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U.S. Geological Survey

Identification of Nitrate Sources Contributing to Ground Water in the Indian Hills Area of Douglas County, Nevada

Water-Resources Investigations Report 99-4042

Prepared in cooperation with
DOUGLAS COUNTY COMMUNITY DEVELOPMENT DEPARTMENT



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By JAMES M. THOMAS, CARL E. THODAL, and RALPH L. SEILER

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Carson City, Nevada
1999

**U.S. DEPARTMENT OF THE INTERIOR
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**U.S. GEOLOGICAL SURVEY
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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

	Multiply	By	To obtain
	acre	4,047	square meter
	foot (ft)	0.3048	meter
	foot per second(ft/s)	0.3048	meter per second (m/s)
	mile (mi)	1.609	kilometer
	square mile (mi ²)	2.590	square kilometer

Temperature: Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the formula °F = [1.8(°C)]+32. Degrees Fahrenheit can be converted to degrees Celsius by using the formula °C = 0.556 (°F-32).

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called “Sea-Level Datum of 1929”), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

Abbreviated water-quality units used in this report:

mg/L, milligram per liter

µg/L, microgram per liter

pg/kg, picogram per kilogram

pH, negative logarithm of hydrogen-ion activity; in dilute waters, activity is comparable to hydrogen-ion concentration.

µS/cm, microsiemen per centimeter

Method of reporting nitrogen concentrations: Nitrogen concentrations can be reported in different ways, and comparison of results between different investigations requires knowledge of how nitrogen concentrations were reported. In older reports, nitrogen concentrations commonly were reported in terms of nitrate, nitrite, or ammonia. More recently, nitrogen concentrations have been reported in terms of equivalent concentration of elemental nitrogen. For example, water containing 62 mg/L nitrate (as NO₃) contains same amount of nitrogen as 14 mg/L nitrate (as N).

Unless stated otherwise, nitrogen concentrations are reported as N in this report. Conversions from other ways of reporting are given in table below.

	Multiply	By	To obtain
	ammonia (as NH ₃)	0.8235	ammonia (as N)
	ammonia (as equivalent NO ₃)	0.2258	ammonia (as N)
	nitrite (as NO ₂)	0.3043	nitrite (as N)
	nitrite (as equivalent NO ₃)	0.2258	nitrite (as N)
	nitrate (as NO ₃)	0.2258	nitrate (as N)

Stable-isotope ratios are presented in terms of permil, or parts per thousand.

Identification of Nitrate Sources Contributing to Ground Water in the Indian Hills Area of Douglas County, Nevada

By James M. Thomas, Carl E. Thodal, and Ralph L. Seiler

Abstract

Sources of nitrate in waters from selected private and public wells in and near the Indian Hills residential area of northern Douglas County are natural-soil organic matter and domestic-sewage effluent from onsite septic systems. Livestock wastes and synthetic fertilizers are possible but apparently insignificant sources of nitrate in ground water in the Indian Hills area. Nitrate in ground water from sampled wells in the Indian Hills residential area ranged from 0.09 to 3.0 milligrams per liter (expressed as nitrogen) in mid-1996, except for public water-supply Well No. 1. Three of the wells, which either are the deepest or have the greatest depths to the top of their well screen's open interval, yielded water containing less than 1 milligram per liter of nitrate (as nitrogen). Nitrate in these waters was derived primarily from natural-soil organic matter as indicated by low specific-conductance values, low chemical-constituent concentrations, the absence of anthropogenic (manmade) methylene-blue active substances and caffeine, low anthropogenic chlorofluorocarbon (CFC) concentrations, nitrogen isotope values characteristic of natural-soil organic matter, and stable-isotope values of water that, with one exception, were the lightest of any samples from sites in and near the Indian Hills residential area. Six other wells had nitrate concentrations from 1.5 to 3.0 milligrams per liter (as nitrogen). Some of the nitrate in five of these six wells may

have been derived from septic-system wastewater. The elevated specific-conductance values and elevated major-ion, minor-ion, trace-element, nutrient, and CFC concentrations are indicative of sewage effluent. None of the Indian Hills area samples contained methylene-blue active substances or caffeine, and data on stable isotopes of nitrate and of water were not helpful in identifying nitrate sources in these waters.

Nitrate concentrations in water from public supply Well No. 1 exceeded the drinking-water standard of 10 milligrams per liter (as nitrogen) at certain times. Concentrations were high within hours of the time that the well is first put into production in the spring or early summer. Thereafter, nitrate concentrations declined as pumping continued because of dilution by ground water with lower nitrate concentration. Most of the nitrate present in samples collected when the well was seasonally first put into production likely originated from domestic wastewater. This finding is indicated by the following: (1) Nitrate concentrations were high at the start of the pumping season, decreased with continued pumping, and later increased if the pumping rate was greatly reduced during the pumping season. (2) Specific-conductance values were higher; major-ion, minor-ion, trace-element, and nutrient concentrations were higher; and pH was lower in the initial sample from public supply Well No. 1 than in later samples from that well or in samples from other wells in and near the Indian Hills residential area.

- (3) High initial CFC concentrations declined during pumping to levels that were similar to those of ground-water samples from other sites in the area.
- (4) Initial deuterium and oxygen-18 values were slightly elevated compared to later values.

INTRODUCTION

In the Indian Hills area of northern Carson Valley, Douglas County, Nev. (fig. 1), water from public water-supply Well No. 1 (formerly known as Ridgeview Estates Well No. 4; site 8, fig. 1 and table 1) had dissolved-nitrate concentrations that sometimes exceeded the drinking-water standard of 10 mg/L (Nevada Legislative Counsel, 1997) during 1993–96. Nitrate concentrations in water that exceed this standard can cause methemoglobinemia in newborns (Rosenfield and Huston, 1950). When the well was first put into production in the spring or early summer, nitrate concentrations may have been less than 1 mg/L. These low nitrate concentrations could have resulted from denitrification. Within minutes after pumping began, nitrate concentrations increased and within hours concentrations commonly exceeded the drinking-water standard, 10 mg/L. As pumping continued, nitrate concentrations declined and eventually approached levels in nearby wells (fig. 2). Sources of the nitrate need to be identified to protect drinking-water supplies in the area.

Well No. 1 is in an area where homes use onsite septic-tank and leach-field systems to dispose of domestic sewage. Although septic systems are one possible source of the nitrate, natural-soil organic matter, synthetic fertilizer, and livestock wastes are other possible sources (Puckett, 1994). High nitrate concentrations in ground water in some areas in Nevada may be from natural sources. For example, ground waters with nitrate concentration exceeding 20 mg/L have been sampled from alluvial-fan deposits in Spanish Springs Valley, about 10 miles northeast of Reno, Nev. (Bostic and others, 1997, p. 546). Water in those deposits is not affected by human activity or livestock.

Nitrate concentrations in ground water that exceed the drinking-water standard (Nevada Legislative Counsel, 1997) are not unique to the Indian Hills area. High nitrate is present in ground water throughout each of several valleys in northern Nevada (Nowlin, 1982; Widmer and McKay, 1994; Thodal, 1996) and

in ground water in other areas throughout the United States (Puckett, 1994; Mueller and Helsel, 1996). Thus, developing methods to identify nitrate sources in ground water in the Indian Hills area has application throughout northern Nevada as well as in other parts of the United States.

Data on a combination of chemical constituents and related measurements potentially can be used to differentiate sources of nitrate in ground water (Seiler, 1996). Several constituents taken together have a greater potential to identify nitrate sources in ground water than only one or two constituents. Measurements useful for source identification include specific conductance, pH, and concentrations of chemical constituents. The useful chemical constituents include major and minor ions and trace elements; nutrients; anthropogenic compounds; and stable isotopes of nitrogen, oxygen, and hydrogen. Specific conductance; pH; dissolved solids; and major-ion (chloride, sulfate, bicarbonate, sodium, calcium, magnesium, and potassium), minor-ion and trace-element (boron, bromide, and fluoride), and nutrient (nitrate and organic carbon) concentrations traditionally have been used to identify sewage-affected ground water (Flipse and others, 1984; Thurman and others, 1984; Nightingale and McCormick, 1985; Robertson and others, 1991; Wilhelm and others, 1994; Umari and others, 1995; Schroeder and others, 1997). Domestic-sewage effluent may be indicated as a nitrate source by the presence of anthropogenic compounds. These include methylene-blue active substances (MBAS) from laundry detergents; caffeine from coffee, tea, and other beverages; and chlorofluorocarbons (CFC's) from various household products (Schultz and others, 1976; Busenberg and Plummer, 1992; Plummer and others, 1993, p. 272). Isotopes of nitrate, nitrogen-15 and oxygen-18, have been used to distinguish sources of nitrate dissolved in ground water, because nitrates from some sources, such as synthetic fertilizer and animal waste, commonly have distinctly different isotopic values (Anderson and Hooper, 1983; Bottcher and others, 1990; Aravena and others, 1993; Macko and Ostrom, 1994; Wassenaar, 1995). Concentrations of isotopes of water, deuterium (hydrogen-2) and oxygen-18, in sewage effluent can be different from those in the local ground water; therefore, hydrogen and oxygen isotopes of water may indicate whether sewage effluent has affected ground water (Aravena and others, 1993).

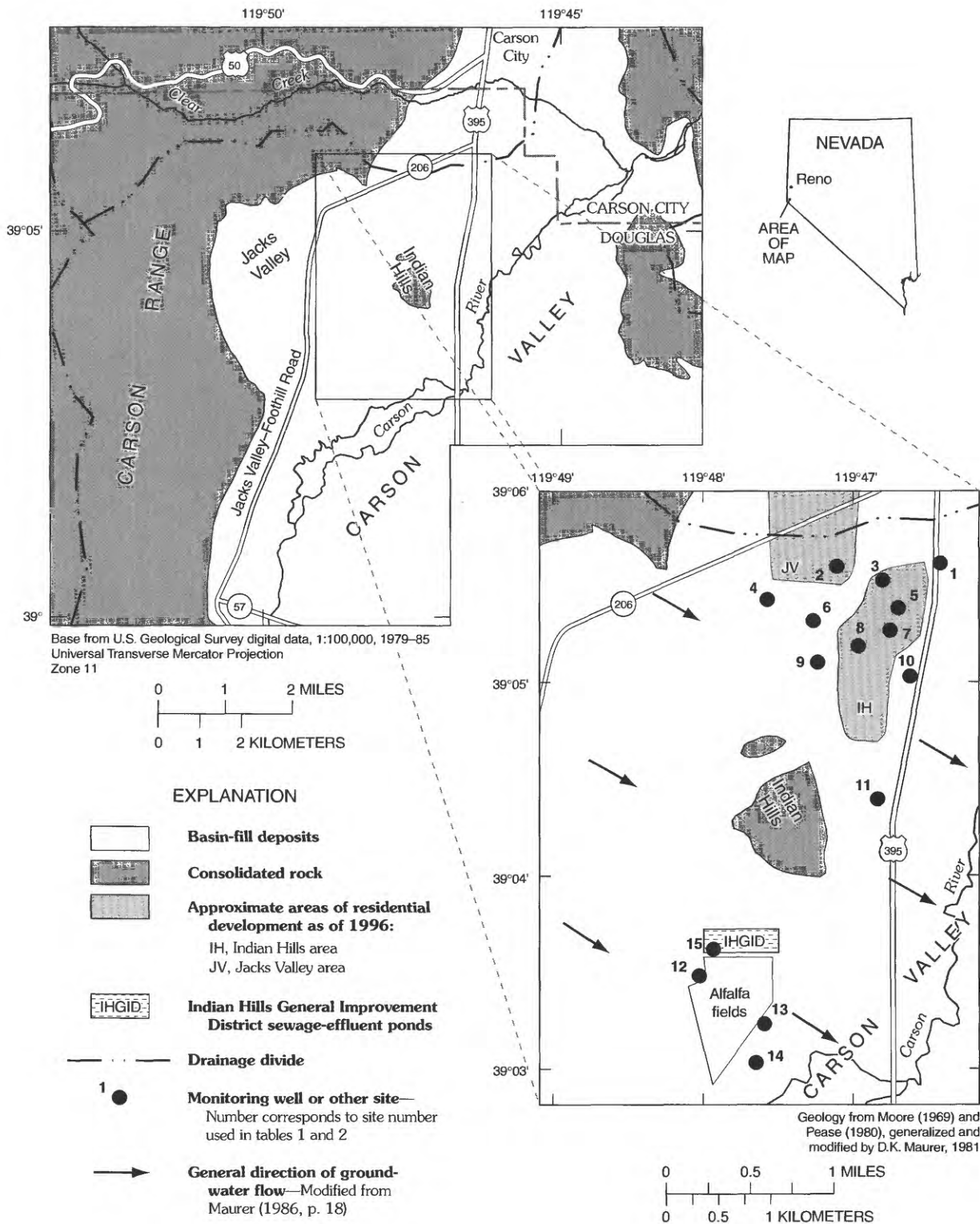


Figure 1. Geographic features of Carson Valley and location of Indian Hills study area and sampling sites. Enlarged area is also area of figure 3.

Table 1. Well and site characteristics, Indian Hills area of Douglas County, Nev.

[Site number, site designations, and station names: Each data-collection site is assigned unique identification on basis of geographic location. Wells and other sites are identified by both standard "latitude-longitude" system and by local (Nevada) system. For convenience, short site number (ranging from 1 through 15) and station name also are used for sites in this report. IHGID, Indian Hills General Improvement District. —, information not available or not applicable]

Site number	U.S. Geological Survey site designations		Station name	Land-surface altitude (feet above sea level)	Depth of well (feet)	Well-screen open interval (feet)
	Standard site identification ¹	Local site identification ²				
1	390538119462401	105 N14 E20 7ADCB1	IHGID East well	4,800	365	284–344
2	390537119470501	105 N14 E20 7BCDB1	Kaiser well	4,970	255	—
3	390533119464601	105 N14 E20 7BDD1	IHGID Opalite well	4,820	252	110–248
4	390527119473201	105 N14 E19 12BAD1	Douglas County School well	4,900	345	100–345
5	390524119464001	105 N14 E20 7DBC1	Harris well	4,770	190	—
6	390520119471401	105 N14 E20 7CBC1	IHGID Little Canyon well	4,800	345	80–345
7	390517119464301	105 N14 E20 7CADD1	Well No. 2	4,780	240	—
8	390512119465601	105 N14 E20 7CDBC1	Well No. 1	4,760	235	135–225
9	390507119471201	105 N14 E20 7CCCC1	IHGID James Lee Park well	4,800	281	55–281
10	390503119463501	105 N14 E20 18ABAB1	IHGID Impala well	4,760	250	168–250
11	390424119464901	105 N14 E20 18CDA1	IHGID Hobo Hot Springs well	4,660	340	74–336
12	390330119480001	105 N14 E19 25BA1	Carson Indian Colony well	4,680	239	—
13	390315119473401	105 N14 E19 25ABDA1	IHGID monitor well 3	4,660	23	0–23
14	390303119473701	105 N14 E19 25ACAD1	IHGID monitor well 4	4,660	23	0–23
15	390338119475401	105 N14 E19 24CADB1	IHGID sewage-effluent ponds	4,670	—	—

¹ Based on grid system of latitude and longitude. Number consists of 15 digits. First six digits denote degrees, minutes, and seconds of latitude; next seven digits denote degrees, minutes, and seconds of longitude; and last two digits (assigned sequentially) identify sites within 1-second grid. For example, site 390338119475401 is at 39°03'38" latitude and 119°47'54" longitude, and it is first site recorded in that 1-second grid. Assigned number is retained as permanent identifier even if more precise latitude and longitude are later determined.

² Used in Nevada to identify site by hydrographic area (Rush, 1968) and by official rectangular subdivision of public lands referenced to Mount Diablo base line and meridian. Each site designation consists of four units: First unit is hydrographic-area number. Second unit is township, preceded by N or S to indicate location north or south of base line. Third unit is range, preceded by E to indicate location east of meridian. Fourth unit consists of section number and letters designating quarter section, quarter-quarter section, and so on (A, B, C, and D indicate north-east, northwest, southwest, and southeast quarters, respectively), followed by number indicating sequence in which site was recorded. For example, site 105 N14 E19 24CADB1 is in Carson Valley (Hydrographic Area 105). It is first site recorded in northwest quarter(B) of southeast quarter (D) of northeast quarter (A) of Section 24, Township 14 North, Range 19 East, Mount Diablo base line and meridian.

Purpose and Scope

The primary objective of this report was to identify the principal sources of nitrate in public water-supply Well No. 1 (site 8, fig. 1) in the Indian Hills residential area of Carson Valley by analyzing for a suite of chemical constituents and by making related measurements. Secondary objectives were to establish the areal distribution of nitrate in ground water in the study area and identify the sources of nitrate in ground water within this area.

The objectives of this report were met by sampling existing wells and sewage-effluent ponds and by measuring and evaluating specific conductance and pH of the water; concentrations of dissolved solids, major and minor ions, trace elements, nutrients, and anthro-

pogenic compounds (MBAS, caffeine, and CFC's) in the water; and isotopes of nitrogen and oxygen in nitrate and of hydrogen and oxygen in water.

Acknowledgments

We thank Ronald J. Roman and Carl Ruschmeyer of the Douglas County Community Development Department, Sharla Keith of the Indian Hills General Improvement District, Dennis Gephart formerly of the Carson Indian Colony, and individual homeowners for permission and access to sample their well water. Douglas County and the U.S. Geological Survey provided funding for this research. Technical reviews of this report were provided by Stephen C. Komor, Terry F. Rees, and Ronald J. Roman.

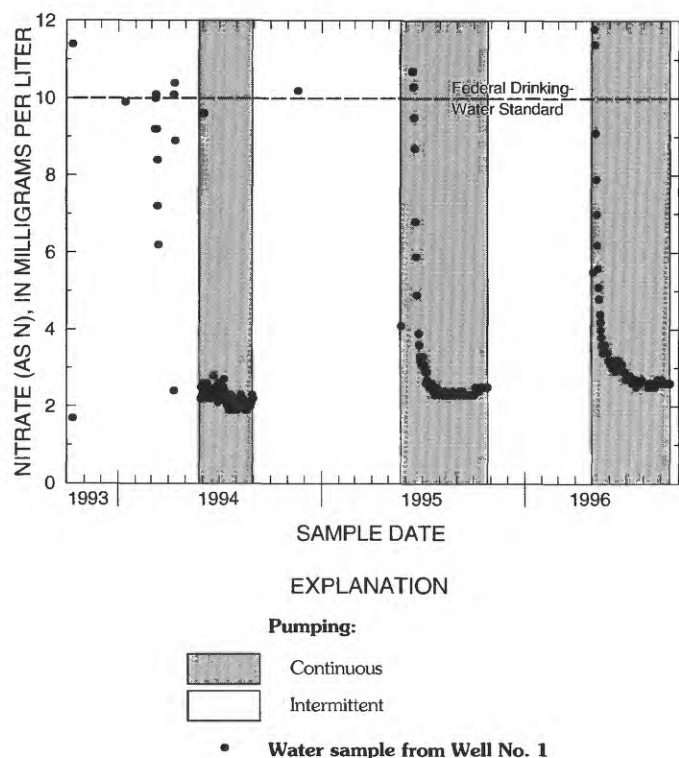


Figure 2. Concentration of nitrate in water samples from Well No. 1 (site 8, fig. 1), 1993–96. Intermittent pumping was often at greatly reduced rates. Data, collected almost daily during pumping season, are from Douglas County Community Development Department (R.J. Roman, written commun., 1997). Federal drinking-water standard is as established by Safe Drinking Water Act (Public Law 93–523).

DESCRIPTION OF INDIAN HILLS AREA

Location and Geography

The study area, referred to in this report as the Indian Hills area, is in northern Carson Valley, just southwest of Carson City (fig. 1). The Indian Hills residential area is in the northeastern part of the study area. Land-surface altitudes range from about 4,700 feet at the Carson River to 5,300 feet in the Indian Hills.

Ridgeview Estates, an area divided into 0.5- to 1-acre residential lots, is a subdivision within the Indian Hills residential area. Residents in this subdivision use septic-tank systems for sewage disposal. They also have some livestock (mostly horses) and use synthetic fertilizers on landscaping.

Geology

Carson Valley is at the west margin of the Basin and Range Province and is bounded on the west by the Carson Range (fig. 1). The consolidated rock that forms the Carson Range has been uplifted more than 4,000 feet (Moore, 1969, p. 17). The downdropped valley floor forms a basin that is partly filled with sediments eroded from the adjacent mountains. Cretaceous granodiorite is the dominant consolidated rock and the source of most of the basin-fill deposits (Pease, 1980). Basin fill in much of the study area consists of Indian Hills pediment deposits (late Tertiary to early Pleistocene), old alluvium (early to middle Pleistocene), Clear Creek alluvial deposits (early Holocene), and young pediment and alluvial-fan deposits (late Holocene) (Pease, 1980). Depth to bedrock (beneath the basin-fill deposits) ranges from about 500 to 1,500 feet below land surface (Maurer, 1985, pl. 2).

Ground Water

Ground water flowing through basin-fill deposits in the Indian Hills area originates primarily from precipitation that falls at high altitudes in the Carson Range. Ground water flows generally eastward from areas of abundant recharge west of the study area and discharges into the Carson River (Maurer, 1986). Local flow directions may vary from the general eastward direction because of pumping in the area. Possible secondary sources of recharge in the area include water applied to residential landscapes, water applied to pastures and fields west of the study area, and domestic wastewater from septic-tank and leach-field systems.

A typical household discharges about 200 gallons of water per day to the septic system (Widmer and McKay, 1994; Seiler, 1996). This water may percolate downward through basin-fill deposits to the water table. The Ridgeview Estates area contains 152 residential units, 69 of which have septic systems (R.J. Roman, Douglas County Community Development Department, written commun., 1998). These 69 systems potentially provide about 5 million gallons (15 acre-feet) of domestic-sewage effluent per year to recharge the water-table aquifer.

Ground water used for domestic and public supplies in the study area is primarily from aquifers in unconsolidated basin-fill deposits tapped by wells that are generally less than 400 feet deep (table 1). Estimated hydrologic properties of these basin-fill aquifers in the study area include a specific yield of about 5 percent, horizontal hydraulic conductivity of about 10^{-5} feet per second, and vertical hydraulic conductivity of about 10^{-9} feet per second (Maurer, 1986, p. 27–31). Water-yielding capabilities are lower in most of the study area than in the rest of Carson Valley; areas near the Carson River are the exception (Maurer, 1992).

Depth-to-water measurements are not generally available for wells sampled for this study. Limited data indicate that depth to water in the study area ranges from more than 100 feet below land surface in the northern part of the study area to near land surface adjacent to the Carson River (Maurer, 1992; Mello, 1996). According to the well driller's report for Well No. 1, the static water level at that site was 52 feet below land surface in February 1985.

METHODS USED TO IDENTIFY NITRATE SOURCES

Samples were collected from municipal water-supply and domestic wells in and near the Indian Hills residential area (sites 1–11, fig. 1) and from sewage-effluent ponds (site 15), two shallow (23-foot) monitoring wells (sites 13 and 14), and an irrigation well (site 12) that are southwest of the Indian Hills residential area and adjacent to alfalfa fields irrigated with effluent from the storage ponds (site 15). Although the effluent ponds are not a source of water or nitrate for the Indian Hills residential-area ground waters, samples from the

effluent ponds and wells adjacent to alfalfa fields irrigated with this effluent were analyzed to determine the chemical characteristics of sewage effluent from the Indian Hills residential area and possibly effluent-contaminated ground water.

The ground-water samples were collected from wells in the study area (sites 1–14, table 1 and fig. 1) by using submersible pumps. A minimum of three well volumes of water was purged from each well before water samples were collected. Prior to sample collection, pumped water passed through a flow-through chamber instrumented to measure temperature, dissolved oxygen, pH, and specific conductance. Samples were collected when these measurements stabilized. Chemical stability is indicated when three successive measurements of temperature, pH, and specific conductance, taken at 5-minute intervals, differ by less than 0.5°C , 0.1 pH unit, and $5\ \mu\text{S}/\text{cm}$, respectively (Hardy and others, 1989, p. 21). Field meters were calibrated at each site by using appropriate pH buffers, conductivity standards, and—for the dissolved-oxygen meter—an air-calibration chamber in water. Alkalinity was determined onsite by incremental titration of filtered sample water with sulfuric acid.

Water samples collected for determination of major- and minor-ion, trace-element, nutrient, and MBAS concentrations were processed in the field following standard U.S. Geological Survey (USGS) methods (Wood, 1976; Hardy and others, 1989) and shipped to the USGS National Water Quality Laboratory in Arvada, Colo., for analysis by standard methods (Wershaw and others, 1987; Fishman and Friedman, 1989; Fishman, 1993).

Water samples were analyzed for caffeine by two different methods developed at different laboratories. A method for caffeine analysis was developed at the University of Nevada–Reno. This method requires no extraction and uses high-performance liquid chromatography (Perkins and others, 1991; Seiler and others, 1999); it has a detection level of $5\ \mu\text{g}/\text{L}$. A second method for caffeine analysis, involving sample extraction and gas-chromatography mass-spectral analysis, was developed by analysts at the USGS National Water Quality Laboratory (Seiler and others, 1999); it has a detection level of $0.04\ \mu\text{g}/\text{L}$.

Water samples for analysis of CFC's were collected by using submersible pumps and specialized sampling equipment that isolates water samples from atmospheric gases. Because this sampling equipment was continually flushed with ultrapure nitrogen gas, a water sample was only in contact with CFC-free nitrogen gas. As a further precaution against atmospheric contamination, a CFC scrubber was placed in-line between the ultrapure-nitrogen gas tank and the CFC-sampling apparatus. After purging the sampling apparatus and borosilicate-glass sample vials with ultrapure nitrogen gas and sample water, samples were collected by sealing the vials with an oxyacetylene torch. Samples were analyzed at the USGS CFC Laboratory in Reston, Va., by using a purge-and-trap gas-chromatography procedure with an electron-capture detector. Details of the sampling and analytical methods are given by Busenberg and Plummer (1992). This method of analysis has a detection level of 1.0 pg/kg.

Water samples were analyzed to determine abundances of selected stable isotopes, which are nonradioactive forms of an element. Isotopes of a given element have the same number of protons but a different number of neutrons. The nitrogen isotopes ^{15}N and ^{14}N and the oxygen isotopes ^{18}O and ^{16}O form isotope pairs. Isotope values are presented in delta (δ) notation, such as that for nitrogen isotopes:

$$\delta^{15}\text{N} = 1000 \left[\frac{\left(\frac{^{15}\text{N}}{^{14}\text{N}} \right)_{\text{sample}}}{\left(\frac{^{15}\text{N}}{^{14}\text{N}} \right)_{\text{standard}}} - 1 \right]$$

Delta values are expressed as the permil difference from the standard. The ratio of the abundance of the heavier isotope to that of the lighter isotope can provide useful information because their mass differences affect their chemical reactivity. Changes in stable-isotopic compositions during chemical reactions are called isotopic fractionations.

Nitrate dissolved in water samples was concentrated on anion-exchange resin columns and shipped to the USGS Stable Isotope Laboratory in Menlo Park, Calif., for determination of nitrogen-15 ($\delta^{15}\text{N}_{\text{NO}_3}$) and oxygen-18 ($\delta^{18}\text{O}_{\text{NO}_3}$) isotopic ratios by mass spectrometry (Kendall and Grim, 1990; Silva and others, 1996). If present, nitrite also was concentrated on the

anion-exchange resin and thus was included in the nitrogen and oxygen isotope analyses. Analytical uncertainties for $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ values were 0.3 and 1.5 permil, respectively.

Ground-water samples for deuterium (δD) and oxygen-18 ($\delta^{18}\text{O}$) analyses were collected in 60-ml (3.7-cubic-inch) glass bottles with Poly-Seal caps. These samples were analyzed by standard methods (Epstein and Mayeda, 1953; Kendall and Coplen, 1985) at the USGS Isotope Laboratory in Reston, Va. Analytical uncertainties for δD and $\delta^{18}\text{O}$ values were 2 and 0.2 permil, respectively.

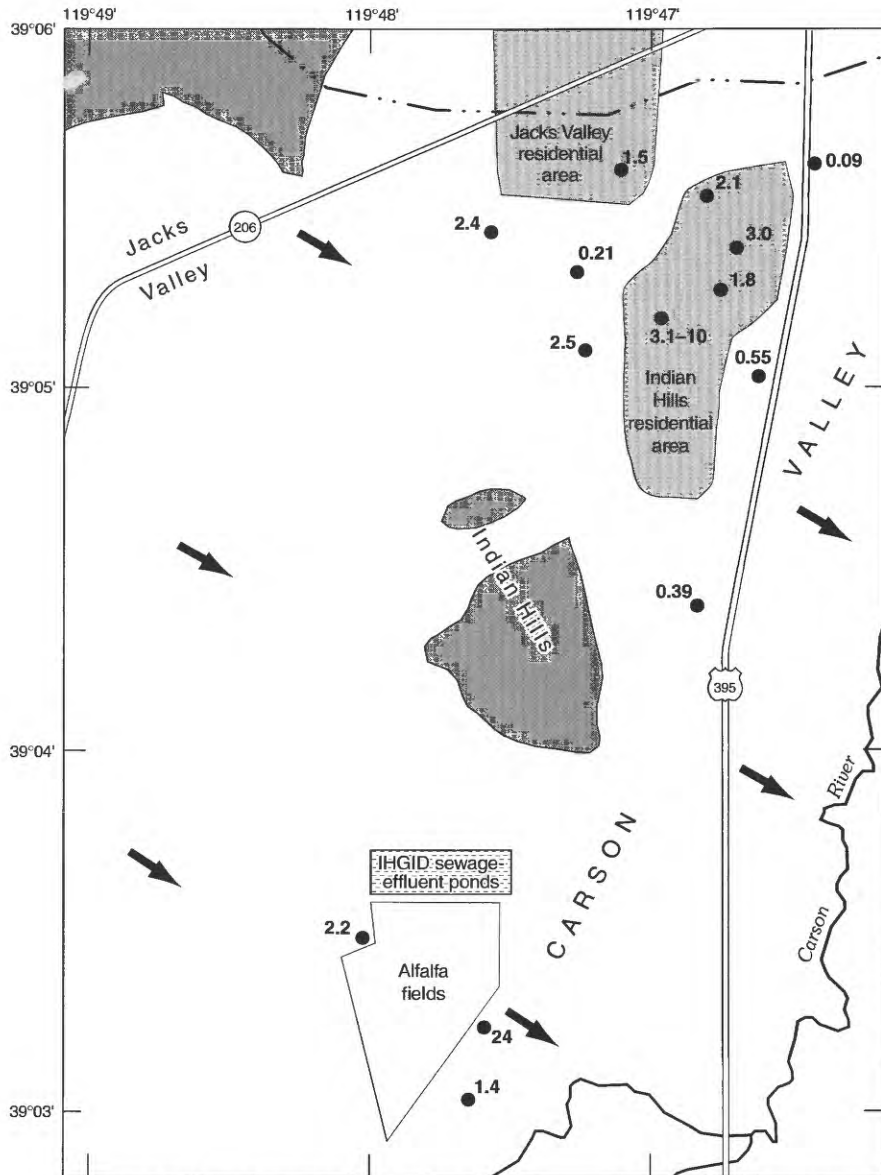
GROUND-WATER CHEMISTRY AND IMPLICATIONS AS TO NITRATE SOURCES

Indian Hills Area

Nitrate

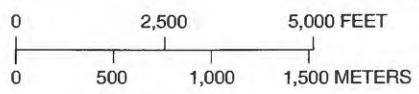
The areal distribution of nitrate in ground water in the study area is shown in figure 3. Nitrate concentrations in samples collected during this study ranged from 0.09 to 10 mg/L in and near the Indian Hills residential area in May and June 1996. With the exception of high nitrate concentrations (3.1 to 10 mg/L) in samples from Well No. 1, the maximum nitrate concentration in ground-water samples from sites in the Indian Hills area was 3.0 mg/L, at site 5 (table 2 and fig. 3).

Samples from four wells adjacent to the Indian Hills residential area (sites 1, 6, 10, and 11, fig. 1) had nitrate concentrations of less than 1.0 mg/L (table 2). The Little Canyon well (site 6; 0.21 mg/L nitrate) is hydrologically upgradient from the Indian Hills residential area, with little development between the well and the adjacent Carson Range recharge area as of 1996. Therefore, water from this well should have represented ground water having natural sources of nitrate. Also, because this was one of the deepest wells sampled in the study area, anthropogenic nitrogen had a reduced chance of entering the well. East well (site 1; 0.09 mg/L nitrate) and Impala Well (site 10; 0.55 mg/L nitrate), the easternmost wells sampled for this study, are downgradient from the Indian Hills residential area.



Base from U.S. Geological Survey digital data, 1:100,000, 1979-85
 Universal Transverse Mercator Projection
 Zone 11

Geology from Moore (1969) and
 Pease (1980), generalized and
 modified by D.K. Maurer, 1981



EXPLANATION



-  **Basin-fill deposits**
-  **Consolidated rock**
- 1.4** ● **Monitoring well**—Number is concentration of nitrate (as N) in milligrams per liter (see table 2)
- ➔ **General direction of ground-water flow**—
 Modified from Maurer (1986, p. 18)

Table 2. Chemical characteristics of ground water and sewage effluent in Indian Hills area of Douglas County, Nev.

[For well or site characteristics, see table 1. Isotopes: $\delta^{15}\text{N}_{\text{NO}_3}$ is reported relative to air; $\delta^{18}\text{O}_{\text{NO}_3}$, $\delta^{18}\text{O}$, and δD are reported relative to Vienna Standard Mean Ocean Water (VSMOW). —, information not available, or not applicable; <, less than, in reference to given detection limit]

Site number	Date of sample or measurement	Specific conductance (microsiemens per centimeter, at 25° Celsius)	pH (standard units)	Water temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)	Dissolved solids (milligrams per liter)
1	06/05/96	250	8.9	21.0	0.4	205
2	06/11/96	300	8.0	16.0	4.2	244
3	06/10/96	440	7.6	17.0	4.1	374
4	06/11/96	270	7.5	14.0	3.9	243
5	06/10/96	390	7.4	16.0	6.5	347
6	06/06/96	220	9.4	18.0	2.8	165
7	06/04/96	400	7.3	17.0	4.2	345
8	05/03/96	660	6.8	16.0	4.4	537
	05/07/96	590	—	15.0	—	476
	06/04/96	400	7.3	15.5	2.4	326
9	06/06/96	360	7.6	17.0	5.6	306
10	06/05/96	250	9.0	20.0	2.2	192
11	06/17/96	430	7.9	16.5	.6	314
12	06/18/96	690	7.0	16.0	.9	486
13	06/17/96	1,310	6.8	12.5	5.6	808
14	06/12/96	650	7.0	13.0	2.5	511
15	06/18/96	—	—	—	—	—

Of all the wells in the study area, these two have the greatest depths below land surface to the top of the well screen's open interval (table 1), so they may have been less susceptible to migration of near-surface anthropogenic nitrate than wells having shallower well-screen

open intervals. Because the source of recharge water for the Hobo Hot Springs well (site 11; 0.39 mg/L nitrate) apparently differs from those for sites 1 through 10, site 11 is discussed only in the section "Isotopes of Nitrate and Water" (under "Indian Hills Area").

South of the Indian Hills residential area, water from a shallow well adjacent to alfalfa fields irrigated with sewage effluent (site 13) had 24 mg/L of nitrate. The high value indicates that water in this well had been contaminated by the effluent. A sample from another shallow well (site 14), about 0.2 mile down-gradient from the alfalfa fields, contained 1.4 mg/L nitrate. A sample from an irrigation well (239 feet deep) adjacent to the alfalfa fields (site 12) contained 2.2 mg/L nitrate.

Figure 3. Concentration of nitrate in ground-water samples from study area. Range of values shown for Well No. 1 (site 8, fig. 1) are for samples collected for this study (table 2). General direction of ground-water flow is from Maurer (1986). See figure 1 for geographic setting. IHGID, Indian Hills General Improvement District.

Table 2. Chemical characteristics of ground water and sewage effluent in Indian Hills area of Douglas County, Nev.—Continued

Site number	Date of sample or measurement	Major constituents (milligrams per liter)								
		Calcium	Magnesium	Sodium	Potassium	Bicarbonate	Carbonate	Sulfate	Chloride	Silicon (as SiO ₂)
1	06/05/96	5.4	0.04	51	0.3	97	8	16	9.3	17
2	06/11/96	16	2.2	44	1.0	135	0	14	10	19
3	06/10/96	30	6.9	55	1.4	210	0	20	15	33
4	06/11/96	19	4.8	30	1.2	127	0	11	9.9	37
5	06/10/96	33	10	34	1.6	185	0	14	15	51
6	06/06/96	4.8	.39	42	.3	57	20	11	8.7	20
7	06/04/96	28	8.6	46	1.5	183	0	18	16	41
8	05/03/96	57	17	57	2.4	292	0	34	29	42
	05/07/96	49	14	54	2.0	¹ 255	¹ 0	29	26	36
	06/04/96	31	8.6	40	1.6	176	0	18	16	31
9	06/06/96	41	3.3	30	1.6	171	0	13	12	31
10	06/05/96	5.6	.12	49	.4	79	10	16	13	18
11	06/17/96	6.1	1.4	79	1.4	78	0	74	29	41
12	06/18/96	27	4.8	110	2.2	171	0	89	57	20
13	06/17/96	90	20	130	5.7	206	0	150	150	30
14	06/12/96	43	8.5	83	3.9	242	0	53	43	31
15	06/18/96	—	—	—	—	—	—	—	—	—

¹Laboratory determination.

Major Ions, Minor Ions, Trace Elements, and Nutrients

Samples from sites 1, 6, and 10 (tables 1 and 2 and fig. 1) were the most likely in and near the Indian Hills residential area to have background concentrations of chemical constituents as indicated by their low nitrate concentrations. Also, the wells at these sites are the deepest and have the greatest depths to the tops of the well-screen open intervals. Examination of chemical data for these sites shows that they were the most dilute samples collected for this study, particularly as indicated by their specific-conductance and dissolved-solids values. Specific-conductance values of samples from the three wells ranged from 220 to 250 $\mu\text{S}/\text{cm}$. The range of pH for the three wells was 8.9 to 9.4. Concentrations of chemical constituents for the three wells had the following ranges: dissolved solids, 165 to 205

mg/L; calcium, 4.8 to 5.6 mg/L; magnesium, 0.04 to 0.39 mg/L; sodium, 42 to 51 mg/L; potassium, 0.3 to 0.4 mg/L; bicarbonate, 57 to 97 mg/L; sulfate, 11 to 16 mg/L; chloride, 8.7 to 13 mg/L; fluoride, 0.5 to 0.6 mg/L; bromide, 0.05 to 0.06 mg/L; boron, 127 to 153 $\mu\text{g}/\text{L}$; and dissolved organic carbon, <0.1 to 0.2 mg/L. The low specific conductance and low concentrations of nitrate, dissolved solids, major ions, minor ions, trace elements, and nutrients suggest that nitrate in these samples (0.09 to 0.55 mg/L) was from natural sources.

If sewage effluent was a significant nitrate source in Indian Hills water-supply wells that had nitrate concentrations greater than 1 mg/L (sites 2–5, 7, and 9), then both specific-conductance values and concentrations of chemical constituents commonly associated with sewage effluent would likely have been elevated.

Table 2. Chemical characteristics of ground water and sewage effluent in Indian Hills area of Douglas County, Nev.—Continued

Site number	Date of sample or measurement	Minor and trace constituents				
		Fluoride (milligrams per liter)	Bromide (milligrams per liter)	Boron (micrograms per liter)	Iron (micrograms per liter)	Manganese (micrograms per liter)
1	06/05/96	0.6	0.06	127	4	<1
2	06/11/96	1.1	.08	154	13	<1
3	06/10/96	.4	.13	113	<3	<1
4	06/11/96	.4	.07	119	<3	<1
5	06/10/96	.5	.15	92	3	2
6	06/06/96	.6	.05	146	<3	<1
7	06/04/96	.7	.11	152	<3	<1
8	05/03/96	.8	.13	—	43	9
	05/07/96	.6	.12	160	5	<1
	06/04/96	.4	.10	107	<3	<1
9	06/06/96	.2	.11	49	5	3
10	06/05/96	.5	.05	153	<3	<1
11	06/17/96	3.3	.07	609	10	22
12	06/18/96	3.0	.10	849	12	7
13	06/17/96	2.1	.28	750	<3	<1
14	06/12/96	2.5	.11	425	3	<1
15	06/18/96	—	—	—	—	—

The associated constituents include dissolved solids, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, bromide, boron, and organic carbon (Flipse and others, 1984; Thurman and others, 1984; Nightingale and McCormick, 1985; Robertson and others, 1991; Wilhelm and others, 1994; Umari and others, 1995; Schroeder and others, 1997). Additionally, pH could have been low because of the nitrification of ammonia and oxidation of organic matter associated with sewage effluent. These processes would have generated acidity (lower pH) in the soil zone provided the ground water did not react with calcite, which would buffer the acidity (raise pH). Conversely, if most of the nitrate in these samples was from natural-soil organic matter, the water associated with this nitrate source should have had roughly background concentrations of the chemical constituents listed above. If some of the nitrate was from synthetic fertilizer or livestock

waste, certain chemical constituents could have been elevated and others would have been at background levels.

Compared to samples from the background sites, samples from sites 3, 5, and 7 had elevated specific conductance; elevated major-ion, minor-ion, trace-element, and nutrient concentrations (except for sodium at sites 5 and 7, sulfate at site 5, and fluoride and boron at all three sites); and substantially lower pH values (7.3 to 7.6). Thus, possibly some of the nitrate in these waters was from sewage effluent. These three wells are close to each other (fig. 1) and to Well No. 1 (site 8). Also, well depth information shows that these are among the shallowest wells in the Indian Hills area (table 1). Shallower wells are more susceptible to contamination than deeper wells because of the shorter vertical distances water has to travel to get from land surface to the water table.

Table 2. Chemical characteristics of ground water and sewage effluent in Indian Hills area of Douglas County, Nev.—Continued

Site number	Date of sample or measurement	Nutrients (milligrams per liter)					
		Nitrate (as N)	Nitrite (as N)	Ammonia (as N)	Ammonia + organic nitrogen (as N)	Total phosphorus (as P)	Dissolved organic carbon
1	06/05/96	0.09	<0.01	0.02	<0.2	0.02	0.2
2	06/11/96	1.5	.03	<.02	<.2	.02	.2
3	06/10/96	2.1	<.01	<.02	<.2	.06	.3
4	06/11/96	2.4	<.01	<.02	<.2	.04	.3
5	06/10/96	3.0	<.01	<.02	<.2	.09	.4
6	06/06/96	.21	<.01	<.02	<.2	.04	<.1
7	06/04/96	1.8	<.01	.02	<.2	.06	.4
8	05/03/96	5.5	<.01	.02	.2	—	1.2
	05/07/96	10	<.01	.03	<.2	—	.9
	06/04/96	3.1	<.01	.02	<.2	.06	.3
9	06/06/96	2.5	<.01	.02	<.2	.04	.2
10	06/05/96	.55	<.01	.02	<.2	.04	.2
11	06/17/96	.39	<.01	.07	<.2	.13	.5
12	06/18/96	2.2	.01	.13	<.2	.18	1.3
13	06/17/96	24	<.01	.03	.3	.03	2.8
14	06/12/96	1.4	.01	.03	<.2	.06	1.1
15	06/18/96	.10	2.7	.06	2.5	—	15

South of the Indian Hills area, two shallow wells adjacent to alfalfa fields that are irrigated with domestic-sewage effluent (sites 13 and 14) had elevated concentrations of all major ions, minor ions, and trace elements commonly associated with sewage effluent, as compared to the three background samples (from sites 1, 6, and 10). These elevated concentrations suggest that these wells had been contaminated by the sewage effluent.

Anthropogenic Compounds

Sulfonated compounds (or MBAS) are common in sewage effluent because they are used as brighteners in detergents. They have been identified in southern California ground waters that contain reclaimed wastewater (T.F. Rees, U.S. Geological Survey, oral commun., 1995). MBAS were present in a sample from the sewage-effluent ponds (site 15) at a concentration of 0.11 mg/L, but they were not detected in any of the ground-water samples collected for this study (table 2). Sulfonated compounds can be removed from ground

water by sorption on organic matter (Barber and others, 1997). Therefore, if sewage effluent was present in the ground water, MBAS may have been removed from the effluent before it reached the well or they may have been diluted with ground water to below the detection level of 0.02 mg/L.

Caffeine has been identified in the Mississippi River downstream from major metropolitan areas that discharge sewage effluent to the river (Barber and others, 1995), and in ground water in southern California where reclaimed wastewater is used for artificial recharge (T.F. Rees, U.S. Geological Survey, oral commun., 1995). Caffeine has been measured at concentrations of 0.04 to 0.23 µg/L in ground water from wells less than 30 feet deep in valleys in northern Nevada (Seiler and others, 1999). However, caffeine was not detected in any of the ground-water samples collected for this study. Potentially caffeine can be removed from ground water by microbial degradation (Seiler and others, 1999) and can be diluted by mixing with caffeine-free ground water.

Table 2. Chemical characteristics of ground water and sewage effluent in Indian Hills area of Douglas County, Nev.—Continued

Site number	Date of sample or measurement	Anthropogenic compounds					Isotopes (permil)			
		Methylene-blue active substances (milligrams per liter)	Caffeine (micrograms per liter)	Chlorofluorocarbons (picograms per kilogram)			$\delta^{15}\text{N}_{\text{NO}_3}$	$\delta^{18}\text{O}_{\text{NO}_3}$	δD	$\delta^{18}\text{O}$
				CFC-11	CFC-12	CFC-113				
1	06/05/96	<.02	<5	54	89	22	—	—	-110	-13.7
2	06/11/96	<.02	<.04	132	169	38	7.6	9.8	-108	-13.6
3	06/10/96	<.02	<.04	162	66	27	4.1	-1.7	-105	-13.6
4	06/11/96	<.02	<5	158	115	28	3.7	.4	-108	-13.9
5	06/10/96	<.02	<5	95	109	28	5.1	2.6	-107	-13.6
6	06/06/96	<.02	<5	123	114	45	3.1	—	-116	-15.1
7	06/04/96	<.02	<.04	102	127	115	6.1	4.0	-107	-13.5
8	05/03/96	<.02	<.04	767	355	63	6.3	5.4	-106	-13.1
	05/07/96	<.02	<5	537	240	41	7.3	2.6	-106	-13.2
	06/04/96	<.02	<.04	200	158	31	6.6	3.4	-108	-13.6
9	06/06/96	<.02	<5	161	183	44	4.7	.2	-107	-13.7
10	06/05/96	<.02	<5	75	82	32	4.3	5.3	-113	-14.4
11	06/17/96	<.02	<5	360	60	7	5.6	15	-127	-16.6
12	06/18/96	<.02	<5	216	205	42	6.3	13	-109	-14.2
13	06/17/96	<.02	<5	595	290	75	4.4	3.4	-96.8	-12.1
14	06/12/96	<.02	<5	581	343	1,680	4.6	7.5	-97.1	-12.5
15	06/18/96	.11	—	—	—	—	27	26	-91.1	-10.2

Among volatile organic compounds, CFC's are relatively stable. They were first produced in the 1930's as the refrigerant dichlorodifluoromethane (CCl_2F_2 or CFC-12). Production of trichlorofluoromethane (CCl_3F or CFC-11) began in the 1940's and production of trichlorotrifluoromethane ($\text{C}_2\text{Cl}_3\text{F}_3$ or CFC-113) began in the 1960's. By 1994, annual world-wide CFC production for use as refrigerants, aerosol propellants, cleaning agents, solvents, and blowing agents (used in the production of foam rubber and plastics) exceeded 44,000 tons. No natural sources of CFC have been identified (Plummer and others, 1993, p. 268).

CFC's in the atmosphere are partitioned into water by gas-liquid exchange equilibria. On the basis of the partial pressure of CFC's in the atmosphere and solubility constants, temperature-dependent concentrations of CFC's dissolved in water can be estimated by using Henry's law. Thus, for a given recharge altitude (partial pressure) and temperature, the expected CFC concentrations in water can be calculated.

Sewage effluent has been shown to contain CFC concentrations above the natural levels that would be in ground water from dissolution of atmospheric gases (Schultz and others, 1976; Busenberg and Plummer, 1992). Consequently, CFC's can be used to indicate the presence of sewage effluent in ground water.

Where CFC concentrations in well water were greater than those measured at the background sites (sites 1, 6, and 10), shallow ground water apparently was entering the well. The CFC-11, CFC-12, and CFC-113 concentrations in the background samples ranged from 54 to 123, 82 to 114, and 22 to 45 pg/kg, respectively (table 2). Of the sites in and near the Indian Hills residential area (sites 1-10), sites 2, 8, and 9 had CFC-12 concentrations significantly higher than background values (fig. 4) and sites 7 and 8 had significantly elevated CFC-113 (table 2). High CFC concentrations in ground water can result from sewage-effluent contamination or from recent exposure to the atmosphere.

CFC concentrations continually increased in the atmosphere from 1950 to 1996. On the basis of known increases in CFC concentrations in the atmosphere over time, the CFC-11, CFC-12, and CFC-113 data indicate that most of the ground water in the Indian Hills area was recharged in the late 1960's to early 1970's. This estimate of recharge timing is consistent with Maurer's (1986) findings. He assumed that most of the ground water in the Indian Hills area was recharged in the Carson Range several miles to the west. If precipitation or lawn watering had resulted in significant recent recharge within the Indian Hills area, synthetic fertilizer or livestock wastes could have contributed nitrate.

Because this recharge water would have been in recent contact with atmospheric CFC's, most ground-water samples from sites in the area would likely have had high CFC concentrations if recent local recharge had been significant. Most samples did not contain high CFC concentrations indicative of significant local recharge in this area. Therefore, CFC concentrations above background levels at four sites (2, 7, 8, and 9) suggest that some of the nitrate in samples from these sites could have been from sewage effluent. (Site 8 CFC's are discussed in detail in the section "Anthropogenic Compounds," under "Well No. 1.")

The high CFC concentrations in samples from sites 13 and 14 are indicative of water that had been either contaminated with sewage effluent or in recent contact (1990's) with atmospheric CFC's. The use of stored effluent for irrigation of alfalfa fields could result in the equilibration of this water with atmospheric CFC's before recharging the shallow water table. The extremely high CFC-113 concentration (1,680 pg/kg) in a sample from site 14 could have resulted only from contamination.

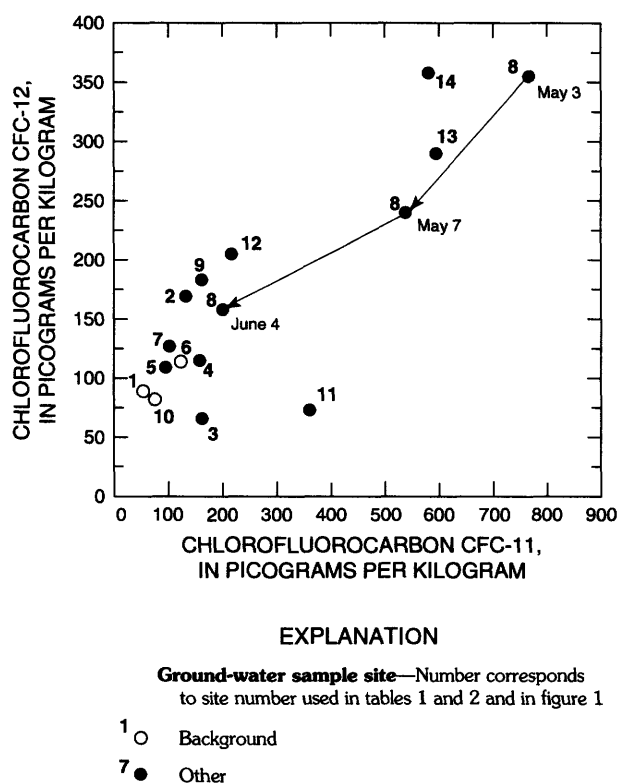


Figure 4. Relation between chlorofluorocarbons CFC-11 and CFC-12 in ground-water samples. Arrows show decline in CFC-11 and CFC-12 in Well No. 1 samples from May 3 through May 7 to June 4, 1996.

Isotopes of Nitrate and Water

The stable isotopes of nitrate, $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$, have been used in studies to identify the sources of nitrate dissolved in ground water (Heaton, 1986; Bottcher and others, 1990; Aravena and others, 1993; Komor and Anderson, 1993; Wassenaar, 1995; Rolston and others, 1996). If no isotope-fractionating processes, such as denitrification, are occurring, then the $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ values of nitrate in ground water derived from natural-soil organic matter should be 1 to 7 and 0 to 5 permil, respectively. Similarly, those from animal waste should be 8 to 22 and 0 to 5 permil, respectively, and those from synthetic fertilizers should be -4 to 4 and 18 to 25 permil, respectively (table 3). Thus, isotopes can be used to identify nitrate sources in ground water because different sources generally have different $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ values. However, most processes affecting dissolved nitrogen fractionate the isotopes. Therefore, even though the original isotopic signatures are usually different for different nitrogen sources, the fractionations commonly result in isotope values that cannot be related directly to the nitrogen source.

Table 3. General range of $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ values for different sources of nitrate in ground water

[Data from Heaton, 1986; Bottcher and others, 1990; Aravena and others, 1993; Komor and Anderson, 1993; Wassenaar, 1995; and Rolston and others, 1996]

Source of nitrate	Isotopes of nitrate (permil)	
	$\delta^{15}\text{N}_{\text{NO}_3}$	$\delta^{18}\text{O}_{\text{NO}_3}$
Natural-soil organic matter	+1 to +7	0 to +5 (depends on ground-water $\delta^{18}\text{O}$)
Sewage effluent and livestock wastes.	+8 to +22	0 to +5 (depends on ground-water $\delta^{18}\text{O}$)
Synthetic fertilizers	-4 to +4	+18 to +25

The $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ data for ground-water samples from the Indian Hills area are presented in table 2 and plotted in figure 5. To help identify the sewage-effluent component that could have been contributing nitrate to ground water in the Indian Hills area, isotopic analyses were obtained for samples from sewage-effluent retention ponds (site 15), a shallow monitor well adjacent to alfalfa fields irrigated with sewage effluent from the ponds (site 13), and a shallow monitor well about 0.2 mile downgradient from the irrigated fields (site 14).

Nitrogen dissolved in the sewage-effluent ponds was principally in the form of nitrite and organic nitrogen (table 2). The $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values for the nitrogen were 27 and 26 permil, respectively. Sewage effluent from the storage ponds has larger $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values than typical isotope values from septic systems (table 3), and thus these values are unlikely to have been representative of values from septic systems in the Indian Hills residential area. Processes of ammonia volatilization, incomplete nitrification, and denitrification may explain the unusual $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ values measured in the pond effluent.

Sewage effluent applied as irrigation water was the most likely source of most nitrate in ground water at sites 13 and 14, as indicated by the major-ion, minor-ion, trace-element, nutrient, and CFC data. However, the $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ values of ground-water

samples from these sites (4.4 and 3.4 permil at site 13 and 4.6 and 7.5 permil at site 14, respectively) indicate that the nitrogen in the sample collected from the effluent ponds (site 15) was not isotopically representative of the effluent applied to the fields. The source of nitrate in the ground-water samples could have been from effluent applied earlier in the year when temperatures were cool and isotopic enrichment would have been minimal. Additionally, decaying alfalfa plants, which could have released nitrogen having $\delta^{15}\text{N}_{\text{NO}_3}$ as light as 0 permil (because of fixation of atmospheric nitrogen), could have been a source of some of the nitrate.

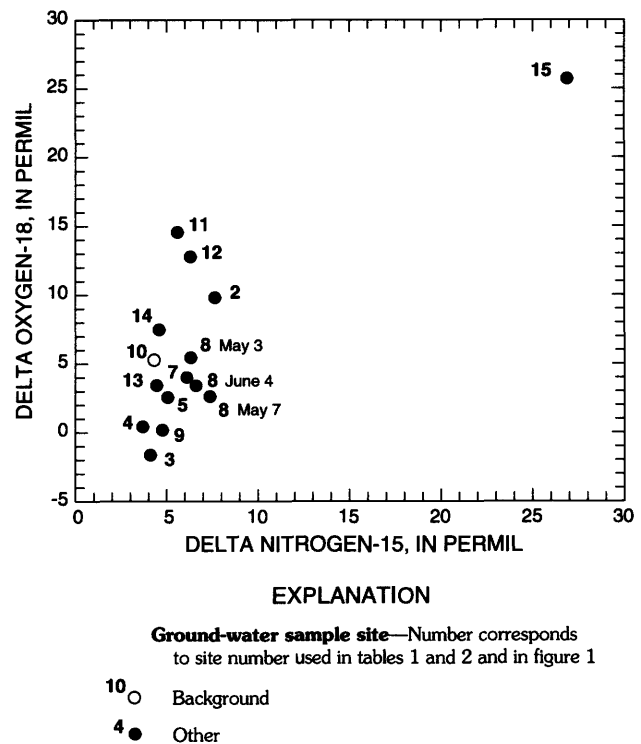


Figure 5. Relation between isotopes of nitrate, $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$, dissolved in water samples from selected wells (sites 2-5, 7-14) and sewage-effluent ponds (site 15). (Water from site 1 did not have high enough nitrate concentration for $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ analyses. Water from site 6 contained only enough nitrate for $\delta^{15}\text{N}_{\text{NO}_3}$ analysis.)

The $\delta^{15}\text{N}_{\text{NO}_3}$ values for sites 13 and 14 were isotopically much lighter than observed values in other studies for nitrate originating as animal waste (table 3) and were in the range of expected values for nitrate derived from natural-soil organic matter. Samples from background sites 6 and 10, which were assumed to contain nitrate primarily from natural-soil organic matter, had $\delta^{15}\text{N}_{\text{NO}_3}$ values of 3.1 and 4.3 permil, respectively; the sample from site 10 had a $\delta^{18}\text{O}_{\text{NO}_3}$ value of 5.3 permil (table 2). These three values were within the range of prior published values for natural-soil organic matter (table 3). The similarity of observed $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ values for all ground-water samples from sites in and near the Indian Hills residential area (sites 2–10), and their similarity to values for ground-water samples from sites 13 and 14 (fig. 5), indicates that these isotopes could not be used in this study to help identify nitrate sources in ground water.

The δD and $\delta^{18}\text{O}$ of ground water from the background sites (1, 6, and 10) ranged from -116 to -110 and from -15.1 to -13.7 permil, respectively. Samples from six other sites in and near the Indian Hills residential area (sites 2–5, 7, and 9) had δD and $\delta^{18}\text{O}$ values that ranged from -108 to -105 and from -13.9 to -13.5 permil, respectively (table 2 and fig. 6). (Site 8 is discussed in section “Isotopes of Nitrate and Water,” under “Well No. 1.”) Samples from these six sites had slightly heavier (more positive) δD values than background values and, except for sites 4 and 9, slightly heavier $\delta^{18}\text{O}$ values. However, these values were not sufficiently different to indicate sewage-effluent input to the ground water, especially given the large range of values in background samples as compared to the other samples. Samples from sites 13 and 14 were isotopically heavier than those from sites 1 through 10 and site 12, indicating that isotopically heavy sewage-effluent water was present in these samples. Ground water from site 11, a site south of the Indian Hills residential area (fig. 1), had significantly lighter isotopic compositions than all other samples. This distinctive composition suggests that site 11 received recharge from a different source than the other sites in the study area.

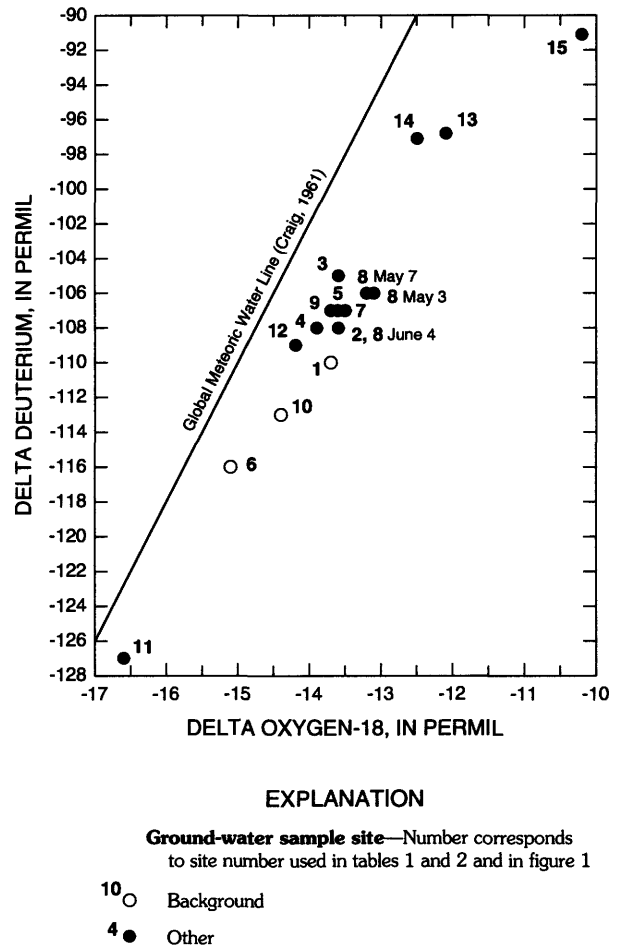


Figure 6. Relation between isotopes of water, δD and $\delta^{18}\text{O}$, in water samples from wells and sewage-effluent ponds.

Conclusions as to Sources of Nitrate

Ground-water samples from background sites 1, 6, and 10 contained less than 1 mg/L nitrate. Evidence that this nitrate was derived primarily from natural-soil organic matter includes (1) low specific-conductance values and low dissolved-solids, major-ion, minor-ion, trace-element, and nutrient concentrations; (2) the absence or low concentrations of anthropogenic compounds (no MBAS, no caffeine, low CFC's); (3) $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ values in the range of prior published values for natural-soil organic-matter sources of nitrate; and (4) δD and $\delta^{18}\text{O}$ values that were lighter than other samples from sites in or near the Indian Hills residential area except for $\delta^{18}\text{O}$ of ground water from sites 4 and 9.

Chemical and isotopic data for ground-water samples from six other wells in and near the Indian Hills residential area (sites 2–5, 7, and 9), all of which contained more than 1 mg/L nitrate, were compared to the three background samples (from sites 1, 6, and 10) to try to identify nitrate sources. (Site 8 is discussed in next section, “Well No. 1.”) Ground water from sites 3, 5, and 7 had comparatively higher specific conductance; lower pH values; and mostly higher dissolved-solids, major-ion, minor-ion, trace-element, and nutrient concentrations. No MBAS or caffeine were detected in any ground-water samples from the study area. Ground-water samples from sites 2, 7, and 9 contained significantly greater CFC-11, CFC-12, or CFC-113 concentrations than the background samples. The $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ values for samples from the Indian Hills residential area sites (except for site 2) were generally in the range of prior published values for natural-soil organic matter (table 3). However, they were also similar to values in ground-water samples from two shallow monitor wells (sites 13 and 14) downgradient from alfalfa fields irrigated with sewage effluent. The δD and $\delta^{18}\text{O}$ of ground-water samples from sites 2 through 5, 7, and 9 were slightly heavier but similar to background values (except for $\delta^{18}\text{O}$ for sites 4 and 9). In summary, specific-conductance values and chemical-constituent (including CFC) concentrations higher than background suggest that some of the ground-water samples may have contained nitrate from sewage effluent. However, only samples from site 7 had elevated specific-conductance values and elevated dissolved-solids, major-ion, minor-ion, trace-element, nutrient, and CFC concentrations that would have been indicative of sewage effluent. That livestock wastes and synthetic fertilizers appear to have been insignificant sources of nitrate is indicated by the elevated concentrations of all chemical constituents coupled with the lack of significant recent local recharge (as indicated by CFC concentrations).

Well No. 1

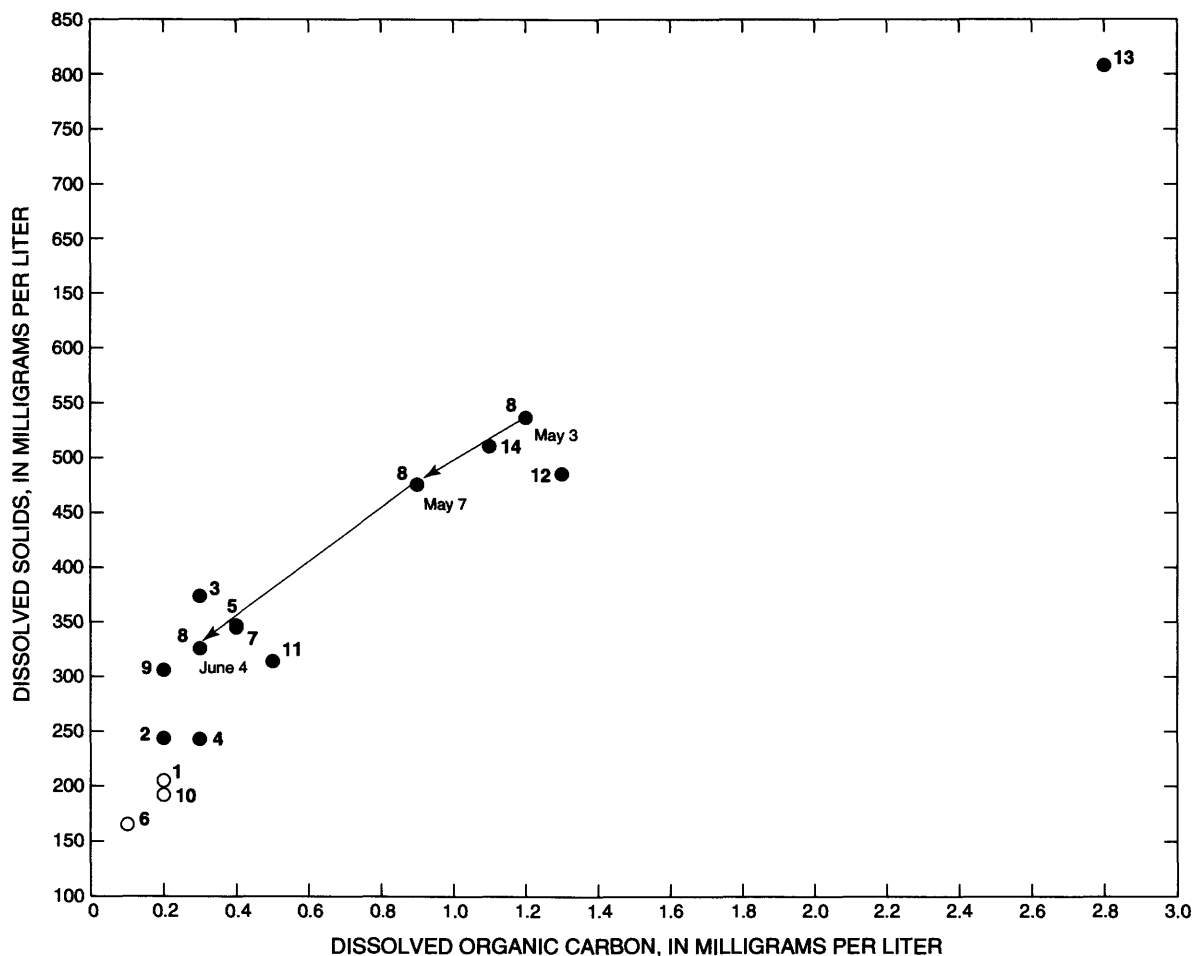
Nitrate

The sources of nitrate in ground water in Well No. 1 (site 8) were identified by the methods described above. Ground water from this well had nitrate concentrations that exceeded the drinking-water standard of 10 mg/L (Nevada Legislative Counsel, 1997) and were

more than four times the nitrate concentration in ground-water samples from other sites in and near the Indian Hills residential area (table 2). Data were collected from Well No. 1 by Douglas County personnel almost daily during the pumping season. These data are shown in figure 2 along with data collected for this study but are not included in table 2. High nitrate concentrations generally occurred soon after the well was put into production, in the spring or early summer (fig. 2), or when the pumping rate was greatly reduced (R.J. Roman, Douglas County Community Development Department, written commun., 1997). When the well was first turned on for the summer production season on May 3, 1996, the nitrate concentration was less than 1 mg/L (measured by onsite colorimetry), possibly because of denitrification. Within minutes after pumping began the nitrate concentration rose to 5.5 mg/L (table 2) and within a day reached almost 12 mg/L (fig. 2). Thereafter, the nitrate concentrations declined with continued pumping of the well (fig. 2). This pattern suggests a nearby source of nitrate-rich water, which was diluted by ground water containing less than 2.5 mg/L nitrate when the well was continually pumped at a sufficiently high rate.

Major Ions, Minor Ions, Trace Elements, and Nutrients

Changes in major-ion, minor-ion, trace-element, and nutrient concentrations for three samples collected from Well No. 1 during the 1996 pumping season were used to identify possible nitrate sources. All major-ion, minor-ion, trace-element, and nutrient concentrations commonly associated with sewage effluent were highest in the initial sample on May 3 and decreased with decreasing nitrate concentration and continual pumping (table 2). Furthermore, except for two bromide values and one fluoride value, these concentrations were higher in the initial sample than in a sample from a nearby well (site 7) completed to almost the same depth (within 5 ft) and all other samples from sites in and near the Indian Hills residential area (sites 1–6, 9, and 10). These constituent concentrations decreased during pumping and on June 4 were similar to those in a sample from site 7. For example, a plot of dissolved organic carbon in relation to dissolved solids (fig. 7) shows that the May 3 sample had dissolved organic-carbon and dissolved-solids concentrations greater than those in all other samples from the Indian Hills residential area.



EXPLANATION

- Ground-water sample site**—Number corresponds to site number used in tables 1 and 2 and in figure 1
- Background
 - Other

Figure 7. Relation between dissolved organic carbon and dissolved solids in ground-water samples. Arrows show decline in dissolved organic carbon and dissolved solids in Well No. 1 samples from May 3 through May 7 to June 4, 1996.

Additionally, these concentrations were most similar to those of a shallow monitoring well downgradient from alfalfa fields irrigated with domestic-sewage effluent (site 14).

In contrast to the concentrations of major, minor, and trace constituents and nutrients, pH was lowest in the May 3 sample from Well No. 1 and highest in the June 4 sample, and the May 3 sample had the lowest pH of any water sample from sites in and near the Indian Hills residential area (table 2). As previously discussed, water affected by sewage effluent could

have had lower pH than water that was not affected by sewage effluent (see section “Major Ions, Minor Ions, Trace Elements, and Nutrients,” under “Indian Hills Area”).

Constituent concentrations that were elevated in Well No. 1 on May 3 were similarly elevated in samples from shallow wells downgradient from alfalfa fields irrigated with domestic-sewage effluent (sites 13 and 14, table 2). Additionally, the pH of samples from these two sites was similar to that of the May 3 sample from site 8.

In summary, the above data indicate that domestic-sewage effluent was a likely source of nitrate-rich water in Well No. 1. This conclusion is also supported by the detection of organic nitrogen (at the detection limit, 0.20 mg/L) in the May 3 sample (table 2). The only other ground-water sample in which organic nitrogen was present was from site 13, adjacent to the fields irrigated with sewage effluent.

Anthropogenic compounds

Caffeine and MBAS were not detected in samples from Well No. 1. The absence of MBAS and caffeine in water from Well No. 1 does not rule out the possibility that high nitrate in the well water was from domestic-sewage effluent because of their possible sorption on organic matter, biodegradation, and dilution with ground water not containing these chemicals.

CFC concentrations were highest in the initial sample and lowest in the last sample (table 2 and fig. 4). The concentrations of CFC-11 and CFC-12 on May 3 and May 7 indicate that the ground water either contained domestic-sewage effluent or had been recently exposed to the atmosphere. In this area, domestic-sewage effluent was more likely than local recharge to have been the source of a large volume of shallow, nitrate-rich ground water. This conclusion is supported by (1) the high initial CFC concentrations in samples from Well No. 1 as compared to ground-water samples from other sites in and near the Indian Hills residential area (except CFC-113, site 7), (2) initial CFC concentrations similar to those in samples from shallow wells (site 13; site 14, except for CFC-113) that are down-gradient from alfalfa fields irrigated with domestic-sewage effluent, and (3) the decline of CFC concentrations during the first month of pumping to levels similar to those in ground-water samples from other sites nearby (fig. 4). If the water table in and near the Indian Hills residential area had received significant recent recharge from precipitation or lawn watering, whereby synthetic fertilizer or livestock wastes could have contributed nitrate to shallow ground water, then ground-water samples from most other sites in the area would likely also have contained high CFC concentrations. A comparison of CFC's dissolved in water indicates that the 1996 atmospheric concentrations of CFC-11 and CFC-12 were about 300 to 400 percent of 1970 values.

All ground-water samples from sites in and near the Indian Hills residential area, except from Well No. 1, contained CFC-11 and CFC-12 concentrations that indicate these ground waters had been recharged about 1970.

Isotopes of Nitrate and Water

The $\delta^{15}\text{N}_{\text{NO}_3}$ and $\delta^{18}\text{O}_{\text{NO}_3}$ values for the three Well No. 1 samples (May 3, May 7, and June 4) did not differ significantly and were similar to values measured for other sites throughout the study area (table 2 and fig. 5). In this study, the analysis of $\delta^{18}\text{O}_{\text{NO}_3}$ was not very useful in separating possible sources of nitrate (table 3). The sources of nitrate in ground-water samples from Well No. 1 could not be identified by using the isotopes of nitrate. For ground-water samples from the study area, these isotopic values apparently did not differ according to whether the nitrates had been derived from natural-soil organic matter or from sewage effluent.

A study done in Ontario, Canada, by Aravena and others (1993) showed that $\delta^{18}\text{O}$ of sewage effluent in some cases can be used to delineate an effluent plume originating from a septic leachfield. In the Indian Hills residential area, sewage effluent apparently was isotopically heavier (more positive) than the local ground water, and thus the same technique may be useful in mapping effluent plumes here. The δD and $\delta^{18}\text{O}$ values in initial samples (May 3) from Well No. 1 were slightly heavier than those in later samples (table 2 and fig. 6). The initially larger isotopic values of water support the conclusion that domestic-sewage effluent was the main source of the excess nitrate in this ground water.

Conclusions as to Sources of Nitrate

That sewage effluent contributed nitrate to Well No. 1 is indicated by several lines of evidence: (1) Initial high nitrate concentrations at the start of a pumping season decreased with continued pumping, and during the pumping season nitrate increased if the pumping rate was greatly reduced. (2) Specific-conductance values were higher; major-ion, minor-ion, trace-element, and some nutrient concentrations were higher; and pH was lower in the initial sample from

Well No. 1 than in samples from other wells in and near the Indian Hills residential area (sites 1–7 and 9–10) or in later samples from the same well. (3) Well No. 1 water contained high initial CFC concentrations that declined during pumping to levels similar to those of other ground-water samples from the area. (4) Initial δD and $\delta^{18}O$ values were slightly elevated compared to later values. Thus, the majority of nitrate in water initially pumped from Well No. 1 in the spring or early summer was likely from domestic-sewage effluent. As the pumping season progressed and nitrate concentrations declined to lower levels, a greater percentage of the nitrate was probably from natural-soil organic matter.

SUMMARY AND CONCLUSIONS

Nitrate in ground water in and near the Indian Hills residential area, excluding nitrate-enriched water from Well No. 1, originated primarily from natural-soil organic matter, with possible contributions from domestic-sewage effluent at some sites. Three of the wells in this area contained less than 1 mg/L nitrate. Evidence that the nitrate in these three wells was derived primarily from natural-soil organic matter includes (1) low specific-conductance values and low dissolved-solids, major-ion, minor-ion, trace-element, and nutrient concentrations, (2) undetected or low concentrations of anthropogenic compounds (no MBAS, no caffeine, and low CFC concentrations), (3) $\delta^{15}N_{NO_3}$ and $\delta^{18}O_{NO_3}$ values in the range of prior published values for natural-soil organic matter, and (4) δD and $\delta^{18}O$ values that included the lightest of any samples from sites in and near the Indian Hills residential area. These three wells are either the deepest wells or have the greatest depths to the top of the well-screen open intervals, and therefore they were less susceptible to contamination from shallow ground water. Data from these three wells were used as background values.

Six sites (excluding Well No. 1) in and near the Indian Hills residential area yielded samples containing more than 1 mg/L nitrate. These samples were compared to the three background samples to identify nitrate sources. Samples from three of the six sites had higher specific-conductance values; mostly higher dissolved-solids, major-ion, minor-ion, trace-element, and nutrient concentrations; and lower pH values than the

background samples. MBAS and caffeine were not detected in any of the Indian Hills area samples. Ground water from three of the six sites contained CFC-11, CFC-12, or CFC-113 concentrations significantly above background values. The $\delta^{15}N_{NO_3}$ and $\delta^{18}O_{NO_3}$ values and δD and $\delta^{18}O$ of ground water were not useful in identifying nitrate sources in these six samples. Some of the nitrate in ground water at five of the six sites may have been derived from domestic-sewage effluent, as indicated by elevated specific-conductance values and chemical-constituent (including CFC) concentrations that are associated with sewage effluent. Only one site had elevated specific-conductance values and elevated dissolved-solids, major-ion, minor-ion, trace-element, nutrient, and CFC concentrations. Livestock wastes and synthetic fertilizers did not appear to be significant sources of the nitrate in ground water in and near the Indian Hills residential area as indicated by chemical-constituent (including CFC) concentrations. Long-term monitoring of nitrate concentration at sites potentially affected by sewage effluent would be helpful in deciding whether a local source of shallow water is supplying nitrate to these wells.

The primary source of nitrate in ground-water samples from Well No. 1 when the well was first put into production was domestic wastewater. This conclusion is based on (1) initially high nitrate concentrations that declined with continued pumping and increased when the pumping rate was greatly reduced; (2) higher specific-conductance values; higher major-ion, minor-ion, trace-element, and nutrient concentrations; and lower pH in the initial sample from Well No. 1 than in later samples from the same well and in samples from other wells in and near the Indian Hills residential area; (3) initially elevated CFC concentrations that declined during pumping until they became similar to those of ground-water samples from other sites in the area; and (4) slightly elevated initial δD and $\delta^{18}O$ values compared to later values. As the pumping season progressed and nitrate concentrations declined to lower levels, a greater percentage of the nitrate was probably from natural-soil organic matter, as indicated by the above-listed constituents and other characteristics becoming similar to those of ground-water samples from other sites in the area.

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