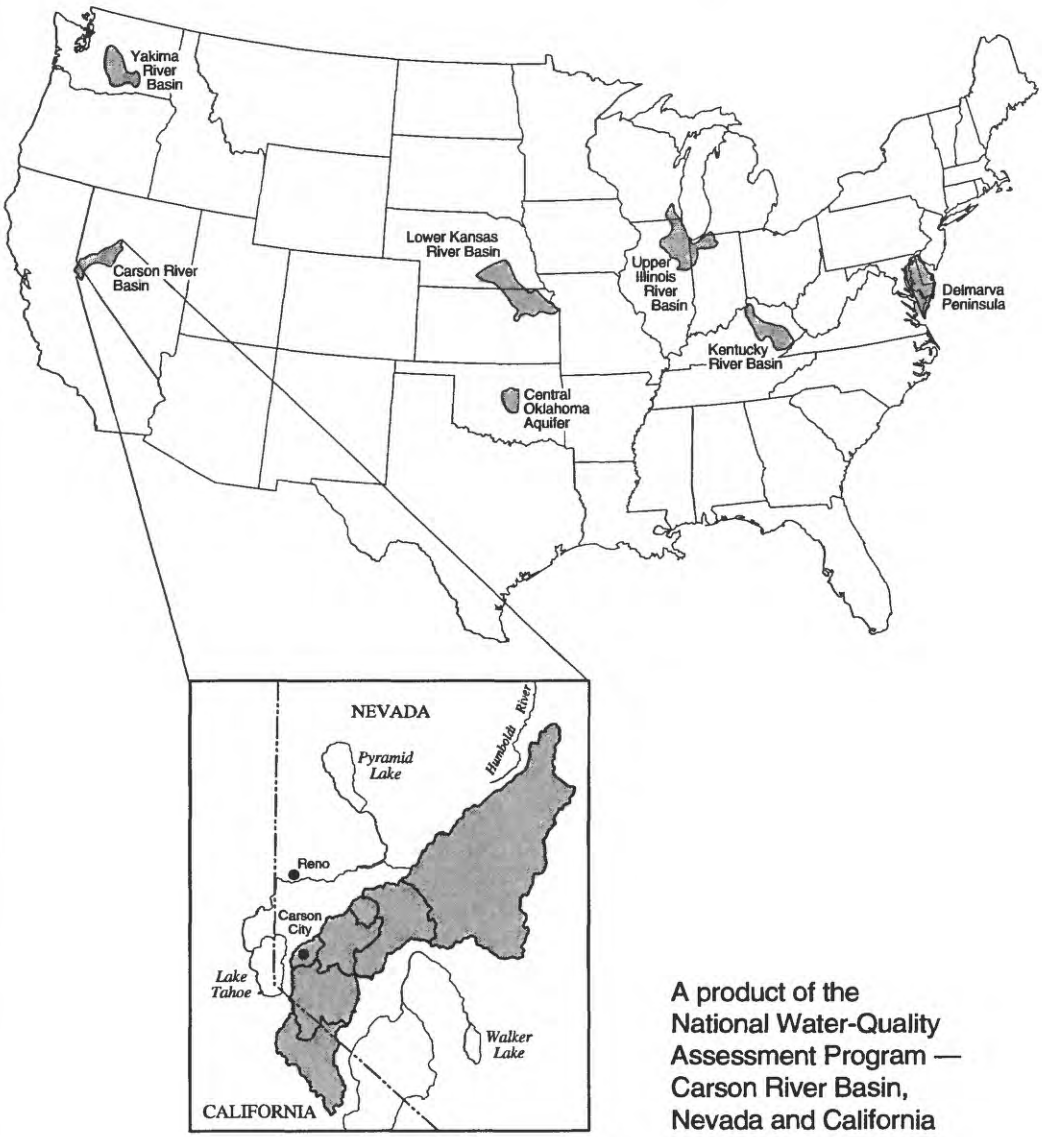
Nitrate and Ammonia in Shallow Ground Water, Carson City Urban Area, Nevada, 1989



A product of the National Water-Quality Assessment Program — Carson River Basin, Nevada and California

UNITED STATES GEOLOGICAL SURVEY
Water-Resources Investigations Report 96-4224

NATIONAL WATER - QUALITY ASSESSMENT PROGRAM

Nitrate and Ammonia in Shallow Ground Water, Carson City Urban Area, Nevada, 1989

By STEPHEN J. LAWRENCE

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96-4224

A product of the
National Water-Quality
Assessment Program—
Carson River Basin,
Nevada and California

Carson City, Nevada
1996

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

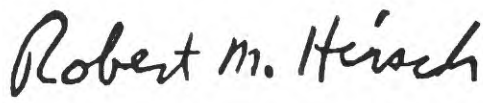
- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.



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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED UNITS

Multiply	By	To obtain
foot (ft)	0.3048	meter
inch (in.)	25.4	millimeter
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 (°F) can be converted to degrees Celsius (°C) 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:

µg/L (microgram per liter)
µS/cm (microsiemens per centimeter at 25°C)
mg/L (milligram per liter)
µm (micrometer)
mL (milliliter)

Nitrate and Ammonia in Shallow Ground Water, Carson City Urban Area, Nevada, 1989

By Stephen J. Lawrence

Abstract

As part of the National Water-Quality Assessment program (NAWQA) of the U.S. Geological Survey, a network of 26 wells at 20 sites was established in 1989 to investigate the quality of shallow ground water beneath the oldest and most developed part of the Carson City urban area. Nitrate was detected in water samples from 16 of the sites. The nitrate, as nitrogen, concentration was between 0.1 and 3.0 mg/L (milligrams per liter) at four sites, greater than 3.0 mg/L but less than 10 mg/L at six sites, and 10 mg/L, the Nevada drinking-water standard, or greater, at six sites; the highest concentration measured during the study was 38 mg/L. Ammonia, as nitrogen, concentrations exceeded 0.15 mg/L at 2 of the 20 sites; the highest concentration detected during the study was 0.26 mg/L. Nitrate concentrations were positively correlated with dissolved-oxygen concentrations, and negatively correlated with ammonia, dissolved-iron, and dissolved-manganese concentrations. Ammonia concentrations were positively correlated with calcium, magnesium, potassium, bicarbonate, iron, manganese, strontium, and dissolved organic carbon concentrations, and were negatively correlated with nitrate and dissolved-oxygen concentrations. Principal components analysis identified five groups of water-quality constituents that suggest that the ammonia or nitrate source might be nitrogen-based fertilizers, septic systems, or leaking municipal sewer lines, and that nitrification and denitrification, or nitrate reduction, control nitrate and ammonia concentrations as well as dissolved-oxygen, iron, and manganese concentrations in the shallow ground water beneath the Carson City urban area.

INTRODUCTION

Nitrogen is present in various forms throughout the natural environment and is needed to sustain biological life. Biological processes are dependent on an abundant and usable supply of nitrogen because nitrogen is a vital component of genetic material, proteins, and enzymes. Nitrate (NO_3^-) and ammonia (NH_4^+) are the nitrogen forms most easily used by organisms. In this report, nitrate and ammonia concentrations are reported as N (nitrogen). NH_4^+ is referred to as ammonia because the laboratory analytical procedure used for this study converted NH_4^+ (ammonium) to NH_3 (ammonia) prior to analysis. Both forms are rapidly cycled through the biosphere by a complex series of transformations. Because of human activities related to agriculture and urbanization, however, the amounts of nitrate and ammonia produced can exceed the assimilative capacity of the environment. When this capacity is exceeded, nitrate can enrich or, if concentrations are higher than 10 mg/L, contaminate ground-water resources.

Every State in the United States has some part of its ground-water resource contaminated by nitrate. Furthermore, the number of contaminated wells is increasing rapidly across the country (Hallberg, 1989, p. 38, 66). Extensive areas of nitrate-contaminated ground water exist in the northeastern part of the United States because of poultry manure, agricultural fertilizers, and a dense rural population that uses septic-tank systems. Contaminated ground water is found in the midwestern grain belt because of intensive agricultural use of ammonia fertilizers and in the southern Central Valley

of California and parts of Texas because of fertilized crops coupled with widespread, intensive agricultural irrigation (Madison and Brunett, 1985).

By the early 1980's, water from 20 percent of all wells sampled in the United States contained nitrate concentrations greater than 3 milligrams per liter (mg/L), and samples from 6 percent had concentrations greater than 10 mg/L, as N (Madison and Brunett, 1985). The maximum nitrate concentration recommended in drinking water supplies in the United States (U.S. Environmental Protection Agency, 1986a) and allowed in Nevada (Nevada Bureau of Health Protection Services, 1992) is 10 mg/L, as N. The 10 mg/L value is a conservative threshold designed to safeguard human health. One human-health problem related to high nitrate concentrations is "blue baby" disease (methemoglobinemia) in infants (U.S. Environmental Protection Agency, 1986b). Generally, infants younger than 1 year lack the enzyme in the intestinal tract that degrades nitrate. When nitrate is absorbed into the blood stream, hemoglobin in red-blood cells preferentially combines with nitrate rather than with dissolved oxygen and the body becomes oxygen deficient; hence, the name blue baby disease. Although uncommon, blue baby disease can be fatal (U.S. Environmental Protection Agency, 1986b). Moreover, nitrate is converted to nitrosamines in the intestinal tracts of adults and infants older than 1 year. Although this prevents blue baby disease, medical research has shown that high concentrations of nitrosamines are carcinogenic, mutagenic, and teratogenic to humans (U.S. Environmental Protection Agency, 1973).

As of 1985, about one-half of all waterborne illness in the United States was related to contaminated ground water (Yates, 1985). This contamination was most frequently traced to effluent from septic-tank systems (Yates, 1985). High nitrate or ammonia concentrations in ground water could indicate that an aquifer is contaminated with sewage effluent (LeBlanc, 1984; Canter and Knox, 1985; Hallberg, 1989; Wilhelm and others, 1994). Besides indicating possible sewage contamination, ammonia concentrations that exceed 0.2 mg/L, as N, may cause objectionable taste and odor in ground water used for drinking (Hallberg, 1989).

Nitrate- and ammonia-contaminated ground water can discharge to and adversely affect rivers, lakes, and estuaries (surface water). One adverse effect is increased eutrophication caused by large increases in algae and plant biomass. Algae and aquatic plants in nitrogen-depleted water may grow rapidly when nitrate and ammonia concentrations increase. Large increases in plant biomass can impair aesthetics and beneficial uses, and can disrupt ecological communities in surface water through changes in the pH and dissolved-oxygen regimes (Hynes, 1970, p. 48-49). The increase in primary production of algae in Chesapeake Bay is thought to be caused, in part, by high nitrate concentrations in the Columbia Aquifer, which discharges into some tributaries of Chesapeake Bay (Weil and others, 1990).

Nitrate and ammonia in ground water are from three major sources: (1) natural (not affected by human activities); (2) agricultural; and (3) urban and domestic. Natural sources of nitrate and ammonia commonly result in nitrate concentrations less than 1 mg/L and ammonia concentrations less than about 0.05 mg/L (Hallberg, 1989, p. 66). Studies by Bormann and others (1968), Likens and others (1977, p. 102), Vitousek and Melillo (1979), Verry and Timmons (1982), and Lawrence and Wigington (1987) show that nitrogen cycling within undisturbed ecosystems is a conservative process. Most of the nitrogen entering the ecosystem is retained and cycled among various inorganic, organic, and biological compartments. As a result, nitrogen losses from undisturbed ecosystems are small. Although naturally elevated nitrate concentrations are uncommon in ground water, elevated nitrate in water samples from wells in Las Vegas Valley, Nev., may be from buried spring mounds containing large amounts of organic matter (Patt and Hess, 1976). Moreover, high nitrate concentrations in water-saturated soil cores from an unaltered alluvial fan in the eastern Mojave Desert, Calif., may be the result of natural processes during the Pleistocene or leaching of decomposed local volcanic rocks that contain high nitrate concentrations (Marrett and others, 1990). Natural nitrate concentrations between 3 and 6 mg/L and dissolved-oxygen concentrations greater than 4 mg/L (Whitney, 1994, table 25) were measured in ground-water samples from wells deeper than 100 ft below land surface in Dayton and Churchill Valleys, Nev. Assuming a closed system, carbon-isotope methods estimated that this water was between 3,700 and 24,000 years old (Thomas and Lawrence, 1994, table 6).

Hallberg (1989, p. 36) states "research since the 1970's has clearly shown that the most extensive source of nitrates to ground water and surface water worldwide is agriculture." Hallberg further states "considering the U.S. as a whole, nitrogen from fertilizers represents at least 60 percent of the total nitrogen

applied to land if all the nitrogen from animal and poultry wastes were reclaimed and applied to land." A direct relation between nitrate concentration in ground water and rates of fertilizer application in agricultural areas has been shown by Hallberg (1989), Milburn and others (1990), and Weil and others (1990).

Nitrogen fertilizers and septic-tank effluent have contaminated shallow ground water in many urban areas including Long Island, N.Y. (Eckhardt and others, 1989), Michigan (D'Itri and others, 1985), and Minnesota (Komor and Anderson, 1993). High density septic-tank systems probably cause the high nitrate concentrations in shallow ground water near Topaz Lake, west-central Nevada (Nowlin, 1982) and in Washoe Valley, 15 mi. south of Reno, Nev. (Armstrong and Fordham, 1977).

Purpose and Scope

In 1986, the U.S. Geological Survey began a program to determine the current conditions and long-term trends in the quality of the Nation's water resources (Hirsch and others, 1988). One component of this program was to evaluate the effect of human activity on water quality. The program, known as the National Water-Quality Assessment (NAWQA), included a ground-water study in the Carson River Basin of west-central Nevada (Welch and Plume, 1987). One aspect of this study was an examination of shallow ground-water quality beneath an urban area, Carson City, Nev., which is in the Carson River Basin. The study was completed in 1989 and encompassed the oldest part of the Carson City urban area and the uppermost part of the shallow aquifer beneath the city.

The purposes of this report are to (1) describe the areal and temporal distribution of nitrate and ammonia in shallow ground water beneath the Carson City urban area and (2) attempt to identify the source or sources of elevated concentrations of nitrate and ammonia. The report is based on data from a network of 26 shallow observation wells at 20 sites that was established within a small part of the Carson City urban area. A single well was constructed at each of eighteen sites. A clustered set of four nested wells was constructed at two additional sites. All single wells and the shallowest wells at both nested sites penetrated the upper 15 ft of saturated sediments in the basin-fill aquifer. Water from the 26 wells was sampled twice during the first 6 months of 1989. Samples were analyzed for nitrate, ammonia, major cations and anions, trace elements, volatile organic compounds, and dissolved organic carbon. Field measurements included depth to water table, pH, specific conductance, and dissolved oxygen. Data were interpreted using nonparametric statistics, robust multiple regression, and a factor analysis using principal components.

Acknowledgments

The author thanks the Nevada State Capital Building and Grounds Department, Nevada Department of Conservation and Natural Resources, Nevada Department of Transportation, Carson City Parks and Recreation Division, Carson City School District, Samuel Lompa, Paul Larquier, Homer Angelo, John Serpa, I.R. Anderson, Joseph Bensinger, and St. Theresa's Catholic Church for allowing the construction of observation wells on property they own or manage.

ENVIRONMENTAL SETTING

Physical Setting, Population, and Climate

Carson City is a small but rapidly expanding urban area in west-central Nevada, approximately 30 mi south of Reno and 14 mi east of Lake Tahoe. The study area encompasses 13 mi^2 of the most urbanized part of the city (fig. 1). The boundaries of the entire Carson City consolidated municipality enclose an area of 143.5 mi^2 that includes Eagle Valley (71 mi^2), parts of three adjacent basins, and a small part of the Sierra Nevada.

Eagle Valley is typical of the basin and range topography in Nevada. The area west of Carson City is the eastern escarpment of the Carson Range of the Sierra Nevada (maximum altitude, 9,214 ft above sea level). To the north of the city is the Virginia Range (maximum altitude, 5,297 ft) and to the east is the Pine Nut Mountains (maximum altitude, 7,629 ft). The southern hydrographic boundary is a subtle topographic high (maximum altitude, 5,000 ft). The altitude of the Carson City urban study area ranges from 4,760 ft on the west to 4,600 ft on the east.

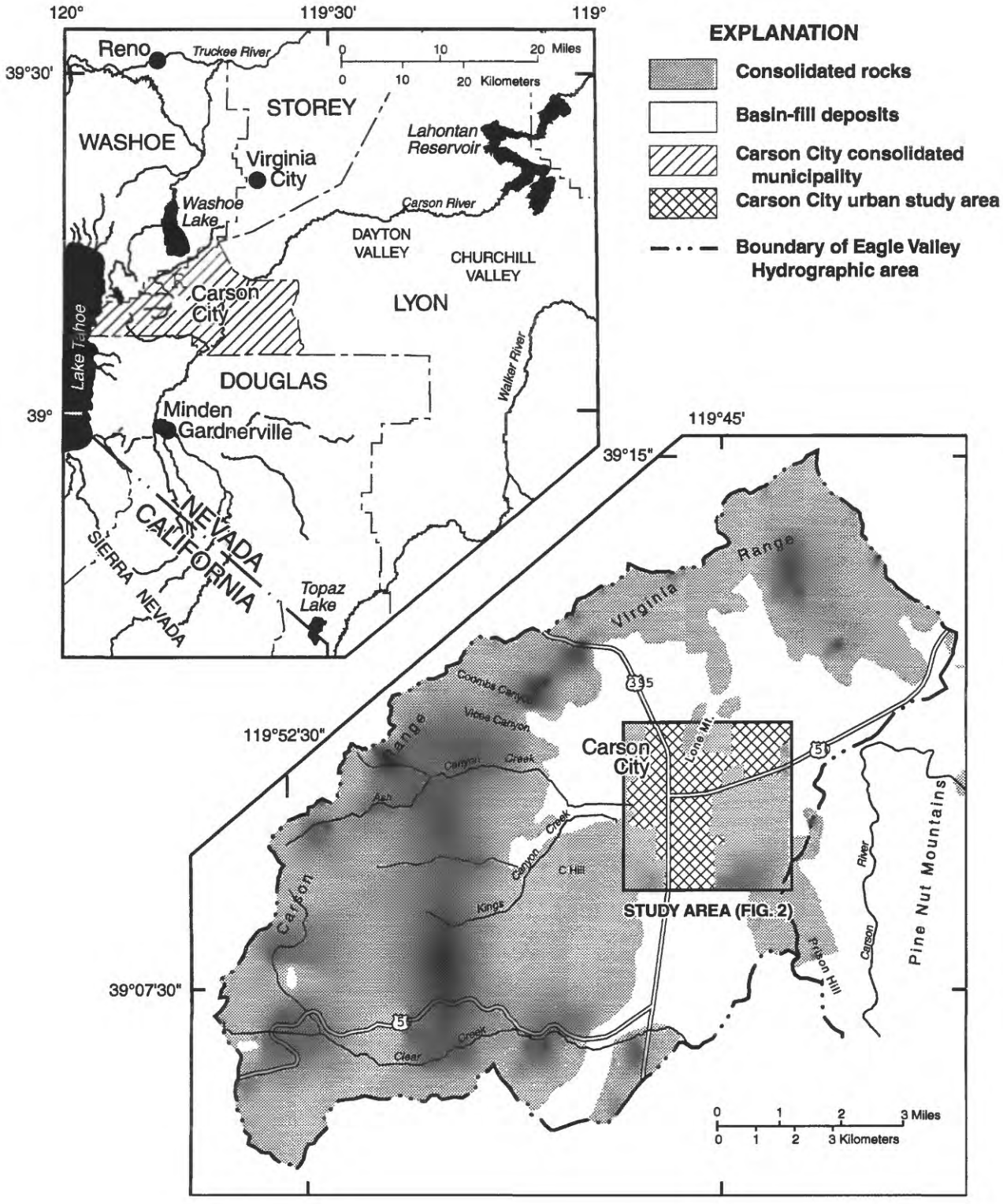


Figure 1. Location of Carson City, Nev., consolidated municipality and the urban study area.

As of 1988, approximately 43 percent of the study area in Carson City was residential, 11 percent was commercial, 9 percent was industrial, 2 percent was public land (parks and schools), and 35 percent was pasture or undeveloped land (Carson City Zoning Map, 1979 base, including amendments as of April 4, 1988). The population of Carson City has increased from 4,500 in 1950 to about 41,000 in 1990 (Maud Naroll, University of Nevada, Reno, Bureau of Business and Economics Research, oral commun., 1990) with growth continuing at a rate of 2-4 percent per year.

The semiarid climate of Carson City is affected by the rain shadow of the Sierra Nevada. The west slope of the Sierra Nevada captures most of the precipitation from frontal storms that originate over the Pacific Ocean, leaving the east slope much drier. During 1951-73, the average daily maximum temperature in the Carson City urban area was 85.4°F during the summer, and the average daily minimum temperature was 21.8°F during the winter. The average annual precipitation was 11.1 in., and the average annual snowfall was 29.6 in. (Candland, 1979, table 1). Most of the precipitation falls between December and March. The prevailing wind is from the west-northwest.

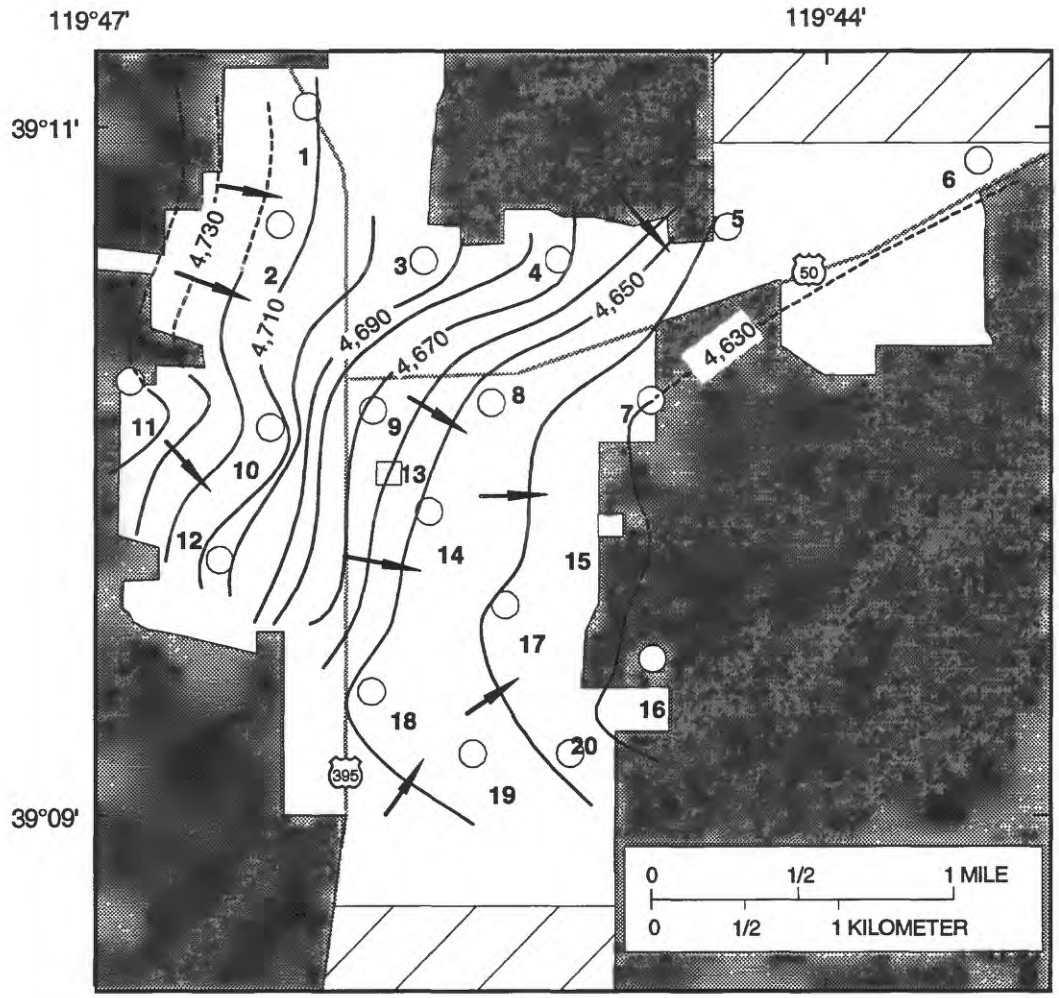
Soils

Because nearly all water entering ground-water flow systems must pass through the soil zone, soils can have a large effect on ground-water quality. The soils in the urban study area may impede or promote the movement of precipitation, urban runoff, or irrigation water into the shallow aquifer. Soils in the urban study area belong primarily to the Bishop group (about 92 percent) and the Dalzell group (about 8 percent; Candland, 1979, p. 9). Soils of the Bishop group are loamy in the upper layer; a sandy, clayey loam in the lower layers; slightly saline and alkaline in all layers; and have low to very low permeability (Candland, 1979, p. 11). The Dalzell soils are a saline loam in the upper layers; a saline, sandy-clay loam in the lower layers; and a silica-cemented hardpan at about 40 in. below land surface. This hardpan effectively prevents water at land surface from moving into deeper layers (Candland, 1979, p. 15). During well drilling for this study, alfisol, or perhaps mollisol, soils were found at sites that were landscaped with grass. Aridosols were found at sites with native vegetation such as sagebrush and rabbitbrush. Alfisol and mollisol soils have definite soil horizons including a highly organic "A" horizon and are commonly found in humid, high rainfall areas such as the grasslands of the midwestern United States. Mollisols have somewhat more organic matter and a higher supply of base ions than alfisols and also are commonly found in more humid environments (Birkeland, 1974, p. 47). Aridosols are soils low in organic matter, have accumulations of silica at depth, and are usually dry for more than 6 months of the year (Birkeland, 1974, p. 47). Irrigated lawns in Carson City may simulate the leaching environments that create mollisol or alfisol soils in the midwestern grassland areas.

Hydrogeology

The hydrogeology of the shallow aquifer beneath the study area generally controls the flow of ground water and, thus, the movement of contaminants within the aquifer. The primary aquifer underlying Eagle Valley is a mixture of basin-fill sedimentary deposits. These deposits consist of unconsolidated to partly consolidated lenses of gravel, sand, silt, and clay (Worts and Malmberg, 1966, table 1). The aquifer is thickest along the east-central edge of Eagle Valley and may extend to a depth of 2,000 ft below land surface (Arteaga, 1986, p. 23). A consolidated-rock basement complex (bedrock) underlies the basin-fill deposits and makes up the bordering hills and mountains. The bedrock is composed of sedimentary, volcanic, granitic, and metamorphic rocks (Worts and Malmberg, 1966, table 1).

Ground water in the basin-fill aquifer underlying the floor of Eagle Valley is recharged by seepage losses from streams that drain the Sierra Nevada and cross alluvial fans west of the city (Worts and Malmberg, 1966, p. 14; Arteaga, 1986, p. 13; Maurer and Fischer, 1988, p. 34). Recharge by direct infiltration of precipitation on the valley floor is assumed to be minor except during infrequent, sustained rainstorms. Landscape watering and agricultural irrigation probably recharge the shallow ground-water system beneath the valley floor to a greater extent than direct precipitation. The flow of shallow ground water in the basin-fill deposits beneath the urban area is generally southeastward (fig. 2). Depths to water measured during the first half of 1989 ranged from 2.8 to 16.7 ft below land surface (fig. 3 and table 1).



EXPLANATION

Urban study area

Area served by septic-tank systems

4,630 ---- **Water-table contour**—Shows altitude of water table, March 1989. Dashed where approximated. Contour interval, 10 feet. Datum is sea level. Contours constructed by simple interpolation

Generalized direction of ground-water flow

1

Single well and site number (table 1)

13

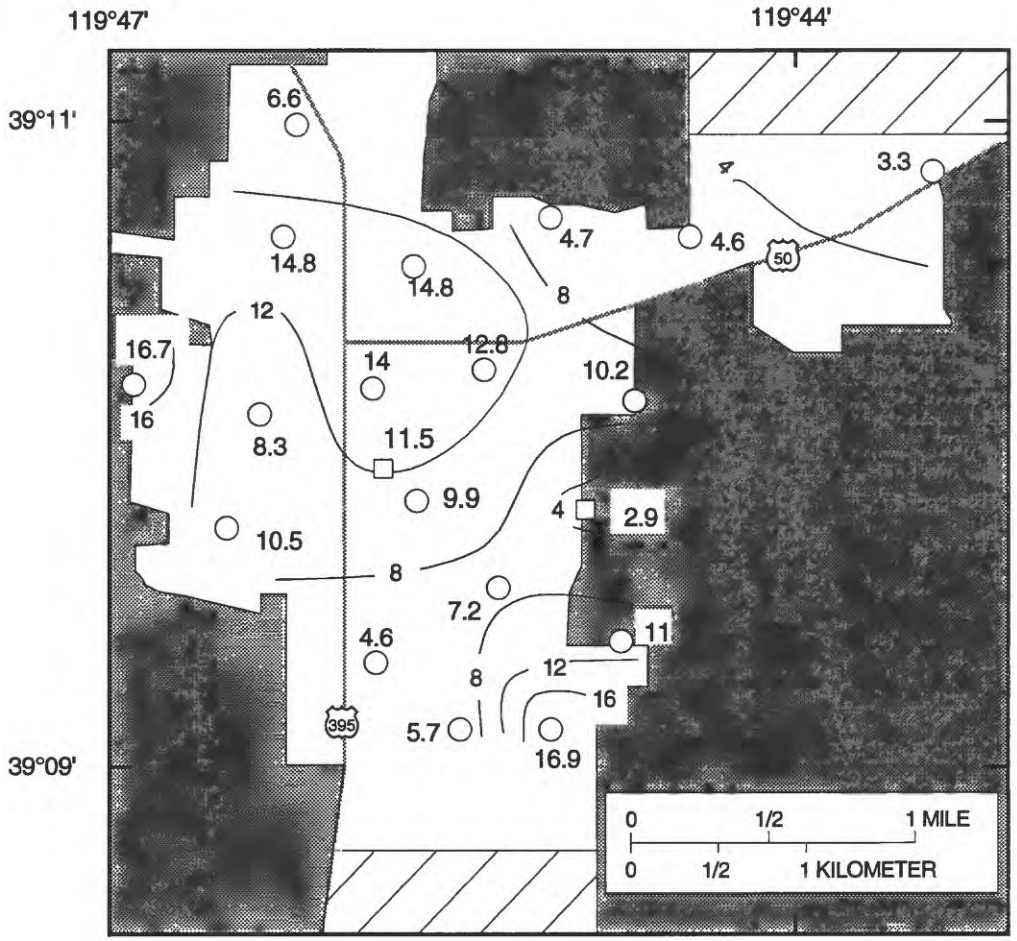
Well cluster and site number (table 1)

Figure 2. Well locations, water-table altitudes, and generalized directions of ground-water flow, Carson City, Nev., urban study area, January-March 1989.

Table 1. Land-surface altitude, well depth, and water-level data, Carson City, Nev., urban study area, January-March and May-June 1989

Well number (figure 2)	Altitude of land surface [1] (feet above sea level)	Feet below land surface			
		Depth to well screen	Depth to water (measurement period [2])		Site number [3]
			(1)	(2)	
1	4,723	18	6.6	6.5	54
2	4,721	21	14.2	8.9	45
3	4,702	19	14.8	13.4	42
4	4,668	35	4.7	4.6	48
5	4,641	11	4.6	4.3	47
6	4,636	18	3.3	3.4	49
7	4,633	21	10.2	7.7	32
8	4,660	19	12.8	10.8	37
9	4,679	19	14.0	11.5	38
10	4,719	21	8.3	11.2	33
11	4,760	30	16.7	9.9	34
12	4,712	20	10.5	10.2	25
13a	4,667	35	12.4	11.7	28
13b	4,667	30	11.7	11.2	29
13c	4,667	25	11.6	11.2	30
13d	4,667	20	11.5	11.1	31
14	4,659	21	9.9	9.1	24
15a	4,637	30	4.4	3.9	20
15b	4,637	25	5.6	3.5	21
15c	4,637	20	2.8	3.2	22
15d	4,637	15	2.9	2.9	23
16	4,634	18	11.0	10.2	14
17	4,643	15	7.2	6.0	17
18	4,650	16	4.6	3.6	15
19	4,655	14	5.7	4.9	11
20	4,661	20	10.0	16.5	13

[1] Altitudes surveyed from benchmarks.
[2] Measurement periods: (1), January-March 1989; (2), May-June 1989.
[3] Site number used by Whitney (1994).



EXPLANATION

Urban study area

Area served by septic-tank systems

4 — **Line of equal depth to water**— Depth to water, in feet below land surface, January-March 1989. Interval, 4 feet. Lines constructed using simple interpolation

7.2 **Single well and depth to water, in feet below land surface**

2.9 **Well cluster and depth to water, in feet below land surface, for shallowest well**

Figure 3. Depth to ground water, Carson City, Nev., urban study area, January-March 1989.

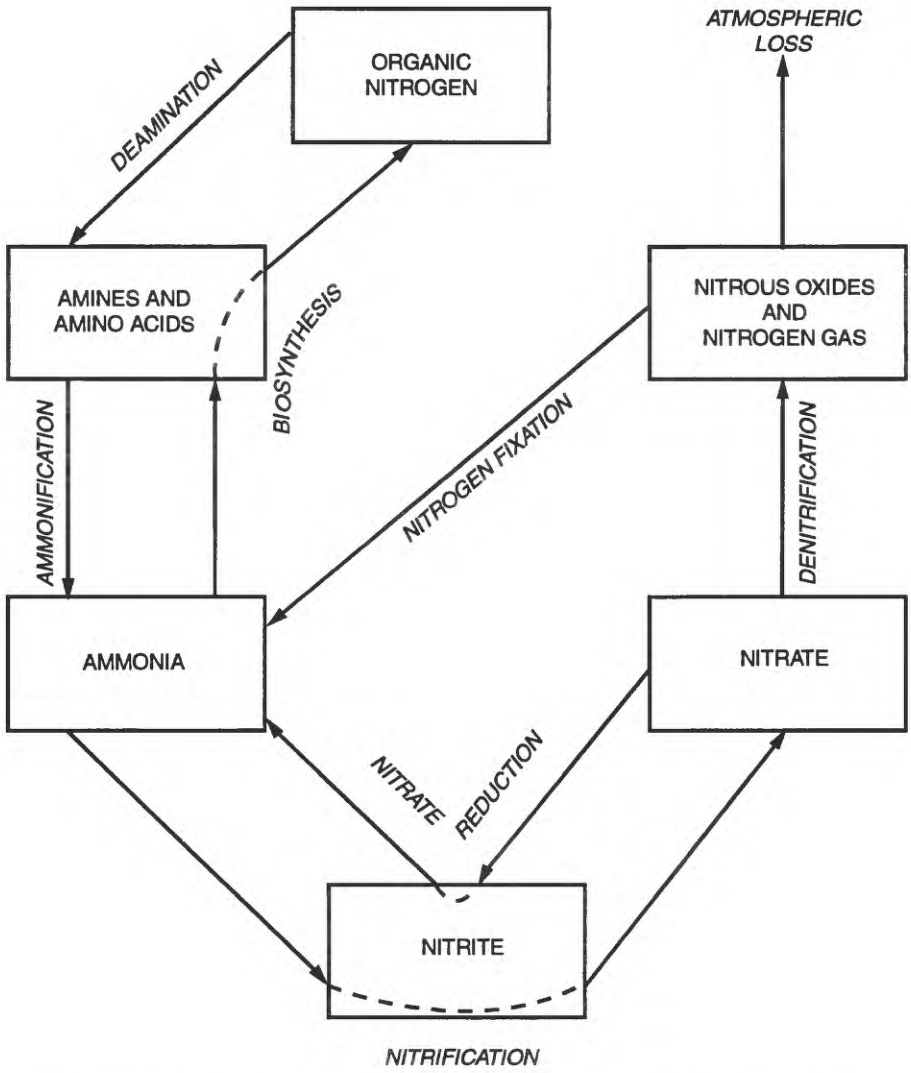


Figure 4. Nitrogen cycle (modified from Snoeyink and Jenkins, 1980, p. 405).

NITROGEN CYCLE IN NATURAL AND STRESSED SYSTEMS

The nitrogen cycle is a complex phenomenon with many processes taking place simultaneously, depending on local conditions. The cycle consists of oxidation and reduction reactions involving various nitrogen forms. Reactions are catalyzed by specific bacterial populations, depending on the presence or absence of oxygen (Snoeyink and Jenkins, 1980, p. 44, 407-411). A catalyst is any substance that increases the rate of a chemical reaction and is itself unchanged in the process. The reactions proceed slowly or not at all in the absence of bacterial populations. Bacteria produce an enzyme that either "shortcuts" the reaction pathways or reduces the activation energy to a level that allows the reaction to proceed (Snoeyink and Jenkins, 1980, p. 44-48). The activation energy can be thought of as an energy "dam" that prevents a chemical reaction. Organic nitrogen is converted to the nitrate ion, chemically the most stable form of nitrogen,

through a series of oxidation steps. A depiction of the nitrogen cycle is shown in figure 4. The following description of the nitrogen cycle is summarized from Drever (1988, p. 310) and Snoeyink and Jenkins (1980, p. 405-407).

Organic nitrogen is decomposed to amine groups ($R\text{-}NH_x$, where R is a carbon-hydrogen chain or ring, N is nitrogen, and $_x$ is the number of hydrogen atoms, which depends on the number of R groups directly bonded to the nitrogen atom). This decomposition, called deamination, is catalyzed by bacteria in both oxic (oxygenated) and anoxic (no oxygen) environments. In an oxic environment, bacteria catalyze the oxidation of amine groups to ammonia (NH_3) in a process called ammonification. Further bacterial oxidation converts ammonia to nitrite, then rapidly to nitrate, in a process called nitrification. If conditions are anoxic, no nitrification occurs.

Nitrification begins whenever ammonia and dissolved oxygen (greater than 1.0 mg/L) are present with appropriate bacteria (generally *nitrobactor* and *nitrosomonas* species), such as occur in soil or aquifer materials. During nitrification, ammonia, dissolved-oxygen, and dissolved organic carbon concentrations decrease while nitrate concentrations increase. Nitrification commonly proceeds until one of the reactants becomes limiting. When ammonia fertilizers are applied to agricultural or urban landscapes, nitrification is often limited by ammonia concentrations (Hallberg, 1989). When ammonia is the limiting factor, nitrate concentrations will be elevated, dissolved-oxygen concentrations will be above 1.0 mg/L, and ammonia concentrations will be below laboratory reporting limits (Hallberg, 1989). However, when manure or sewage effluent is nitrified, the large amounts of proteinaceous organic matter promote large increases in microbial respiration that will deplete dissolved-oxygen concentrations. Nitrification ceases when dissolved-oxygen concentrations fall below 1.0 mg/L.

When dissolved oxygen declines below 1.0 mg/L, reducing conditions exist and nitrate concentrations are depleted by denitrification (Lowrance and Pionke, 1989, p. 377). Microbes need electrons to metabolize nitrogen; when dissolved-oxygen concentrations are greater than 1.0 mg/L, microbes use the electrons in the oxygen molecule. However, under anoxic conditions, microbes use the next readily available source of electrons, which is oxygen within the nitrate molecule. As a result, oxygen atoms are removed from the nitrate molecule; nitrate is reduced and converted to various nitrous oxide gases or gaseous nitrogen (N_2; Drever, 1988). This process is denitrification. As nitrate is reduced, electrons become so scarce that the nitrogen atom itself is reduced and reacts with hydrogen ions to form ammonia. This process is nitrate reduction. Nitrate reduction can increase ammonia concentrations in ground water and also create conditions that liberate iron and manganese ions that are attached to oxide coatings on aquifer grains. Thus, ground water can lose ammonia and gain nitrate by nitrification under aerobic conditions, and in the absence of dissolved oxygen, can lose nitrate by denitrification, or lose nitrate and gain ammonia by nitrate reduction.

Under anoxic conditions, bacteria reduce nitrate to nitrogen gas or various nitrous oxides that are lost to the atmosphere (denitrification) or convert nitrate to ammonia in the reverse of nitrification (nitrate reduction). Generally, denitrification takes place before nitrate reduction because bacteria get more energy from denitrification than from nitrate reduction. Nitrogen gas can be converted to ammonia by certain plants in a process called nitrogen fixation. Ammonia can then be incorporated into plants by root uptake or into animals by ingestion and converted to protein in a process called biosynthesis.

METHODS USED IN THE STUDY

Well Construction

An aligned square-grid design (Gilbert, 1987, p. 93) was used to locate 20 sampling sites within the most densely developed part of the Carson City urban area. The distance between grid lines was 1/2 mi, which fixed the total number of sites at 20. The grid was placed over a map of the urban study area and the first well site was picked at random. This first well site was the reference point from which all subsequent well sites were located using the 1/2-mi grid spacing. Twenty-six wells were constructed at the 20 sites (table 1 and fig. 2); most were in or downgradient from residential areas. At 18 sites, a single well was screened no deeper than 35 ft below land surface (most of these wells were screened within the upper 15 ft of the saturated zone); at two sites, clusters of four nested wells were constructed. The deepest well in the cluster was screened within the upper 25 ft of the saturated zone,

but less than 35 ft below land surface (well "a"). Each subsequent well in the cluster (wells b, c, and d) was screened 5 ft shallower than the previous well. At each cluster site, well designations "a, b, c, d" identify both the well-construction sequence and the sampling sequence. Well "a," the deepest, was constructed and sampled first, then well "b," and so on, to prevent shallow ground water from contaminating the deeper wells.

All wells were drilled with either a 4-in.-diameter, solid-stem auger or an 8-in.-diameter, hollow-stem auger using methods of Hardy and others (1989). Each well was cased with threaded, 2-in.-diameter, polyvinyl chloride (PVC) pipe. At the 18 single well sites, the bottom section of well casing was a 5-ft length of 0.01-in. slotted PVC screen. At the two well cluster sites, the bottom section of the well casing was a 2-ft length of 0.01 in. screen. At all sites, including the shallowest well at each cluster site, the screen was set 5-10 ft below the water table.

Sampling Methods

Two water samples were collected from each well, the first during January-March 1989 and the second during May-June 1989. Before sampling, each well was pumped for 10-20 minutes with a positive-displacement, nitrogen-driven, Teflon bladder pump. During that time, approximately 20 casing volumes of water were removed from each well. Specific conductance and pH measurements had stabilized before the end of pumping. Measurements of pH, specific conductance, dissolved oxygen, and temperature were taken from a flow-through chamber on site.

Water was pumped from the well to sample bottles through Teflon tubing attached to the bladder pump. Samples were analyzed by the U.S. Geological Survey National Water-Quality Laboratory in Arvada, Colo., for dissolved ammonia, nitrite, nitrate plus nitrite, major cations and anions, trace elements, volatile organic compounds, and dissolved organic carbon (DOC), using methods described by Fishman and Friedman (1989) and Wershaw and others (1987). Before sample bottles were filled, ground water was filtered through a membrane filter with a pore size of 0.45 µm. Before filtering, membrane filters were rinsed with 500 mL of ground water. Samples for volatile organic analysis were not filtered. All samples were chilled and nutrient samples were preserved with mercuric chloride. Samples for trace-element analysis were preserved with nitric acid. Whitney (1994) compiled the data collected for this study. Data used in this report are in table 2.

Statistical Analysis of Water-Quality Data

Several methods were used to explore possible interactions among water-quality constituents and properties. Scatterplots were constructed for pairs of constituents (see appendix). Specific conductance, nitrate, and ammonia concentrations were plotted on maps of the urban study area. Nonparametric statistics, robust multiple-regression analysis (RMRA), and a factor analysis using principal components (PCA) were used to explore associations among the data. These data consist of nitrate, ammonia, major cation and anion, selected trace-element, and dissolved-oxygen concentrations, and pH, well depth, and depth to water.

Nonparametric statistical methods transform the original data to ranks, then use the ranks in the analysis. Before rank transformation, the concentrations of major cations, major anions, and trace elements were normalized by converting to milliequivalents per liter (meq/L). The following discussion on rank-transformation is from Conover (1980, p. 250-256) and Ott (1988, p. 319-323). Data are sorted from the lowest to the highest value. The rank of the lowest value is 1 and the rank of the highest value is equal to the total number of samples for that constituent. Each constituent is ranked. Values below a laboratory reporting limit are given the lowest ranks. Samples that have the same value, including values below a laboratory reporting limit, are given the mean of their ranks. For example, if three samples have a constituent value below its laboratory reporting limit, their ranks will be 2 (the average of 1, 2, and 3).

The Mann-Whitney Rank-Sum test and Spearman's rank-correlation analysis were used to analyze the data. The Mann-Whitney method is the nonparametric counterpart to the parametric t-test and compares the medians, rather than the means, of constituents in two data sets. The Mann-Whitney method tests whether the data fit one of two possible hypotheses: (1) The medians of the data sets are equal; therefore, the data sets belong to the same population; or (2) the medians are not equal; therefore, they do not belong to the same population.

The Spearman rank-correlation analysis tests the independence of a variable *X* from a variable *Y* by comparing their ranks rather than their measured values. Therefore, the method can include censored values reported as above or below a threshold value. The method tests for changes in the value of one constituent as the value of another constituent changes and can detect linear or curvilinear relations between two constituents. For this study, the Statistical Analysis System (SAS Institute Inc., 1990) was used to compute the Spearman correlation coefficients (r) and a value (p) that measures the probability of an association between two constituents. If high ranks of one constituent are associated with high ranks of another constituent, then the correlation coefficient will be close to +1 and the constituents are positively correlated. If high ranks of one constituent are associated with low ranks of another constituent, then the correlation coefficient will be close to -1 and the constituents are negatively correlated. If the ranks of one constituent are random with respect to the ranks of another constituent, then the correlation coefficient will be close to zero and the constituents are considered not correlated.

The statistical significance, or strength, of a correlation between two constituents is determined using the p-value; the smaller the p-value, the greater the likelihood of correlation (Conover, 1980, p. 254; Ott, 1988, p. 150). Thus, a p-value of 0.001 indicates stronger correlation than a p-value of 0.05. Correlations between two constituents in this report are considered statistically significant if the p-value is 0.05 or less.

Robust multiple-regression analysis (RMRA), along with factor analysis using principal components (PCA), are used in this report as exploratory tools to identify multivariate relations among data from each well in the urban study area. RMRA was also used as a check on the PCA. RMRA is a multiple linear-regression of rank-transformed data (Conover, 1980, p. 338). The method is robust because it is insensitive to outliers, nonnormally distributed data, and censored data (Conover, 1980, p. 338). The set of independent constituents that maximized the coefficient of determination, r^2, and minimized Mallow's Cp were used in the regression analysis. The coefficient of determination is the proportion of the total variability in the dependent constituent that is accounted for by variability in the independent constituents (Ott, 1988, p. 320). Mallow's Cp is a value that helps identify the optimal regression equation (Montgomery and Peck, 1982, p. 251). Mallows Cp identifies the best combination of independent variables (constituents) that maximize r^2 (minimize bias) while minimizing the standard error of the regression. A large number of variables can account for nearly 100 percent of the variance in *Y*, the dependent variable, but the standard error of the regression is then so high that the equation is useless as a predictive tool.

The PCA for this study used the same rank-transformed data used in the correlation and multiple regression analyses; the set of Spearman rank-correlation coefficients was the initial matrix for the PCA. Except where noted, the following explanation of PCA is from Afifi and Clark (1984, p. 328-360).

PCA provides a way to examine the interrelations among data. The output from PCA consists of four major elements—a set of components, a set of communalities, a set of loading coefficients, and a partitioning of variance.

The set of components is a set of new, uncorrelated variables that contain the original correlated constituents. The PCA computes components so they account for as much of the total variance as possible. The analysis can produce 20 or more components, but the first 3 to 6 generally account for most (as much as 95 percent or more) of the variance and are considered the principal components of the data set. The first component accounts for most of the total variance and is commonly the most stable. Subsequent components account for smaller proportions of the total variance and are less stable. A component is stable when adding or removing constituents or observations from the data set does not change the variance of the component or alter the constituent groupings within the component. Because the goal of PCA is to reduce the complexity of a data set, only the principal components are used for interpretation.

Varimax rotation was used to optimize the association of original constituents with the principal components (table 4). This rotation changes the component loadings so that the original constituents are either very high (as close to +1.0 or -1.0 as possible) or close to zero. It changes the relation between constituents and a component axis, but does not change the relations among the constituents (Davis, 1986, p. 555). Varimax rotation helps the interpretation of the principal components by identifying more discrete groups of constituents.

The PCA associates two values, the communality and the loading coefficient, with each constituent (table 4). The communality is "the proportion of the variance for each original constituent accounted for by the

retained components" (Puckett and Bricker, 1992). Thus, the communality is an index of the amount of total variance that a constituent contributes to the data set. The more variance contributed, the more important that constituent is to the data set and to the interpretation of the PCA. The importance of a constituent increases as the communality approaches 1.0 (table 4). Constituents with a communality greater than 0.60 are used for the interpretation of components. Varimax rotation does not change the communality of a constituent.

Loading coefficients range between -1 and +1; values close to ±1 indicate strong correlation with a particular component. Values from -0.5 to +0.5 indicate weak or no correlation; therefore, constituents with loading coefficients from -0.5 to +0.5 are not included in the interpretation. Constituents with loading coefficients from -0.75 to -0.5 and from +0.50 to +0.75 are important to the interpretation of a component, and constituents with loading coefficients from -1 to -0.75 and from +0.75 to +1 are the most important (Puckett and Bricker, 1992). A constituent, such as sulfate in table 4, can be represented in more than one component. Loading coefficients can be depicted graphically several ways; for example, figure 8 is the visual equivalent to table 4 and shows those constituents that are correlated with each component in this study.

PCA partitions the total variance in a data set among the components. The total variance is the sum of variances for each constituent in the data set. The variance for each constituent, a measure of variability among the samples, is calculated as the square of the positive and negative deviations from the constituent mean. In PCA, the first component contains the correlated constituents that have the greatest variance in the data set. Thus, the first component accounts for the largest proportion of the total variance and each subsequent component accounts for a smaller proportion.

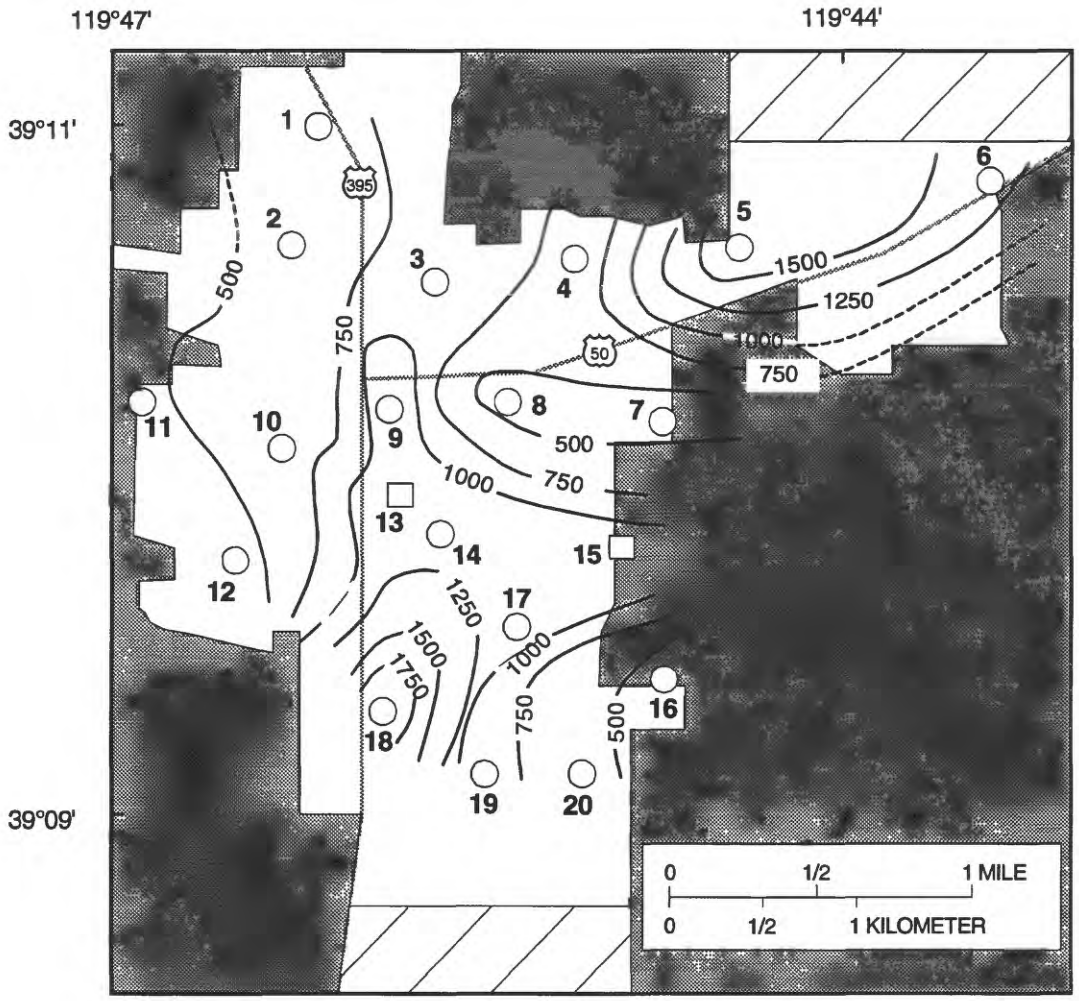
Because each component is a group of related constituents, each component may represent sources or processes common to all constituents within the component. However, PCA can force functionally unrelated data into components, thereby leading to erroneous interpretations (Rexstad and others, 1988). The correct interpretation, therefore, depends on knowledge of hydrologic, geochemical, and physical factors. Since 1966, PCA has been used in several water-quality studies; Meglen and Sistko (1985) used PCA on a large data set to distinguish anomalous samples, samples from three different aquifers, samples that represented a mixture of water from different aquifers, and samples that identified a leak in one of the three holding ponds in the study area; Ruiz and others (1990) used PCA to detect saltwater intrusion in a coastal aquifer in Spain and Puckett and Bricker (1992) used PCA to examine regional chemistry patterns in low-order streams in the Blue Ridge Mountains of Virginia and Maryland.

PCA can be used to areally map each component by assigning a score (sample score) to each sample or observation in the data set. The sample score indicates the relation between the sample and a principal component and, by extension, those constituents important to the component. The sample score is the sum of all the constituent scores for a particular sample and specific component; the constituent score is a constituent's original value multiplied by its loading coefficient for the component.

For example, the sample score for sample 1, well 1, and component 1 in table 5 was computed as follows: For each sample, the component 1 loading coefficients (second column, table 3) for each constituent were multiplied by the constituent's original value. The resulting constituent scores were then summed to get the sample score. Principal components that are interpreted as depicting either the presence of a contaminant in an aquifer, or a geochemical process, or a particular source of water can be delineated on a map. For example, Ruiz and others (1990) mapped sample scores to delineate an area of seawater intruding into a coastal aquifer.

GENERAL GROUND-WATER QUALITY

Water-quality data used in this report are listed in table 2. The specific conductance and dominant cations and anions were markedly different in different parts of the urban study area. Specific conductance ranged from 380 µS/cm to 1,970 µS/cm (table 2). The highest specific conductance was measured in the southwestern part of the area and the second highest was measured in the northeastern part (fig. 5). With several exceptions, the dominant ions in shallow ground water in the urban study area were calcium and bicarbonate. The codominant ions at sites 3, 4, and 13d were sodium, calcium, and bicarbonate. The dominant ions at sites 5 and 18 were sodium and bicarbonate, and sodium and sulfate, respectively.



EXPLANATION

Urban study area

Area served by septic-tank systems

— 1000 --- **Line of equal specific conductance**—Specific conductance of shallow ground water, in microsiemens per centimeter at 25 degrees Celsius (µS/cm), January-March 1989. Interval, 250 µS/cm. Dashed where approximated. Lines constructed by simple interpolation

13 **Single well and well number**

3 **Well cluster and well number**

Figure 5. Areal distribution of specific conductance in shallow ground water, Carson City, Nev., urban study area, January-March 1989.

Table 2. Water-quality data from shallow wells in the Carson City, Nev., urban study area,1989

[Sampling period indicated by "1" or "2": 1, January-March 1989; 2, May-July 1989. All concentrations in milligrams per liter, except where indicated; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius.]

Well number (figure 2)	Specific conductance, field (µS/cm)		Laboratory pH (units)		Dissolved											
					Oxygen		Calcium		Magnesium		Sodium		Potassium		Bicarbonate	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	720	720	7.4	7.0	3.8	3.7	93	89	23	22	38	38	1.8	1.6	363	376
2	550	580	7.1	7.2	3.1	2.6	70	69	20	20	26	26	2.3	2.2	289	405
3	900	880	7.2	7.2	1.2	2.4	77	71	23	21	110	99	4.0	3.3	512	390
4	510	630	8.0	7.6	4.0	5.4	54	70	9.3	12	43	50	2.3	2.0	220	395
5	1730	1730	7.6	7.4	.4	1.8	73	74	14	14	310	330	1.8	1.6	682	857
6	1300	1180	7.2	7.1	1.7	2.0	120	120	55	53	94	100	5.4	5.5	504	574
7	390	390	7.4	7.3	.4	1.6	51	53	11	11	22	21	1.1	1.0	239	312
8	470	670	6.5	6.6	2.1	4.3	48	81	10	18	24	30	5.8	6.5	200	218
9	1090	750	6.9	6.7	--	2.4	110	68	26	16	66	62	5.0	3.6	265	249
10	640	--	7.3	7.3	--	--	84	94	26	27	23	25	3.7	4.2	420	467
11	380	240	6.6	6.3	.6	2.0	33	29	7.5	5.9	41	14	4.0	2.5	148	161
12	460	500	6.8	6.6	3.9	4.5	53	58	17	18	20	21	1.1	1.1	172	229
13a	770	810	6.7	6.7	.5	1.2	95	95	23	22	38	40	3.9	4.1	290	347
13b	1050	1110	6.8	6.6	.5	1.0	120	110	28	27	72	73	4.6	4.9	350	515
13c	1130	1140	6.9	6.7	.5	1.1	120	110	28	26	88	88	5.4	5.5	380	380
13d	1070	1170	7.0	6.9	3.9	1.2	100	110	22	22	95	97	4.0	3.9	390	400
14	1060	1010	6.7	6.8	1.1	1.9	130	120	31	31	60	68	3.7	3.3	490	530
15a	460	470	7.2	7.2	1.3	1.1	55	53	19	18	21	21	1.9	1.9	250	290
15b	730	720	7.0	7.2	1.0	.7	85	79	30	27	37	38	2.4	2.4	540	405
15c	730	700	7.2	7.2	.8	.6	79	76	29	26	46	39	2.3	2.4	550	400
15d	1280	960	7.3	7.3	.9	1.5	120	87	33	50	97	69	1.4	1.1	680	420
16	370	380	7.2	7.2	3.4	6.0	37	39	12	11	26	25	1.3	1.0	180	240
17	--	1020	7.1	7.0	.5	1.7	130	130	33	30	62	61	3.4	2.7	480	560
18	1940	2050	6.9	6.8	.4	2.1	160	170	32	35	260	310	4.5	3.3	520	510
19	780	760	7.3	7.3	4.9	4.5	79	79	21	20	57	57	.7	.7	386	370
20	540	540	7.0	6.8	4.5	5.6	67	65	17	16	38	37	.9	.7	250	340

Table 2. Water-quality data from shallow wells in Carson City, Nevada urban study area, 1989—Continued

Well number (figure 2)	Dissolved													
	Sulfate		Chloride		Silica (SiO_2)		Nitrate, as N		Ammonia, as N		Orthophosphorus as P		Boron (µg/L)	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	50	47	13	12	53	52	8.5	8.6	0.03	0.03	0.04	0.05	40	40
2	28	25	8.8	8.8	42	41	7.2	8.4	< .01	.01	.07	.07	0	20
3	49	40	27	44	40	38	3.2	2.7	.01	.02	.04	.04	150	150
4	34	51	23	29	29	29	5.4	7.3	.04	.01	.05	.04	20	30
5	260	240	85	83	54	52	< .1	< .1	.03	.02	.13	.15	2,900	2,700
6	220	220	43	40	58	59	11	10	.02	.04	.05	.07	260	320
7	7.7	9.0	8.2	9.0	35	33	< .1	< .1	.04	.05	.19	.20	20	10
8	16	18	25	97	28	26	1.9	2.4	.01	< .01	.06	.05	20	0
9	140	61	88	73	24	22	17	5.4	.04	< .01	.05	.05	120	50
10	11	8	6.4	5.7	38	40	.1	< .1	.08	.09	.01	.01	30	30
11	16	5	49	5.0	29	30	.3	< .1	.04	.02	.01	<.01	10	10
12	32	32	19	24	44	43	12	11	< .01	.01	.03	.03	20	20
13a	78	79	63	63	39	38	< .1	< .1	.21	.21	.06	.04	10	10
13b	110	110	110	120	34	32	< .1	< .1	.26	.18	.09	<.01	50	50
13c	110	110	120	120	31	29	< .1	.2	.19	.17	.10	.04	80	80
13d	100	110	93	92	29	29	38	3.7	.03	.02	.09	.10	90	90
14	100	100	68	65	35	32	< .1	< .1	.24	.18	.39	.02	40	40
15a	12	12	17	17	31	30	.3	< .1	< .01	< .01	.14	.15	10	20
15b	29	26	31	35	32	31	< .1	< .1	.05	.04	.19	.10	30	60
15c	28	25	37	35	32	31	< .1	< .1	.04	.02	.19	.08	40	40
15d	38	53	89	76	38	39	< .1	< .1	.03	< .01	.23	.22	60	60
16	25	27	9	13	41	41	3.2	3.3	< .01	< .01	.05	.07	30	20
17	110	96	71	67	32	31	5.7	4.7	.05	.04	.26	.25	20	20
18	670	760	53	63	36	36	< .1	< .1	.09	.09	.19	<.01	180	190
19	76	74	31	36	54	56	18	17	.02	.01	.19	.18	160	160
20	39	37	12	11	50	49	15	5.5	.01	.02	.13	.12	60	70

Table 2. Water-quality data from shallow wells in Carson City, Nevada urban study area, 1989—Continued

Well number (figure 2)	Dissolved								Tetrachloro-ethylene (µg/L)		Trichloro-ethylene (µg/L)	
	Iron (µg/L)		Manganese (µg/L)		Strontium (µg/L)		Organic carbon					
	1	2	1	2	1	2	1	2	1	2	1	2
1	10	11	66	40	1,100	1,100	2.0	1.4	< 0.2	< 0.2	< 0.2	< 0.2
2	14	35	30	26	980	980	1.3	1.0	< .2	< .2	< .2	< .2
3	29	8	1	2	870	800	2.6	2.3	.2	< .2	.3	.3
4	45	2	7	4	460	640	1.1	1.2	< .2	< .2	< .2	< .2
5	31	23	540	540	700	730	5.4	5.1	< .2	< .2	< .2	< .2
6	6	12	46	39	1,600	1,600	2.9	3.0	.2	.2	< .2	< .2
7	20	10	380	430	490	500	7.0	1.4	< .2	< .2	< .2	< .2
8	61	24	3	4	490	790	1.5	1.3	< .2	< .2	< .2	< .2
9	28	13	28	12	980	570	3.9	2.2	.3	< .2	< .2	< .2
10	2,200	1,800	1,200	1,600	860	940	3.6	3.7	< .2	< .2	< .2	< .2
11	31	40	410	190	300	260	1.1	1.0	< .2	< .2	< .2	< .2
12	41	30	4	2	560	620	1.4	1.8	< .2	< .2	< .2	< .2
13a	12,000	12,000	970	970	880	880	1.8	1.8	< .2	< .2	< .2	< .2
13b	8,900	8,300	1,000	970	1,000	1,000	2.1	2.3	< .2	< .2	.7	.5
13c	7,700	7,400	760	700	1,000	980	2.2	2.4	< .2	< .2	.3	.3
13d	23	11	170	140	890	890	2.6	2.6	< .2	< .2	< .2	< .2
14	10,000	9,000	3,400	3,400	1,200	1,200	1.8	2.8	23	44	20	18
15a	18	13	330	260	550	540	1.1	1.3	< .2	< .2	< .2	< .2
15b	660	640	880	830	940	860	2.2	2.1	< .2	< .2	< .2	< .2
15c	610	310	1,000	830	910	840	2.2	2.3	< .2	< .2	< .2	< .2
15d	26	19	68	12	1,500	1,100	3.3	2.7	< .2	< .2	< .2	< .2
16	19	7	16	200	510	510	1.4	1.3	< .2	< .2	< .2	< .2
17	18	8	710	340	1,100	1,000	3.6	3.1	< .2	< .2	< .2	< .2
18	2,600	3,000	1,500	1,300	1,200	1,400	5.5	3.7	< .2	< .2	< .2	.7
19	16	23	3	1	1,100	1,000	1.8	1.8	< .2	.2	< .2	< .2
20	8	7	2	1	880	850	2.6	1.9	< .2	< .2	< .2	< .2

NITRATE AND AMMONIA IN SHALLOW GROUND WATER

The most likely sources of nitrate and ammonia in shallow ground water beneath an urban area are anthropogenic, such as urban runoff, sewage effluent, and nitrogen-based fertilizers (Madison and Brunett, 1985; Hallberg, 1989; Eckhardt and others, 1989; and Komor and Anderson, 1993). Urban runoff was not a likely source of nitrate or ammonia to the shallow aquifer in the urban study area because the amount of surface runoff is generally small and soil permeability is low. Also, no detention ponds where urban runoff could accumulate and infiltrate were in or upgradient from the study area in 1989. Thus, sewage effluent or nitrogen fertilizers were more likely sources. Municipal sewer pipes contribute sewage effluent to shallow ground water if these pipes leak. In addition, septic-tank systems northeast and south of the urban study area (fig. 2) might be a source because they are upgradient from the study area. Nitrogen-based fertilizers may be a major source of nitrate or ammonia in landscaped areas in residential parts of the urban study area. Residential areas, including public parks, have large expanses of lawn and landscaping, and probably receive nitrogen-based fertilizers regularly.

Nitrate and ammonia concentrations are presented as the nitrogen form (NO_3-N) and (NH_4-N), respectively, and the terms "nitrate" and "ammonia" are used in the rest of this report. Nationwide data indicate that nitrate concentrations below 3.0 mg/L represent background, or "natural," conditions in ground water (Hallberg, 1989, p. 66). Therefore, in this report, ground-water samples with nitrate concentrations below 3.0 mg/L are assumed to represent natural concentrations in the shallow aquifer, samples with nitrate concentrations between 3.0 and 10.0 mg/L are assumed to be nitrate-enriched, and samples with nitrate concentrations at or above 10.0 mg/L are considered contaminated.

Areal and Temporal Differences in Nitrate Concentrations

Shallow ground-water samples from the urban study area contained nitrate concentrations that were highly variable, both areally and temporally (fig. 6). Nitrate concentrations for the study as a whole ranged from less than 0.1 to 38 mg/L and had a coefficient of variation of 153 percent. The median concentration of 1.1 mg/L was similar to the median nitrate concentration of 1.2 mg/L measured near Topaz Lake, about 30 mi south of the study area (Nowlin, 1982, p. 69-73). The maximum nitrate concentration in the urban study area was nearly eight times higher than the maximum concentration measured near Topaz Lake, where nitrate ranged from 0.02 to 5.0 mg/L (Nowlin, 1982, p. 69-73). Septic-tank systems were the suspected source of nitrate in shallow ground water near Topaz Lake.

A nonparametric t-test showed that nitrate concentrations in the urban area's shallow ground water during sampling period one (January-March 1989) were not statistically different ($p=0.38$) from those measured in sampling period two (May and June 1989), even though nitrate concentrations at some wells changed markedly between the two sampling periods. During the first sampling period, nitrate concentrations ranged from less than 0.1 to 38 mg/L (fig. 6); the median concentration and coefficient of variation were 1.1 mg/L and 155 percent, respectively. During this same period, samples from 12 of the 20 shallow wells contained more than 3.0 mg/L of nitrate (fig. 6*A*). Six of the first-period samples equaled or exceeded the Nevada drinking-water standard of 10 mg/L (Nevada Bureau of Health Protection Services, 1992). Wells 9, 13d, 19, and 20 contained particularly high nitrate concentrations during the first sampling period (table 2).

During the second sampling period, nitrate concentrations ranged from less than 0.1 to 17 mg/L; the median concentration and coefficient of variation were 1.3 mg/L and 130 percent, respectively. Water from two shallow wells had higher nitrate concentrations, from eight shallow wells had lower nitrate concentrations, and from ten shallow wells had nitrate concentrations that were unchanged (within 1 mg/L) from those measured in first-round samples (table 2). Most samples that contained more than 3.0 mg/L of nitrate in the first sampling period also had concentrations greater than 3.0 mg/L in the second period (fig. 6). However, in the second sampling period, water from only 3 of 20 shallow wells had nitrate concentrations that equaled or exceeded 10 mg/L (fig. 6*B*), and water from 3 of 20 shallow wells had concentrations that were at least 3 mg/L lower than first-round samples (fig. 6).

The decrease in nitrate concentrations between sampling periods might be caused by a number of factors: (1) ground-water flow paths changed or concentrations were diluted as the water table rose before the second round of sampling; (2) the amount of nitrogen

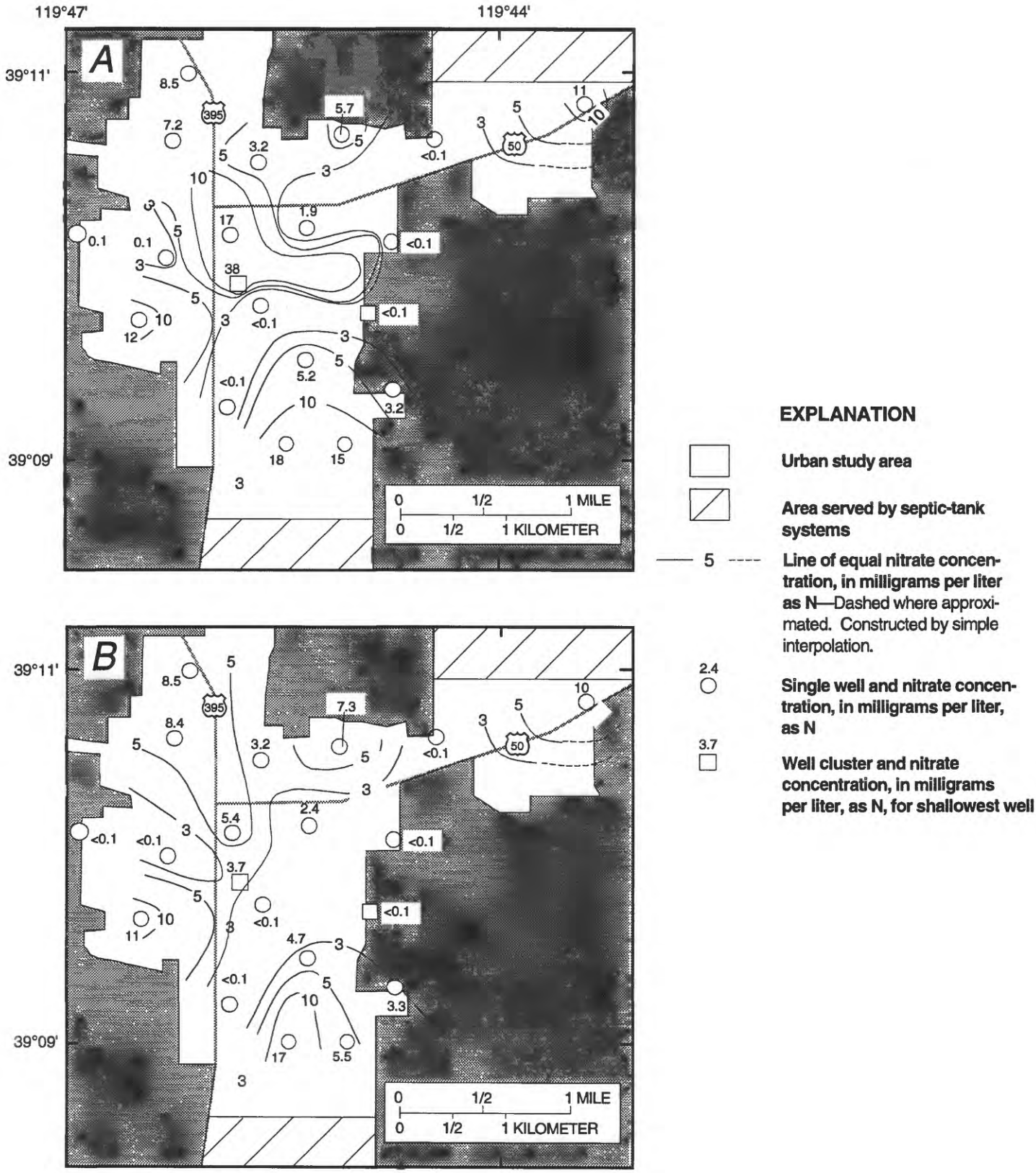


Figure 6. Areal distribution of nitrate concentrations in shallow ground water for (A) January-March 1989 and (B) May-June 1989, Carson City, Nev., urban study area.

entering the aquifer decreased; or (3) denitrification began or increased. The water table at 18 of 20 sites was closer to land surface during the second round of ground-water sampling than during the first round. The decrease in depth to water ranged from 0.3 to 6.8 ft, but the average decrease among all 26 wells was about 1 ft (table 1). Although a rising water table might change ground-water flow paths and divert contaminated water away from specific wells, broad changes in ground-water flow were not apparent. Moreover, the well network was not dense enough to detect changes in ground-water flow at or near individual wells.

Decreases in nitrate concentrations with a rising water table are commonly attributed to dilution (Hallberg, 1989, p. 48). Chloride and boron concentrations from both sampling periods were compared to see if dilution was likely in the urban study area. Chloride and boron are commonly used as tracers in ground-water studies because they are highly mobile, do not interact with other chemical constituents, and are not attenuated by cation exchange (LeBlanc, 1984; Canter and Knox, 1985; Hallberg, 1989). Decreases in chloride, boron, and nearly all other dissolved constituents between the two sampling periods indicated that nitrate concentrations (table 2) at 3 wells (9, 11, and 14) might have been diluted as the water table rose (table 1). However, changes in chloride and boron concentrations were not consistent with changes in nitrate concentrations in samples from most wells in the urban study area. In the second sampling period, chloride concentrations were more than 1 mg/L lower at eight shallow wells, higher at six shallow wells, but unchanged at six wells (table 2). Boron concentrations were lower at 5 shallow wells (2 of these also had lower chloride concentrations), higher at 5 shallow wells (2 of these also had higher chloride concentrations), but unchanged at 10 shallow wells (table 2). Furthermore, nonparametric correlation showed that changes in depth to water between sampling periods were not associated with changes in dissolved oxygen, chloride, nitrate, ammonia, or boron concentrations (p greater than 0.20). In addition, when samples from both sampling periods were combined, depth to water did not correlate with dissolved oxygen, chloride, nitrate, ammonia, or boron concentrations (see appendix).

The decreases in nitrate concentrations in the second sampling period might be caused by seasonal application of nitrogen fertilizers to grass in residential landscapes. According to several local gardeners, lawn fertilizer is applied in both spring and autumn, but commonly is applied at a higher rate in autumn. Hallberg (1989) noted that in many areas of the U.S. where agricultural fertilizers were applied seasonally, changes in ground-water nitrate concentrations were seasonal. In contrast, water from a well contaminated by septic-tank effluent near Topaz Lake showed neither short- nor long-term changes in nitrate concentration (Nowlin, 1982). Similarly, water from a well in western Iowa that was contaminated by septic-tank effluent contained high nitrate concentrations that changed little during a 40-year period (Hallberg, 1989, p. 57). Thus, seasonal changes in nitrate concentrations can result from seasonal applications of fertilizer and concentrations that remain elevated through time can result from a constant source of nitrogen, such as sewage effluent.

Areal and Temporal Differences in Ammonia Concentrations

Ammonia concentrations were variable in water from the 20 shallow wells in the urban study area. Ammonia concentrations for all samples ranged from less than 0.01 to 0.26 mg/L (table 2). The median ammonia concentration and coefficient of variation were 0.03 mg/L and 128 percent, respectively. Ammonia concentrations in the urban study area were markedly higher than those in the Topaz Lake study area, most of which were less than the 0.01 mg/L laboratory reporting limit (Nowlin, 1982, p. 69-73).

Based on a nonparametric t-test, ammonia concentrations between the two sampling periods were not statistically different (p=0.63). The ammonia concentrations for sampling period one ranged from less than 0.01 to 0.26 mg/L (table 2); the median ammonia concentration and coefficient of variation were 0.035 mg/L and 127 percent, respectively. Ammonia concentrations for sampling period two ranged from less than 0.01 to 0.21 mg/L (table 2); the median concentration and coefficient of variation were 0.02 mg/L and 130 percent. Ammonia concentrations at five wells (4, 9, 13b, 14, and 15d) decreased between the first and second sampling periods (table 2). The largest decrease in ammonia concentration, 0.08 mg/L, was measured at well 14. The difference in ammonia concentrations between the two sampling periods (fig. 7) was associated neither with differences in depth to water nor with differences in dissolved oxygen, chloride, nitrate, or boron concentrations (p greater than 0.73).

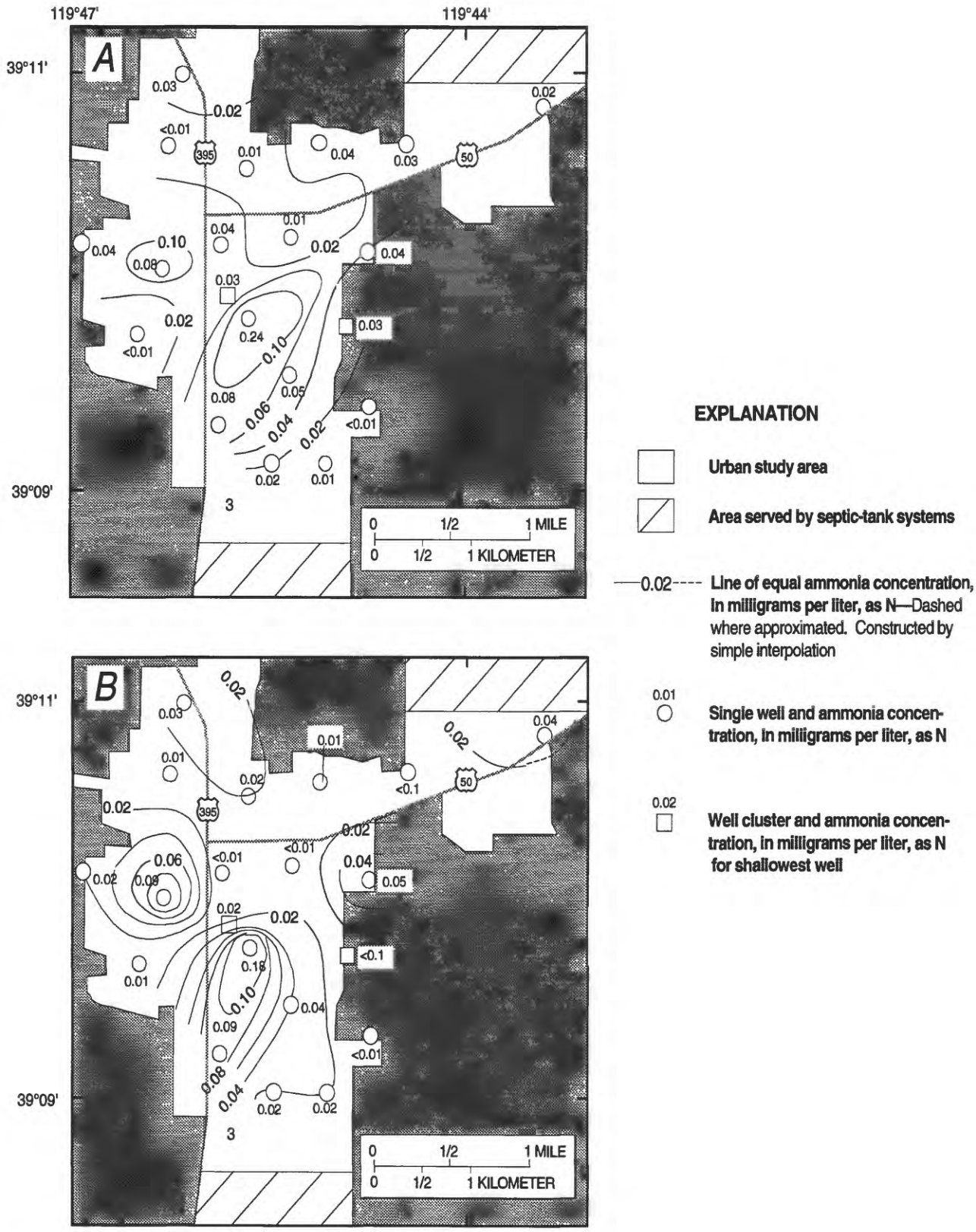


Figure 7. Areal distribution of ammonia concentrations in shallow ground water for (A) January-March 1989 and (B) May-June 1989, Carson City, Nev., urban study area.

Relations Among Nitrate, Ammonia, and Other Properties and Constituents

Nitrate, ammonia, well depth, depth to water, pH, dissolved oxygen, major cations, major anions, selected trace elements, and selected organic compounds were measured in ground-water samples collected in the Carson City urban study area (table 2) and compared statistically (see appendix). Concentrations of nitrate and ammonia generally are highly variable within the urban study area because of the variety of pathways available during nitrogen cycling. Because nitrate and ammonia concentrations in the first sampling period were not statistically different from those in the second, samples for each well from both periods were combined for statistical analysis.

Strong correlations among several constituents in the urban study were consistent with correlations reported for other areas for ground water contaminated with sewage effluent and nitrogen fertilizer (LeBlanc, 1984; Canter and Knox, 1985). Nonparametric correlation showed that several constituents were statistically correlated to nitrate and ammonia (see appendix). Nitrate concentrations were positively correlated with dissolved oxygen and negatively correlated with ammonia, iron, and manganese concentrations. Ammonia concentrations were positively correlated with calcium, magnesium, bicarbonate, iron, manganese, strontium, and dissolved organic carbon (DOC). Ammonia concentrations were negatively correlated with nitrate and dissolved oxygen. Because of the number of correlated constituents, particularly with ammonia, robust multiple-regression analysis (RMRA) was used to search for multivariate relations in the data set.

RMRA indicated that nitrate and ammonia concentrations are related to some of the same constituents as in the nonparametric correlation analysis. RMRA indicated that nitrate had a positive relation with potassium and sulfate, a negative relation with sodium, iron, and manganese, and no relation with ammonia (table 3). This contrasts with the results from the correlation analysis, which indicates that iron and manganese correlated with nitrate, but sodium, potassium, and sulfate were not correlated (see appendix). RMRA indicated that ammonia concentrations were positively related to well depth and to calcium, manganese, and DOC concentrations (table 3). The correlation analysis indicated that ammonia was positively correlated to calcium, manganese, and DOC, but not to well depth (see appendix). RMRA indicated that some relations were consistent with the correlation results; the differences could result partially from the Mallow's Cp method used to select the variables for RMRA.

Varimax rotation was used to optimize the relation between constituents and components that were defined in the initial PCA. Because dissolved oxygen was not measured for three samples (two sites), it was not included in the PCA. Table 3 lists the principal components and their related constituents, and figure 8 depicts those constituents that are most important to the principal components. Varimax rotated PCA resulted in five principal components that accounted for 74 percent of the total variance in the data (fig. 8; table 4).

Principal component 1 explains 24 percent of the total variance and may represent carbonate dissolution because calcium, magnesium, bicarbonate, and strontium, which are present in carbonate or plagioclase feldspar minerals, group within that component (Hem, 1985, p. 89; Welch, 1994). Component 1 may describe water affected by dissolution of soil minerals during landscape irrigation or dissolution of aquifer minerals. DOC also groups with the carbonate elements, although its contribution is minor (table 4). Correlation analysis showed that DOC is correlated with well depth, dissolved oxygen, calcium, magnesium, sodium, bicarbonate, sulfate, ammonia, barium, boron, manganese, and strontium (see appendix). Correlation coefficients for most of the relations with DOC were at least 0.60 and p-values were less than 0.001. Some of these relations with DOC might indicate that these constituents have a common source, such as sewage effluent, a rising water table that intercepts shallow organic-rich layers in the unsaturated zone, or leaching of organic acids (humic and fulvic acids) from landscape areas. Detergents containing anionic or ionic surfactants can make large contributions to DOC (LeBlanc, 1984). However, principal component 1 provides no other indication that sewage effluent is the source of carbonate constituents or nitrate concentrations in the study area. Scatterplots and correlation results show a strong correlation among the elements in component 1 (see appendix).

Principal component 2 explains 18 percent of the total variance and may represent evaporite dissolution because of its relation to sodium, boron, sulfate, and chloride (fig. 8; table 4). Evaporites consist of minerals such as halite (sodium and chloride), thenardite (sodium and sulfate), trona, soda, or nahcolite (various combinations of sodium carbonate and sodium bicarbonate minerals), and gypsum (calcium and sulfate).

Table 3. Robust multiple-regression equations for water-quality constituents in shallow ground water, Carson City, Nev., urban study area, January-March and May-June 1989

[Measurements of water-quality constituents were rank transformed before robust multiple regression analysis. The procedure is robust in that it is insenstitive to outliers, censored values, and data that is not normally distributed (Conover, 1980, p. 338). Mallow's Cp was used to select the constituents that formed the regression equation. Mallow's Cp is a coefficient that optimizes the balance between minimum bias with minimum total error of an equation (Montgomery and Peck, 1982, p. 253). The best equation is one that minimizes bias while minimizing the total error in the regression. Bias in a regression equation is the tendency to overestimate or underestimate the true value. Explanation: Form of regression equations, $Y = a + b(depth) + c(pH) + d(DO) + e(Ca) + f(Na) + g(K) + h(HCO_3) + i(SO_4) + j(Cl) + k(NO_3) + l(NH_4) + m(PO_4) + n(Silica) + o(Boron) + p(Fe) + q(Mn) + r(Sr) + s(DOC)$; pH, rank of the negative log of hydrogen ion concentration; depth, rank of well depth in feet below land surface; DO, rank of dissolved-oxygen concentration; Ca, rank of calcium concentration; Na, rank of sodium concentration; K, rank of potassium concentration; HCO_3 rank of bicarbonate concentration; SO4, rank of sulfate concentration; Cl, rank of chloride concentration; NO_3, rank of nitrate as N concentration; NH_4, rank of ammonia concentration; PO_4, rank of orthophosphorous concentration; Silica, rank of silica concentration; Boron, rank of boron concentration; Fe, rank of iron concentration; Mn, rank of manganese concentration; Sr, rank of strontium concentration; DOC, rank of dissolved organic-carbon concentration; --, not included in regression; r^2, coefficient of determination, the amount of variance in Y accounted for by the b to s constituents up to a maximum of 100 percent.]

Coefficients	Dependent constituents (Y)									
	DO	Ca	Na	K	HCO_3	Cl	NO_3	NH_4	Mn	DOC
a	39.78	1.556	-4.747	34.27	3.534	26.58	31.87	-7.978	28.36	21.60
b	--	--	--	--	--	-.369	--	.362	--	--
c	--	--	.219	-.330	.220	--	--	--	--	--
d	--	--	--	-.453	--	--	--	--	-.324	-.554
e	--	--	--	--	[1].814	--	--	.338	--	.272
f	--	--	--	.388	--	.569	-.937	--	-.621	--
g	-.290	--	.209	--	--	--	.209	--	--	-.187
h	--	--	--	--	--	--	--	--	--	--
i	.301	0.221	.302	--	--	--	1.009	--	.659	--
j	--	--	.274	--	--	--	--	--	--	--
k	--	--	-0.163	0.300	-0.206	--	--	--	-0.438	--
l	--	0.174	--	--	--	--	--	--	.340	--
m	--	--	--	-.251	--	--	--	--	--	--
n	--	-0.238	--	-.325	--	-0.496	--	--	--	--
o	--	--	.391	--	--	--	--	--	--	0.415
p	--	--	--	--	--	--	-0.242	--	--	--
q	-.422	--	--	--	--	--	-.594	0.438	--	--
r	--	0.767	--	--	--	--	--	--	--	--
s	-.530	--	--	--	--	--	--	.252	--	--
r^2	.68	.91	.90	.60	.68	.72	.63	.62	.70	.68

[1] The coefficient is for magnesium rather than calcium.

These minerals can be found in the unsaturated zone within arid and semiarid environments (Doner and Lynn, 1977, p. 77). Sodium, chloride, and sulfate were the most important constituents in component 2. Although boron accounts for only a minor part of the total variance explained by component 2, it may indicate the presence of sewage effluent (LeBlanc, 1984; Canter and Knox, 1985). Boron is a common ingredient in detergents and is a good tracer of sewage effluent (LeBlanc, 1984). LeBlanc reported boron concentrations averaged about 500 µg/L in the center of a sewage plume in Cape Cod, Mass., or about 8 times higher than ambient concentrations. Boron concentration in the Carson City urban study area ranged from less than 10 µg/L to 2,200 µg/L (table 2).

Principal component 3 explains 13 percent of the total variance and may represent the oxidation/reduction of nitrogen by nitrification, denitrification, or nitrate reduction (fig. 8; table 4). Principal component 3 shows a positive relation between ammonia and

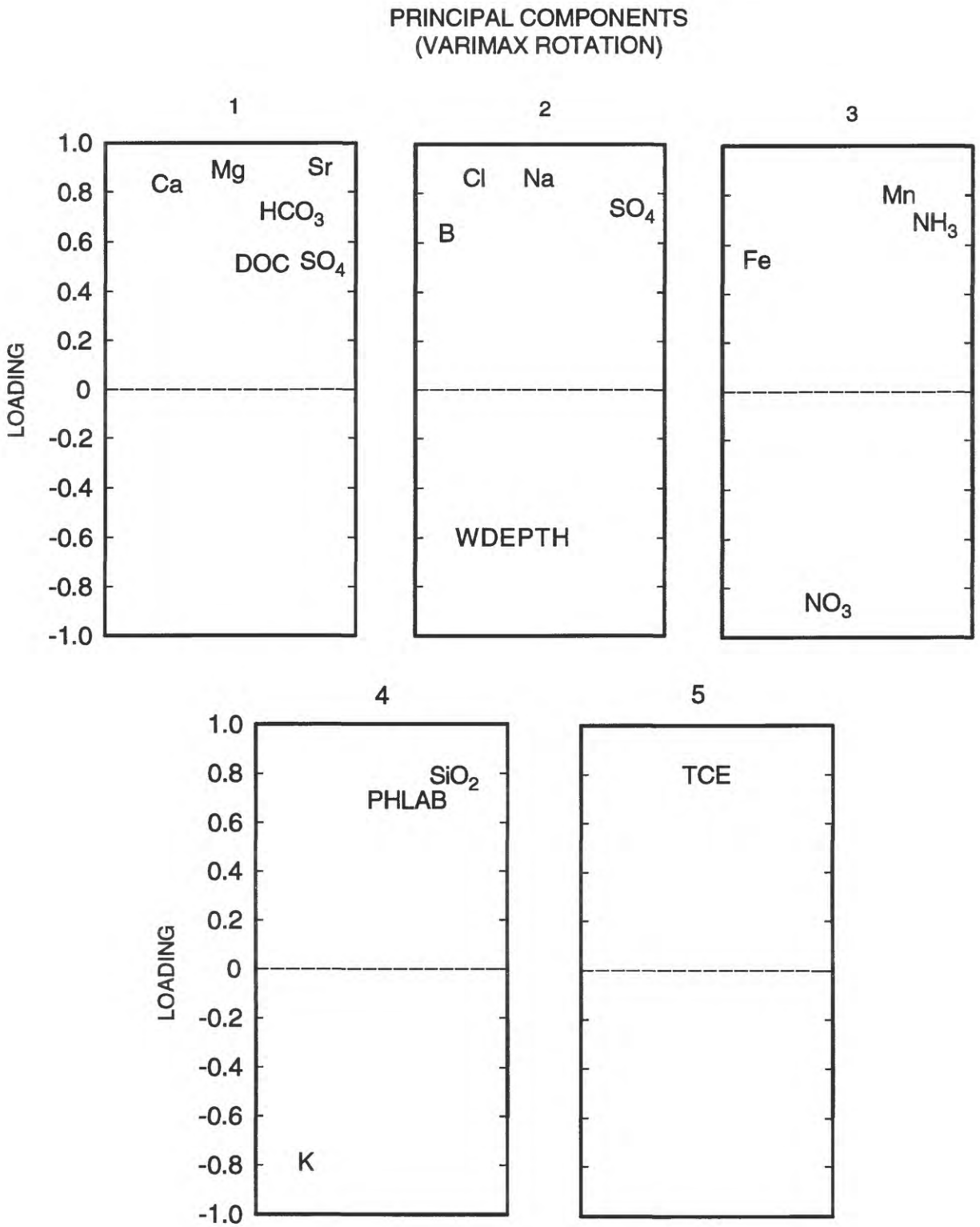


Figure 8. Principal component loadings (varimax rotation) for hydrologic properties and chemical constituents at shallow wells in the Carson City, Nev., urban study area, January-March and May-June 1989. Abbreviations: B, boron; Ca, Calcium; Cl, chloride; DOC, dissolved organic carbon; Fe, iron; HCO_3, bicarbonate; K, potassium; Mg, magnesium; Mn, manganese; Na, sodium; NH_3, ammonium; NO_3, nitrate; PHLAB, laboratory measured pH; $Si0_2$, Silica; SO_4, sulfate; Sr, strontium; TCE, trichloroethylene; WDEPTH, well depth.

Table 4. Loading coefficients from varimax-rotated principal components analysis of rank-transformed well-depth and water-quality measurements at shallow ground-water sampling sites, Carson City, Nev., urban study area

[Coefficients in **bold** indicate constituent or property important to interpretation of a principal component. The closer the coefficient is to one (positive or negative), the stronger the association between the constituent or property and the component and, thus, the more important the constituent or property to the interpretation of the principal component. Abbreviations and symbol: DOC, dissolved organic carbon; TCE, trichloroethylene; PCE, tetrachloroethylene; --, constituent or property not included in interpretation of component]

Constituent or property	Principal component [1]					
	1	2	3	4	5	Communality [2]
Depth of well	-0.33	-0.60	0.08	-0.37	0.25	**0.68**
pH	-.11	.38	-.07	**.69**	-.13	**.66**
Calcium	**.83**	.38	.23	-.18	.01	**.92**
Magnesium	**.89**	.21	.13	-.08	.08	**.86**
Sodium	.36	**.86**	.11	.03	.20	**.92**
Potassium	.26	.15	.12	**-.79**	.18	**.76**
Bicarbonate	**.72**	.27	.32	.10	.11	**.72**
Sulfate	.52	**.74**	-.02	.04	.12	**.84**
Chloride	.17	**.86**	.01	-.35	-.05	**.89**
Silica	.37	-.13	-.24	**.78**	.07	**.82**
Nitrate	.24	-.08	**-.86**	.01	-.10	**.82**
Ammonia	.45	-.03	**.69**	-.15	.10	**.70**
Orthophosphorus	--	--	--	--	--	.55
Barium	--	--	--	--	--	.51
Boron	.45	.64	-.07	.31	.27	**.78**
Iron	--	--	--	--	--	.56
Manganese	.30	-.02	**.80**	-.17	-.11	**.76**
Strontium	**.90**	.22	.04	.09	.07	**.86**
DOC	.51	.42	.44	.08	-.09	**.65**
TCE	.14	.17	.29	-.04	**.80**	**.77**
PCE	--	--	--	--	--	.51
Variance, in percent	24	18	13	11	8	

[1] Each principal component explains part of the data set's total variance. The first component commonly accounts for most of the variance; each subsequent component accounts for part of the remainder. Each component is a collection of constituents or properties from the original data set. Each constituent or property has an associated loading coefficient for each component. Loading coefficients with an absolute value of 0.5 or greater are most important to a component (that is, account for most of the component's variance). Each principal component might relate to a process or a source of the constituents within it.

Principal component 1 represents ground water affected by carbonate dissolution. Principal component 2 represents water affected by evaporite dissolution. Principal component 3 represents ground water affected by the oxidation/reduction of nitrogen. Principal component 4 represents ground water affected by potassium, silica, and pH. Principal component 5 represents ground water affected by trichloroethylene.

[2] The communality is "the proportion of the variance for each original variable accounted for by the retained components" (Puckett and Bricker, 1992). Thus, the communality is an index of the amount of total variance that a constituent contributes to the data set. The closer the communality is to 1.0, the more variance contributed by the constituent and the more important that constituent is to the data set and to the interpretation of the principal component analysis. Constituents with a communality greater than 0.60 are used to interpret components.

manganese, and a negative relation with nitrate concentrations (fig. 8; table 4). Correlation analysis and RMRA also support the relations in principal component 3 (table 3; appendix). Nitrification of ammonia is indicated by the positive correlation between dissolved-oxygen concentrations and nitrate concentrations in scatterplots (appendix), the relation between dissolved oxygen and principal component 3 sample scores (fig. 9), and the negative correlations between nitrate and ammonia and between ammonia and dissolved oxygen (appendix). These relations indicate nitrification (Snoeyink and Jenkins, 1980, p. 405-407; Ceazan and others, 1984; LeBlanc, 1984; Drever, 1988, p. 310; Druliner, 1989, Hallberg, 1989). For more details about the processes in the nitrogen cycle, see section titled "Nitrogen Cycle in Natural and Stressed Systems."

Figure 9 shows that low dissolved-oxygen concentrations correspond to positive component 3 scores. Positive component 3 scores were related to positive correlations among ammonia, iron, and manganese concentrations. Negative correlations between dissolved oxygen and ammonia concentrations (appendix) and between ammonia and nitrate concentrations, and positive correlations among ammonia, iron, and manganese indicate denitrification (Snoeyink and Jenkins, 1980, p. 405-407; LeBlanc, 1984; Smith and Duff, 1984; Trudell and others, 1986; Drever, 1988, p. 310; Hallberg, 1989; Weil and others, 1990; Starr and Gilham, 1993) or nitrate reduction, particularly at wells where iron and manganese concentrations are very high (Drever, 1988, p. 310; Ceazan and others, 1984). Iron and manganese concentrations were probably regulated by the oxidation/reduction conditions created by the nitrification/denitrification reactions and solubility constraints of siderite ($FeCO_3$) and rhodochrosite ($MnCO_3$; Welch, 1994, p. 88).

Principal component 4 explains 11 percent of the total variance and is not easily interpreted. Silica and pH are positively related, and potassium is negatively related with this component. Component 4 might represent nitrogen fertilizer used on residential lawns in the urban study area because potassium is an ingredient in the nitrogen fertilizers commonly used on lawns

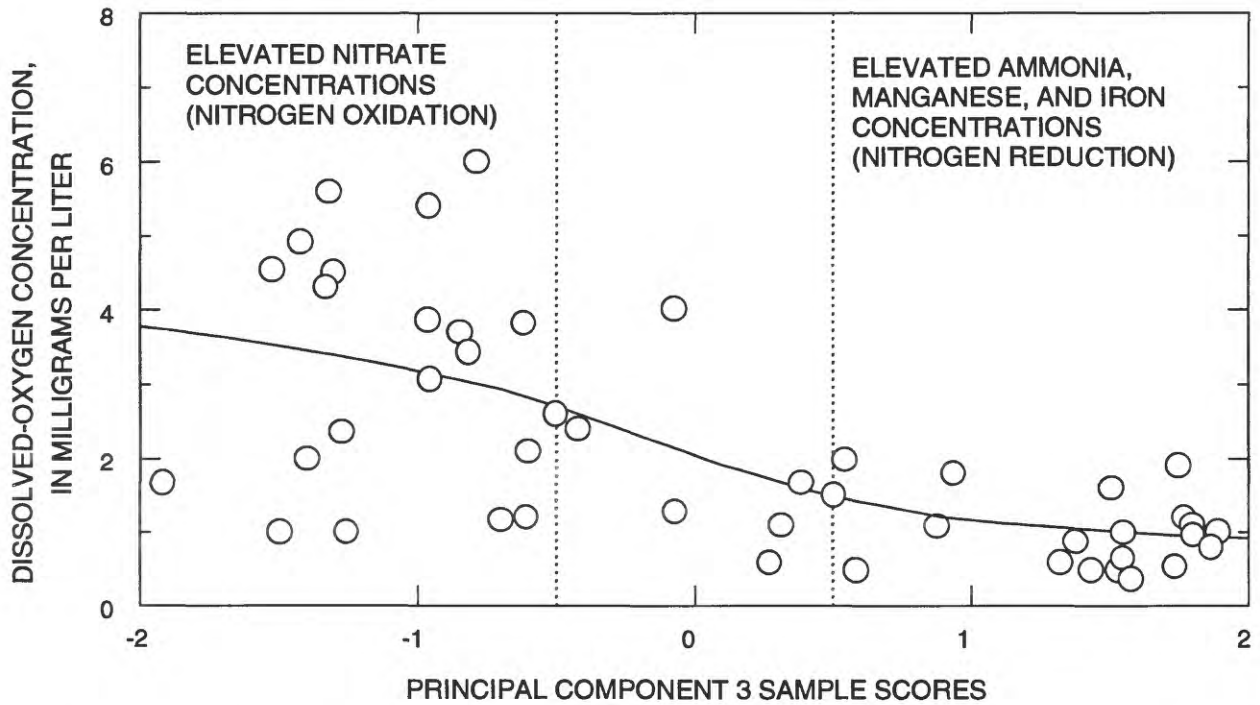


Figure 9. Relation between dissolved-oxygen concentrations and sample scores for principal component 3. Scores below -0.5 indicate nitrification; scores above 0.5 indicate nitrogen reduction (denitrification or nitrate reduction).

(Berg, 1984). Potassium concentrations can be elevated in ground water beneath fertilized agricultural areas (Hallberg, 1989, p. 53; Weil and others, 1990). The silica might be related to dissolution of the silica-cemented hardpan in Dalzell soils (Candland, 1979, p. 15) when lawns and other landscape areas are irrigated.

Principal component 5 explains 8 percent of the total variance and represents trichloroethylene (TCE) concentrations in the study area. No other constituent is related to this component. TCE is an organic compound commonly used in degreasing operations, dry cleaning, and offset-printing businesses. TCE is also commonly found in sewage-contaminated areas, particularly where there are septic-tank systems (Canter and Knox, 1985, p. 82), because it is commonly contained in commercial products used to rejuvenate septic-tank systems. TCE was detected at three sites (3, 14, and 18) in the urban study area at concentrations of 0.2, 0.3, and 20 µg/L (table 2). The ground-water samples from site 14 had the highest concentration of TCE in the urban study area, 44 µg/L (table 2).

Areal Relations Among Nitrate, Ammonia, and Other Properties and Constituents

Principal component sample scores (table 5) were used to map the estimated areal extent of principal components 1, 2, and 3 in the urban study area. These are illustrated in figures 10 and 11. Principal components depict constituents and properties that might be found together because they have the same source or are affected by the same processes. The component sample scores provide a way to relate individual ground-water samples to a principal component. These scores can be used to identify wells where the water quality might be affected by the source or process identified by the principal component. However, a sample might have high concentrations of several constituents that are not correlated and, therefore, will not associate with a component. A principal component will only consist of correlated data and not necessarily those with the highest values.

Figure 10 shows the estimated areal extent of sample scores for principal component 1, carbonate dissolution, in the first sampling period. This map indicates that ground water at wells 1, 2, 6, 9, 10, and 13d (only the shallowest of each cluster well was used for mapping), 14, 15d, 17, 18, 19, and 20 was strongly affected by carbonate dissolution (sample scores equal to or greater than 0.75; table 5).

Figure 10 also shows the estimated areal extent of sample scores for principal component 2, evaporite dissolution, in the first sampling period. These sample scores indicate that ground water at wells 3, 5, 9, 13d, 15d, 17, and 18 was strongly affected by evaporite dissolution (sample scores equal to or greater than 0.75; table 5). Ground water at wells 4, 6, and 19 was moderately affected by evaporite dissolution (sample score between 0.5 and 1.00). Ground water at 10 sites was not affected by evaporite dissolution (sample scores less than 0.50). However, ground water was affected by both carbonate and evaporite dissolution at wells 6, 9, 13d, 15d, 17, 18, and 19.

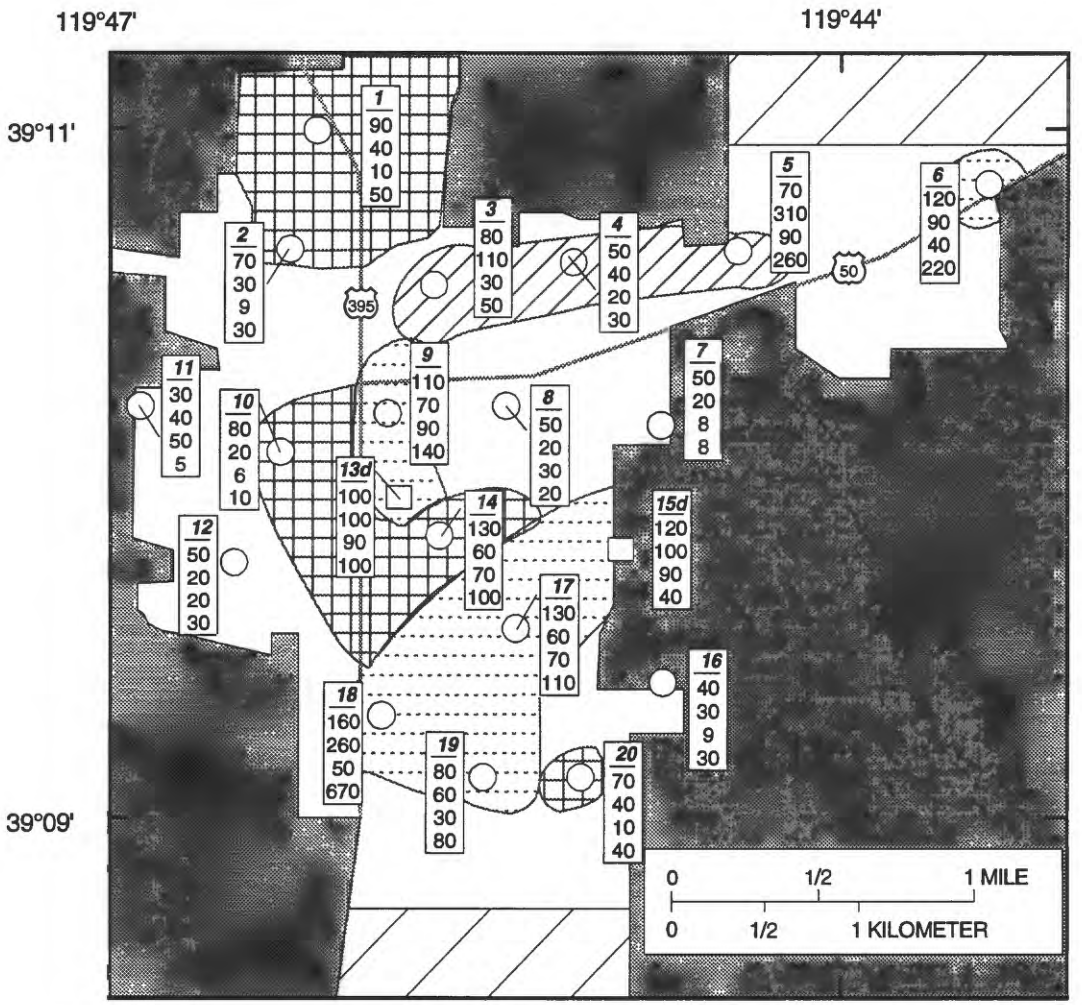
Figure 11 shows the estimated areal extent of sample scores for principal component 3, nitrogen oxidation or reduction, in the first sampling period. Nitrification appears to strongly affect ground water at wells 2, 6, 9, 12, 13d, 16, 19, and 20 (sample scores equal to or smaller than -0.75; table 5); ground water was moderately affected at wells 1, 3, and 8 (sample scores between 0.50 and 0.75). Denitrification or nitrate reduction appears to have strongly affected ground water at wells 5, 7, 10, 14, 15d, and 18 (sample scores equal to or greater than 1:00; table 5); ground water was moderately affected at well 17 (sample score between 0.50 and 1.00). Nitrate reduction may have affected the nitrate and ammonia concentrations in ground water at wells 10, 14, and 18 as indicated by the relations among ammonia, iron, and manganese concentrations (table 2). Large iron and manganese concentrations have been related to nitrate reduction (Potsma and others, 1991). Some studies suggest that denitrification or nitrate reduction is uncommon in ground water because labile DOC concentrations are not high enough to sustain microbial populations (Smith and Duff, 1984; Starr and Gillham, 1993; Wilhelm and others, 1994). However, other research has shown that the requirement for labile DOC is not universal because reactions involving sulfide and iron may serve as a surrogate for DOC (Potsma and others, 1991; Komor and Anderson, 1993). Also, Smith and Duff (1984) and Trudell and others (1986) show that denitrification depends more on organic carbon from soil than on DOC in ground water.

Table 5. Principal component sample scores calculated for shallow ground-water samples, Carson City, Nev., urban study area

[Principal component score is a unitless, numerical index that associates each ground-water sample with a principal component (table 4). For each principal component, the score is calculated as follows: each constituent or property (chemical concentration, depth to water, well depth) associated with a sample is multiplied (normalized) by its loading coefficient (table 4); the new values are summed.]

Well number [1] (figure 2)	Principal component					Well number [1] (figure 2)	Principal component				
	1	2	3	4	5		1	2	3	4	5
1	1.70	-0.60	-0.60	1.70	0.30	13b	1.20	1.00	1.70	-1.20	2.50
1	1.80	-1.00	-.80	1.20	.20	13b	1.40	.80	1.50	-1.70	3.10
2	.80	-1.4	-1.00	.60	.10	13c	1.00	1.70	1.50	-1.30	2.20
2	.80	-1.5	-.50	.90	.70	13c	1.00	1.50	.90	-2.20	2.60
3	.40	1.40	-.70	1.00	4.40	13d	1.20	1.90	-1.00	-1.70	-.20
3	-.40	1.80	-.40	1.00	2.90	13d	.90	2.10	-.60	-1.40	-.30
4	-1.70	.50	-.10	-.03	1.40	14	2.30	.20	1.80	-.60	3.20
4	-.80	.70	-1.00	.06	.90	14	2.20	0.10	1.70	-0.60	4.20
5	-.10	2.90	1.60	2.40	.70	15a	-.50	-.80	-.10	.10	-.20
5	-.80	3.20	.90	2.10	.40	15a	-.80	-.50	.30	.20	-.10
6	3.40	.70	-1.90	.40	1.30	15b	1.70	-.70	1.80	-.10	-.40
6	3.70	.60	-1.40	.20	1.30	15b	.70	-.10	1.50	.04	.30
7	-.80	-.60	2.00	2.00	-.40	15c	1.20	.10	1.90	.40	-.40
7	-.70	-.90	1.50	1.70	-.60	15c	.50	.30	1.30	.20	.10
8	-1.10	.10	-.60	-2.00	.40	15d	1.50	1.60	1.40	1.40	-.70
8	-.20	.70	-1.30	-3.10	-.40	15d	.70	1.80	.50	1.60	-.40
9	1.70	1.60	-1.50	-2.30	1.20	16	-.50	-.40	-.80	1.40	.40
9	-.70	1.90	-1.30	-1.70	.20	16	-.70	-.30	-.80	1.50	.50
10	1.50	-1.80	1.90	.50	.60	17	2.40	1.00	.60	-.60	-1.90
10	1.90	-1.90	2.30	.60	.50	17	2.20	1.00	.40	-.50	-1.90
11	-1.50	-.20	.30	-2.10	.90	18	2.10	1.50	2.30	-.20	-.40
11	-1.30	-1.80	.50	-1.00	1.30	18	1.60	1.40	2.30	.10	3.00
12	-.20	-1.10	-1.30	.50	1.10	19	1.50	.70	-1.40	2.30	.10
12	.20	-1.10	-1.30	.20	.90	19	1.30	.80	-2.00	2.30	1.70
13a	1.30	-.80	1.40	-1.40	.40	20	.90	-.30	-1.50	1.70	.20
13a	.90	-.40	1.80	-1.30	2.30	20	.80	-.60	-1.30	1.60	.50

[1] Samples collected twice at each well: January to March 1989 and May to June 1989



EXPLANATION

Urban study area—No carbonate or evaporite dissolution

Area served by septic-tank systems

Principal component 1—Carbonate dissolution. Area estimated by simple interpolation

Principal component 2—Evaporite dissolution. Area estimated by simple interpolation

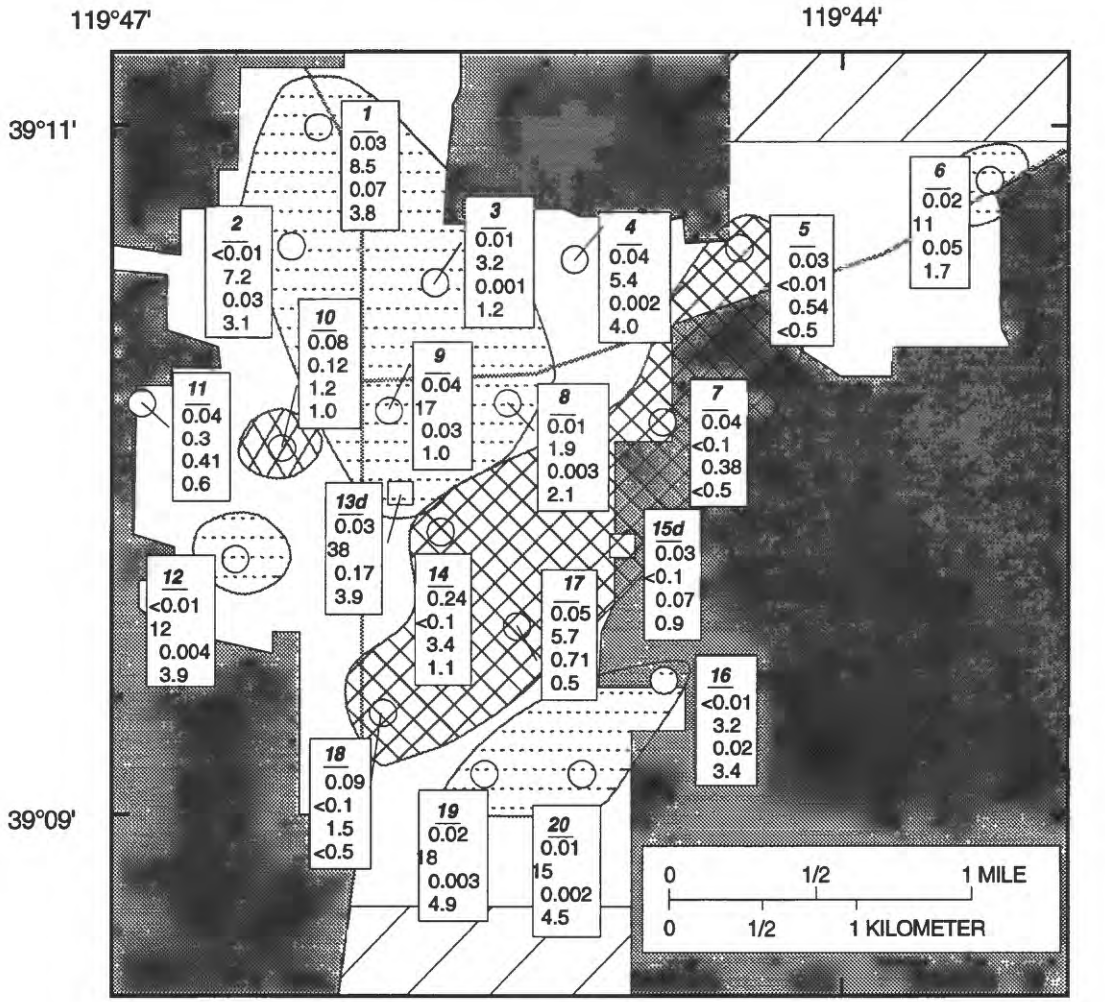
Principal components 1 and 2—Evaporite and carbonate dissolution. Area estimated by simple interpolation

Well **Well cluster**

Constituent concentrations, in milligrams per liter

1	Well number
90	Calcium
40	Sodium
10	Chloride
50	Sulfate

Figure 10. Estimated areal distribution of sample scores for principal component 1 (carbonate dissolution) and principal component 2 (evaporite dissolution) in shallow ground water beneath the Carson City, Nev., urban study area, January-March 1989.



EXPLANATION

Urban study area—Neither oxidation nor reduction of nitrogen

Area served by septic-tank systems

Principal component 3—Denitrification / reduction of nitrogen; area estimated by simple interpolation

Principal component 3—Nitrification of nitrogen; area estimated by simple interpolation

○ **Well** □ **Well cluster**

Constituent concentrations, in milligrams per liter

1	Well number
0.03	Ammonia, as N
8.5	Nitrate, as N
0.07	Manganese
3.8	Dissolved oxygen

Figure 11. Estimated areal distribution of sample scores for principal component 3 (nitrification or denitrification/nitrate reduction) in shallow ground water beneath the Carson City, Nev., urban study area, January-March 1989.

Relations Among Nitrate, Ammonia, and Well Depth

The well clusters at sites 13 and 15 (fig. 2) were constructed to measure nitrate and ammonia concentrations at increasing depths within the shallow part of the basin-fill aquifer. At these two sites, only water samples from site 13 had nitrate concentrations greater than background levels and showed distinct differences in concentration with depth. Site 13 is within the landscaped areas of a city park that receives nitrogen-based fertilizers and site 15 is in an irrigated pasture. The shallowest well (d) at site 13 had 38 mg/L of nitrate in a water sample collected during the first sampling period (table 2).

In both sampling periods, at site 13, nitrate and dissolved-oxygen concentrations were highest in well 13d while TCE, specific conductance, ammonia, iron, and manganese concentrations were lowest (fig. 12). Nitrate and dissolved-oxygen concentrations were lowest in wells 13a, b, and c, while TCE, specific conductance, ammonia, iron, and manganese were highest (fig. 12). The highest ammonia concentrations were in samples from well 13b; the highest iron concentrations (12 mg/L) were in water samples from well 13a, the deepest well in this cluster (fig. 12).

PCA showed that ground-water samples from well 13d were related to principal component 1 (carbonate dissolution), principal component 2 (evaporite dissolution), the nitrification part of principal component 3, and to potassium in principal component 4 (table 5). PCA showed that water samples from well 13c were related to components 1 and 2 (carbonate and evaporite dissolution), the denitrification/reduction part of component 3, the potassium part of component 4, and component 5 (TCE). PCA showed that water samples from well 13b and 13a were related to component 1 (carbonate dissolution), the nitrogen reduction part of component 3, the potassium part of component 4, and component 5 (TCE). Water samples from well 13b were related to component 2 (evaporite dissolution), but water samples from well 13a were not (table 5).

The elevated ammonia, TCE, and specific conductance; the apparent relations among dissolved oxygen, nitrate, ammonia, iron, and manganese relative to well depth; and PCA suggest that sewage effluent is undergoing denitrification or nitrate reduction, perhaps in a plume, about 20 ft below land surface at site 13. Nitrate reduction, the microbial mediated conversion of nitrate to ammonia under anoxic conditions, is commonly associated with high iron or manganese concentrations (Stumm and Morgan, 1981, p. 516-517; Drever, 1988, p. 310-314). The strong PCA signature for potassium in water samples from wells 13c and b was similar to that in samples from well 13d. This potassium signature is difficult to interpret, but could be associated with either sewage effluent or shallow ground water containing potassium from fertilizers that mixes with deeper water, possibly as a result of fertilizer and lawn irrigation applied upgradient from site 13.

Although PCA seems to be capable of identifying sources of nitrogen in wells, ambiguities and uncertainties in the interpretation remain. A more definitive identification of nitrate and ammonia sources in the ground water beneath the Carson City urban area would require more study. Information on nitrogen and oxygen isotopes in the nitrate ion and sewage-related constituents, such as caffeine, ascorbic acid, or derivatives of fecal steroids, could determine sources of nitrate and ammonia. Data from additional wells would help define the ground-water flow regime and determine nitrate and ammonia sources.

SUMMARY

A network of 26 shallow observation wells at 20 sites was established within a small part of the Carson City urban area. Single wells were constructed at 18 sites. Clustered sets of four nested wells were constructed at 2 sites. All single wells and the shallowest wells at both nested sites penetrated the upper 15 ft of saturated sediments in the basin-fill aquifer. All 26 wells were sampled twice during the first 6 months of 1989.

Water-table altitudes increased an average of 1 ft between the first and second sampling periods in the urban study area. Specific conductance ranged from 380 to 1,970 µS/cm. The highest specific conductance was measured in the southwestern part of the study area and the second highest was measured in the northeastern part of the study area.

Water samples collected from the wells in 1989 contained concentrations of nitrate, as nitrogen, that ranged from below the laboratory reporting limit of 0.1 mg/L to 38 mg/L. A nonparametric t-test showed that nitrate concentrations measured in the shallow ground water during sampling-period one (January-March

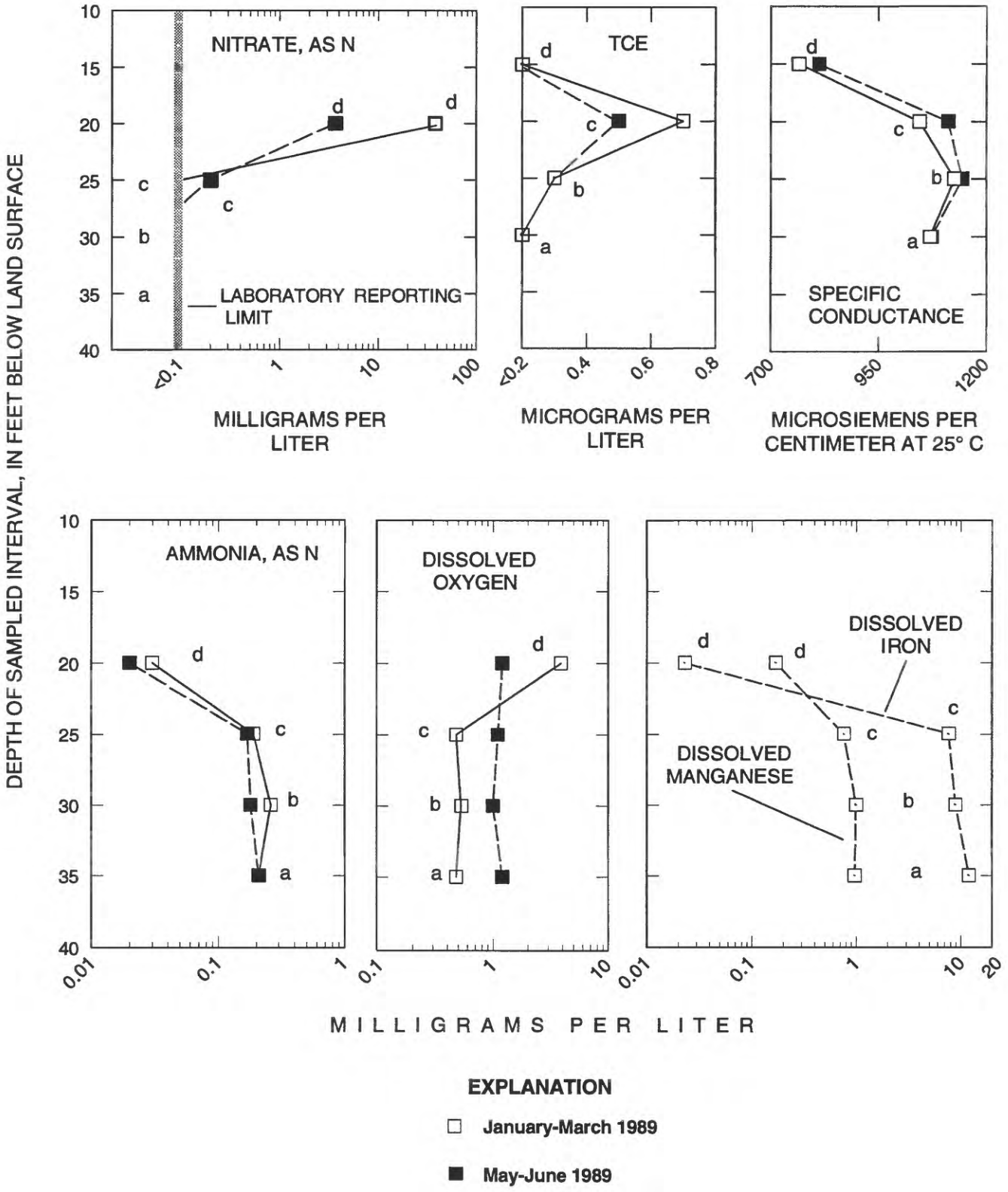


Figure 12. Relations between well depth and nitrate, trichloroethylene, ammonia, dissolved-oxygen, dissolved-iron, and dissolved-manganese concentrations, and specific conductance for wells a, b, c, and d at well cluster 13, Carson City, Nev., urban study area, January-March 1989 and May-June 1989. Concentrations of iron and manganese are shown only for March 1989 because concentrations were equal for both sampling periods. Some X-axis scales are logarithmic.

1989) were not statistically different from those measured in sampling-period two (May-June 1989). The first-period samples from 12 of the 20 shallow wells contained more than 3.0 mg/L of nitrate. Samples from six of the first-period wells and three of the second-period wells had nitrate concentrations that exceeded the Nevada drinking-water standard of 10 mg/L. Nitrate concentrations decreased by an average of 2 mg/L between the first and second sampling periods. This difference in nitrate concentrations was not related to changes in the depth to water between the two sampling periods. A comparison of chloride and boron concentrations between the two sampling periods showed that the higher water table during the second sampling period generally did not affect nitrate concentrations.

Ammonia concentrations for all samples ranged from less than 0.01 to 0.26 mg/L. Concentrations were not statistically different in the two sampling periods and were not affected by the higher water table in the second period, although concentrations were lower in second-period samples from five wells.

Scatterplots and nonparametric correlation showed many statistically significant relations among nitrate and ammonia concentrations and the other constituents and properties measured during the study. Robust multiple regression showed relations similar to those of the correlation analysis; the differences were probably partly caused by the method used to select the regression variables (Mallow's Cp).

A principal components analysis with varimax rotation resulted in five principal components that accounted for 74 percent of the data-set variance. The first component represents carbonate dissolution (24 percent of total variance), the second represents evaporite dissolution (18 percent of the total variance), the third represents nitrification/denitrification or nitrogen reduction (13 percent of the total variance), the fourth component represents potassium, silica, and pH relations (11 percent of the total variance), and the fifth component represents trichloroethylene (TCE; 8 percent of the total variance).

The estimated areal extent of principal component scores in the urban study area is shown on maps (figs. 10, 11). Sample scores for principal component 1 (carbonate dissolution) indicate that calcium, magnesium, bicarbonate, and dissolved organic carbon (DOC) were strongly related in samples from 12 wells during the first sampling period of the urban study. Scores for principal component 2 (evaporite dissolution) from the first sampling period indicate that sodium, sulfate, chloride, and boron were strongly related in samples from seven wells and moderately related in samples from three wells. Seven of those samples were also related to calcium, magnesium, bicarbonate, and DOC. Sample scores for principal component 3 (nitrification/denitrification or reduction) showed that nitrification affected nitrate and ammonia concentrations at 11 wells during the first sampling period. Ammonia, iron, and manganese were related in samples from seven wells. This indicates that reducing conditions exist that favor either denitrification or nitrate reduction. Samples from three wells had high iron and manganese concentrations that may indicate nitrate reduction. Samples scores for principal components 4 and 5 could not be interpreted and therefore were not mapped.

Clusters of four wells screened at different depths were installed at two sites to assess nitrate and ammonia concentrations in the shallow part of the basin-fill aquifer. Of water samples from the two sites, only those from site 13 had measurable concentrations of nitrate and distinct differences in nitrate with depth. In both sampling periods, nitrate and dissolved-oxygen concentrations were highest in the shallowest well (20 ft below land surface), whereas TCE, specific conductance, ammonia, iron, and manganese concentrations were lowest. In contrast, nitrate and dissolved-oxygen concentrations were lowest in the three deepest wells, whereas TCE, specific conductance, ammonia, iron, and manganese were highest. The highest ammonia, iron, and manganese concentrations were in samples from the second deepest well at site 13. The associations among nitrate, ammonia, iron, and manganese concentrations in the principal components analysis (PCA) indicate that nitrate concentrations in samples from the shallowest well were related to nitrification. The source of nitrate may be fertilizer application. The PCA associations indicate that ammonia, iron, and manganese concentrations may be related to denitrification or nitrate reduction in the deeper wells at site 13. The elevated TCE, specific conductance, ammonia,

iron, and manganese values in water from the deeper wells at site 13 suggest that those wells may be affected by sewage.

Correlation analysis, robust multiple regression analysis, and principal components analysis were used to evaluate water-quality data collected from the Carson City urban area shallow aquifer. Wells where ground-water quality is affected by carbonate and evaporite constituents and where nitrification or nitrogen reduction has affected nitrogen concentrations were identified. However, the source or sources of nitrate and ammonia concentrations could not be identified.

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Appendix

Scatterplots of well depth, depth to water, and hydrogeologic and water-quality properties in shallow ground water, Carson City, Nev., urban study area, January-March 1989. r, Spearman's rank-correlation coefficient; p, p-value (probability that correlation is due to chance). p-value of 0.05 or less indicates statistically significant correlation.

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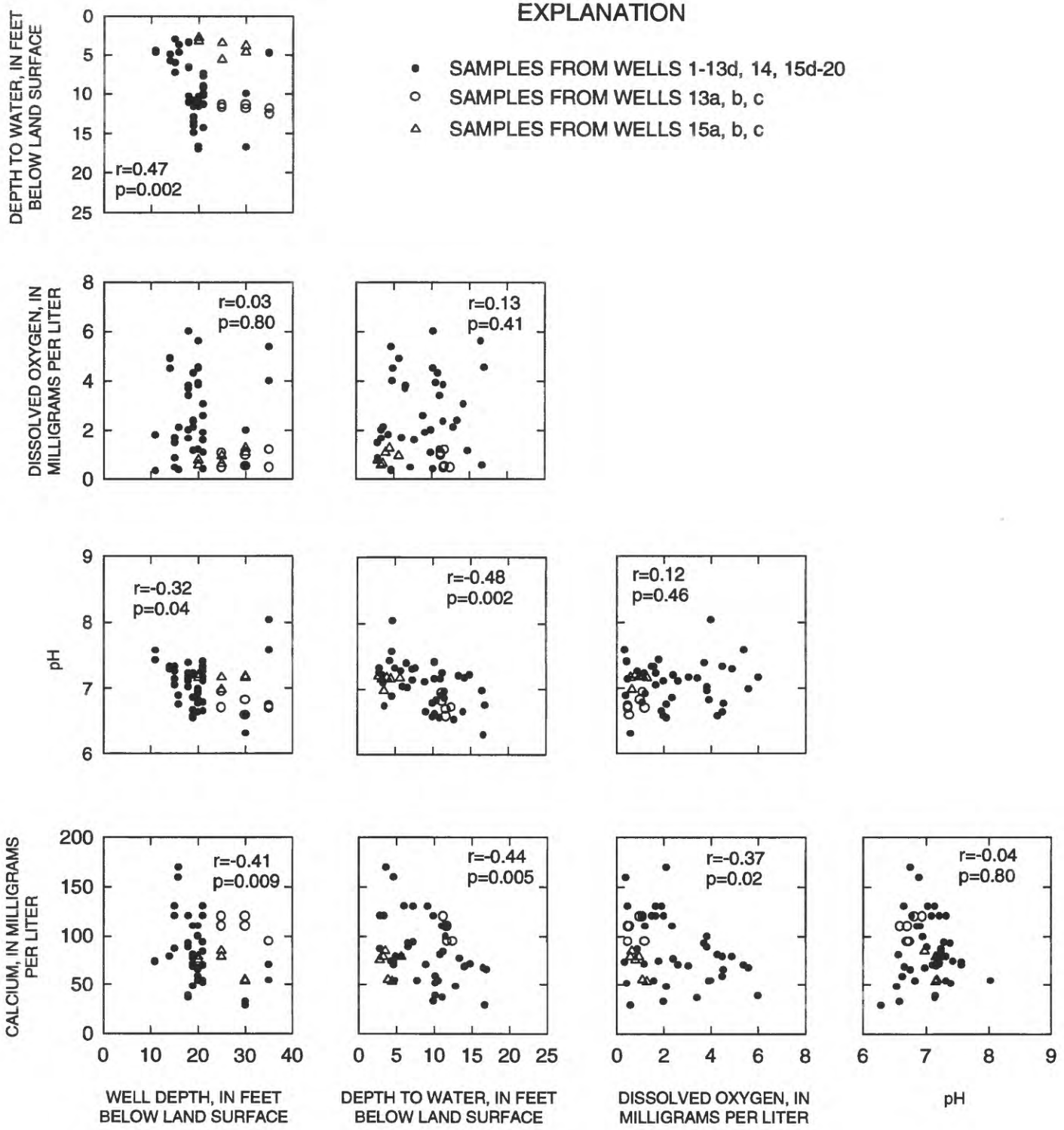
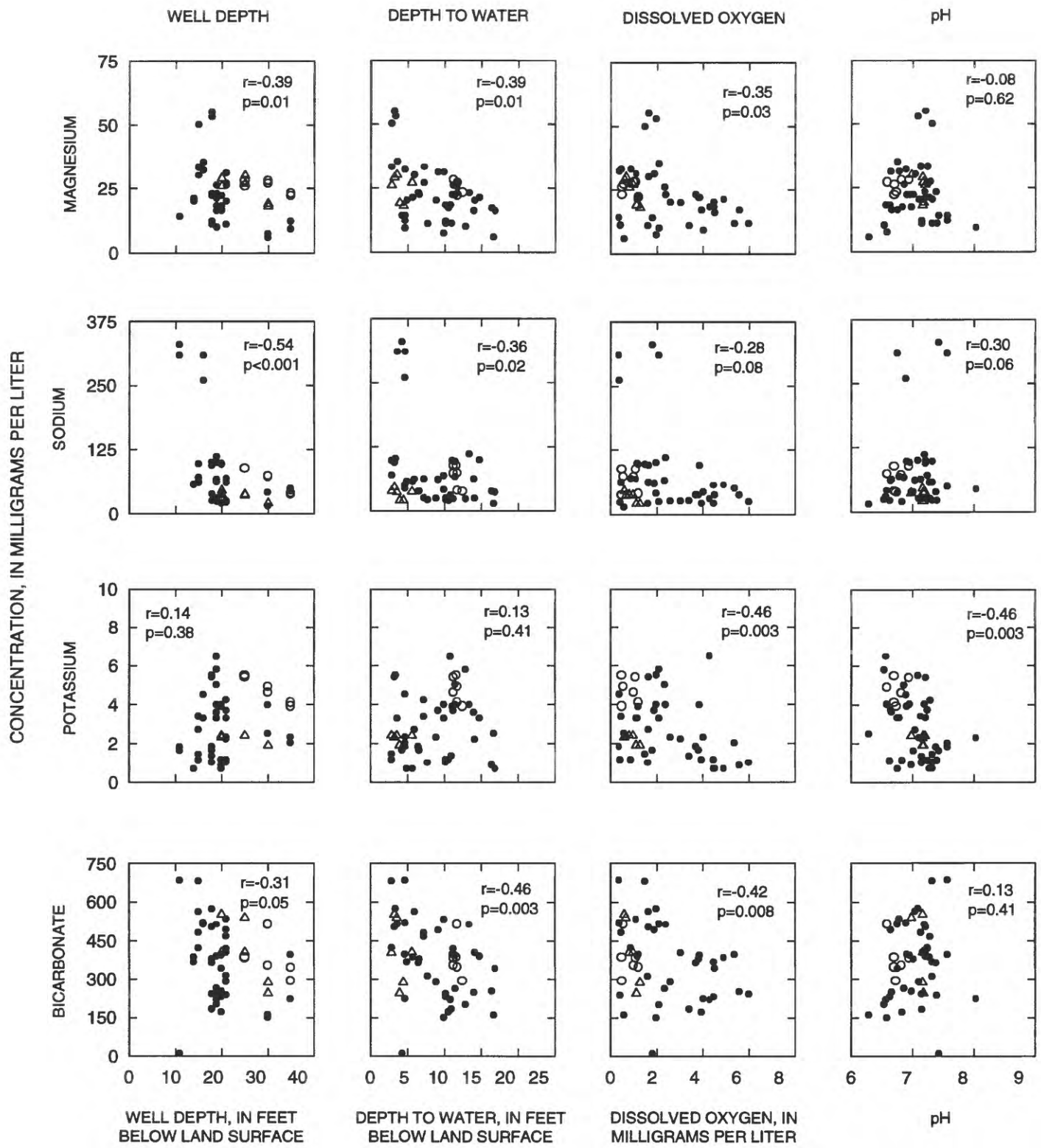
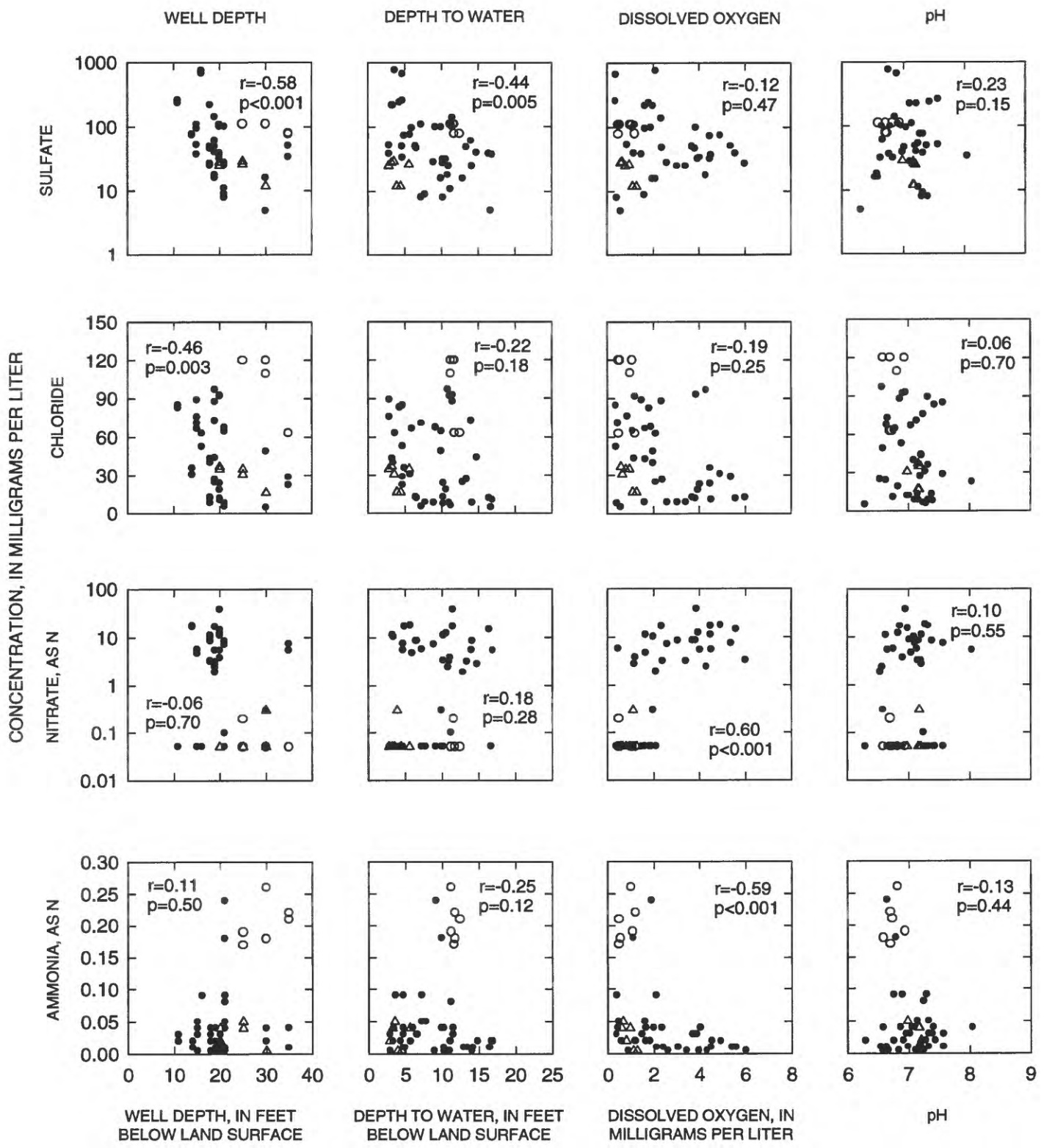
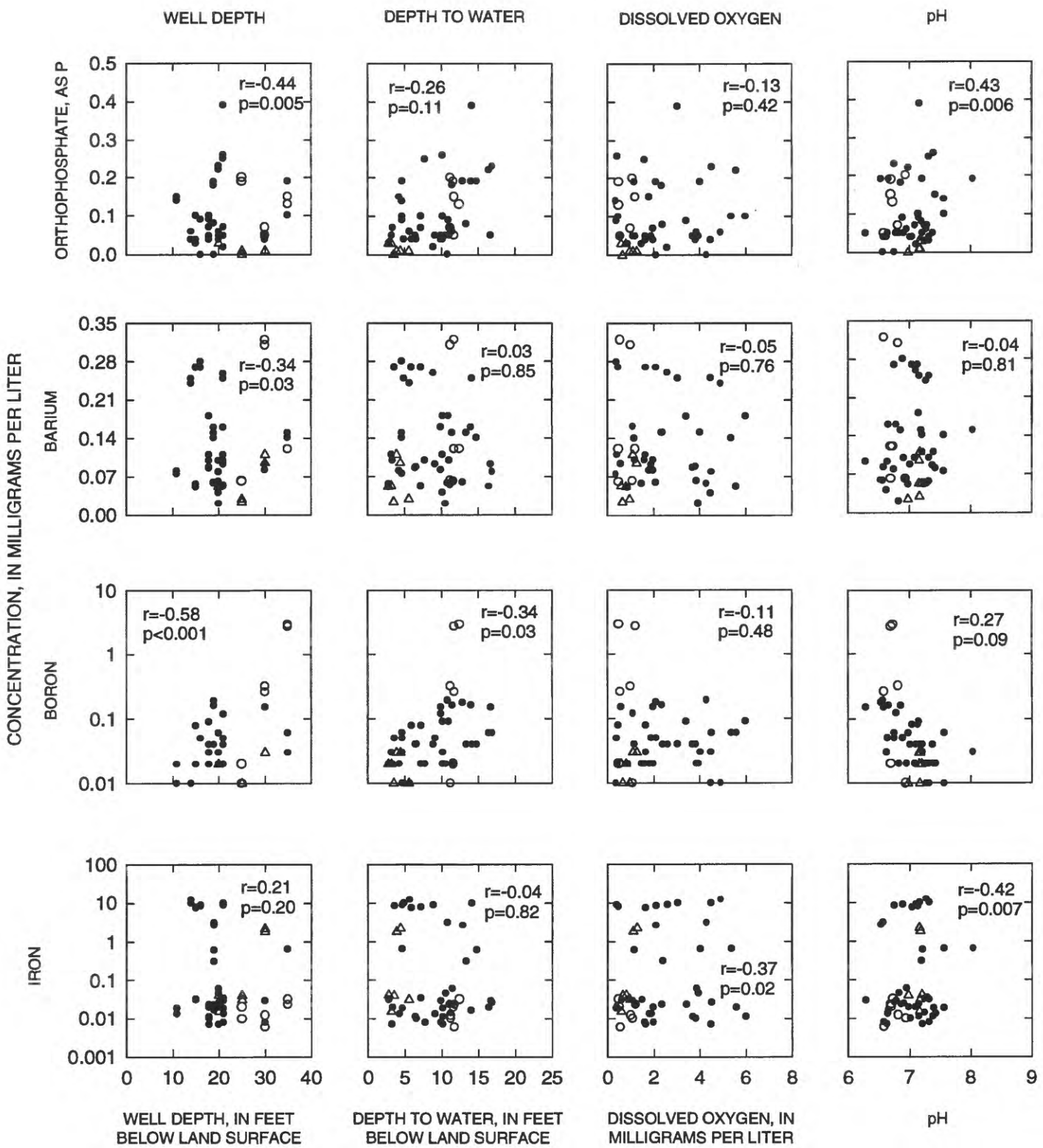
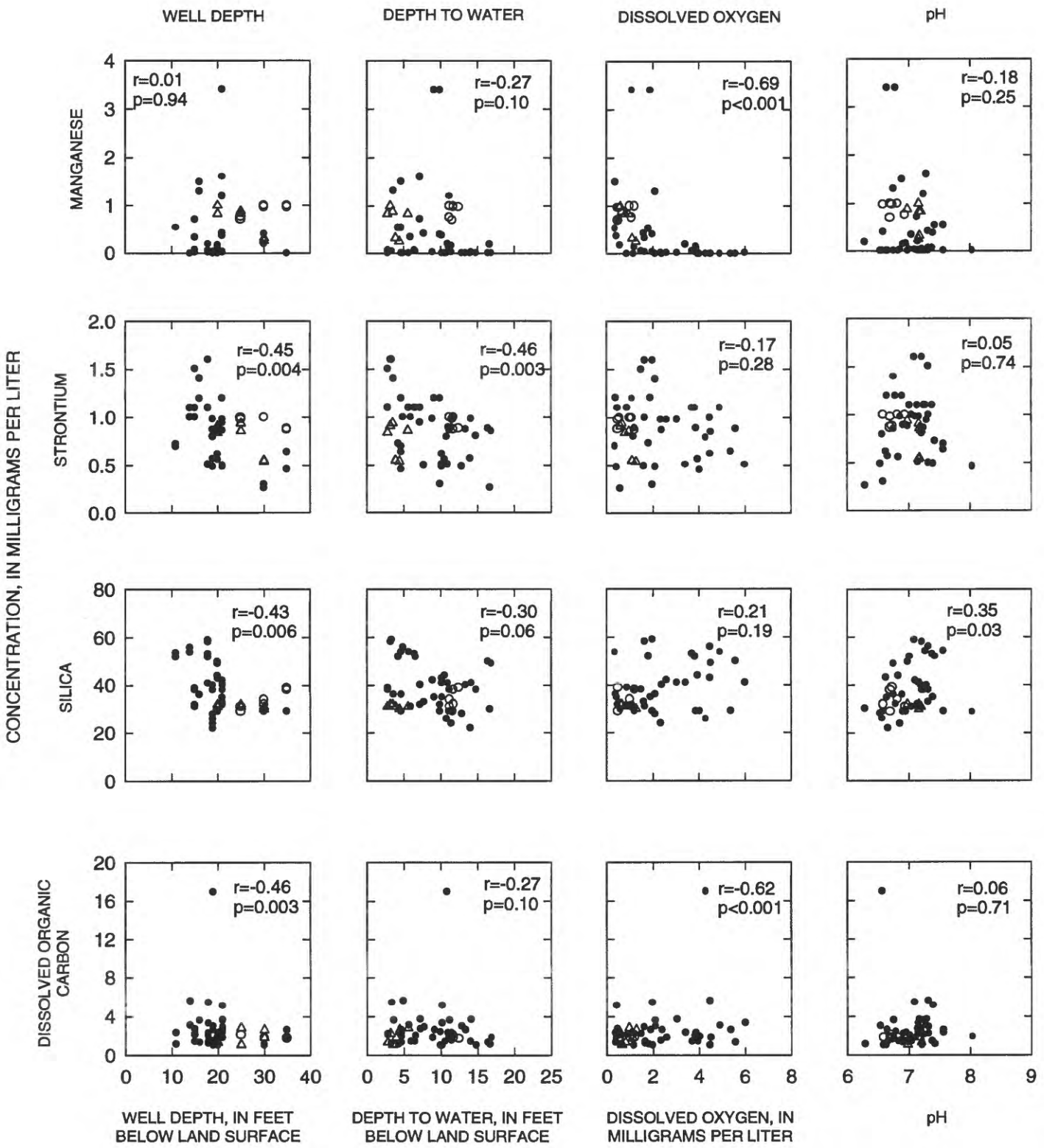
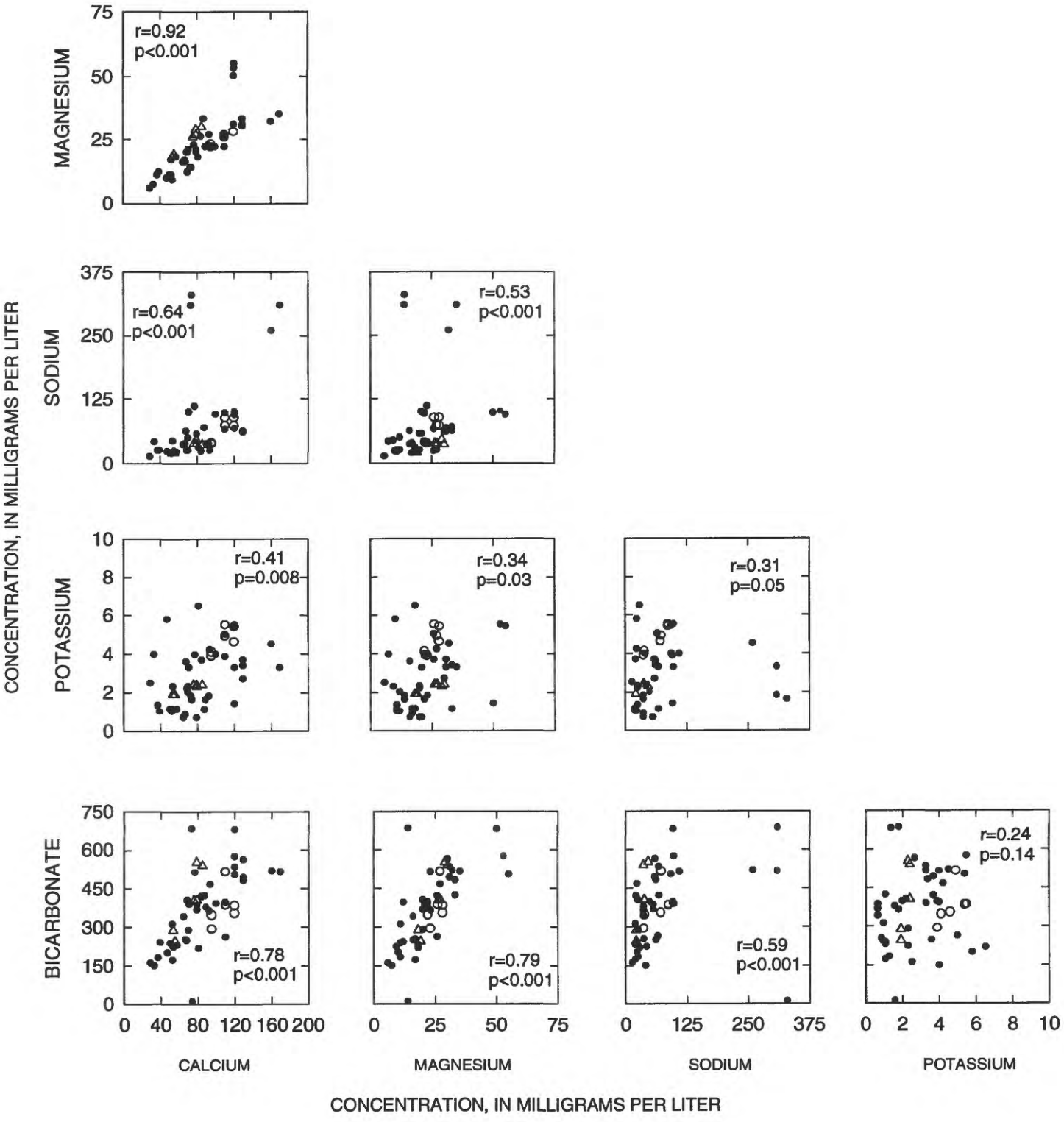

EXPLANATION
SAMPLES FROM WELLS 1-13d, 14, 15d-20
SAMPLES FROM WELLS 13a, b, c
SAMPLES FROM WELLS 15a, b, c
DEPTH TO WATER, IN FEET BELOW LAND SURFACE
DISSOLVED OXYGEN, IN MILLIGRAMS PER LITER
pH
CALCIUM, IN MILLIGRAMS PER LITER
r=0.47
p=0.002
r=0.03
p=0.80
r=0.13
p=0.41
r=-0.32
p=0.04
r=-0.48
p=0.002
r=0.12
p=0.46
r=-0.41
p=0.009
r=-0.44
p=0.005
r=-0.37
p=0.02
r=-0.04
p=0.80
WELL DEPTH, IN FEET BELOW LAND SURFACE
DEPTH TO WATER, IN FEET BELOW LAND SURFACE
DISSOLVED OXYGEN, IN MILLIGRAMS PER LITER
pH

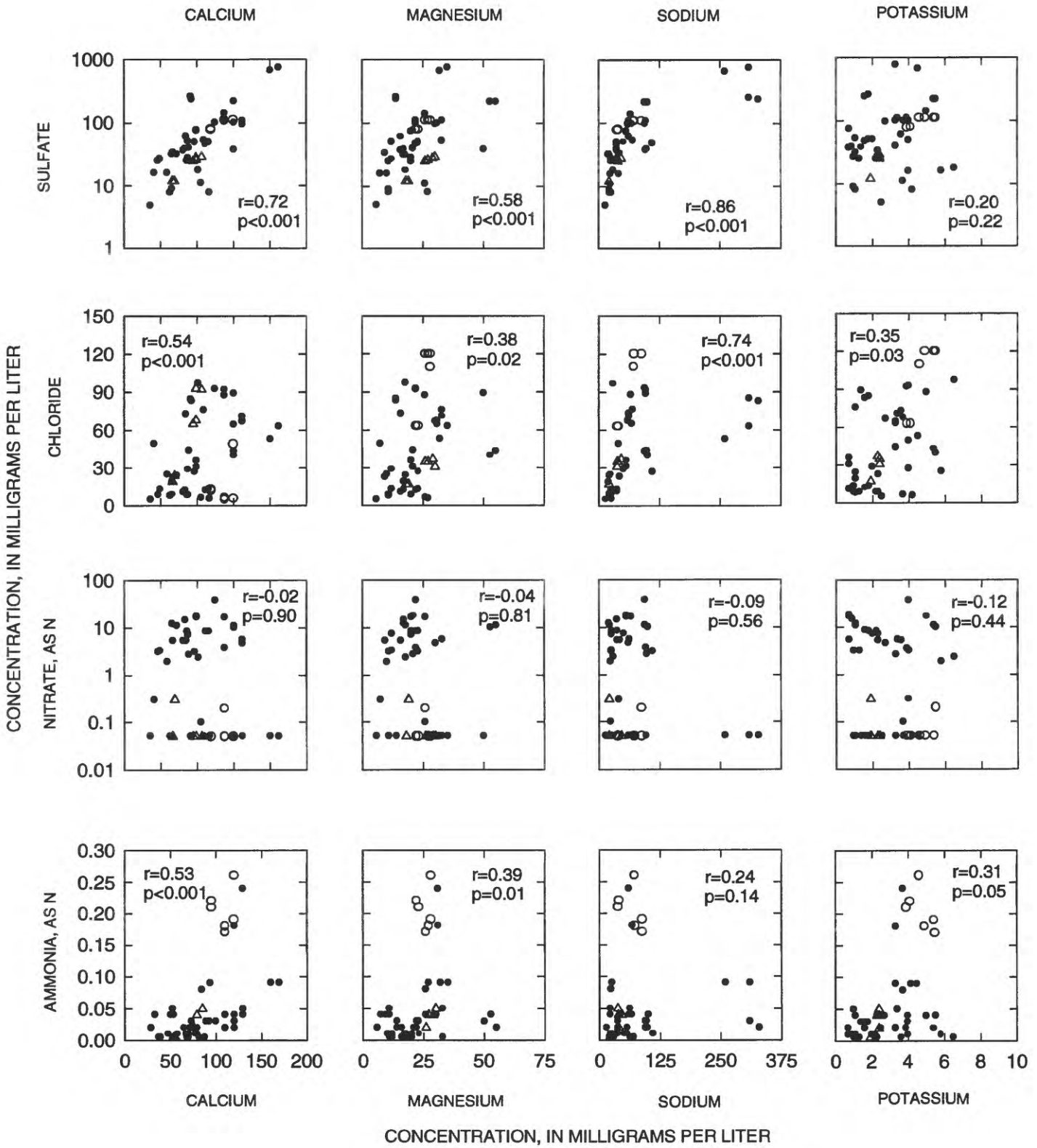

WELL DEPTH
DEPTH TO WATER
DISSOLVED OXYGEN
pH
MAGNESIUM
SODIUM
POTASSIUM
BICARBONATE
CONCENTRATION, IN MILLIGRAMS PER LITER
r=-0.39
p=0.01
r=-0.39
p=0.01
r=-0.35
p=0.03
r=-0.08
p=0.62
r=-0.54
p<0.001
r=-0.36
p=0.02
r=-0.28
p=0.08
r=0.30
p=0.06
r=0.14
p=0.38
r=0.13
p=0.41
r=-0.46
p=0.003
r=-0.46
p=0.003
r=-0.31
p=0.05
r=-0.46
p=0.003
r=-0.42
p=0.008
r=0.13
p=0.41
WELL DEPTH, IN FEET BELOW LAND SURFACE
DEPTH TO WATER, IN FEET BELOW LAND SURFACE
DISSOLVED OXYGEN, IN MILLIGRAMS PER LITER
pH

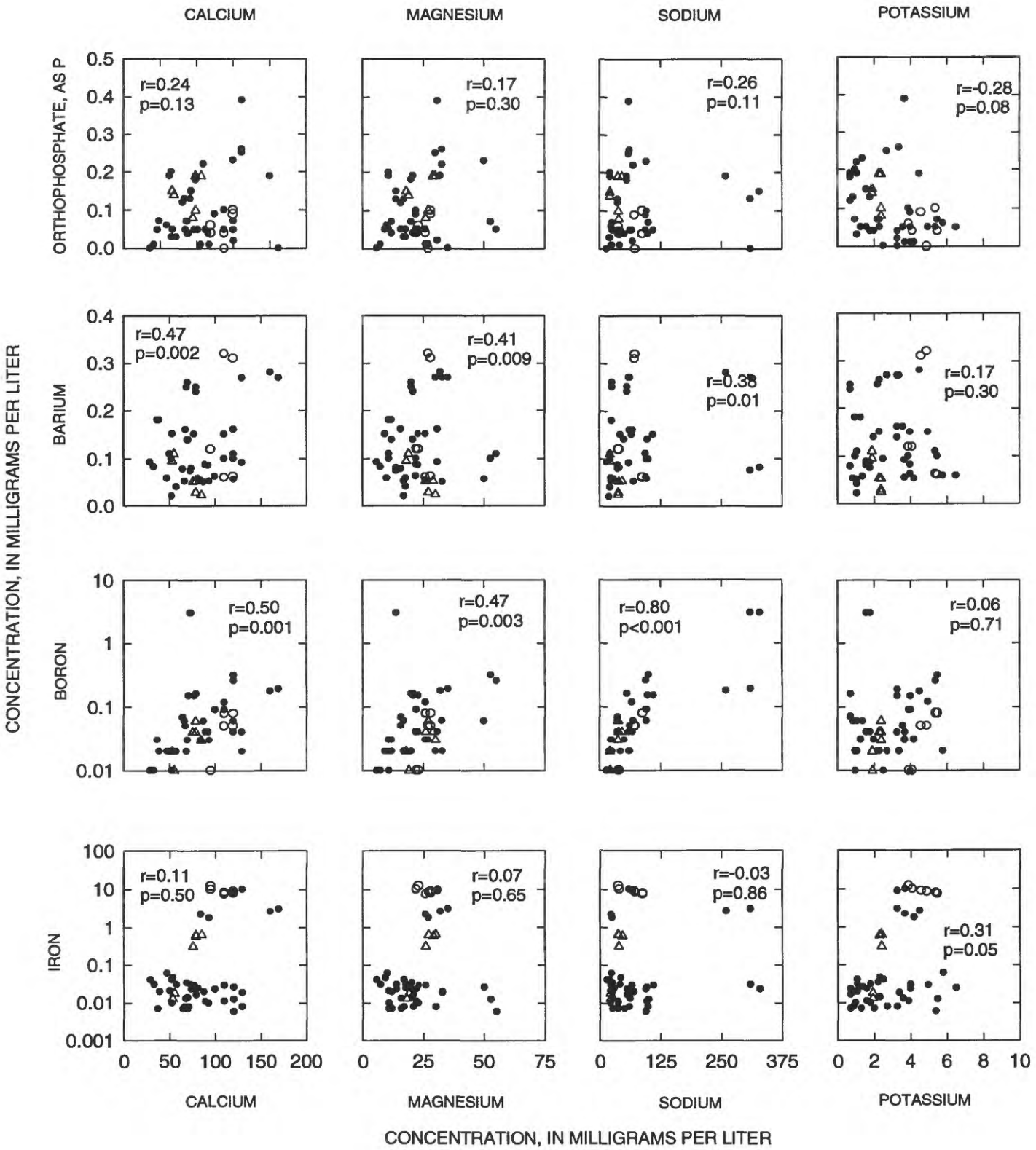

WELL DEPTH
DEPTH TO WATER
DISSOLVED OXYGEN
pH
SULFATE
CHLORIDE
NITRATE, AS N
AMMONIA, AS N
CONCENTRATION, IN MILLIGRAMS PER LITER
r=-0.58
p<0.001
r=-0.44
p=0.005
r=-0.12
p=0.47
r=0.23
p=0.15
r=-0.46
p=0.003
r=-0.22
p=0.18
r=-0.19
p=0.25
r=0.06
p=0.70
r=-0.06
p=0.70
r=0.18
p=0.28
r=0.60
p<0.001
r=0.10
p=0.55
r=0.11
p=0.50
r=-0.25
p=0.12
r=-0.59
p<0.001
r=-0.13
p=0.44
1000
100
10
1
150
120
90
60
30
0
100
10
1
0.1
0.01
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0 10 20 30 40
0 5 10 15 20 25
0 2 4 6 8
6 7 8 9
WELL DEPTH, IN FEET BELOW LAND SURFACE
DEPTH TO WATER, IN FEET BELOW LAND SURFACE
DISSOLVED OXYGEN, IN MILLIGRAMS PER LITER
pH

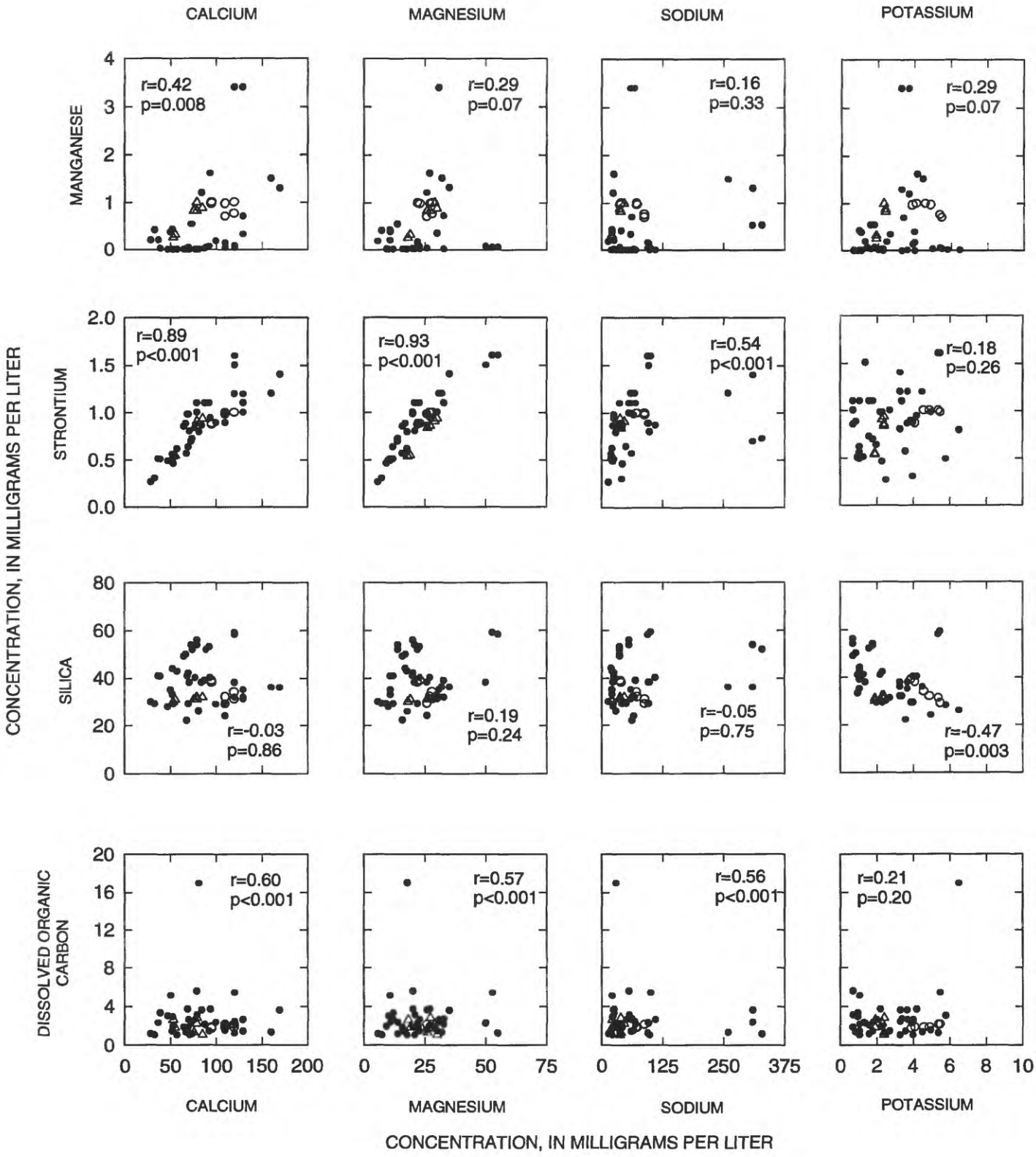

WELL DEPTH
DEPTH TO WATER
DISSOLVED OXYGEN
pH
CONCENTRATION, IN MILLIGRAMS PER LITER
ORTHOPHOSPHATE, AS P
BARIUM
BORON
IRON
r=-0.44 p=0.005
r=-0.26 p=0.11
r=-0.13 p=0.42
r=0.43 p=0.006
r=-0.34 p=0.03
r=0.03 p=0.85
r=-0.05 p=0.76
r=-0.04 p=0.81
r=-0.58 p<0.001
r=-0.34 p=0.03
r=-0.11 p=0.48
r=0.27 p=0.09
r=0.21 p=0.20
r=-0.04 p=0.82
r=-0.37 p=0.02
r=-0.42 p=0.007
WELL DEPTH, IN FEET BELOW LAND SURFACE
DEPTH TO WATER, IN FEET BELOW LAND SURFACE
DISSOLVED OXYGEN, IN MILLIGRAMS PER LITER
pH

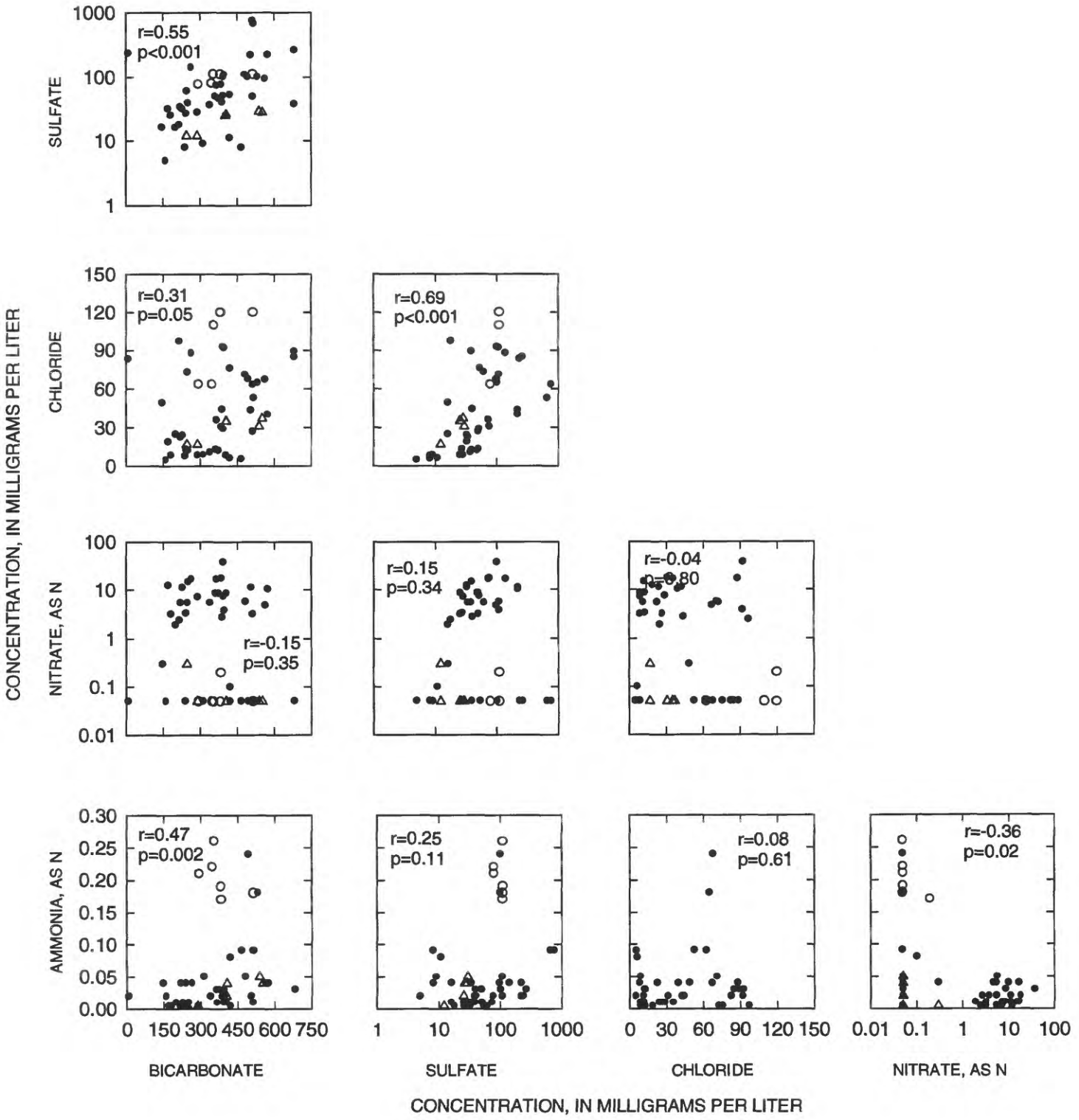

WELL DEPTH
DEPTH TO WATER
DISSOLVED OXYGEN
pH
MANGANESE
STRONTIUM
SILICA
DISSOLVED ORGANIC CARBON
CONCENTRATION, IN MILLIGRAMS PER LITER
r=0.01
p=0.94
r=-0.27
p=0.10
r=-0.69
p<0.001
r=-0.18
p=0.25
r=-0.45
p=0.004
r=-0.46
p=0.003
r=-0.17
p=0.28
r=0.05
p=0.74
r=-0.43
p=0.006
r=-0.30
p=0.06
r=0.21
p=0.19
r=0.35
p=0.03
r=-0.46
p=0.003
r=-0.27
p=0.10
r=-0.62
p<0.001
r=0.06
p=0.71
WELL DEPTH, IN FEET BELOW LAND SURFACE
DEPTH TO WATER, IN FEET BELOW LAND SURFACE
DISSOLVED OXYGEN, IN MILLIGRAMS PER LITER
pH

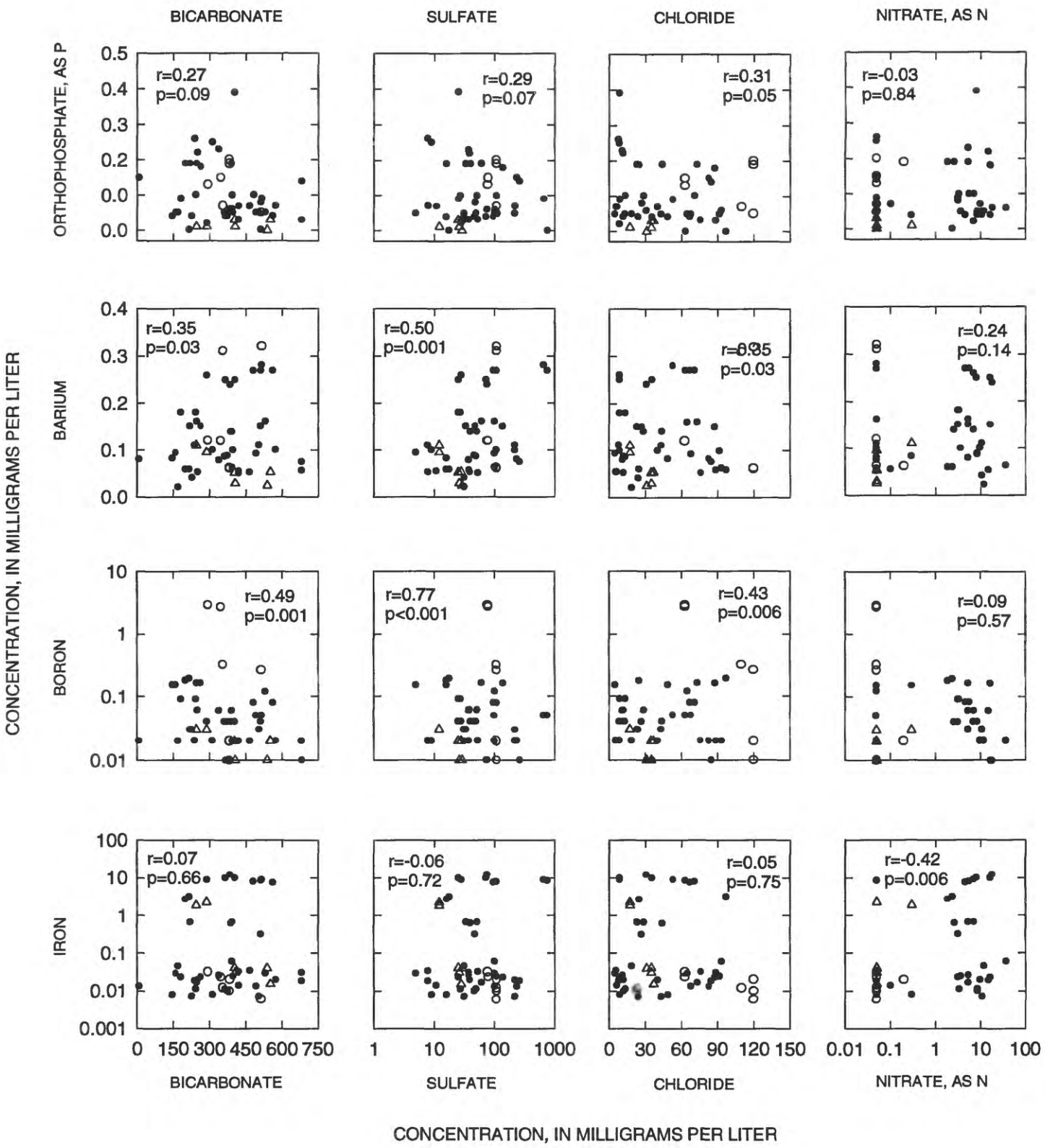

MAGNESIUM
r=0.92
p<0.001
SODIUM
r=0.64
p<0.001
r=0.53
p<0.001
POTASSIUM
r=0.41
p=0.008
r=0.34
p=0.03
r=0.31
p=0.05
BICARBONATE
r=0.78
p<0.001
r=0.79
p<0.001
r=0.59
p<0.001
r=0.24
p=0.14
CONCENTRATION, IN MILLIGRAMS PER LITER
CALCIUM
MAGNESIUM
SODIUM
POTASSIUM
CONCENTRATION, IN MILLIGRAMS PER LITER

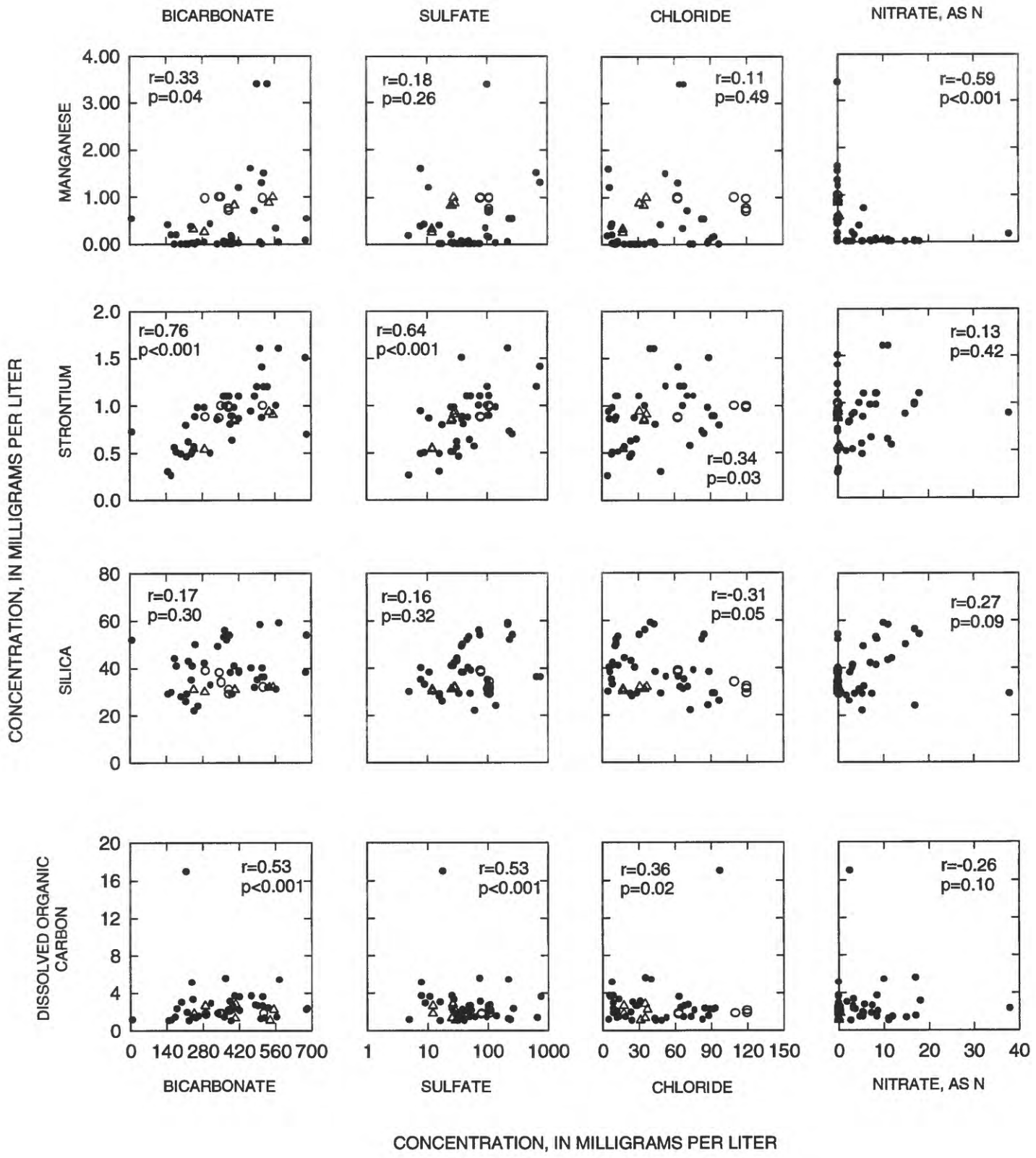

CALCIUM
MAGNESIUM
SODIUM
POTASSIUM
SULFATE
CHLORIDE
NITRATE, AS N
AMMONIA, AS N
r=0.72 p<0.001
r=0.58 p<0.001
r=0.86 p<0.001
r=0.20 p=0.22
r=0.54 p<0.001
r=0.38 p=0.02
r=0.74 p<0.001
r=0.35 p=0.03
r=-0.02 p=0.90
r=-0.04 p=0.81
r=-0.09 p=0.56
r=-0.12 p=0.44
r=0.53 p<0.001
r=0.39 p=0.01
r=0.24 p=0.14
r=0.31 p=0.05
CONCENTRATION, IN MILLIGRAMS PER LITER
CONCENTRATION, IN MILLIGRAMS PER LITER

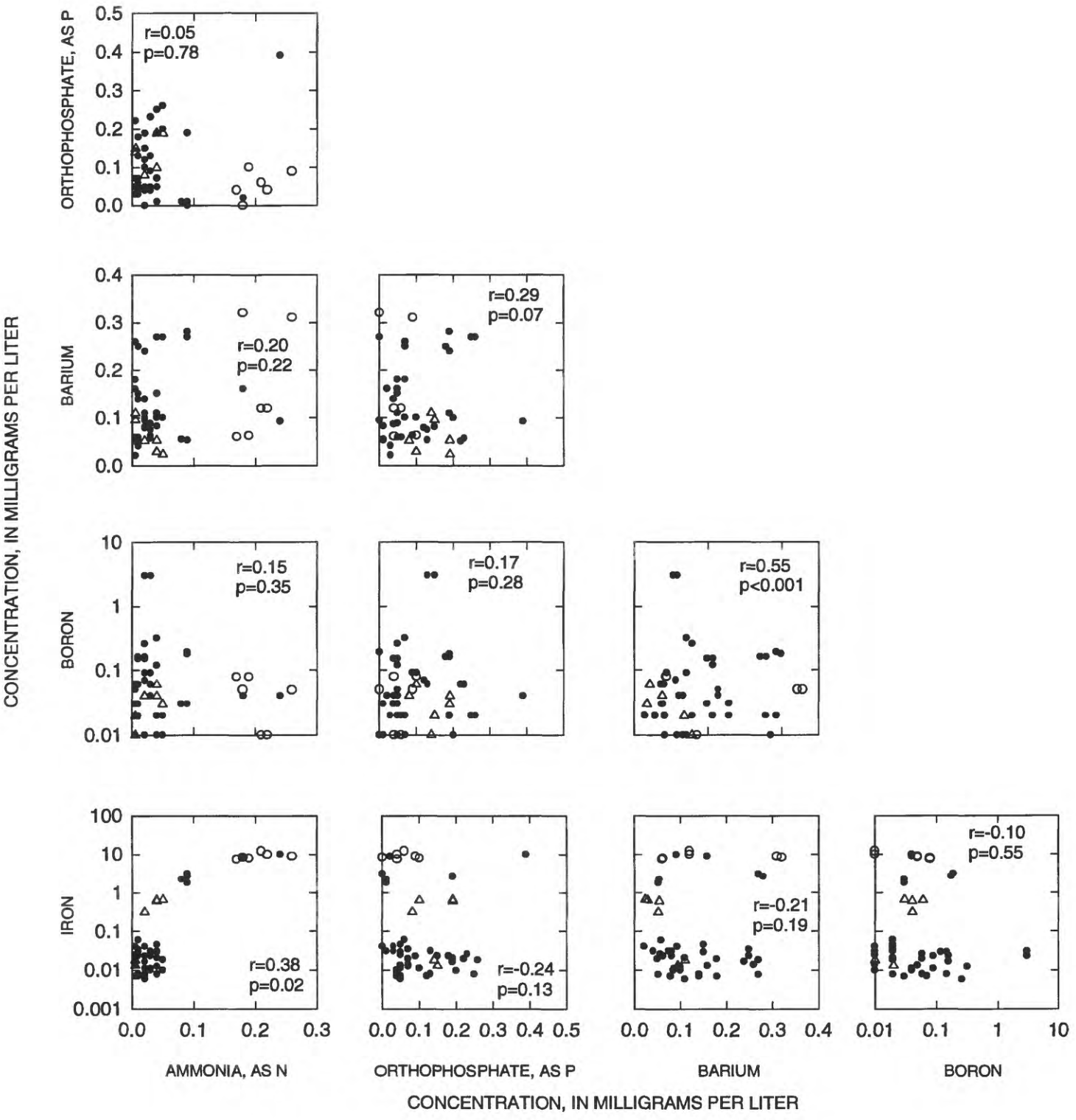

CALCIUM
MAGNESIUM
SODIUM
POTASSIUM
ORTHOPHOSPHATE, AS P
r=0.24
p=0.13
r=0.17
p=0.30
r=0.26
p=0.11
r=-0.28
p=0.08
BARIUM
r=0.47
p=0.002
r=0.41
p=0.009
r=0.38
p=0.01
r=0.17
p=0.30
BORON
r=0.50
p=0.001
r=0.47
p=0.003
r=0.80
p<0.001
r=0.06
p=0.71
IRON
r=0.11
p=0.50
r=0.07
p=0.65
r=-0.03
p=0.86
r=0.31
p=0.05
CONCENTRATION, IN MILLIGRAMS PER LITER
CONCENTRATION, IN MILLIGRAMS PER LITER

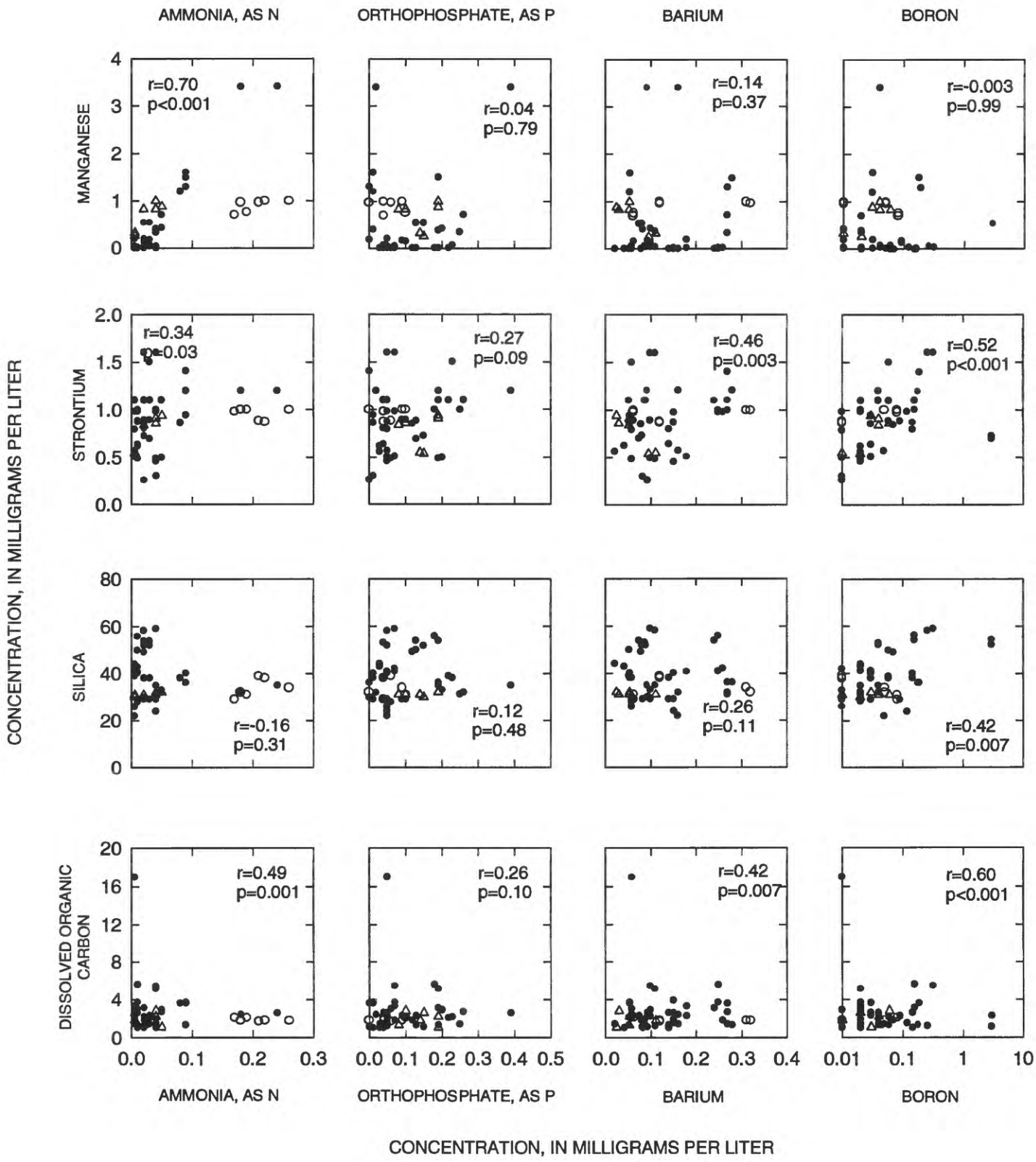

CALCIUM
MAGNESIUM
SODIUM
POTASSIUM
MANGANESE
STRONTIUM
SILICA
DISSOLVED ORGANIC CARBON
r=0.42
p=0.008
r=0.29
p=0.07
r=0.16
p=0.33
r=0.29
p=0.07
r=0.89
p<0.001
r=0.93
p<0.001
r=0.54
p<0.001
r=0.18
p=0.26
r=-0.03
p=0.86
r=0.19
p=0.24
r=-0.05
p=0.75
r=-0.47
p=0.003
r=0.60
p<0.001
r=0.57
p<0.001
r=0.56
p<0.001
r=0.21
p=0.20
0 50 100 150 200
0 25 50 75
0 125 250 375
0 2 4 6 8 10
CONCENTRATION, IN MILLIGRAMS PER LITER
CONCENTRATION, IN MILLIGRAMS PER LITER

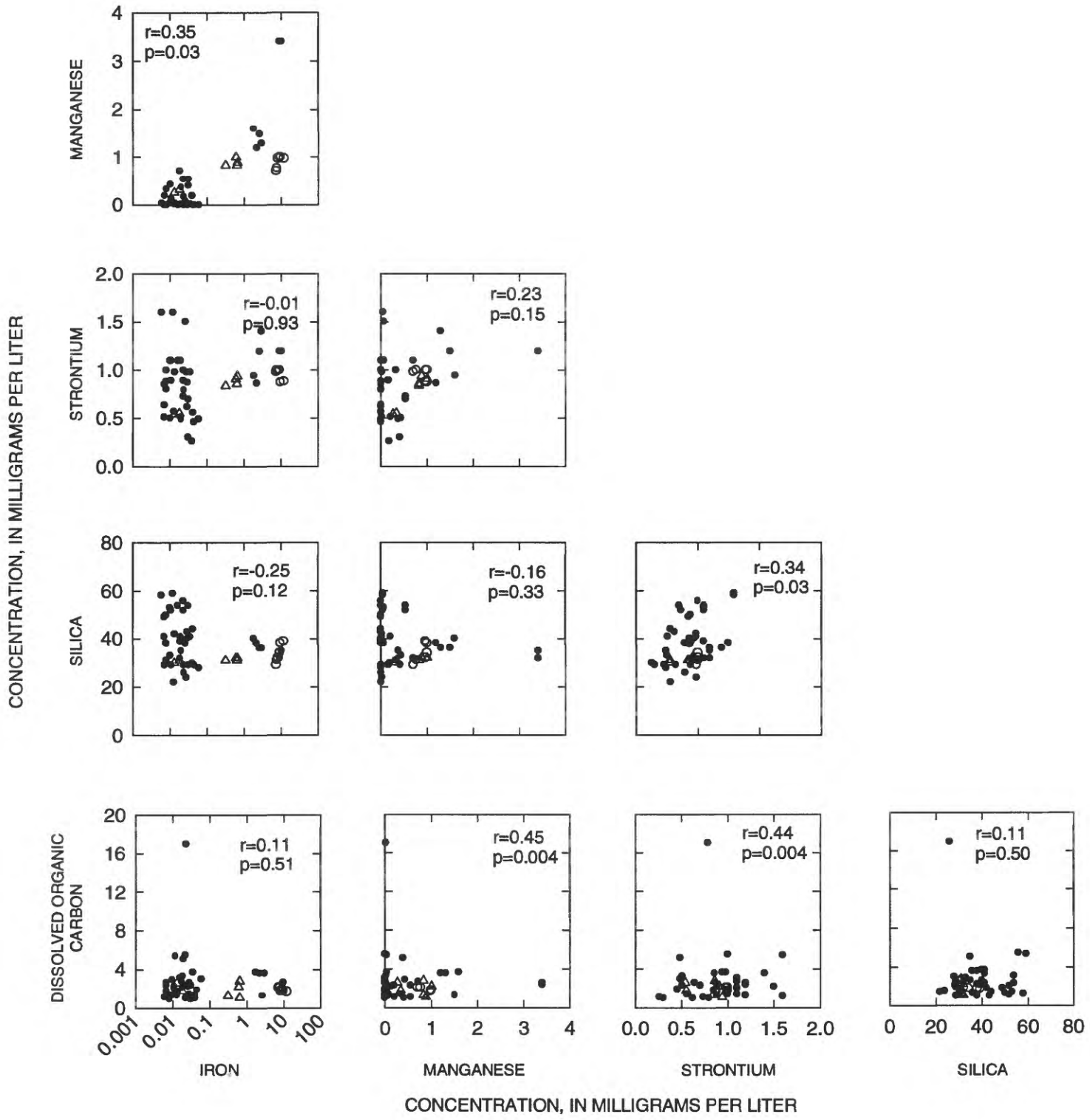

CONCENTRATION, IN MILLIGRAMS PER LITER
SULFATE
1000
100
10
1
r=0.55
p<0.001
CHLORIDE
150
120
90
60
30
0
r=0.31
p=0.05
r=0.69
p<0.001
NITRATE, AS N
100
10
1
0.1
0.01
r=-0.15
p=0.35
r=0.15
p=0.34
r=-0.04
p=0.80
AMMONIA, AS N
0.30
0.25
0.20
0.15
0.10
0.05
0.00
r=0.47
p=0.002
r=0.25
p=0.11
r=0.08
p=0.61
r=-0.36
p=0.02
0 150 300 450 600 750
BICARBONATE
1 10 100 1000
SULFATE
0 30 60 90 120 150
CHLORIDE
0.01 0.1 1 10 100
NITRATE, AS N
CONCENTRATION, IN MILLIGRAMS PER LITER


BICARBONATE
SULFATE
CHLORIDE
NITRATE, AS N
ORTHOPHOSPHATE, AS P
BARIUM
BORON
IRON
r=0.27
p=0.09
r=0.29
p=0.07
r=0.31
p=0.05
r=-0.03
p=0.84
r=0.35
p=0.03
r=0.50
p=0.001
r=0.35
p=0.03
r=0.24
p=0.14
r=0.49
p=0.001
r=0.77
p<0.001
r=0.43
p=0.006
r=0.09
p=0.57
r=0.07
p=0.66
r=-0.06
p=0.72
r=0.05
p=0.75
r=-0.42
p=0.006
0 150 300 450 600 750
1 10 100 1000
0 30 60 90 120 150
0.01 0.1 1 10 100
BICARBONATE
SULFATE
CHLORIDE
NITRATE, AS N
CONCENTRATION, IN MILLIGRAMS PER LITER
CONCENTRATION, IN MILLIGRAMS PER LITER


BICARBONATE
SULFATE
CHLORIDE
NITRATE, AS N
MANGANESE
r=0.33
p=0.04
r=0.18
p=0.26
r=0.11
p=0.49
r=-0.59
p<0.001
STRONTIUM
r=0.76
p<0.001
r=0.64
p<0.001
r=0.34
p=0.03
r=0.13
p=0.42
SILICA
r=0.17
p=0.30
r=0.16
p=0.32
r=-0.31
p=0.05
r=0.27
p=0.09
DISSOLVED ORGANIC CARBON
r=0.53
p<0.001
r=0.53
p<0.001
r=0.36
p=0.02
r=-0.26
p=0.10
CONCENTRATION, IN MILLIGRAMS PER LITER
CONCENTRATION, IN MILLIGRAMS PER LITER


ORTHOPHOSPHATE, AS P
BARIUM
BORON
IRON
CONCENTRATION, IN MILLIGRAMS PER LITER
r=0.05
p=0.78
r=0.20
p=0.22
r=0.29
p=0.07
r=0.15
p=0.35
r=0.17
p=0.28
r=0.55
p<0.001
r=0.38
p=0.02
r=-0.24
p=0.13
r=-0.21
p=0.19
r=-0.10
p=0.55
AMMONIA, AS N
ORTHOPHOSPHATE, AS P
BARIUM
BORON
CONCENTRATION, IN MILLIGRAMS PER LITER


AMMONIA, AS N
ORTHOPHOSPHATE, AS P
BARIUM
BORON
MANGANESE
r=0.70
p<0.001
r=0.04
p=0.79
r=0.14
p=0.37
r=-0.003
p=0.99
STRONTIUM
r=0.34
p=0.03
r=0.27
p=0.09
r=0.46
p=0.003
r=0.52
p<0.001
SILICA
r=-0.16
p=0.31
r=0.12
p=0.48
r=0.26
p=0.11
r=0.42
p=0.007
DISSOLVED ORGANIC CARBON
r=0.49
p=0.001
r=0.26
p=0.10
r=0.42
p=0.007
r=0.60
p<0.001
CONCENTRATION, IN MILLIGRAMS PER LITER
CONCENTRATION, IN MILLIGRAMS PER LITER


MANGANESE
r=0.35
p=0.03
STRONTIUM
r=-0.01
p=0.93
r=0.23
p=0.15
SILICA
r=-0.25
p=0.12
r=-0.16
p=0.33
r=0.34
p=0.03
DISSOLVED ORGANIC CARBON
r=0.11
p=0.51
r=0.45
p=0.004
r=0.44
p=0.004
r=0.11
p=0.50
IRON
MANGANESE
STRONTIUM
SILICA
CONCENTRATION, IN MILLIGRAMS PER LITER
CONCENTRATION, IN MILLIGRAMS PER LITER