-6[1]	13.8	<.05	.013	.3	1.6	220	--	38	20	42	Clay
	4.5-6[1]	13.1	<.05	.012	.3	1.6	167	--	47	16	37	Sandy clay
	6-8	4.0	<.05	.002	<.1	.8	66	--	88	5	7	Loamy sand/sand
	8-10	6.0	<.05	.003	<.1	.8	70	--	86	3	11	Loamy sand

Table 6. Physical characteristics and nitrogen species in soil samples collected from backhoe pits in the Flaxville Formation on June 21-22, 1995, Fort Peck Indian Reservation, northeastern Montana (Continued)

Soil pit name	Depth (feet below land surface)	Water content at 35°C (percent)	Organic matter (percent)	Total Kjeldahl nitrogen (percent)	Nitrate (mg/kg as N)	Ammonia (mg/kg as N)	Non-exch. ammonia (mg/kg as N)	Gravel (percent)	Sand (percent)	Silt (percent)	Clay (percent)	Texture
H-W	0-1	8.2	1.96	.114	1.6	1.0	--	--	65	16	19	Sandy loam
	1-2	13.5	1.1	.088	.9	.9	--	--	42	24	34	Clay loam
	2-3	9.9	.26	.031	.2	1.0	--	--	72	9	19	Sandy loam
	3-4	9.4	.06	.019	.2	1.4	--	51	32	7	10	Sandy gravel
	4-6	9.1	<.05	.016	<.1	2.1	--	--	56	17	27	Sandy clay loam
	6-8	6.2	<.05	.004	<.1	.8	--	--	59	30	11	Sandy loam
	8-10	7.0	<.05	.005	.8	1.0	--	--	83	8	9	Loamy sand
R-E	0-1	8.3	1.96	.103	.8	1.6	145	--	43	26	31	Clay loam
	1-2	9.2	1.37	.085	.6	1.3	125	--	51	26	23	Sandy clay loam
	2-3	6.3	.66	.037	.3	.7	89	--	67	13	20	Sandy clay loam/sandy loam
	3-4	7.7	.16	.023	.2	.9	116	--	40	31	29	Clay loam
	4-6	4.5	<.05	.004	<.1	.3	83	--	84	10	6	Loamy sand
	6-8	4.3	<.05	.004	<.1	.5	74	--	87	6	7	Loamy sand
	8-10	4.0	<.05	.003	<.1	.5	70	--	90	4	6	Sand
R-W	0-1	8.2	1.1	.065	.6	3.2	--	--	66	13	21	Sandy clay loam
	1-2[1]	9.3	.94	.057	.4	.9	--	--	68	13	19	Sandy loam/sandy clay loam
	1-2[1]	9.4	.91	.058	.5	1.1	--	--	66	13	21	Sandy clay loam/sandy loam
	2-3	13.2	.91	.072	.6	2.0	--	74	12	4	10	Sandy gravel
	3-4	6.0	<.05	.005	<.1	1.1	--	79	18	1	2	Sandy gravel
	4-6	3.8	<.05	.002	<.1	1.0	--	71	26	1	2	Sandy gravel
	6-8	2.7	<.05	.004	.3	1.3	--	44	50	2	4	Gravelly sand
	8-10	3.5	<.05	.001	<.1	.5	--	--	92	3	5	Sand

[1]Replicate analysis.

Table 7. Chemical and isotopic data for deionized-water extracts of soil samples collected from backhoe pits in the Flaxville Formation, June 21-22, 1995, Fort Peck Indian Reservation, northeastern Montana

[Chemical analyses by Soil Analytical Laboratory, Plant and Soil Science Department, Montana State University, Bozeman, Mont. Nitrogen isotope analyses by U.S. Geological Survey, Menlo Park, Calif. Analytical data are for the water extract from either a saturated paste or a mixture of 1 part sample to 10 parts water (by weight). Abbreviation: ft, foot; mg/L, milligrams per liter. Symbols: <, less than; --, no data]

		Saturated paste extract										1:10 extract	
Soil pit name	Depth (ft)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Potassium (mg/L as K)	Alkalinity (mg/L as HCO_3)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Nitrate (mg/L as N)	Dissolved solids, calculated (mg/L)	Water in saturated paste (percent)	Nitrate (mg/L as N)	$^{15}N_{NO3}$ (permil)
B-N[1]	6-8	8.7	42.0	197	2.9	189	309	25.6	93.7	1,170	42.5	1.32	7.33
	8.5-10	4.2	21.7	222	.8	193	307	14.6	34.2	1,100	115.1	.56	7.99
B-S	7-9[2]	6.1	40.0	59.9	1.1	260	26.3	1.3	26.0	652	36.5	.24	6.80
	7-9[2]	6.7	47.0	70.0	1.1	293	27.9	1.3	32.5	678	38.1	--	--
	9-11	5.8	46.0	104	1.6	287	27.8	2.1	128	807	35.7	.65	7.52
W-N	6-8	9.0	24.5	34.5	1.0	140	33.0	1.4	17.9	613	31.7	.12	6.74
	8-10	6.2	33.2	55.0	1.2	205	28.1	1.4	44.6	661	41.6	.36	6.83
W-S	6-8	17.6	17.2	3.7	4.2	103	4.8	5.8	5.0	550	20.8	--	--
	8-10	9.7	18.1	4.5	3.9	98	2.5	1.1	4.7	536	30.5	--	--
H-E	6-8	6.7	19.7	13.2	1.1	109	9.0	1.1	1.4	544	30.1	--	--
	8-10	8.1	19.5	17.3	1.3	120	9.6	.8	1.2	550	29.9	--	--
H-W	6-8	4.4	24.0	48.2	1.1	168	25.0	5.0	4.2	604	30.9	--	--
	8-10	4.6	14.1	80.0	1.2	191	27.7	2.6	14.6	637	32.9	--	--
R-E	6-8	7.9	27.8	13.6	11.4	133	23.6	5.5	1.9	583	29.0	--	--
	8-10	6.1	23.8	11.7	6.7	117	18.4	2.3	1.2	562	29.3	--	--
R-W[1]	6-8	18.8	12.8	5.7	4.6	86	14.6	4.6	.6	553	28.9	<.01	--
	8-10	10.3	12.6	7.9	4.7	83	11.6	1.1	.5	540	28.9	--	--

[1]Sample was dried and sieved to remove coarse fragments prior to preparation of saturated paste.
[2]Replicate analysis.