Trends in Chloride, Dissolved-Solids, and Nitrate Concentrations in Ground Water, Carson Valley and Topaz Lake Areas, Douglas County, Nevada, 1959-88

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CONTENTS

Figures

Tables

CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY UNITS USED

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square foot (ft^2)	0.0929	square meter
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.

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.

Water-Quality Units:
mg/L (milligram per liter)
mg/L/yr (milligram per liter per year)

Trends in Chloride, Dissolved-Solids, and Nitrate Concentrations in Ground Water, Carson Valley and Topaz Lake Areas, Douglas County, Nevada, 1959-88

By Carl E. Thodal

ABSTRACT

Rapid population growth in Douglas County, an area of approximately 750 square miles in west-central Nevada, has led to concern about the present and future effects of development on ground water, which is the principal source of drinking water for most of Douglas County. This report describes the results of two nonparametric statistical procedures applied to detect trends in concentrations of chloride, dissolved solids, and nitrate in ground water. The water-quality data are from (1) samples collected and analyzed by the U.S. Geological Survey (USGS) and (2) provided by the Nevada Bureau of Consumer Health Protection Services, for ground water in the Carson Valley and Topaz Lake areas of Douglas County, Nevada.

Ground water in the study area generally is suitable for most purposes. Of the available data, 14 samples (about 2 percent) from 6 wells exceeded the primary drinking-water standard for nitrate (10 milligrams per liter, as nitrogen), and 45 samples (about 6 percent) from 27 wells exceeded the secondary drinking-water standard for dissolved solids (500 milligrams per liter). The secondary drinking-water standard for chloride (250 milligrams per liter) was not exceeded.

With rapid population growth in the county, resource planners and managers are concerned about whether or not available data indicate any trends in decreasing quality of ground water. Differences in concentrations for two selected time intervals were tested for statistical significance by applying a version of the Mann-Whitney-Wilcoxon rank-sum test to the entire data set of 795 analyses of ground-water samples collected from 1959 to 1988, and to subsets of the data that represent seven land-use areas. Tests for monotonic trends were made by applying Kendall's Tau test and slope estimator to time-series data available for samples from 25 individual wells that were operated as monitoring wells by the USGS, in cooperation with Douglas County. Results from both tests are considered exploratory because of the limited period of network operation and uncertainties associated with historical data.

A significant, increasing step trend (p-value, 0.035) was detected for nitrate concentrations in the Johnson Lane area, and a moderately significant increasing step trend (p-value, 0.085) was detected for dissolved-solids concentrations throughout the study area. Decreasing step trends for chloride concentrations (p-value, 0.037) and dissolved-solids concentrations (p-value, 0.028) were detected in the west Carson Valley area. No other statistically significant trends were indicated by the rank-sum test.

Statistically significant monotonic trends (p-value, less than 0.1) were detected for increasing nitrate concentrations in water at one domestic well in the Jacks Valley-Indian Hills area (p-value, 0.089), at one domestic well in the Johnson Lane area (p-value, 0.027) and at two domestic wells in the Topaz Lake area (p-values,

0.043 and 0.086). The highest nitrate concentrations (2.1-6.1 milligrams per liter) of these four wells were associated with samples from the Topaz Lake area where contamination of ground water by individual sewage-disposal systems has been previously indicated. The other two wells had nitrate concentrations in water that were less than 1 milligram per liter.

Increasing monotonic trends were detected also in data on dissolved-solids concentrations, in water from one domestic well near the Douglas County landfill (p-value, 0.086) and from one domestic well in the Topaz Lake area (p-value, 0.027). Samples from the former well may have been affected by leachate from the nearby landfill. The latter well is also one of the two wells from the Topaz Lake area with data that shows increasing trends in nitrate concentrations. Trends indicating increasing concentrations of nitrate or dissolved solids do not imply that concentrations will continue to increase or that they may eventually exceed drinking-water standards. But they can be an indication of potentially problematic land-use practices. This information may be useful when refining monitoring strategies or developing future land-use plans.

INTRODUCTION

Background

Ground water is the primary source of domestic water for most of Douglas County. Rapid population growth and associated changes in land use prompted the U.S. Geological Survey, in cooperation with Douglas County, to start a ground-water monitoring program in the Carson Valley and Topaz Lake areas of the county in 1985. A primary goal of the monitoring program, in addition to general surveillance of ground-water quality, is to determine whether ground-water quality is changing as a result of land-use activities.

Traditional methods of trend assessment rely on parametric hypothesis tests, which assume the data to be normally distributed. However, water-quality data frequently negate this assumption because of seasonality of hydrologic loadings, serial correlation of related variables, or skewness in data distributions (van Belle and Hughes, 1984, p. 127). One problem of using parametric statistical techniques for time-series analysis, developed specifically to process serially correlated data, is that they require the data to be evenly spaced over time (McLeod and others, 1983, p. 537). This condition is not always met. Other problems in parametric statistical analysis of time-series water-quality data include the following: (1) Existing periods of records for data are short; (2) sampling frequency or location, or analytical methods, have changed; and (3) the sampling plans that generated the data may not have been designed to describe temporal variability (Wolman, 1971, p. 916-917). Because these complications are common, trend-assessment techniques have recently shifted to nonparametric tests that are less sensitive to the distribution of the data. Nonparametric tests for trends are based on hypothesis testing and, because distribution assumptions are less restrictive, these tests are used most appropriately as exploratory procedures to glean information from non-ideal data sets. The results may then be used to refine monitoring strategies and to test specific hypotheses about the timing, magnitude, and mechanisms of change (Hirsch and others, 1982, p. 107).

Purpose and Scope

This report describes the results of two nonparametric procedures applied to detect trends in ground-water concentrations of chloride, dissolved solids, and nitrate in Douglas County, Nev. Water-quality data are from (1) samples collected and analyzed by the U.S. Geological Survey (USGS) and (2) provided by the Nevada Bureau of Consumer Health Protection Services (NBCHPS)[1], for the Carson Valley and Topaz Lake areas of Douglas County. The Mann-Whitney-Wilcoxon rank-sum test was used to determine differences in the distribution of ground-water concentrations between two selected time intervals. The statistical test was applied to the entire data set of 795 historical analyses and to subsets of the data representing seven subareas in the study area delineated by land use. Tests for monotonic trends were made

[1]In 1991, NBCHPS shortened its name to Nevada Bureau of Health Protection Services. Because this study was made before then, the original name is used herein.

by applying Kendall's Tau test and slope estimator to time-series data available for samples from 25 individual wells included in a monitoring network operated by the USGS in cooperation with Douglas County. These results are not considered conclusive because of the uncertainties associated with available historical data and the limited period of network operation.

Study Area

Douglas County encompasses approximately 750 mi^2 in west-central Nevada (fig. 1). The county is bounded on the west by Lake Tahoe and the Carson Range of the Sierra Nevada, and on the east by the Pine Nut Mountains. The north-trending mountain ranges divide the county into three major valleys: the Lake Tahoe Basin along the western border (57 mi^2), Carson Valley in the west-central part (420 mi^2), and the Nevada part of Antelope Valley in the southeastern part (110 mi^2). Mountainous terrain occupies the remainder of the county area. Two major river systems flow northward through the county: the Carson River flows through Carson Valley, and the West Walker River flows through Antelope Valley. The economics of the county are dominated by (1) tourism and gaming, which are concentrated along the south-eastern shore of Lake Tahoe at Stateline, Nev., and (2) agriculture in Carson and Antelope Valleys. The major population centers are Stateline and the Minden-Gardnerville area in Carson Valley.

Douglas County has been one of the fastest growing counties in the Nation, with a 182-percent increase in population between the 1970 and 1980 censuses. The 1990 census reported about 27,600 inhabitants in Douglas County (U.S. Bureau of Census, 1991), which indicates a population growth rate of about 140 percent for the 1980-1990 decade. Available residential property, esthetic qualities, and recent growth in northwestern Nevada's gaming industry probably are responsible for the population growth in the area.

The rapid population growth in Douglas County has led to concern about present and future effects of development on available land and water resources. The principal source of drinking water for most of Douglas County, outside of the Lake Tahoe Basin, is ground water. Ground water also is used for irrigation in Carson and Antelope Valleys. In 1969, when the population was 6,000 inhabitants, Douglas County withdrew approximately 7,000 acre-ft of ground water for irrigation and about 420 acre-ft for public supply. By 1985, the county population had increased to 23,200 inhabitants and estimated annual ground-water withdrawals had increased to 10,500 acre-ft for irrigation and 3,900 acre-ft for public supply. Estimated surface-water withdrawals for irrigation decreased from 240,000 acre-ft in 1969 to 220,000 acre-ft in 1985, while surface-water withdrawals for public supply increased from 1,200 acre-ft in 1969 to about 2,200 acre-ft in 1985 (Smales and Harrill, 1971, p. 18; Frick and Carman, 1990).

Six public-supply systems of various sizes serve developed areas in and near the Minden and Gardnerville areas in southern Carson Valley and Indian Hills, a residential area in the northern part of the valley. Smaller community systems in Antelope Valley serve developments adjacent to and northeast of Topaz Lake. The remainder of the county, outside the Lake Tahoe Basin, is served by individual domestic wells.

Potential sources of ground-water contamination in Douglas County include (1) natural, localized sources of mineralized water, and uranium and its radioactive daughter products (Otton and others, 1985); (2) a gold mining and milling operation in the southeastern corner of Carson Valley; (3) a large regional landfill in Carson Valley; (4) agricultural fertilizers and livestock wastes in Carson and Antelope Valleys; (5) land application of treated municipal sewage effluent in Carson Valley; (6) percolation of domestic wastes from individual sewage-disposal systems in more densely developed residential parts of the county (Garcia, 1989, p. 46); and (7) localized contamination by improper disposal of organic solvents and leakage of petroleum products from underground storage tanks. Potentially adverse health effects of organic compounds, the increasing reliance on land application for disposal of treated municipal sewage effluent, and percolation of domestic wastes are the principal ground-water-quality concerns. Currently, communities in Carson Valley operate two land effluent-disposal systems, and effluent is imported for land application from three sewage-treatment systems in the Lake Tahoe Basin. Some of these operations are considering increased use of land application to accommodate expansion of their sewage-collection and treatment facilities.

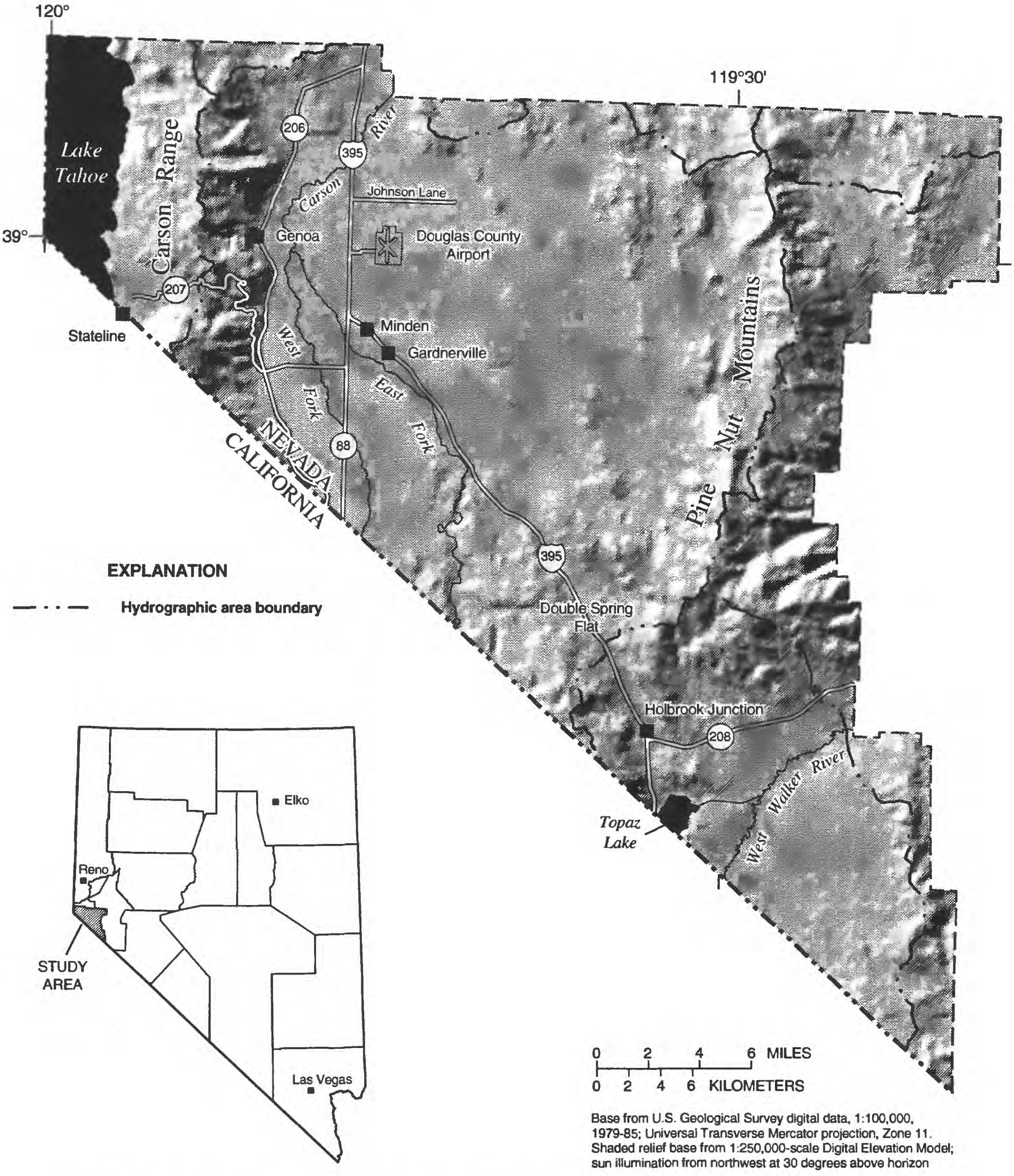

Figure 1. Location and geographic features of Douglas County, Nevada.

Twelve areas in Carson Valley have been zoned for "urban development" as part of the General Plan for Douglas County (Douglas County Planning Division, written commun., 1980). For the purposes of this investigation, discrete but similar areas have been grouped into seven land-use areas (including the Topaz Lake area) and are shown in figure 2 and described in table 1. These land-use areas are not restricted to the areas zoned by the Douglas County Planning Division; rather, the zoned areas delineated indicate dominant land-use activities which may affect local ground-water quality. Figure 3 shows cumulative residential construction rates in Douglas County and in each land-use area, as recorded by the Douglas County Assessor's Office (Barbara Byington, written commun., 1991). Water-quality data are available for domestic wells that are not located within the land-use areas delineated for this study. For example, site 39 (table 2 and fig. 4) is a domestic well in a rural area that is known locally as Double Spring Flat. These data are included in the trend analysis for the large historical data but not the time-series data sets because of the limited number of sampling for the specific sites.

Acknowledgments

The author thanks the residents and water purveyors of Douglas County who allowed use of their private wells as monitoring sites, and staff of the Douglas County Planning Division and Assessor's Office for providing land-use information.

SIGNIFICANCE OF CHLORIDE, DISSOLVED SOLIDS, AND NITRATE IN GROUND WATER

Solutes in ground water are contributed by natural and cultural sources. Chloride, dissolved solids, and nitrate were selected as variables for trend analysis in this study because they are considered to be indicators of human effects on water supplies and because historical data are available for those constituents.

Chloride is a major dissolved constituent in natural water, but is present in most rock types at concentrations that are much lower than other major constituents. Sedimentary rocks, particularly evaporites and marine deposits, contribute chloride to ground water and, combined with precipitation-borne chloride from the ocean, account for most of the chloride in natural water (Hem, 1985, p. 118-119). Chloride also occurs in household and community wastewater at concentrations reported to range from 37 to 101 mg/L (Canter and Knox, 1985, p. 79). Because chloride generally is not removed from wastewater by either individual sewage-disposal systems or conventional community wastewater-treatment systems, it often is used as an indicator of contamination from sewage-disposal systems (Canter and Knox, 1985, p. 79). Increased chloride concentration also may be an indicator of ground-water contamination by landfill leachate (Canter and others, 1987, p. 92).

Table 1. Residential areas used to group ground-water data by land use, Douglas County, Nevada

Local area name (figs. 1 and 2)	Zoned acreage [1]	Residential density [2]	Method of wastewater disposal
Jacks Valley-Indian Hills	3,000	Rural-low	Secondary waste-treatment facility and individual septic-tank systems
Johnson Lane	4,200	Low	Individual septic-tank systems
West Carson Valley	2,100	Rural-low	Individual septic-tank systems
Minden-Gardnerville	1,900	Medium-high	Secondary waste-treatment facility and individual septic-tank systems
East Carson Valley	12,000	Rural-medium	Individual septic-tank systems
Gardnerville Ranchos	3,100	Rural-high	Secondary waste-treatment facility and individual septic-tank systems
Topaz Lake area	960	Low-medium	Individual septic-tank systems

[1] Area, in acres, delineated in 1980 by the Douglas County Planning Division as part of the General Plan for Douglas County (written commun., 1980), except for the Topaz Lake area where acreage was reported by Nowlin (1982, p. 3).

[2] Rural, zoned for 5 or 2 acres per dwelling unit; low, zoned for 1 or 0.5 acre per dwelling unit; medium, zoned for 12,000 or 8,500 square feet per dwelling unit; high, zoned for 8, 12, or 15 dwelling units per acre (Douglas County Planning Division, written commun., 1980).

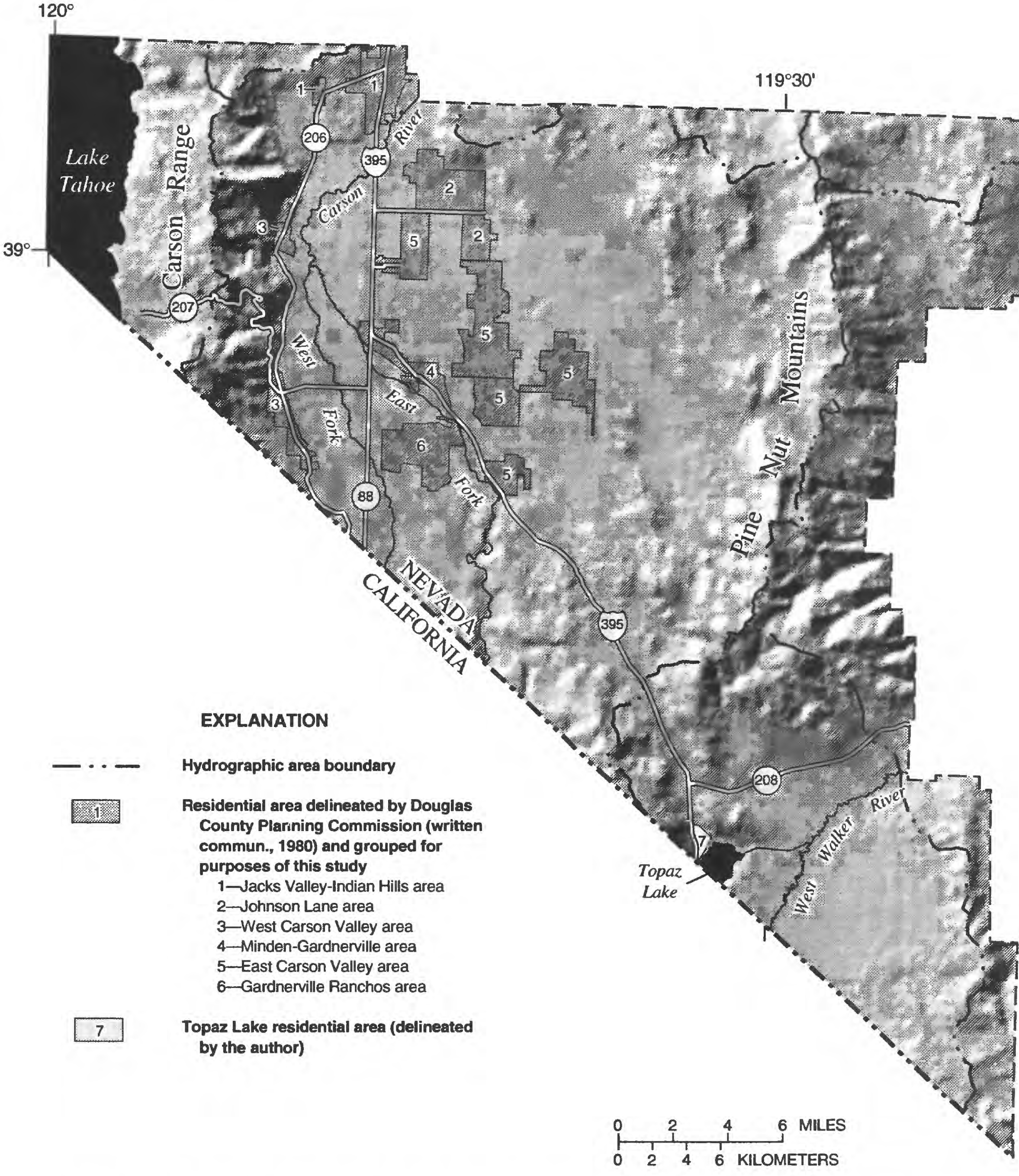

Figure 2. Residential areas used to group ground-water data by land use, Douglas County, Nevada.

A secondary preferred drinking-water standard for chloride of 250 mg/L for public-water supplies has been adopted by the State of Nevada. This standard should be met by public water-supply systems, if possible. If supplies that meet the preferred standard are not available, the secondary maximum contaminant level of 400 mg/L must be met and is enforceable by the State of Nevada (Nevada Bureau of Consumer Health Protection Services, 1980).

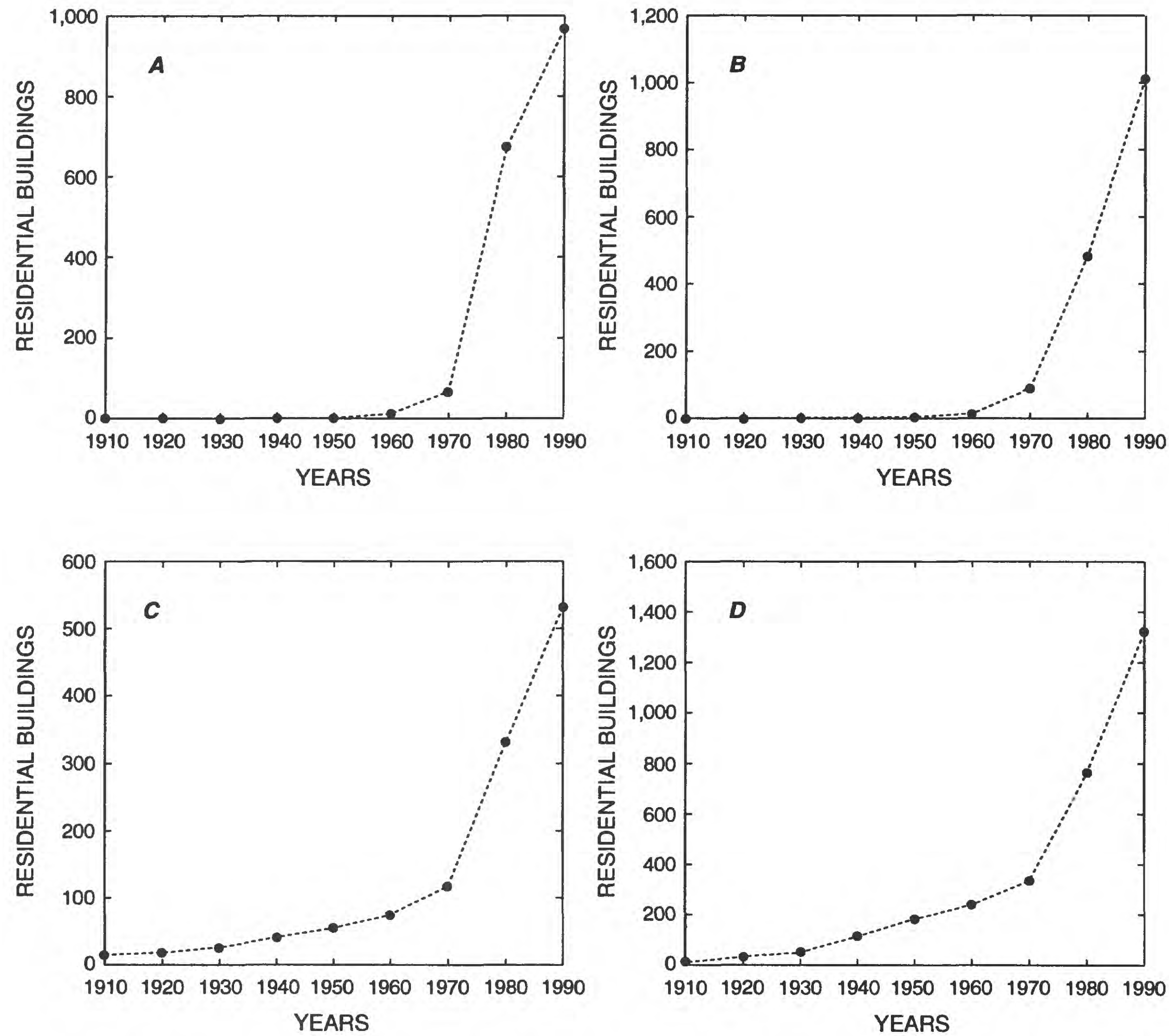

Figure 3. Residential construction in land-use areas, 1910-90, Douglas County, Nevada (Barbara Byington, Douglas County Assessor's Office, written commun., 1991). *A*, Jacks Valley–Indian Hills area; *B*, Johnson Lane area; *C*, West Carson Valley area; *D*, Minden–Gardnerville area; *E*, East Carson Valley area; *F*, Gardnerville Ranchos area; *G*, Topaz Lake area; *H*, entire study area.

Dissolved solids, the total concentration of dissolved material in water, are derived primarily from minerals in rocks near the land surface and in the aquifer. Trace contaminants added to ground water generally do not increase the dissolved-solids concentration appreciably. However, dissolved-solids concentrations may indicate altered ground-water circulation in aquifers that are stressed by excessive withdrawals or are receiving secondary recharge from lawn irrigation or individual sewage-disposal system leachate. Increased dissolved-solids concentration also may indicate that agricultural drainage, sewage, geothermal water, or industrial wastes are contaminating an aquifer.

A secondary preferred drinking-water standard for dissolved solids of 500 mg/L for public-water supplies has been adopted by the State of Nevada. If water supplies that meet the preferred standard are not available, the secondary maximum contaminant level of 1,000 mg/L goes into effect and is enforceable by the State (Nevada Bureau of Consumer Health Protection Services, 1980).

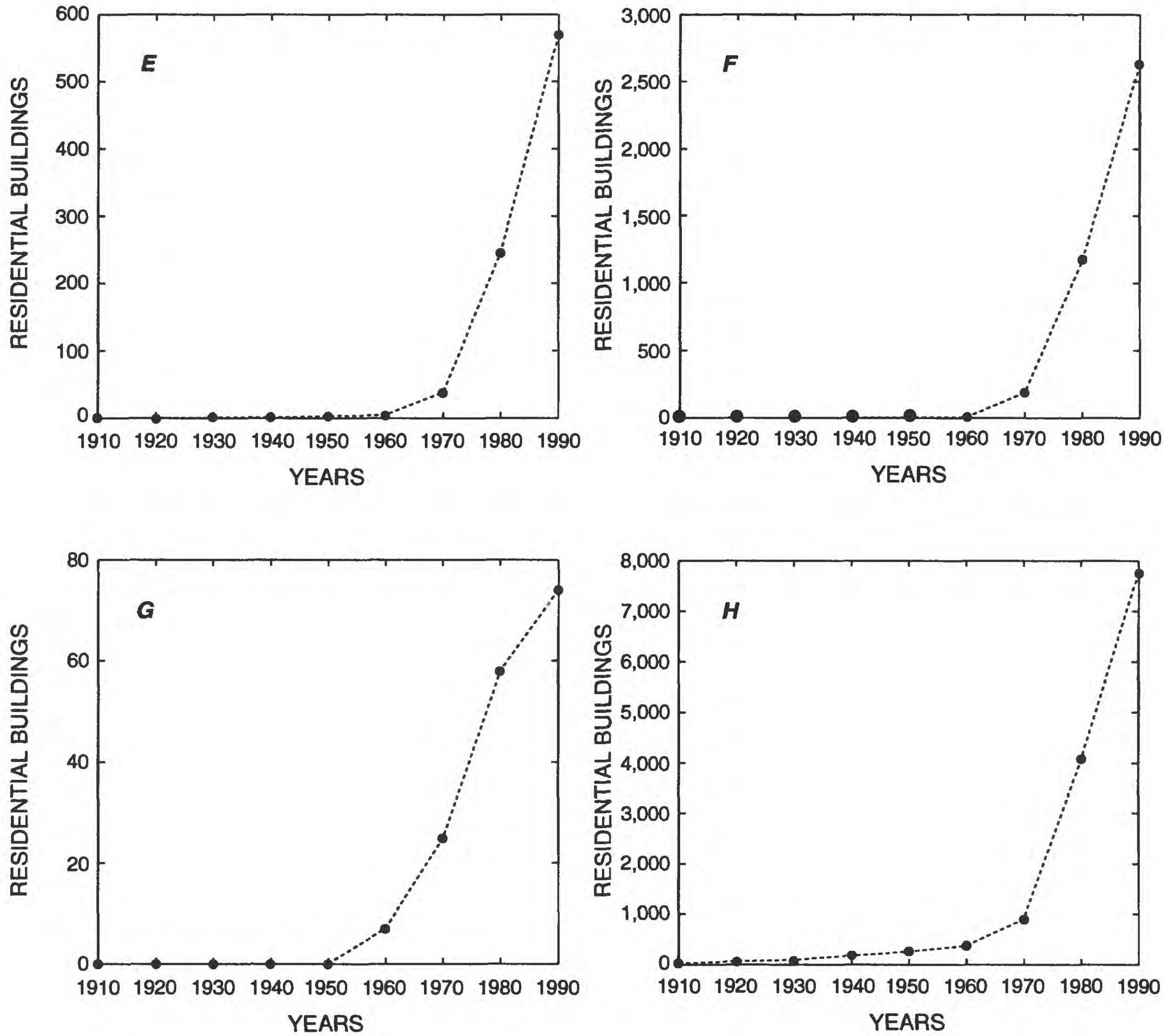

Figure 3. Continued.

Nitrate is the oxidized nitrogen compound that is most stable in aerated water. Because concentrations of nitrate that exceed 10 mg/L as elemental nitrogen in drinking water may cause methemoglobinemia in infants, the State of Nevada has adopted this concentration as a primary drinking-water standard (Nevada Bureau of Consumer Health Protection Services, 1980).

Nitrate can enter ground water from many sources, including natural ones. Natural, biologically mediated processes can hydrolyze organic nitrogen (amides, amines, amino acids, proteins, and urea) to ammonium, which is oxidized to nitrite and then to nitrate by nitrification. Agricultural activities have been cited as primary sources of nitrate contamination by fertilizer application and by livestock feedlot operations. Land application of wastewater effluent, sewage spills, landfill leachate, and lawn fertilizer have all been identified as man-induced contributions of nitrate to ground water. In addition, individual sewage-disposal leachate is rich in ammonium, which can be oxidized to nitrate as it discharges from the anaerobic conditions of the septic tank into the oxygenated unsaturated zone. Nitrate moves freely with ground-water flow, but may be biologically removed by denitrification under anaerobic conditions (Hem, 1985, p. 125-126).

METHODS OF INVESTIGATION

Water-Quality Data

The data used in this study are from analyses of 203 ground-water samples collected from 39 wells during 1985-88 by USGS personnel (Thodal, 1989; 1992) and analyses of 592 ground-water samples from 345 wells and springs collected during 1959-84 and compiled from the Nevada Bureau of Consumer Health Protection Services (NBCHPS) files and published by Garcia (1989). The entire data set of 795 samples includes 784 chloride concentrations, 749 dissolved-solids concentrations, and 769 nitrate-nitrogen concentrations. The locations of these 380 data-collection sites are shown in figure 4.

The USGS network of wells for monitoring ground-water quality in the Carson Valley and Topaz Lake areas was designed to (1) document 1985-87 conditions of ground-water quality, (2) establish a baseline from which future responses to changing land-use practices can be assessed, and (3) characterize seasonal variability of ground-water quality. Data were collected every other month at 6 "primary" sites, quarterly at 20 "long-term trend" sites, and annually at 7 "supplemental" sites during the first year of network operation (October 1985-September 1986). Sampling frequency was reduced during the second period of operation (January-August 1987) to quarterly at primary sites and biannually for long-term trend sites; nine supplemental sites were sampled once. Monitoring wells from this network are described in table 2 and locations are shown in figure 4.

Table 2. U.S. Geological Survey monitoring wells used in this study, Douglas County, Nevada

[Symbols: *, site has sufficient time-series data for individual-site trend analysis; --, no information available]

Site number[1] (fig. 4)	U.S. Geological Survey site designations[1]: Standard identification	Local identification	Land-surface altitude (feet above sea level)	Depth (feet below land surface): Well	Top of open interval	Bottom of open interval	Casing diameter (inches)	Land-use area[2] (fig. 2)
1 *	390503119463501	105 N14 E20 18ABAB1	4,760	425	151	301	8	JV/IH
2 *	385719119454701	105 N13 E20 29CDC 1	4,720	400	--	--	--	M/G
3 *	385604119435601	105 N12 E20 4ADA 1	4,780	300	100	300	16	M/G
4 *	385414119425401	105 N12 E20 15ADD 1	4,850	375	183	372	16	GR
5 *	385412119401401	105 N12 E21 18CAB 1	5,110	--	--	--	8	ECV
6 *	384333119301701	106 N10 E22 15DCB 1	5,120	--	--	--	--	TL
7	390622119470301	105 N14 E20 6CBA 1	4,835	94	70	90	8	JV/IH
8 *	390542119472001	105 N14 E19 12ADA 1	4,895	150	120	150	7	JV/IH
9 *	390457119491301	105 N14 E19 14BBD 1	5,040	100	76	96	8	JV/IH
10 *	390446119451401	105 N14 E20 17ADC 1	4,640	27	--	--	2	JL
11 *	390232119443201	105 N14 E20 28CDC 1	4,690	88	68	88	7	JL
12 *	390208119433201	105 N14 E20 34BDC 1	4,760	100	--	--	6	JL
13 *	390106119424301	105 N13 E20 2CBB 1	4,860	176	156	176	6	JL
14 *	390021119504301	105 N13 E19 9ADC 1	4,820	180	156	176	8	WCV
15 *	390017119453901	105 N13 E20 8CAA 1	4,695	130	110	125	7	ECV

Table 2. U.S. Geological Survey monitoring wells used in this study, Douglas County, Nevada—Continued

[Symbols: *, site has sufficient time-series data for individual-site trend analysis; --, no information available]

Site number[1] (fig. 4)	U.S. Geological Survey site designations[1]: Standard identification	Local identification	Land-surface altitude (feet above sea level)	Depth (feet below land surface): Well	Top of open interval	Bottom of open interval	Casing diameter (inches)	Land-use area[2] (fig. 2)
16 *	390015119500101	105 N13 E19 10DBB 1	4,680	115	80	115	8	WCV
17 *	385926119481601	105 N13 E19 13BCC 1	4,675	500	150	500	16	WCV
18 *	385801119421501	105 N13 E20 26ABB 1	4,870	130	90	130	9	ECV
19 *	385742119453801	105 N13 E20 29BDD 1	4,720	118	93	114	7	M/G
20 *	385654119431801	105 N13 E20 34ACC 1	4,790	80	--	--	8	ECV
21 *	385509119414801	105 N12 E20 11ADD 1	4,900	125	105	125	6	ECV
22 *	385352119455401	105 N12 E20 17CCD 1	4,760	91	67	87	8	WCV
23 *	385321119405002	105 N12 E20 24ADC 2	4,980	145	122	142	8	ECV
24 *	385255119482301	105 N12 E19 23DDD 1	4,740	141	121	141	9	WCV
25 *	384156119323301	106 N10 E22 29CAD 1	5,067	183	140	183	6	TL
26 *	384136119323901	106 N10 E22 32BAA 2	5,075	105	80	105	7	TL
27	390205119464301	105 N14 E20 30DCCB1	4,654	20.5	10.5	20.5	2	JL
28	390137119453601	105 N14 E20 32DCCC1	4,679	21.0	11	21	2	JL
29	390024119453501	105 N13 E20 8ACBC1	4,692	21.1	--	--	1	ECV
30	390006119453601	105 N13 E20 8CAD 1	4,700	423	123	423	16	ECV
31	385948119464401	105 N13 E20 18BAAA1	4,682	20.5	10.5	20.5	2	ECV
32	385834119464101	105 N13 E20 19ACCC1	4,694	11.0	2	11	2	ECV
33	385434119430001	105 N12 E20 15AAB 1	4,820	450	167	442	18	GR
34	390623119470501	105 N14 E20 6CBAB2	4,830	96	73	93	8	JV/IH
35	385738119465301	105 N13 E20 30BCAD1	4,695	360	200	360	16	M/G
36	385703119381301	105 N13 E21 33BCAB1	5,200	163	140	160	12	ECV
37	385410119494501	105 N12 E19 15DBAA1	4,910	300	125	--	10	WCV
38	385342119451701	105 N12 E20 20ABAA1	4,795	450	200	450	16	GR
39	384640119351801	105 N11 E21 35ABB 1	5,870	115	93	115	8	DSF

[1] In this table, wells are identified by a short site number, and by the standard identification (ID) and the local (Nevada) ID used by the U.S. Geological Survey. Except in this table, only the short site numbers (1-39) are used, for convenience, in this report.

The standard Geological Survey site ID is based on the grid system of latitude and longitude. The ID indicates the geographic location of each site, and provides a unique number for each. The ID consists of 15 digits: The first 6 denote the degrees, minutes, and seconds of latitude; the next 7 denote degrees, minutes, and seconds of longitude; and the last 2 digits (assigned sequentially) identify the sites within a 1-second grid. For example, site 385604119435601 is at 38°56'04" latitude and 119°43'56" longitude, and it is the first site recorded in that 1-second grid. The assigned number is retained as a permanent identifier even if a more precise latitude and longitude are later determined.

The local well-identification system is based on an index of hydrographic areas in Nevada (Rush, 1968) and the rectangular subdivision of the public lands referenced to the Mount Diablo base line and meridian. Each designation consists of four units separated by spaces: The first unit is the hydrographic area number. The second unit is the township, preceded by an N or S to indicate location north or south of the base line. The third unit is the range, preceded an E to indicate location east of the meridian. The fourth unit consists of the section number and letters designating the quarter section, quarter-quarter section, and so on (A, B, C, and D indicate the northeast, northwest, southwest, and southeast quarters, respectively), followed by a number indicating the sequence in which the well was recorded. For example, well 105 N12 E21 18CAB1 is in Carson Valley (hydrographic area 105). It is the first well recorded in the NW quarter of the NE quarter of the SW quarter of section 18, Township 12 North, Range 21 East, Mount Diablo base line and meridian.

[2] JV/IH, Jacks Valley-Indian Hills area; JL, Johnson Lane area; M/G, Minden-Gardnerville area; GR, Gardnerville Ranchos area; ECV, east Carson Valley area; WCV, west Carson Valley area; DSF, Double Springs Flat area; TL, Topaz Lake area.

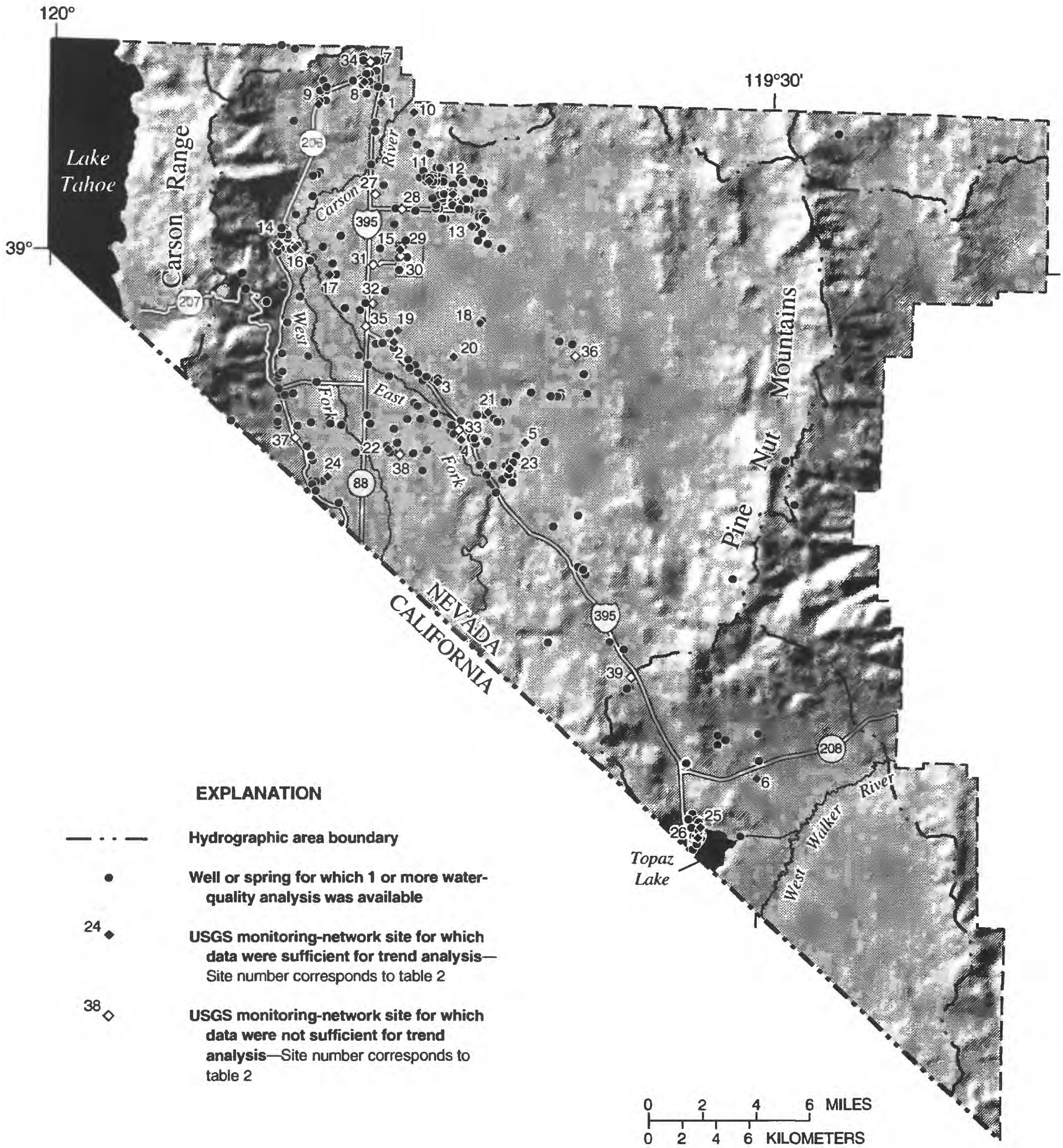

Figure 4. Location of 380 ground-water quality sites used in study, Douglas County, Nevada.

All water samples collected from the network by USGS personnel were sent to the USGS National Water Quality Laboratory in Arvada, Colo., for analysis. Concentrations of dissolved chloride were determined colorimetrically using the automated ferric thiocyanate method (Skougstad and others, 1979, p. 333-335). Concentrations of dissolved solids were determined gravimetrically by evaporating an aliquot of field-filtered sample just to dryness, using a steam bath. The residue was then dried at 180°C for 2 hours, cooled in a desiccator, and immediately weighed (Skougstad and others, 1979, p. 577-578). Water samples collected for nitrate determination were field filtered, preserved at the time of sample collection with mercuric chloride (a biocide), chilled to 4°C, and analyzed by the laboratory within 16 days. Concentrations of nitrate-nitrogen were determined by first measuring (1) the combined concentration of nitrite-nitrogen plus nitrate-nitrogen using the automated colorimetric cadmium reduction-diazotization method (Skougstad and others, 1979, p. 437-439) and (2) the concentration of just nitrite-nitrogen by the colorimetric diazotization method (Skougstad and others, 1979, p. 431-432). Nitrate-nitrogen was then determined by subtracting the concentration of nitrite from the concentration of nitrite plus nitrate.

Most of the historical data are from NBCHPS records of ground-water samples collected and submitted for analysis to the Nevada State Health Laboratory (NSHL) by property owners interested in domestic well-water quality. Additionally, public water purveyors that use ground water as the sole source of water are required to submit samples once every 3 years for analyses of inorganic constituents (Nevada Bureau of Consumer Health Protection Services, 1980). Methods of sample collection and preservation, and the elapsed time between collection and analysis, are unknown for historical data. Analytical methods reportedly used by NSHL include potentiometric titration with silver nitrate solution with a glass and silver-silver chloride electrode system for the determination of chloride concentration (Franson, 1985, p. 209-292); residue on evaporation of a laboratory-filtered sample for determination of dissolved-solids concentration (Franson, 1985, p. 95-96); and brucine colorimetry for determination of nitrate concentration (Skougstad and others, 1979, p. 429-430).

Ideally, data collected for examination of trends are obtained over a period of years in a consistent and reliable manner. Uniform methods of sample collection, handling, preservation, laboratory measurement, and data-reporting conventions should not bias the resulting data. Protocols to document changes in these factors, however, have only recently been implemented. For example, historical water-quality data are often reported as zero for concentrations that are below a minimum analytical detection level. However, analytical precision precludes measurements below a level of detection that is larger than zero. For statistical tests in this study, the reported zeros have been replaced with the detection level reported for those constituents by the USGS laboratory.

The NSHL has been a participant in a USGS quality-assurance program known as the Standard Reference Water Samples (SRWS) program since 1975, and NSHL performance has generally been excellent for determination of chloride, dissolved-solids, and nitrate concentrations (David E. Erdmann, U.S. Geological Survey, written commun., 1991). Under the SRWS program, carefully prepared reference samples approximating field samples are distributed twice yearly to more than 100 laboratories for chemical analysis. The most probable value for each constituent is determined by evaluating the results from all the laboratories using statistical techniques recommended by the American Society for Testing and Materials (Janzer, 1985, p. 330-333). NSHL standard deviations from the most probable SRWS values are shown in figures 5, 6, and 7 for chloride, dissolved solids, and nitrate-nitrogen, respectively (David E. Erdmann, U.S. Geological Survey, written commun., 1991). These graphs provide a qualitative indication that NSHL data are comparable and representative—at least since 1975. Because of the uncertainty associated with data generated prior to 1975, tests for trends in these data are not considered conclusive.

The complete data set was divided into 32 subsets and used to investigate water-quality trends in samples from individual wells that have at least 2 years of seasonal data and for areas of homogeneous land use, in addition to trends throughout the study area. Twenty five subsets consist of time-series data from 25 individual sites that were established as monitoring wells by the USGS and for which at least 2 years of data were available (table 2).

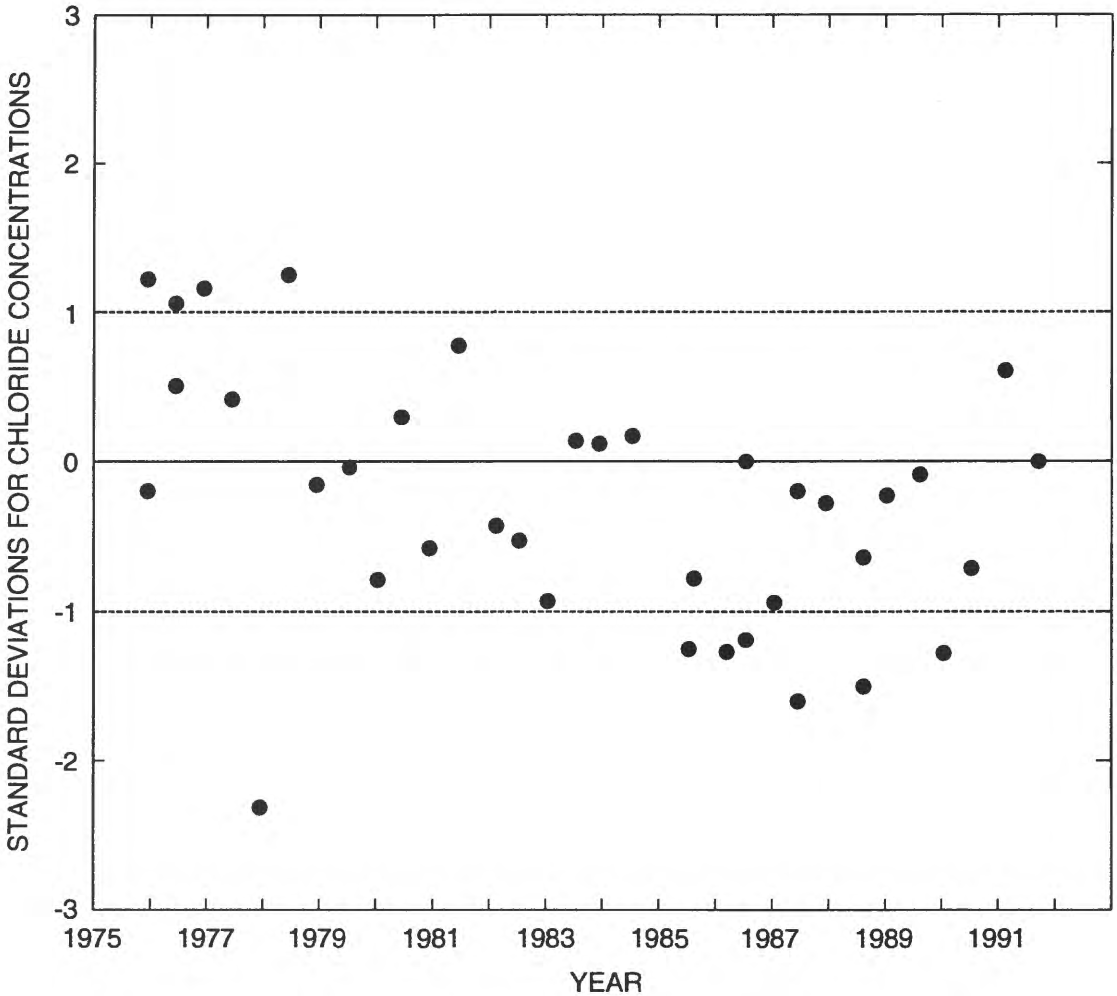

Figure 5. Nevada State Health Laboratory standard deviations from U.S. Geological Survey most probable Standard Reference Water Sample value for chloride concentrations.

Trend Detection

Trends are increases or decreases observed in a random variable through time. In water resources, trends can result from human activities or can be natural. The ability to detect trends is important for water-resources managers to identify when remedial action is warranted, and then to evaluate the effectiveness of an implemented remedial action.

Water-quality data can be analyzed qualitatively for trends by graphical display of time-series plots or quantitatively by hypothesis testing. Graphical methods are useful for illustrating extreme values, the presence and timing of interventions that may have initiated time-related changes, seasonal cycles, long-term cycles, as well as distributional characteristics of the data set (Ward and Loftis, 1986, p. 761). Hypothesis testing for trends consists of stating the hypothesis to be tested, commonly that no trend exists in the data set (null hypothesis), and calculating an appropriate test statistic from the available data. A level of statistical significance is preselected to minimize the probability of detecting a false trend (trend detected in a data set when no trend actually exists; Smith and others, 1982, p. 3-5).

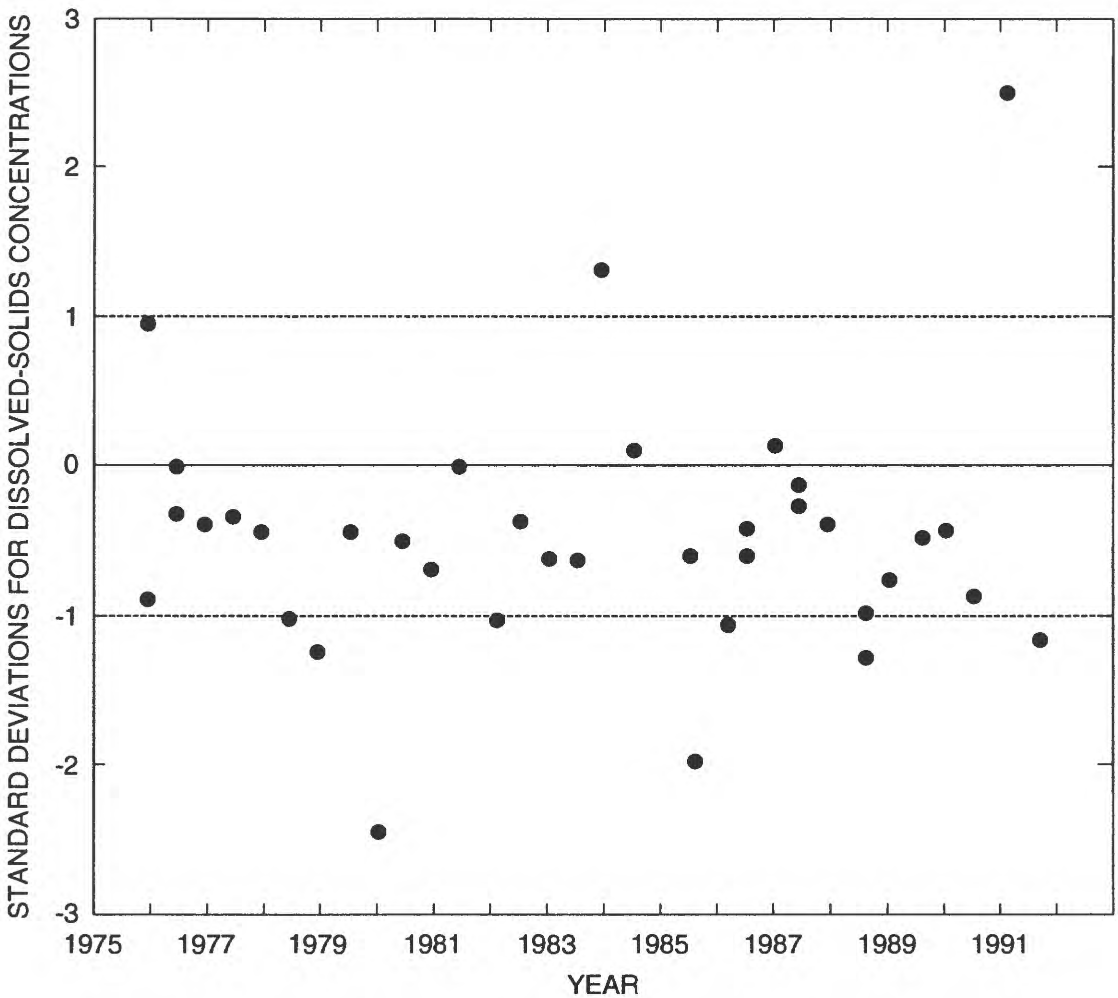

Figure 6. Nevada State Health Laboratory standard deviations from U.S. Geological Survey most probable Standard Reference Water Sample value for dissolved-solids concentrations.

Parametric hypothesis tests are based on parameter estimations (slope of a regression line, for example) that are dependent on the observed data and on the distribution of the test statistic. Test statistics are dependent on assumptions about the probability distribution of the random variable. However, the probability distribution of water-quality data commonly does not meet one or more of the assumptions on which the test statistic is based. Specifically, parametric test statistics assume normality, stationarity, and independence of the random variable (Smith and others, 1982, p. 5).

Nonparametric tests typically transform the random variable data into ranked data which makes the probability distribution of the data insignificant (Smith and others, 1982, p. 5). Because nonparametric tests are less sensitive to data-distribution features common to water-quality data, they may be applied as an exploratory tool to extract information from historical data sets and to design monitoring strategies for areas where trends are likely. False trends, however, may be inferred from changes in the sample source; from inconsistencies in analytical methods; or from different sample collection, preservation, or handling methods. Where trends are detected, data sets need to be carefully reviewed to determine whether these factors have affected the test results.

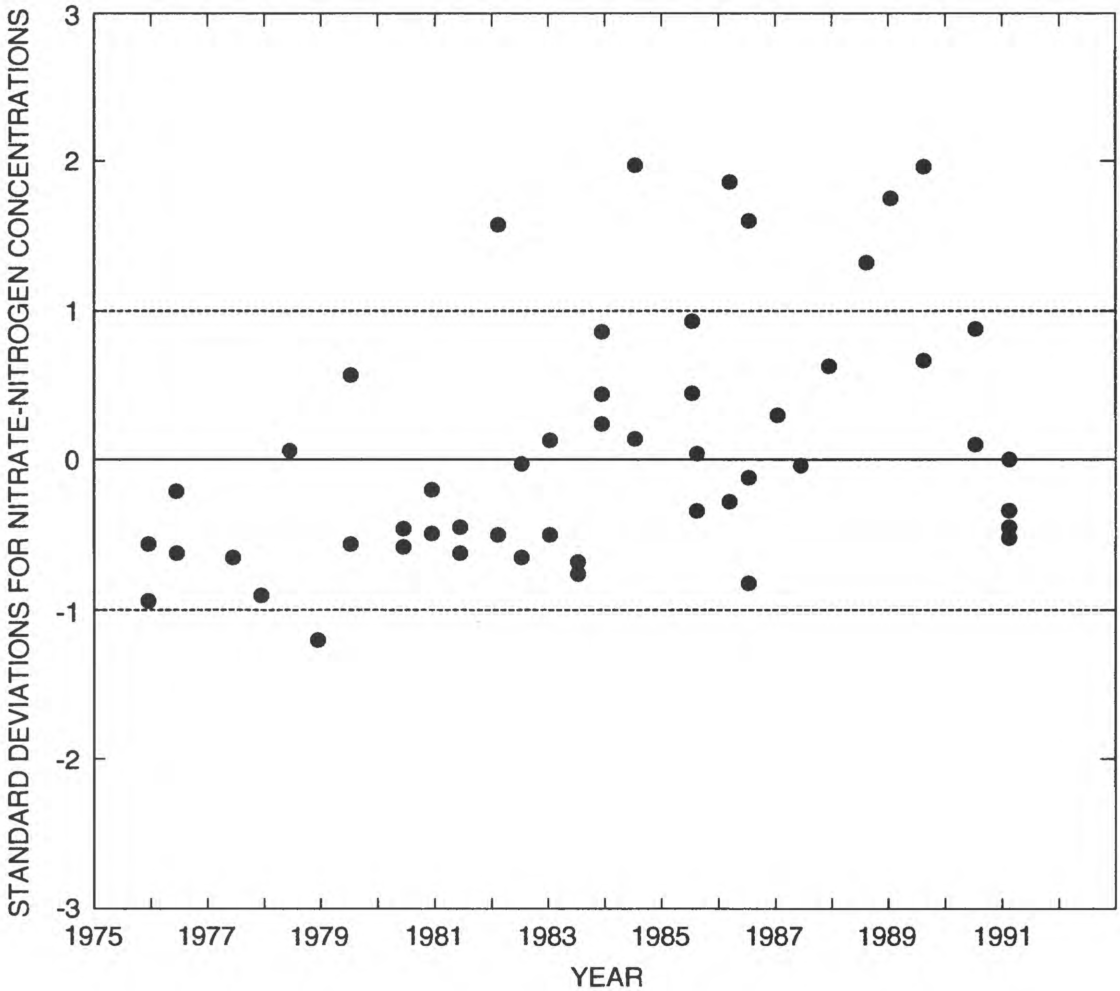

Figure 7. Nevada State Health Laboratory standard deviations from U.S. Geological Survey most probable Standard Reference Water Sample value for nitrate concentrations.

The statistical significance of a trend is expressed in terms of the p-value (or p-level), which is the smallest level of significance that will allow rejection of the null (no trend) hypothesis. The p-value is related to the level of significance, alpha (α), that is selected prior to hypothesis testing as the maximum acceptable probability of rejecting a true null hypothesis. The p-value is the level of statistical significance actually attained by the test. Thus, it provides information on the strength of the trend by indicating how small an α value can be and still reject the null hypothesis that no trend exists.

Seasonality

Seasonality is defined as the variation observed in a constituent that is dependent on the time of year. Significant seasonality will cause different probability distributions for data collected at different times of the year. Seasonality will increase the variance used to calculate the test statistic and can invalidate most statistical hypothesis tests (Smith and others, 1982, p. 5).

Seasonal variation may be natural or anthropogenic (Hipel, 1985, p. 616). For example, natural seasonality is common in surface-water-quality data as a result of seasonal variation in the source or volume of streamflow, ambient temperature, or biological activity. Seasonal variation in ground-water quality has been reported to result from seasonal fluctuation of the ground-water table caused by natural recharge. Human-induced seasonality in ground-water quality has been attributed to seasonal patterns of water use, irrigation, and land application of agricultural fertilizers (Montgomery and others, 1987, p. 180). Problems associated with seasonality may be avoided by computing test statistics for data collected during a common season (for example, traditional 3-month seasons, semiannual seasons, or monthly seasons) and then calculating a weighted average of the seasonal statistic to provide a single test for a trend (van Belle and Hughes, 1984, p. 127).

Seasonality can be evaluated graphically by displaying the distribution of data values from each season as boxplots (fig. 9). The "box" of the plot defines the distribution of the central 50 percent of the data (that is, the data between the 25th and 75th percentiles). The line dividing the box represents the median value, or the 50th percentile. Lines beyond the box, known as "whiskers," extend to the extreme (maximum and minimum) values (Montgomery and others, 1987, p. 180-182).

Seasonal Rank-Sum Test

The seasonal rank-sum procedure is a version of the Wilcoxon-Mann-Whitney rank-sum test (Iman and Conover, 1983, p. 280-287) that accounts for seasonality. All of the observations are ranked and then grouped into two data sets, before and after a specified cut-off date. The two-sample t-test is then calculated on the rank-transformed data. Step trends are detected using this test, which commonly is applied to assess the impact of an intervention, such as an abrupt land-use change or a mitigative action to clean up contamination. The null hypothesis for this test is that observations from both time periods are from the same population; thus, there are no significant differences between the seasons for that constituent. The rank transformation satisfies the assumption that both sample population distributions are normal and reduces the sensitivity of the t-test to the assumption of equal variance. Therefore, the rank-sum test may be used as an approximate test if equal variance is not a valid assumption (Iman and Conover, 1983, p. 280). Effects of seasonality are removed by computing an individual test statistic and an expected test statistic for data from each season. Composite statistics are then computed by summing all the seasonal test statistics. The individual test statistic W_i is

$$W_i = \sum_{i=1}^{n_i} R_n, \quad (1)$$

where n_i is the number of observations for season i in the first period in the time series, and

R_n is the rank of the observations for season i in the first period of the time series.

The expected test statistic $E[W_i]$ is

$$E[W_i] = [n_i(n_i + m_i + 1)]/2, \quad (2)$$

where m_i is the number of observations for season i in the second period of the time series.

The variance is

$$\mathrm{Var}[W_i] = [n_i m_i (n_i + m_i + 1)]/12. \quad (3)$$

The seasonal statistics are summed to compute the composite test statistic:

$$W = \sum_{i=1}^{\text{season}} W_i . \quad (4)$$

The composite expectation of W is

$$E[W] = \sum_{i=1}^{\text{season}} E[W_i], \quad (5)$$

and the composite variance is

$$\mathrm{Var}[W] = \sum_{i=1}^{\text{season}} W_i . \quad (6)$$

The standard normal deviate, Z, is

$$Z = \frac{W - E[W]}{(\mathrm{Var}[W])^{1/2}} . \quad (7)$$

The p-value of the test is the probability of obtaining a Z value that is as large as, or larger than, in absolute value, the value obtained if the null hypothesis were true (both data sets are from the same population; no trend). The p-value is determined from Z using the standard normal distribution (Crawford and others, 1983, p. 73-74). If the p-value is less than the significance level α, then the null hypothesis is rejected. For this study, p-values less than 0.1 are considered to be moderately significant, and p-values less than 0.05 are considered to be strongly significant. The median sample date was selected as the division between the two periods designated for each data group. Because no abrupt interventions that would have affected ground-water quality are known to have happened, use of the median date is appropriate for exploratory objectives.

Seasonal Kendall Test and Slope Estimator

The seasonal Kendall test was developed by Hirsch and others (1982, p. 108-111) on the basis of Kendall's Tau test for trends. The value of Tau (τ) can vary between -1.00 and 1.00, and indicates the frequency with which the random variable decreases (τ is less than 0) or increases (τ is greater than 0) as time increases. That is, the procedure tests for monotonic trends (sequential observations whose successive values consistently increase or decrease but do not oscillate in relative value) by comparing all possible pairs of data values with respect to time. If the later value of a pair is greater, a plus is assigned; if it is smaller, a minus is assigned. The number of pluses should approximately equal the number of minuses if no trend exists in the data (the probability of a later value being higher or lower than any previous value is 0.50). An increasing trend is indicated if the number of pluses significantly exceeds the number of minuses. A decreasing trend is indicated if the number of minuses significantly exceeds the number of pluses. The seasonal Kendall test assumes only that the random variable is independent and identically distributed. Seasonality is avoided by considering only paired values from common seasons (Smith and others, 1982, p. 5-6). The test statistic S_i is

$$S_i = \sum_{k=1}^{n_i-1} \sum_{j=k+1}^{n_i} \operatorname{sgn}(X_{ij} - X_{ik}), \qquad (8)$$

where n_i is the number of annual values for season i,

X_{ij} is the seasonal value for season i and year j, and

X_{ik} is the seasonal value for season i and year k.

Sgn $(X_{ij} - X_{ik})$ has a value of +1 if the seasonal value in year j is greater than the seasonal value in year k, a value of -1 if the seasonal value in year j is less than the seasonal value in year k, and a value of 0 if the seasonal values for years j and k are equal.

The expected value of S_i ($E[S_i]$) is 0, and its variance is

$$\operatorname{Var}[S_i] = \frac{n_i(n_i-1)(2n_i+5) - \sum_{t_i} t_i(t_i-1)(2t_i+5)}{18}, \qquad (9)$$

where t_i is the number of X's involved in a given tie for season i, and

$\sum_{t_i}$ is the summation of all ties.

The composite statistic of the seasonal statistics, S_i, is S':

$$E[S'] = \sum_{i=1}^{\text{season}} E[S_i] = 0, \qquad (10)$$

and the variance of S' is

$$\operatorname{Var}[S'] = \sum_{i=1}^{\text{season}} \operatorname{Var}[S_i]. \qquad (11)$$

The standard normal deviate, Z, is calculated by:

$$Z = \begin{cases} \dfrac{S'-1}{(\operatorname{Var}[S'])^{1/2}} & \text{if } S' > 0 \\ 0 & \text{if } S' = 0 \\ \dfrac{S'-1}{(\operatorname{Var}[S'])^{1/2}} & \text{if } S' < 0 \end{cases} \qquad (12)$$

The p-value (the probability of obtaining a Z value that is as large as, or larger than, in absolute value the value obtained if the null [no trend] hypothesis were true) is determined from the standard normal deviate using the standard normal distribution. The null hypothesis is rejected, and the alternative hypothesis that a trend exists is accepted, when the p-value is less than the preselected level of significance, α.

The test statistic τ is determined by:

$$\tau = \sum_{i=1}^{season} \frac{S_i}{n_i(n_i - 1)/2} . \qquad (13)$$

Trend magnitude is evaluated using the seasonal Kendall slope estimator, which is an expression of change per unit time (Hirsch and others, 1982, p. 117-118). This is defined as the median of the differences of the ordered pairs of data values that are compared in the seasonal Kendall test, divided by the time between the data pairs. Whereas the seasonal Kendall test evaluates the direction of the trend, the slope estimator indicates the magnitude of the trend, expressed as a slope, d_{ijk} which is computed as:

$$d_{ijk} = (X_{ij} - X_{ik}) / (j - k) \qquad (14)$$
$$\text{for all } (X_{ij}, X_{ik}) \text{ pairs ,}$$

where X is concentration value,

i is each season in year j and in year k, and j is greater than k.

The median of these seasonal slopes is taken to be the change per year due to the trend (Smith and others, 1982, p. 6).

RESULTS OF TIME-TREND ANALYSES

Summary Statistics

Populations of water-quality data generally are skewed, rather than being normally distributed. Skewness is determined by the relation of the mean to the median. Because the mean is influenced by extreme values (low or high), it will be on the same side of the median as the most extreme values. If the mean is greater than the median, the population distribution is positively skewed; if the mean is less than the median, the population is negatively skewed. Mean, standard deviation, median, maximum, minimum, and the 25^{th} and 75^{th} percentile values reported in table 3 indicate that the population distributions are positively skewed.

Locations where the primary drinking-water standard for nitrate and the secondary drinking-water standard for dissolved solids were exceeded are shown in figure 8. Fourteen samples (about 2 percent of the available data) from 6 wells exceeded the primary drinking-water standard for nitrate, and 45 samples (about 6 percent) from 27 wells exceeded the secondary drinking-water standard for dissolved solids. The secondary drinking-water standard for chloride was not exceeded in any of the samples.

Table 3. Summary statistics for all water-quality data examined in this study (1959-88), Douglas County, Nevada

[Concentrations are in milligrams per liter; values in the historical data set that were reported as zero have been replaced with the analytical reporting limits determined for the corresponding USGS analytical method.]

Constituent	Number of analyses	Mean	Standard deviation	Maximum	75th percentile	Median	25th percentile	Minimum
Chloride	784	12.3	26.0	240	11	6.0	4.0	0.1
Dissolved solids	749	290	362	3,270	288	228	161	27
Nitrate-nitrogen	769	1.4	2.2	21	1.7	.70	.27	.01

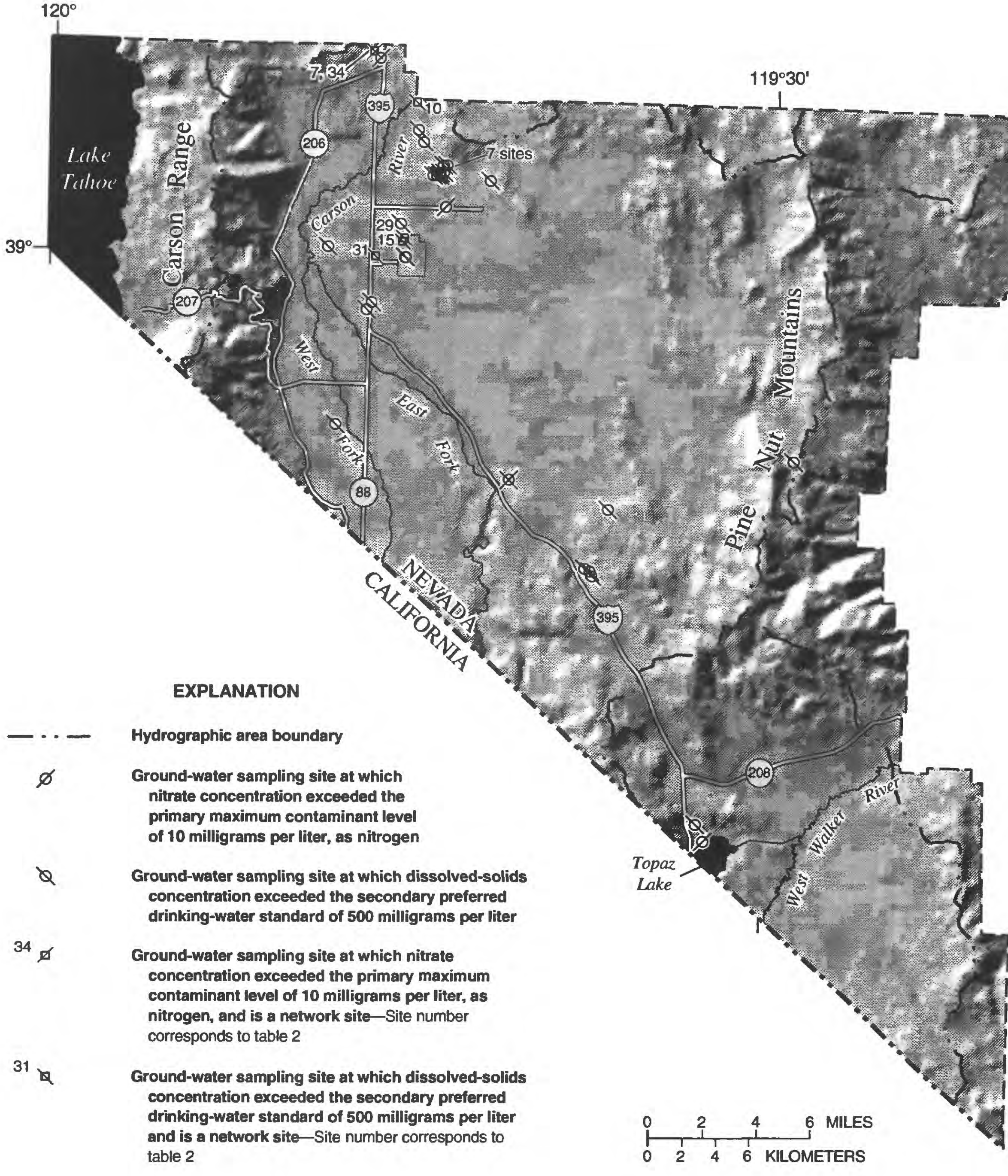

Figure 8. Location of sites where drinking-water standards for nitrate and dissolved solids were exceeded, Douglas County, Nevada.

Seasonal Distributions

Figures 10, 11, and 12graphically display the seasonal distributions of chloride, dissolved-solids, and nitrate concentrations, respectively, for both the USGS monitoring-network data (1985-88) and the complete data set (1959-88). Figure 9 provides an explanation of the boxplot components shown in figures 10-15 and 18-19. Seasonality does not appear to have affected the ground-water data used for this study. Because nonparametric tests are used for this study, the extreme values (outliers) do not unduly affect the test results. Therefore, only one season (no seasonality) was specified for analyses of data from individual wells and for analyses of data grouped by area.

Results of Trend Procedures

Rank-Sum Test

Results of rank-sum tests for step trends in data grouped by area are reported in table 4. Statistically significant decreasing step trends in chloride (-2 mg/L at a p-value of 0.037) and dissolved solids (-37 mg/L at a p-value of 0.028) were detected in the west Carson Valley data set. A moderately significant (p-value, 0.085) increasing step trend was detected in dissolved-solids concentrations (34 mg/L) for the complete data set, and significant (p-value, 0.035) increasing step trend (0.42 mg/L) was detected in nitrate data from the Johnson Lane area. No other data sets demonstrated statistically significant trends by the rank-sum test. The step values in table 4 express the difference in concentration between the two

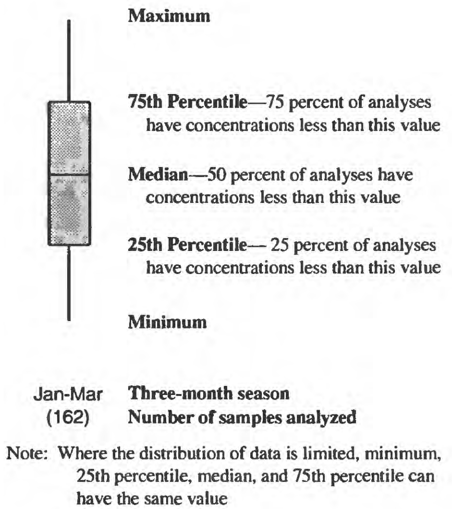

Figure 9. Components of boxplots shown in figures 10-15 and 18-19.

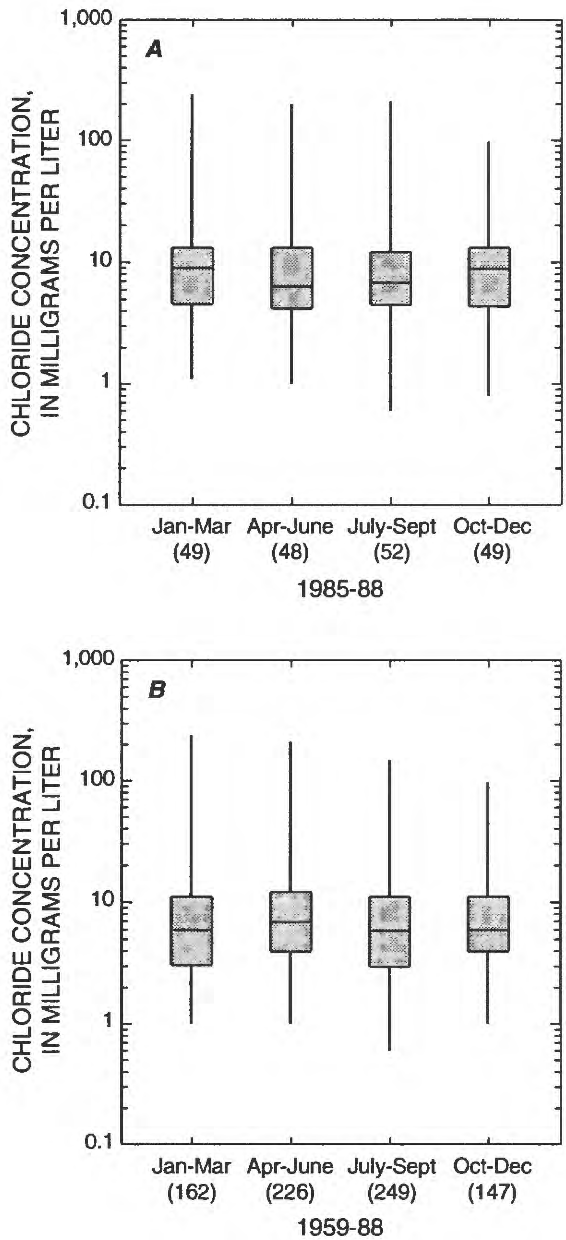

Figure 10. Seasonal distribution of chloride concentrations, Douglas County, Nevada. *A*, U.S. Geological Survey monitoring-network data, 1985-88. *B*, Complete data set, 1959-88. Analytical reporting limit, 0.1 milligram per liter.

periods. For example, the nitrate step in the Johnson Lane data set is 0.42 mg/L as N (nitrogen) and represents the difference in averaged rankings between the two periods (1971-1979 and 1979-1988). Concentrations are transformed back from averaged rank-values to estimate the change in concentrations.

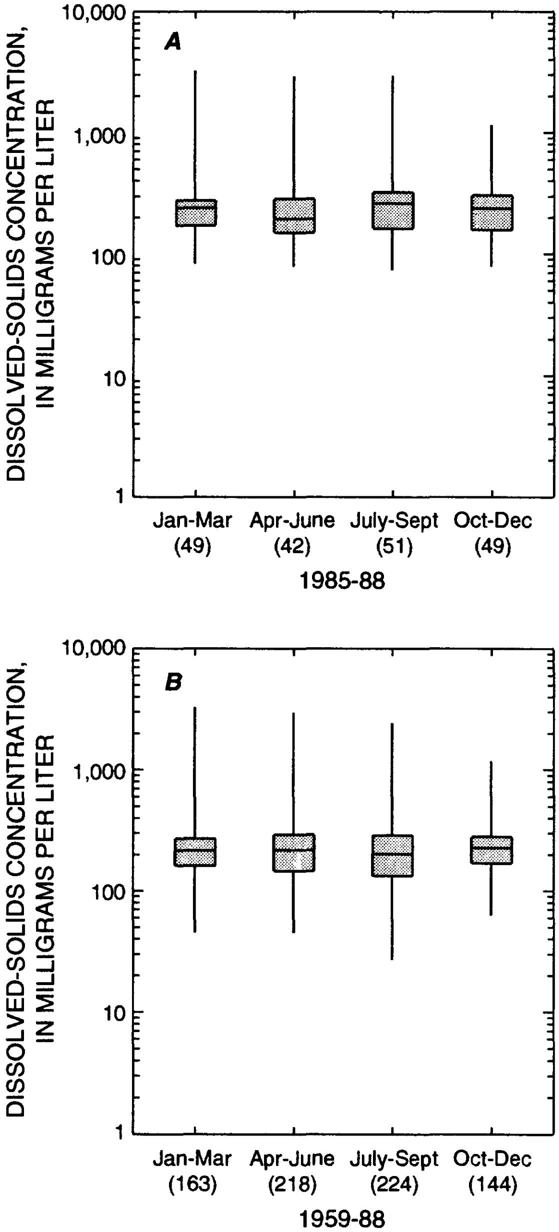

Figure 11. Seasonal distribution of dissolved-solids concentrations, Douglas County, Nevada. *A*, U.S. Geological Survey monitoring network data, 1985-88. *B*, Complete data set, 1959-88. Analytical reporting limit, 1.0 milligram per liter.

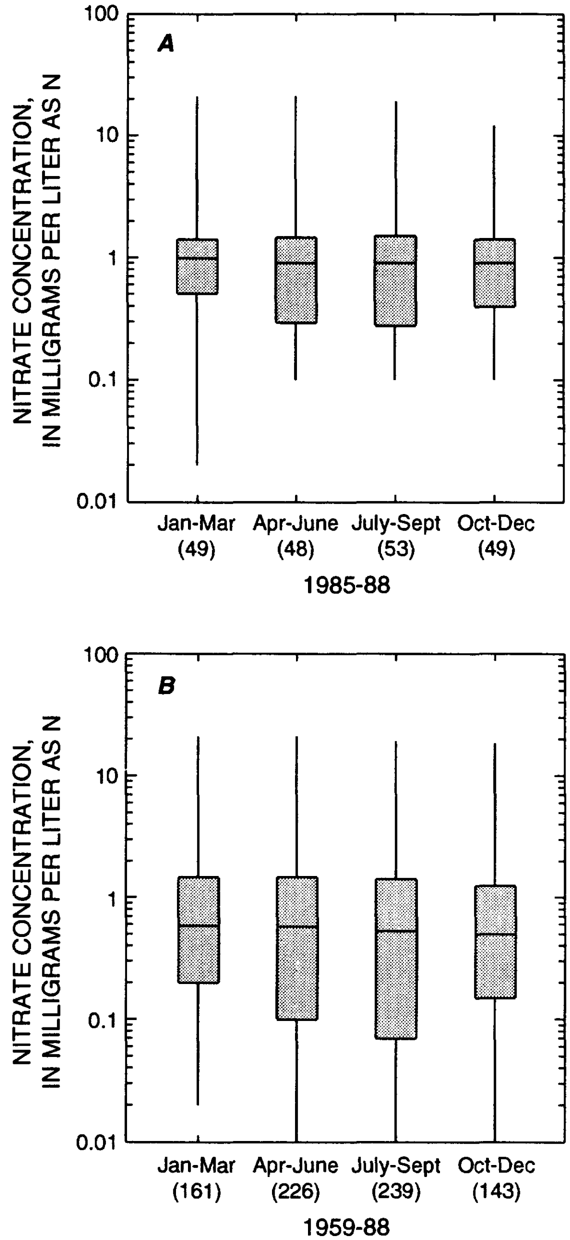

Figure 12. Seasonal distribution of nitrate concentrations, Douglas County, Nevada. *A*, U.S. Geological Survey monitoring network data, 1985-88. *B*, Complete data set, 1959-88. Analytical reporting limit, 0.01 milligram per liter.

Table 4. Results of rank-sum tests on data grouped by area, Douglas County, Nevada

[Abbreviations: NOA, number of analyses in the original data set; NOM, number of annual median concentrations determined from the original data set; Step, concentration, in milligrams per liter (mg/L), that corresponds to the difference in average ranks computed for the two time series; only shown when p-value was less than or equal to 0.1.]

Constituent	First series		Second series		P-value	Step (mg/L)
	NOA	NOM	NOA	NOM		
Jacks Valley-Indian Hills (First series, 1972-82, cutoff date, May 1982; second series, 1982-88)						
Chloride	25	9	24	4	0.754	--
Dissolved solids	25	9	23	3	.711	--
Nitrate-nitrogen	25	9	24	4	.165	--
Johnson Lane (First series, 1971-79, cutoff date, October 1979; second series, 1979-88)						
Chloride	40	7	45	7	0.949	--
Dissolved solids	40	7	43	5	.935	--
Nitrate-nitrogen	40	7	45	7	.035	0.42
Minden-Gardnerville (First series, 1968-80, cutoff date, January 1981; second series, 1981-88)						
Chloride	33	10	30	5	0.496	--
Dissolved solids	33	10	30	5	.358	--
Nitrate-nitrogen	31	9	30	5	1.000	--
Gardnerville Ranchos (First series, 1970-79, cutoff date, January 1981; second series, 1981-88)						
Chloride	14	7	16	4	0.255	--
Dissolved solids	14	7	16	4	.705	--
Nitrate-nitrogen	14	7	17	5	.871	--
East Carson Valley (First series, 1962-83, cutoff date, July 1983; second series, 1983-87)						
Chloride	42	12	44	3	0.716	--
Dissolved solids	42	12	44	3	1.000	--
Nitrate-nitrogen	42	12	44	3	.515	--
West Carson Valley (First series, 1969-78, cutoff date, July 1978; second series, 1979-87)						
Chloride	27	8	25	5	0.037	-2.0
Dissolved solids	27	8	25	5	.028	-37
Nitrate-nitrogen	27	8	25	5	.770	--
Topaz Lake area (First series, 1961-76, cutoff date, October 1976; second series, 1977-87)						
Chloride	92	10	119	9	0.653	--
Dissolved solids	67	9	116	9	.757	--
Nitrate-nitrogen	87	9	116	9	.930	--
Complete data set (First series, 1959-79, cutoff date, June 1979; second series, 1980-88)						
Chloride	424	18	354	8	0.403	--
Dissolved solids	391	18	352	8	.085	34
Nitrate-nitrogen	409	17	353	8	.907	--

Figure 13 is a graphical comparison of the distribution of chloride concentrations from the west Carson Valley area for the two periods and a similar comparison of dissolved-solids concentrations. Samples collected during the early period (1969-78) probably represent water with naturally higher concentrations compared to those represented by samples collected during the later period (1979-87). Well depths reported for these data indicate a median depth of 103 feet below land surface for 22 of the 27 samples collected during the early period compared to a median of 141 ft for 9 of the 25 samples collected for the latter period. Forty percent of these historical samples came from unknown well depths. Figure 14 compares the distribution of dissolved-solids concentrations from the entire data set divided between the two periods. The distribution of the 25th through 75th percentiles are similar. However, both the maximum and minimum of the second data set are noticeably larger, resulting in a moderately significant increasing trend.

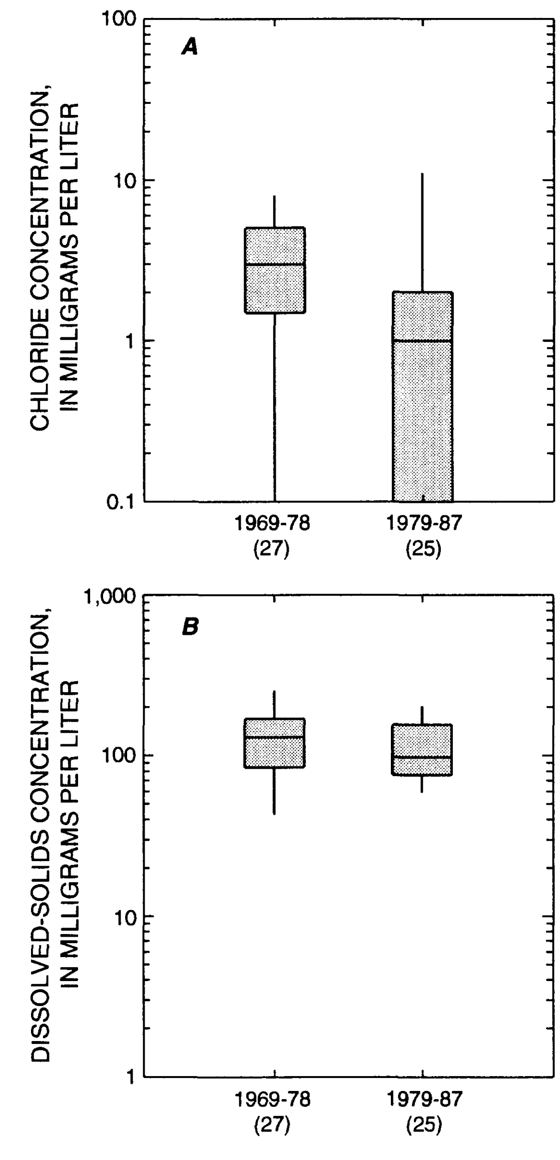

Figure 13. Distribution of (A) chloride concentrations and (B) dissolved-solids concentrations for the West Carson Valley area for two periods (1969-78 and 1979-87), Douglas County, Nevada. Number in parentheses is number of analyses. Analytical reporting limit, (A), 0.1 milligram per liter; (B), 1.0 milligram per liter.

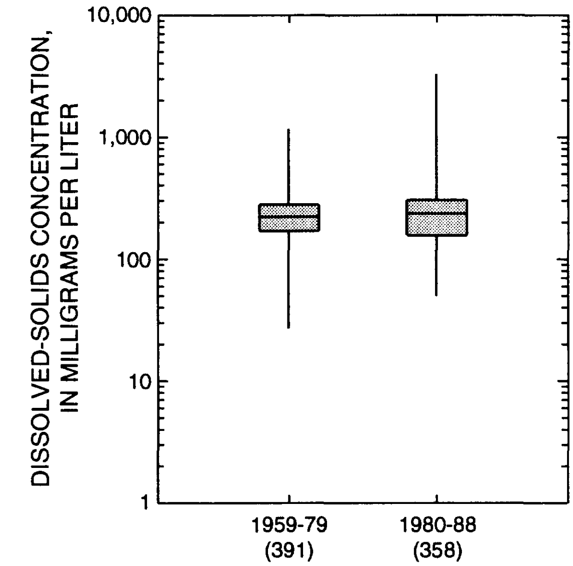

Figure 14. Distribution of dissolved-solids concentrations for complete data set for two periods (1959-79 and 1980-88), Douglas County, Nevada. Number in parentheses is number of analyses. Analytical reporting limit, 1.0 milligram per liter.

Figure 15 shows nitrate data from the Johnson Lane data set for the two periods. Although 75 percent of the sample concentrations are less than 1.0 mg/L, figure 15 shows that the trend procedure detected a significant increasing trend: 50 percent of the data from the first period are less than 75 percent of the data from the second period.

Because these data are from different sites and were collected, processed, and analyzed by different personnel and methods, the trends are not considered conclusive and indicate only that the available data on ground-water quality for the two periods represent statistically different distributions.

Kendall's Tau Test

Results of Kendall's Tau test for trends in water samples from 25 monitoring wells are reported in table 5. No trends in chloride concentrations were found to be significant at a p-value of 0.1 or less. Moderately

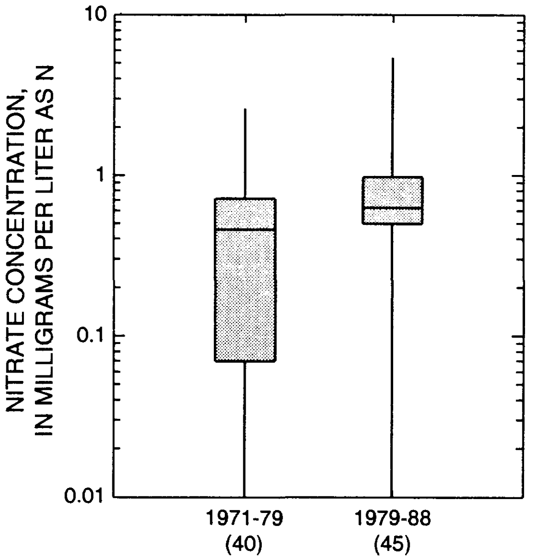

Figure 15. Distribution of nitrate concentrations for Johnson Lane area for two periods (1971-79 and 1979-88), Douglas County, Nevada. Number in parentheses is number of analyses. Analytical reporting limit, 0.01 milligram per liter.

significant (p-value, less than 0.1) increasing trends in dissolved-solids concentrations were detected at one domestic well at the Douglas County landfill (site 5) and at one domestic well in the Topaz Lake area (site 26). A moderate level of statistical significance was detected for increasing nitrate concentrations at one domestic well in the Jacks Valley-Indian Hills area (site 8), at one domestic well in the Johnson Lane area (site 11), and at two domestic wells in the Topaz Lake area (sites 25 and 26). Of these sites, trends in nitrate concentration at site 11 and site 25 and the trend in dissolved-solids concentration at site 26 are significant at p-values of 0.05 or less.

Figures 16 and 17 are time-series graphs of dissolved-solids and nitrate concentrations, respectively, for the wells where significant trends (p-value, less than 0.1) were detected. Magnitudes of trends (slope estimates) for these wells are shown as trend lines in these figures and are reported in table 5. Trend magnitudes are estimated as the median of the differences of the ordered pairs that are compared in Kendall's Tau test. Dissolved-solids concentrations have increased at an average rate of 8.5 mg/L/yr from 1980 to 1987, at a well near the Douglas County landfill (site 5) and at 4.5 mg/L/yr from 1976 to 1987, at site 26 in the Topaz Lake area. Concentrations of nitrate, as N, in the residential areas of Jacks Valley-Indian Hills and Johnson Lane (sites 8 and 11) have only increased 0.03-0.05 mg/L/yr from 1976 to 1988, whereas concentrations in the Topaz Lake area (sites 25 and 26) have increased about 0.2 mg/L/yr, as N, from 1976 to 1987.

Nitrate concentrations in ground water at these wells were below the drinking-water standard of 10 mg/L set for nitrate-nitrogen (45 mg/L, as nitrate), and the highest nitrate concentration was measured at site 26 (6.1 mg/L, as N). Concentrations of dissolved solids were below the secondary standard of 500 mg/L. If the indicated trends are the result of contamination (for example, individual sewage-disposal system leachate, fertilizer from secondary recharge from lawn irrigation, or landfill leachate), drinking-water standards may be exceeded in the future, and other waterborne substances that may be associated with the contaminant source (pathogenic microorganisms or toxic substances) could adversely affect water from domestic wells in some areas.

Detected Trends in Relation to Land Use

Statistically significant decreasing trends were detected in chloride and dissolved-solids concentrations data for wells in the west Carson Valley residential areas by the rank-sum test. Increasing trends were detected in dissolved-solids concentrations for the entire data set by rank sum and in two individual wells (sites 5 and 26; fig. 4) using Kendall's Tau. Increasing trends in nitrate concentrations were statistically significant in samples from wells in the Johnson Lane area, using the rank-sum test for step trends, and in four individual wells (sites 8, 11, 25, and 26; fig. 4) using Kendall's Tau test for monotonic trends. Monitoring sites 8, 11, 25, and 26 are privately owned and maintained domestic wells in residential areas, and site 5 is a domestic well near the Douglas County land-fill.

Areas that rely on individual domestic wells for water may be subject to ground-water contamination by direct downward migration of surface water and shallow ground water along inadequately sealed well casings (Canter and Knox, 1985, p. 59). Domestic wells are commonly drilled larger than the diameter of the well casing to accommodate a gravel pack around the perforated interval of the well. The length of the gravel-packed interval and the length of the annular space around the well casing that is backfilled with drill cuttings can be of higher permeability and can create a vertical connection between permeable zones that were previously isolated from one another by low-permeability material.

Table 5. Results of Kendall's Tau tests on data for monitoring wells, Douglas County, Nevada

[Slope, expressed as milligrams per liter per year, shown only for p-values less than or equal to 0.1; median is median concentration, in milligrams per liter, from each time-series data set.]

Site number (fig. 4)	Period of record	Number of analyses	Chloride Tau	Chloride P-value	Chloride Slope	Chloride Median	Nitrate Tau	Nitrate P-value	Nitrate Slope	Nitrate Median	Dissolved solids Tau	Dissolved solids P-value	Dissolved solids Slope	Dissolved solids Median
1	1986-87	10	1.00	1.000	--	12	-1.00	1.000	--	1.2	1.00	1.000	--	163
2	1969-87	13	-.24	.548	--	4.6	-.14	.764	--	.32	.14	.764	--	132
3	1984-87	11	-1.00	.296	--	10	1.00	.296	--	1.2	.33	1.000	--	254
4	1979-88	12 (13 nitrate)	.0	1.000	--	6	.33	.452	--	.91	.0	1.000	--	151
5	1980-87	13	.0	1.000	--	15	-.70	.130	--	4.4	.80	.086	8.5	244
6	1978-87	11	-.33	1.000	--	3.4	-.33	1.000	--	.56	-.33	1.000	--	316
8	1976-88	8 (7 dissolved solids)	-.17	1.000	--	13	1.00	.089	0.03	.35	-1.00	.296	--	161
9	1986-88	7 (6 dissolved solids)	-.33	1.000	--	1.0	.0	1.000	--	1.0	-1.00	1.000	--	80
10	1986-88	12 (11 nitrate)	1.00	.296	--	215	-.67	.540	--	.1	1.00	.296	--	3,060
11	1979-88	9 (8 dissolved solids)	.0	1.000	--	13	1.00	.027	.05	.61	.67	.308	--	338
12	1979-87	7	1.00	.296	--	11	1.00	.296	--	.93	.33	1.000	--	262
13	1979-87	7	.33	1.000	--	9.4	.67	.540	--	1.4	1.00	.296	--	271
14	1986-87	6	-1.00	1.000	--	1.2	-1.00	1.000	--	.2	-1.00	1.000	--	174
15	1976-87	6	-.33	1.000	--	19	1.00	.296	--	.1	-.33	1.000	--	280
16	1986-87	6 (5 dissolved solids)	-1.00	1.000	--	2.1	.0	1.000	--	1.5	-1.00	1.000	--	127
17	1983-87	7	1.00	.296	--	4	1.00	.296	--	.32	1.00	.296	--	146
18	1983-87	8	-.33	1.000	--	7.7	-1.00	.296	--	.64	1.00	.296	--	234
19	1986-88	7 (6 dissolved solids)	-1.00	.296	--	5.6	-.67	.540	--	2.0	-1.00	1.000	--	288
20	1983-87	7	.33	1.000	--	4.3	.33	1.000	--	.59	-1.00	.296	--	203
21	1981-87	7	.33	1.000	--	9.0	1.00	.296	--	1.0	-.33	1.000	--	180
22	1978-88	8 (7 dissolved solids)	.67	.308	--	5.2	.67	.308	--	1.3	1.00	.296	--	153
23	1977-87	7	.33	1.000	--	22	.33	1.000	--	2.9	1.00	.296	--	348
24	1981-87	7	-.33	1.000	--	1.1	.67	.540	--	.1	.33	1.000	--	82
25	1976-87	13 (12 dissolved solids)	.40	.462	--	4.5	.90	.043	.05	2.5	.40	.221	--	340
26	1976-87	14 (13 dissolved solids)	.60	.221	--	12	.80	.086	.24	3.8	1.00	.027	4.5	271

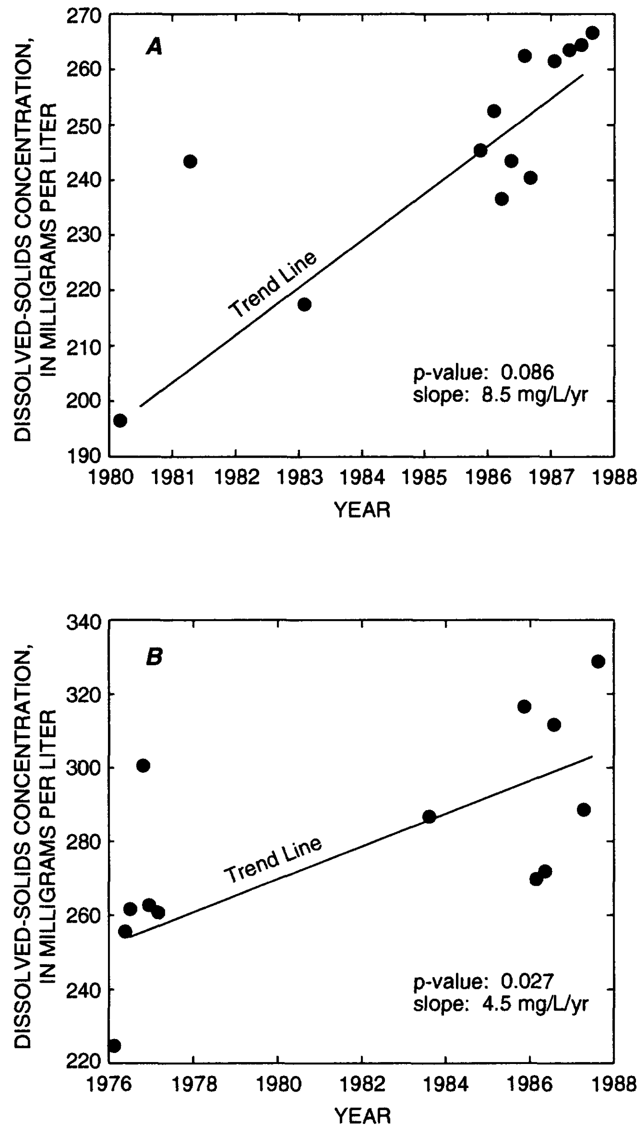

Figure 16. Time series (1980-87 and 1976-87) concentrations of dissolved solids for monitoring wells where statistically significant trends were indicated, Douglas County, Nevada. *A*, site 5, east Carson Valley area. *B*, site 26, Topaz Lake area. Abbreviation: mg/L/yr, milligrams per liter per year.

The decreasing step-trends in concentrations of chloride and dissolved solids for water samples from the west Carson Valley area suggest that data collected during the early time period (1969-1978) may not represent the same aquifers as data collected during the later time period (1979-1987). This is one of the potential problems of not using data collected from an established monitoring network. The decreasing trend in chloride concentrations may have been caused by varying precision of analyses or reporting conventions, because eight values (32 percent) were reported as zero after 1978 compared to just one zero value (4 percent) reported in the first period (1969-1978), but no obvious explanation is available for the associated decrease in dissolved-solids concentrations. In light of these potential problems, the exploratory nature of these statistical analyses can not be overemphasized.

The increasing trend in dissolved-solids concentrations at site 5 is probably due to leachate from the nearby landfill. Concentrations of dissolved solids in landfill leachate normally range from 1,000 to 45,000 mg/L (Canter and others, 1987, p. 90). The estimated magnitude of the trend at site 5 is 8.5 mg/L/yr. In addition to the indicated trend in dissolved-solids, analyses of samples from this well have also identified low-level concentrations of man-made organic compounds (Thodal, 1992, p. 39), which are not found in natural ground water, but are common in landfill leachate (Freeze and Cherry, 1979, p. 424-5).

Data from site 26 (in the Topaz Lake area) indicate an increasing trend in dissolved-solids concentrations, in addition to an increasing trend detected in nitrate concentrations. Leachate from individual sewage-disposal systems may cause the increasing concentrations of dissolved solids. Water-level measurements made in this well during the 1985-87 monitoring period were frequently below the top of the perforated intake interval. This condition is likely to result in increasing concentrations of dissolved solids because solutes from land-surface sources are in higher concentrations near the water table and decrease with depth due to dilution.

The apparent increasing trend in dissolved-solids concentrations for the entire data set may be an artifact of changes in the characteristics of the sample population (wells) over time. For example, samples from shallow (less than 40 ft below land surface) observation wells in Carson Valley typically have dissolved-solids concentrations in excess of the secondary drinking-water standard (500 mg/L; Thodal, 1989; 1992) and greatly in excess of dissolved-solids concentrations found in domestic water in Carson Valley. Prior to 1980, only 2 samples were collected from 2 shallow wells and both exceeded that standard, but after 1980, that standard was exceeded in 11 ground-water samples from 7 shallow observation wells.

Physical mechanisms, which might result in trends of increasing nitrate concentrations in ground water, include dissolution of mineral deposits

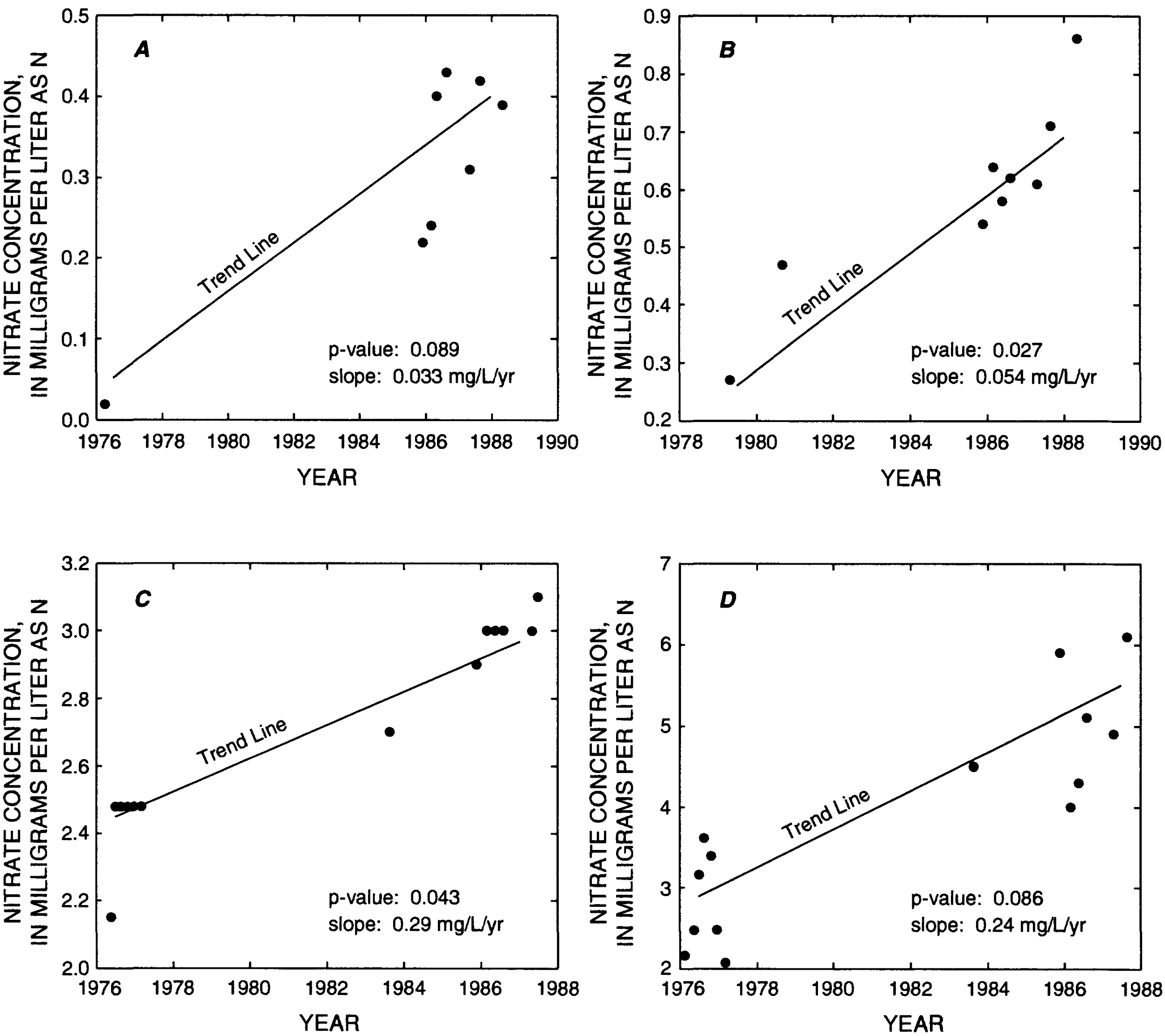

Figure 17. Time-series (1976-88) concentrations of nitrate for monitoring wells where statistically significant trends were indicated, Douglas County, Nevada. *A*, site 8, Jacks Valley–Indian Hills area. *B*, site 11, Johnson Lane area. *C*, site 25, Topaz Lake area. *D*, site 26, Topaz Lake area. Abbreviations: mg/L/yr, milligrams per liter per year; N, nitrogen.

containing nitrate, decomposition of natural organic deposits in recharge areas or buried in the aquifers, contamination from individual sewage-disposal system effluent, livestock waste, or from lawn and landscape fertilizers. In addition, "false trends" could be a result of the different handling, preservation, or analytical methods that were used. Because the effects of past sample-collection and analytical methods cannot be evaluated, and because omitting past data would eliminate much of the temporal data set, historical data values are presumed to be accurate.

In agricultural areas, fertilizer application and livestock feedlots are potential contaminant sources for nitrate in ground water (Canter and others, 1987, p. 17-18). However, feedlots are not common in the study area except at small- to medium-sized dairy farms. A feedlot is on Centerville Lane in the west Carson Valley land-use area, another is about 2 mi southeast of Genoa, and a third is just north of Airport Road in the east Carson Valley land-use area. No feedlots are in residential areas. Surrounding agricultural land is used predominantly for pasture and alfalfa—

crops which require minimal fertilizer application. Because alfalfa has the capability of converting atmospheric nitrogen into ammonium, this crop potentially can contribute nitrogen to the local ground water.

Natural sources are not likely to cause the indicated trends unless ground-water flow patterns or the oxidation-reduction potential of the ground water has changed during the period considered (1959-88). Rather, nitrate sources to ground water underlying residential areas are probably due to individual sewage-disposal systems or lawn and landscape fertilizers. Nitrate contamination by either of these sources could be facilitated by construction characteristics of individual domestic wells.

Nationally, of all sources of ground-water contamination, individual sewage-disposal systems discharge the greatest volume of wastewater to ground water and have been the most frequently reported source of ground-water contamination (Canter and Knox, 1985, p. 2). All of the statistically significant trends in nitrate concentration detected for this study are in residential areas that rely on individual sewage-disposal systems for treatment of domestic waste. Individual sewage-disposal systems typically consist of a water-tight, covered receptacle (septic tank) designed to receive domestic waste, separate solids, digest organic wastes, store digested solids, and clarify liquids that are then discharged for final disposal to a soil-absorption system, a leach field (Nevada Bureau of Health Protection Services, 1992).

Design of individual sewage-disposal systems is determined by factors such as lot size, septic-tank volume, soil-percolation tests, depth to seasonal high ground-water table, and the location of property lines, structures, and water sources. Individual sewage-disposal systems constructed in Nevada prior to 1972, when these design standards were adopted, are not subject to enforceable guidelines (Nevada Bureau of Health Protection Services, 1992).

The highest nitrate concentrations of the four wells with statistically significant trends in nitrate were 2.1-6.1 mg/L, as N, for site 26, and the second highest concentrations were 2.1-3.1 mg/L, as N, for site 25. Both these sites are in the Topaz Lake area where possible contamination of ground water by individual sewage-disposal systems has been reported previously (Nowlin, 1982, p. 41).

Density of individual sewage-disposal systems is greatest in the Topaz Lake area where lot sizes are less than one-half an acre. In addition, all domestic and commercial water uses are supplied by ground water, primarily by individual wells. State regulations require a minimum area of 1 acre for lots using both an individual sewage-disposal system and an individual well, but the Topaz Lake area was subdivided prior to the regulations (Nowlin, 1982, p. 7-8). The very stony, sandy-loam soil dominating the Topaz Lake area has a moderate rating for septic-tank absorption fields due to flooding, slope, and large stones (Candland, 1984, p. 396). Soil permeability is "the quality of the soil that enables water to move downward through the profile" (Candland, 1984, p. 282); in the Topaz Lake area, soil permeability is described as moderately rapid (2.0-6.0 in/hr; Candland, 1984, p. 73-74).

Grouped nitrate data from Topaz Lake ground-water samples show no significant trend by the rank-sum test. Figure 18 shows the data distribution for the two periods for nitrate concentrations from the Topaz Lake area. The median concentration increased from 0.42 mg/L, as N, in the first period (1961-1976) to 0.56 mg/L, as N, in the second period (1977-1987), but the distribution of the sample population has not shifted sufficiently to result in a statistically significant step trend.

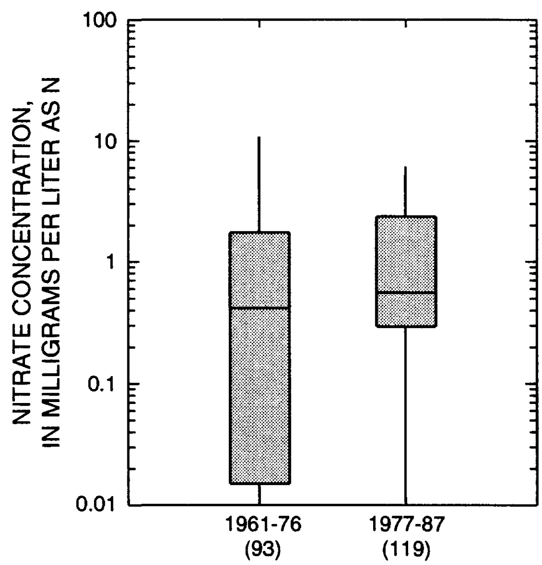

Figure 18. Distribution of nitrate concentrations for the Topaz Lake area for two periods (1961-76 and 1977-87), Douglas County, Nevada. Abbreviation: N, nitrogen. Number in parentheses is number of analyses. Analytical reporting limit, 0.01 milligram per liter.

Site 11 (in the Johnson Lane area) had the third highest nitrate concentrations (0.3-0.9 mg/L, as N) and site 8 (in the Jacks Valley-Indian Hills area) had the lowest nitrate concentrations (0.02-0.43, mg/L as N) of the four individual sites with statistically significant trends. Both of these residential areas have a minimum lot size of 1 acre, rely on ground water (individual domestic wells and public-supply wells) for all water uses, and treat domestic wastes by individual sewage-disposal systems. Soil classes that dominate in these areas range from fine sandy loam and clayey-loam sand (slow permeability, 0.06-0.20 in/hr; Candland, 1984, p. 54-63) to loamy coarse sand and gravelly loamy coarse sand (rapid permeability, 6.0-20 in/hr; Candland, 1984, p. 104-105). The dominant soil types in both areas have severe limitations for septic-tank absorption fields. Properties of these soil types are considered unfavorable due primarily to ineffective filtering of wastewater effluent as a result of rapid permeability or an impermeable layer near land surface (Candland, 1984, p. 394-403).

Compared to the nitrate concentrations from ground water in the Topaz Lake area, the lower nitrate concentrations at sites 8 (in the Jacks Valley-Indian Hills area) and 11 (in the Johnson Lane area) indicate that the larger lot sizes and, thus, the lower density of individual sewage-disposal systems have resulted in a lesser effect on the ground-water quality. However, other factors—including effects of commercial use of individual sewage-disposal systems in the Topaz Lake area, the age and design of individual systems, the proximity of wells to individual systems, and the effectiveness of the receiving soil in treatment of septic-tank effluent—can affect the concentrations of nitrate in ground-water samples.

The step trend in nitrate concentrations from the Johnson Lane data set has an estimated 0.42 mg/L, as N, increase in concentration over the 18-year period of record. Figure 15 illustrates the change in distribution between the two sample populations and shows that median values of nitrate concentrations increased from 0.46 mg/L, as N, in the first period (1971-1979) to 0.63 mg/L, as N, in the second period (1979-1988).

Although the test for a step trend in nitrate concentrations in the Jacks Valley-Indian Hills historical data set was not statistically significant, the monotonic trend for the time-series data at monitoring site 8 indicates a statistically significant increase in nitrate concentrations for that particular well. Figure 19 shows the data distribution of nitrate concentrations in the Jacks Valley-Indian Hills area for the two periods. The median values of nitrate concentrations for the two time periods have increased only slightly (1972-82: 0.99 mg/L, as N; 1982-88: 1.2 mg/L, as N). However, the increased range in nitrate values in the third quartile (50^{th} to 75^{th} percentile) indicates that the two sample-population distributions may be different.

Results of trend analysis on historical data sets are questionable due to the many uncertainties about sample acquisition, handling, analyses, and reporting. These uncertainties restrict the interpretations and conclusions from such trend analysis to an exploratory level. Futhermore, identified statistical trends may not continue in the future at the estimated rate derived from the historical data. Rather, this type of analysis is best suited for identifying potential problem areas or activities and for designing monitoring programs that allow for more accurate evaluation of ground-water quality. The quality of ground water in Douglas County currently is suitable for most uses. Continued, long-term operation of a ground-water monitoring program permits surveillance of ground-water quality and develops a consistent data base to use in analysis of trends and effects of land use.

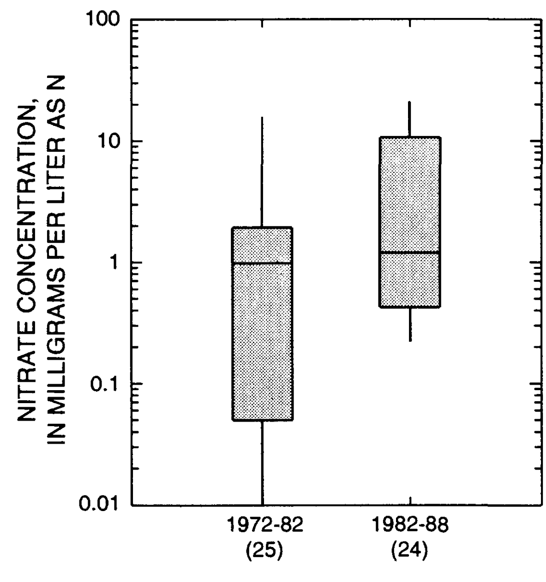

Figure 19. Distribution of nitrate concentrations for the Jacks Valley-Indian Hills area for two periods (1972-82 and 1982-88), Douglas County, Nevada. Abbreviation: N, nitrogen. Number in parentheses is number of analyses. Analytical reporting limit, 0.01 milligram per liter.

SUMMARY

Rapid population growth in Douglas County, an area of about 750 mi^2 in northwestern Nevada, has led to concern about the present and future effects of development on ground water, the principal source of drinking water for most of Douglas County. This report describes the results of two nonparametric statistical procedures applied to detect trends in ground-water concentrations of chloride, dissolved solids, and nitrate. The water-quality data set includes analyses of 203 ground-water samples collected from 39 wells during 1985-88 by USGS personnel and analyzed at the USGS National Water Quality Laboratory, and analyses of 592 ground-water samples from 345 wells and springs collected during 1959-84 and compiled from the Nevada Bureau of Consumer Health Protection Services files. The entire data set includes 795 analyses from wells and springs in the Carson Valley and Topaz Lake areas of Douglas County and comprises 784 chloride concentrations, 749 dissolved-solids concentrations, and 769 nitrate-nitrogen concentrations.

Statistically significant differences in the distribution of concentrations between selected time intervals were tested by applying a version of the Mann-Whitney-Wilcoxon rank-sum test to the entire data set and to subsets of the data set that represent seven areas in the study area delineated by land use. Tests for monotonic trends in routinely sampled wells were made by applying Kendall's Tau test and slope estimator to time-series data available from 25 individual wells that were operated as monitoring wells by the USGS, in cooperation with Douglas County.

The water-quality data used for this study indicate that ground water in the study area is generally suitable for most purposes. The secondary drinking-water standard for chloride was not exceeded. Forty-five samples (about 6 percent) at 27 wells exceeded the secondary drinking-water standard for dissolved solids, and 14 samples (about 2 percent of the available data) at 6 wells exceeded the primary drinking-water standard for nitrate.

Statistically significant decreasing step trends in chloride data (p-value, 0.037) and dissolved-solids data (p-value, 0.028) were detected in the west Carson Valley data set. A moderately significant increasing step trend (p-value, 0.085) was detected in dissolved-solids data for the complete data set for the entire county, and an increasing step trend (p-value, 0.035) was detected in nitrate data from the Johnson Lane area. No other data sets had statistically significant trends by the rank-sum test.

The decreasing step trends in concentrations of chloride and dissolved solids for water samples from the west Carson Valley area suggest that data collected during the early time period may not represent the same aquifers as data collected during the later period. Differing analytical precisions or reporting conventions may have caused the apparent decreasing trend in chloride concentrations: eight concentrations (32 percent) were reported as zero after 1978 compared to just one zero concentration (4 percent) reported in the first period (1969-1978). However, because no obvious explanation is available for the associated decreasing trend in dissolved-solids concentrations for the area, concentrations of chloride may have decreased during the period of record. Similarly, the increasing trend in dissolved-solids concentrations in the entire data set probably results from testing for trends in data sets that do not necessarily sample the same population (ground-water source) over time. However, because detailed information about historical land uses, construction, and water-yielding characteristics of sample sites are generally unknown, potential causes of the indicated trends cannot be conclusively identified.

The increasing step trend in nitrate concentrations from the Johnson Lane data set has an estimated 0.42-mg/L, as N, change in concentration over the 18-year period of record. The change in distribution between the two sample populations shows that median values of nitrate concentrations increased from 0.46 mg/L, as N, in the first period (1971-1979) to 0.63 mg/L, as N, in the second period (1979-1988).

Kendall's Tau tests that had a moderate level of statistical significance (p-value less than 0.1) detected increasing dissolved-solids concentrations in samples from one domestic well near the Douglas County landfill (site 5) and from one domestic well in the Topaz Lake area (site 26). Moderately significant increasing trends in nitrate concentrations were detected in samples from one domestic well in the Jacks Valley-Indian Hills area (site 8), from one domestic well in the Johnson Lane area (site 11), and from two domestic wells in the Topaz Lake area (sites 25 and 26). Of these sites, the trend in dissolved-solids concentrations at site 26 and trends in nitrate concentrations at site 11 and

site 25 are significant at p-values of 0.05 or less. No trends in chloride concentrations were found to be significant at a p-value of 0.1 or less.

The increasing trend in dissolved-solids concentrations (8.5 mg/L/yr) detected at site 5 is probably due to leachate from the nearby landfill. In addition to the indicated trend in dissolved solids, analyses of samples from this well have also identified low-level concentrations of man-made organic compounds, which are not found in natural ground water but are common in landfill leachate (Thodal, 1992, p. 39).

The highest nitrate concentrations of the four sites with statistically significant increasing trends in nitrate concentrations were reported for site 25 (2.1-6.1 mg/L, as N) and the second highest nitrate concentrations were reported for site 26 (2.1-3.1 mg/L, as N). Both these sites are in the Topaz Lake area, where the density of individual sewage-disposal systems is greatest and lot sizes are less than one-half acre. Data from site 26 also indicate an increasing trend in dissolved-solids concentrations in addition to an increasing trend in nitrate concentrations. Leachate from individual sewage-disposal systems may cause the increasing concentrations of dissolved solids. Site 11 had the third highest nitrate concentrations (0.3-0.9 mg/L, as N), and site 8 had the lowest nitrate concentrations (0.02-0.43 mg/L, as N) of the four trend sites. These two sites are in residential areas that have a minimum lot size of 1 acre and treat domestic wastes by individual sewage-disposal systems.

Compared to the nitrate concentrations from ground water in the Topaz Lake area, the lower nitrate concentrations at site 8 in the Indian Hills-Jacks Valley area and at site 11 in the Johnson Lane area indicate that the larger lot size and, thus, the lower density of individual sewage-disposal systems, has resulted in a smaller effect on the ground-water quality. However, other factors, including effects of commercial use of individual sewage-disposal systems in the Topaz Lake area, the age and design of individual systems, the proximity of wells to individual sewage-disposal systems, and the effectiveness of the receiving soil in treatment of septic-tank effluent, can affect the concentration of nitrate in ground-water samples.

Although the test for a step trend in nitrate concentrations for the Jacks Valley-Indian Hills data set was not statistically significant, the significant trend detected at site 8 indicates that nitrate concentrations have increased, at least in the immediate vicinity of that particular well. The median values of nitrate concentrations for the two periods has increased only slightly (1972-82: 0.99 mg/L, as N; 1982-88: 1.2 mg/L, as N). However, the increased range in the third quartile (1972-82: 0.99-1.9 mg/L, as N; 1982-88: 1.2-11 mg/L, as N) suggests that the two sample population distributions may be different.

Results of trend analysis on historical data sets are subject to question due to the many uncertainties about sample acquisition, handling, analyses, and reporting conventions. These uncertainties restrict the interpretations and conclusions from such trend analyses; identified trends may not continue at an estimated magnitude or rate into the future. Rather, this type of analysis is best suited for identifying potential problem areas or activities and for designing monitoring programs that allow for a more accurate evaluation of ground-water quality. The quality of ground water in Douglas County is currently suitable for most uses. Trends indicating increasing concentrations of nitrate or dissolved solids do not imply that concentrations will continue to increase or that they may eventually exceed drinking-water standards. But they can be an indication of potentially problematic land-use practices. This information may be useful when refining monitoring strategies or developing future land-use plans.

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