Isotopic Compositions and Sources of Nitrate in Ground Water from Western Salt River Valley, Arizona

By D.J. Gellenbeck

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FIGURES

1.-2. Maps showing:

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TABLES

CONVERSION FACTORS

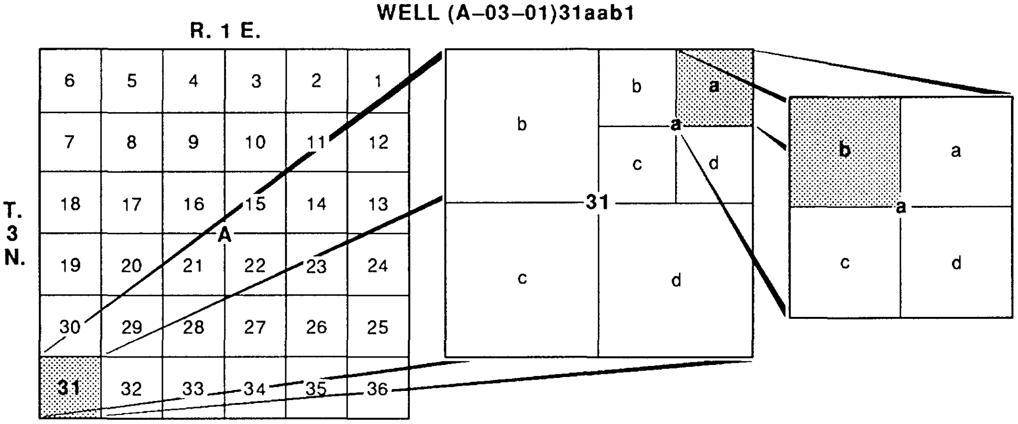
Multiply	By	To obtain
centimeter (cm)	0.394	inch (in)
meter (m)	3.28	foot (ft)
cubic meter (m^3)	0.0008	acre-foot (acre-ft)
kilometer (km)	0.622	mile (mi)
square kilometer (km^2)	0.386	square mile (mi^2)
cubic kilometer (km^3)	0.24	cubic mile (mi^3)
gram (gm)	0.035	ounce (oz)
Curie (Ci)	10^{-12}	picoCurie (pCi)
picoCurie per liter (pCi/L)	0.435	tritium unit (TU)

Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8(°C) + 32$$

Chemical concentration and water temperature are given only in metric units. Chemical concentration in water is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 milligrams per liter, the numerical value is about the same as for concentrations in parts per million. Specific conductance is given in microsiemens per centimeter (µS/cm) at 25 degrees Celsius. Radioactivity is expressed in picoCuries per liter (pCi/L), which is the amount of radioactive decay producing 2.2 disintegrations per second in a unit volume (liter) of water.

WELL-NUMBERING AND NAMING SYSTEM



Quadrant A, Township 3 North, Range 1 East, section 31, quarter section a, quarter section a, quarter section b, first well inventoried in 10-acre tract

The well numbers used by the U.S. Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the state into four quadrants and are designated by capital letters A, B, C, and D in a counterclockwise direction, beginning in the northeast quarter. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, and the third the 10-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the 10-acre tract, three lowercase letters are shown in the well number. In the example shown, well number (A-03-01)31aab1 designates the well as being in the NW1/4, NE1/4, NE1/4, section 31, Township 3 North, and Range 1 East. Where more than one well is within a 10-acre tract, consecutive numbers beginning with 1 are added as suffixes.

VERTICAL DATUM

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

Isotopic Compositions and Sources of Nitrate in Ground Water from Western Salt River Valley, Arizona

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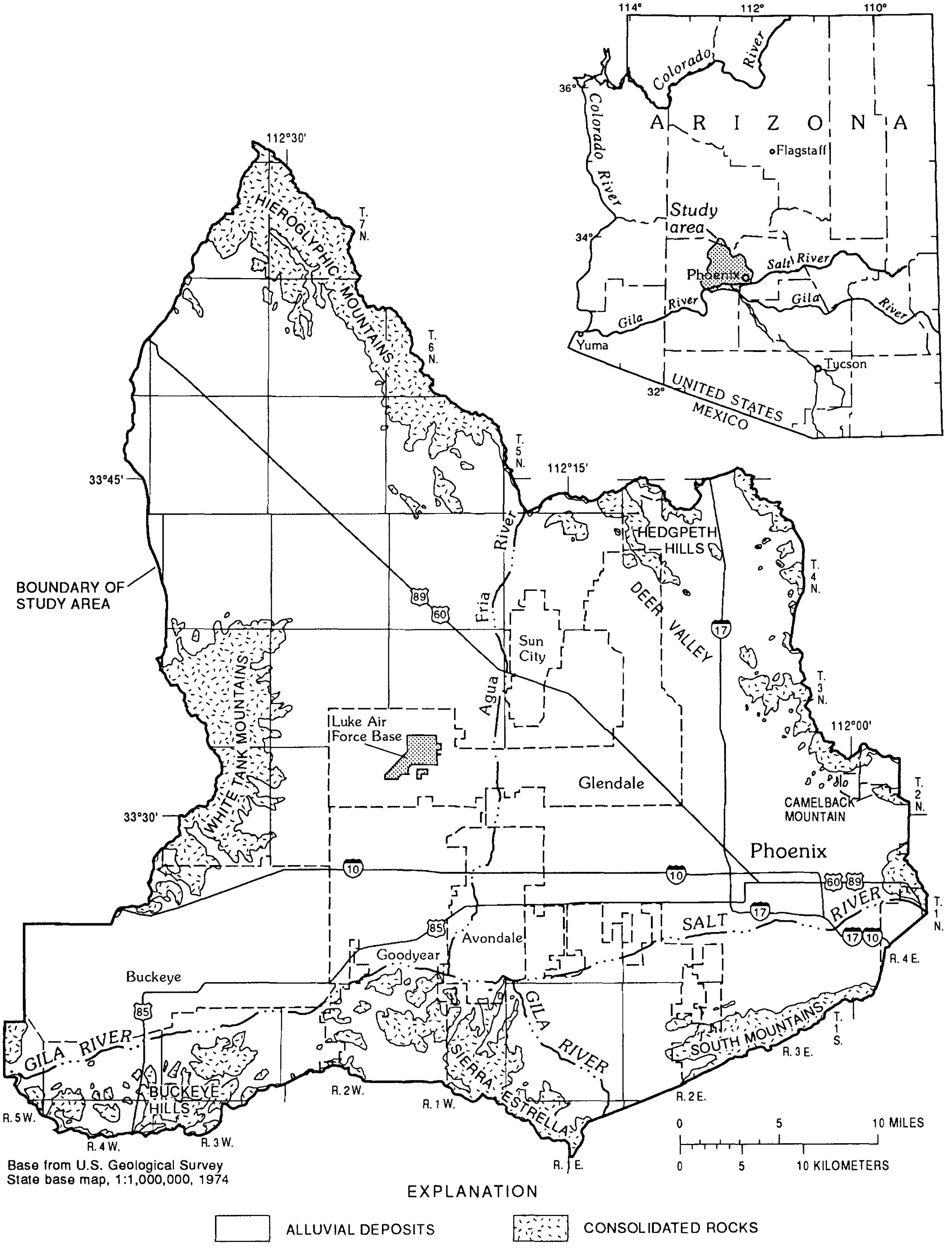
Abstract

Isotopic and chemical compositions of ground water near Phoenix, Arizona, were used to develop identification techniques for sources of nitrate in ground water. Ground-water nitrate is located primarily in shallow ground water in the study area. Four possible sources of nitrate were studied: dairies and feedlots, sewage-treatment plants, agricultural activities, and natural sources—decomposed vegetation or nitrogen fixed by bacteria associated with desert legumes. End members that represent these sources were analyzed for a variety of chemical and isotopic constituents. These compositions were compared with the compositions in ground water from generally shallow depths to identify nitrate sources. Identification techniques were successful for some nitrate sources. Nitrate from dairies and feedlots was identified by $\delta^{15}N$ values higher than +9.0 per mil. Nitrate from sewage-treatment plants was identified by some chemical constituents and values of $\delta^{15}N$, $\delta^{34}S$, $\delta^{7}Li$, and $\delta^{11}B$ that were lighter than the values determined for ground water not affected by sewage-treatment plants. Nitrate from agricultural activities was identified by $\delta^{15}N$, ^{3}H, and $\delta^{34}S$ compositions. Natural nitrate derived from decomposing plants and accumulated by biological fixation was identified by $\delta^{15}N$ values that range between +2 and +8 per mil.

In addition to identifying nitrate sources, some chemical and isotopic characteristics of ground water were determined on the basis of data collected during this study. Concentrations of major ions, lithium, and boron, and $\delta^{7}Li$, $\delta^{11}B$, ^{3}H, δD, and $\delta^{18}O$ data identify ground water in different geographic regions in the study area. These differences probably are related to different sources of ground water (precipitation or surface water), geochemical processes, or geologic deposits. The Luke salt body and a geothermal anomaly alter the chemical and isotopic content of some ground water.

INTRODUCTION

Ground water in extensive areas in western Salt River Valley near Phoenix, Arizona (fig. 1), has nitrate concentrations that exceed the maximum contaminant level (MCL) of 10 mg/L of nitrate as nitrogen set by the U.S. Environmental Protection Agency (USEPA; U.S. Environmental Protection Agency, 1991) for public drinking water. As agricultural use of the ground water decreases and domestic use increases in the study area, these high concentrations have greater importance. High nitrate concentrations have been linked to cancer (National Academy of Sciences, 1977) and are known to cause other severe health problems such as methemoglobinemia (blue-baby syndrome) and possible birth defects (National Governors' Association, 1991). Management strategies to deal with the cause of these health effects require reliable and reproducible techniques to determine



Base from U.S. Geological Survey
State base map, 1:1,000,000, 1974

Figure 1. Location of western Salt River Valley, Arizona.

the spatial extent and sources of nitrate contamination.

The U.S. Geological Survey (USGS), in cooperation with the Arizona Department of Environmental Quality, designed a study to better understand the ground-water nitrate problem near Phoenix, Arizona. The first objective of this study was to develop a geochemical technique to identify sources of nitrate in ground water. The second objective was to establish a geostatistical method for unbiased and reproducible spatial estimates of nitrate concentrations in ground water.

Purpose and Scope

This report describes the geochemical techniques developed during this study to identify sources of nitrate in ground water from the study area. To develop geochemical identification techniques, four possible sources of ground-water nitrate were selected: dairies and feedlots, sewage-treatment plants (STP's), areas of agricultural activities, and areas of naturally occurring nitrate. End-member samples mentioned in this report are materials that are considered to be the origin of nitrogen from three of the four possible sources listed above. The materials collected to represent end members included manure from dairies and feedlots, outflow from STP's, and irrigation return flow and nitrogen fertilizers from agricultural areas. Ground water from areas with little or no anthropogenic activity was selected to represent areas of naturally occurring nitrate. The chemical and isotopic compositions of end-member materials were characterized and compared with compositions of ground water near suspected sources of nitrate. The assumption was made that some constituents in the end-member samples would help identify the source of nitrate in ground water affected by a given source.

Samples collected during the summers of 1990 and 1991 included 57 samples from 25 locations. A large suite of chemical and isotopic constituents were determined in each sample. Field measurements and major-ion, nutrient, and metal constituents were used to characterize the chemical content of the samples and to define any relation between chemical content and sources of nitrate. Isotopic compositions of oxygen, hydrogen, nitrogen, sulfur, boron, lithium, and strontium were used to define any relation between isotopic compositions and sources of nitrate or geochemical processes. Isotopic compositions of strontium also were analyzed to distinguish geochemical processes but were not included to identify nitrate sources; therefore, these data are not included in this report, but are available in project files.

Physical Setting

The study area is western Salt River Valley in central Arizona and includes Phoenix, which is surrounded by smaller communities to the west and northwest. The study area includes about 3,900 km^2 of the Salt River Valley (fig. 1). The Salt River Valley covers about 7,800 km^2 in central Arizona. The study area is identified by the Arizona Department of Water Resources as the West Salt River Sub-basin of the Phoenix Active Management Area.

The drainage basin boundaries of western Salt River Valley are the Hieroglyphic Mountains and Hedgpeth Hills on the north; the Buckeye Hills, Sierra Estrella, and South Mountain on the south; the White Tank Mountains on the west; and Camelback Mountain on the east that divides western and eastern Salt River Valley. Three major rivers—the Salt, Gila, and Agua Fria Rivers—flow through the area and are supplemented by many small streams within the basin. The rivers flow into the basin from the east, south, and north parts of the study area, respectively. The Salt and Agua Fria Rivers merge with the Gila River within the basin and flow out of the basin in the western part of the study area.

Climate

The climate of western Salt River Valley is characterized by high temperatures in the summer and mild temperatures in the winter. The average annual temperatures for 1985–90 were 24°C (75°F) for the Phoenix area and 22°C (72°F) for the town of Buckeye in the southwestern part of the study area (U.S. Department of Commerce, 1985–1990a). Average monthly temperatures for January were 13°C (55°F) for the Phoenix area and 12°C (54°F) for Buckeye (U.S. Department of Commerce, 1985–1990a). Average monthly temperatures for June were 34°C (93°F) for Phoenix and 32°C (90°F) for Buckeye (U.S. Department of Commerce, 1985–1990a). The Phoenix metropolitan area might be affected by a heat-island effect, which could account for some of the variation in the temperature throughout the basin (Sargent, 1988). Precipitation occurs as local high-intensity storms in summer and regional low-intensity storms in winter. The average annual rainfall for 1985–90 was 18.5 and 21.6 cm for Phoenix and Buckeye, respectively (U.S. Department of Commerce, 1985–1990a).

Historical Changes

Development in the study area has had a significant effect on the hydrologic system. In the late 1860's, the Salt River Valley was developed initially as an agricultural area (Sargent, 1988). Agricultural activity in the study area was initiated to provide goods for local mining ventures and the new territorial capital of Prescott. By 1880, 10,000 acres north of the then-perennial Salt River were irrigated by a canal system originally designed by the Hohokam Indians. Crops cultivated in the valley during this period included barley, wheat, corn, sorghum, potatoes, various vegetables, and some cotton and tobacco. During the mid-1890's, extensive orange orchards were planted when railroad transportation became available. During World War I, cotton acreage increased because of a larger demand for Arizona long-staple cotton. Since the 1950's, agricultural activity has decreased as urbanized areas have expanded. Cotton as well as citrus, vegetables, and alfalfa are currently grown.

The population of the Phoenix metropolitan area increased from approximately 300 in 1871 to approximately 5,500 by 1900 (Sargent, 1988). In 1890, nearby towns and rural areas had a total population of approximately 14,000 (Sargent, 1988). Between 1940 and 1950, the population in the Salt River Valley increased from 185,000 to 330,000 (Sargent, 1988). By 1990, about 2,100,000 people lived in the Salt River Valley (U.S. Department of Commerce, 1990b).

Previous Investigations

For this study, results from previous investigations were used for background information on: (1) chemical composition of ground water, (2) possible techniques that could be used to identify sources of nitrate, and (3) isotopic variation of some constituents. Lee (1905) included well records, lithologic information, and descriptions of areas with high nitrate concentrations in the first examination of the chemical composition of ground water in the region. Kam and others (1966) compiled ground-water data that included well logs, discharge rates, drawdown measurements, and ground-water chemistry. Kister (1974) and Osterkamp (1974) mapped the dissolved-solids, fluoride, hardness, and nitrate concentrations in ground water from the Phoenix area. Osterkamp (1974) found high nitrate concentrations in three areas: (1) Deer Valley to the Salt River, (2) the metropolitan area of Phoenix to Goodyear, and (3) near the town of Buckeye.

Brown and Pool (1989) studied the hydrogeology of the area and identified three possible sources of nitrate: sewage outflow, irrigated agricultural areas, and "natural or geologic origins." Personnel from the Salt River Project (SRP; Salt River Project, 1982, 1986) compiled data for a 60-year time period, analyzed trends, and identified areas with high nitrate concentrations. Kenneth D. Schmidt for the Maricopa Association of Governments (1978, 1979, 1981, 1983) also identified areas that contained high nitrate concentrations and presented possible sources of nitrate.

Another possible source of nitrate in the study area was identified by Hem (1985); nitrogen fixation by bacteria associated with desert legume growth results in nitrate accumulation in the soil, which may leach to the ground water. Hem (1985) and Rice and others (1989) indicated that leaching of irrigated agricultural areas also could be a possible source of nitrate in ground water from the study area. Rice and others (1989) determined that 25 percent of the nitrogen fertilizer applied to fields in the study area is leached out by the soil and may percolate to the ground water as nitrate.

Techniques used to identify the source of nitrate in other studies include correlation of nitrate with other dissolved constituents, correlation of land use and nitrate, and isotopic signatures. Piskin (1973) used orthophosphate and chloride concentrations to determine if fertilizers or septic tanks were the primary source of nitrate, and Robertson (1979) used chloride and nitrate concentrations to determine if nitrate was derived from local poultry operations. Steenvoorden (1976) proposed that a correlation might exist between phosphate and nitrate in fertilized farmland in the Netherlands.

Tinker (1991) used land-use delineations to determine that lawn fertilizer and septic-tank soil-adsorption systems caused high nitrate concentrations in ground water beneath unsewered subdivisions in western Wisconsin. A national evaluation by Cain and others (1989) determined that, in general, water samples collected from regions used primarily for agricultural purposes had higher concentrations of nitrate in the ground water than concentrations in samples collected from other land-use types.

Sources of nitrate in ground water have been successfully identified by nitrogen isotopic values in other investigations (Jones, 1973; Kreitler, 1975; Kreitler and Jones, 1975; Gormly and Spalding, 1979; Kreitler, 1979; Spalding and others, 1982; Kreitler and Browning, 1983; Aravena and others, 1993; Komor and Anderson, 1993). Edwards (1973), Heaton (1986), and C.A. Cravotta (hydrologist, U.S. Geological Survey, written commun., 1991) concluded that the successful application of nitrogen isotopes as identifiers of nitrate sources is based on a thorough understanding of the hydrologic system.

Bassett (1990) summarized the available boron isotope data excluding those data determined by inductively coupled plasma-mass spectroscopy (ICP–MS) or gas-source mass spectroscopy (GC–MS). Different rock types were characterized by ranges of $\delta^{11}B$ values. The natural variation of $\delta^{11}B$ ranges from -31 to +40 per mil (‰) relative to NBS–951. Bassett (1990) proposed that this isotopic composition may be a good environmental indicator because $\delta^{11}B$ compositions have a large natural variation, few fractionation processes affect the element, and boron exists in all types of materials including different rock types and anthropogenic sources.

Chan (1987), Chan and Edmond (1988), and Chan and others (1992) examined lithium isotopic variations in the marine environment. Alteration of lithium isotopic compositions in the oceans and preferential removal of ^6Li during the formation of secondary minerals are some of the findings published in these papers. A range of δ^7Li values between +3.4‰ in young basalts to +33.4‰ in ocean water was measured by Chan and others (1992). Current investigations by Thomas D. Bullen (hydrologist, U.S. Geological Survey, oral commun., 1992) of lithium isotopic compositions in ground water, surface water, and a variety of geologic materials have included lighter and substantially heavier lithium isotopic values than values summarized by Chan and others (1992). Prior to investigations by Bullen and this study, no application of lithium isotopic compositions to environmental studies had been done.

Acknowledgments

The City of Phoenix, Buckeye Irrigation Company, Roosevelt Irrigation District, SRP, and Sunnyboy Water company provided data and access to wells. The City of Peoria, Sun City Recreation Department, SunCor, Chrysler Corporation, and Morton Salt Company provided access to private property to collect water samples. Special appreciation goes to the many individuals who allowed USGS personnel to collect ground water, nitrogen fertilizer, and manure for analyses from their private property.

Randall L. Bassett, University of Arizona, Department of Hydrology and Water Resources, determined the boron isotopic compositions and provided guidance during the interpretation of the data. Thomas D. Bullen, USGS, determined the strontium and lithium isotopic compositions. In addition to these analyses, he was available for consultation about interpretation and application of the results.

METHODS OF INVESTIGATION

Sample locations that represented four types of nitrate sources or areas that contained high ground-water nitrate concentrations were selected and ground-water, surface-water, and end-member samples were analyzed to determine geochemical techniques that identify nitrate sources. Isotopic data, chemical analyses, and some field determinations were used to evaluate the various sample types.

In addition to data from samples collected as part of this study, ground-water data from other public agencies and private companies were used to characterize the chemical composition of the ground water. These data include one major-ion analysis per well from samples collected during 1986 to 1991 that had ionic balances that were less than 10 percent. All but three analyses completed for this study have an ionic balance that was less than 10 percent, and most analyses balanced to within 5 percent.

Selection of Sample Locations

Sample locations generally were restricted to areas at or near suspected sources of high ground-water nitrate concentrations. Suspected sources included dairies and feedlots, STP's, naturally occurring nitrate, and agricultural areas. From these types of locations, 24 sample locations were selected and 57 samples were collected during the summers of 1990 and 1991 (table 2; at end of the report). Samples included 38 ground-water samples, 7 surface-water samples, 3 fertilizers, 5 manure leachates, 2 equipment blanks, 1 distilled-water blank, and 1 duplicate ground-water sample. Forty-four water samples were collected within the study area—40 near possible sources of nitrate, 1 site where no anthropogenic effects were suspected, 2 sites near the Luke salt body, and 1 site near a geothermal anomaly (fig. 2). Of the 38 ground-water samples, one was outside the study area because high concentrations of nitrate had been measured in the ground water and no anthropogenic activity was present. A site with no anthropogenic activity was difficult to locate within the study area so a site outside the study area was found. Project identifiers were assigned to each sampling site (table 2).

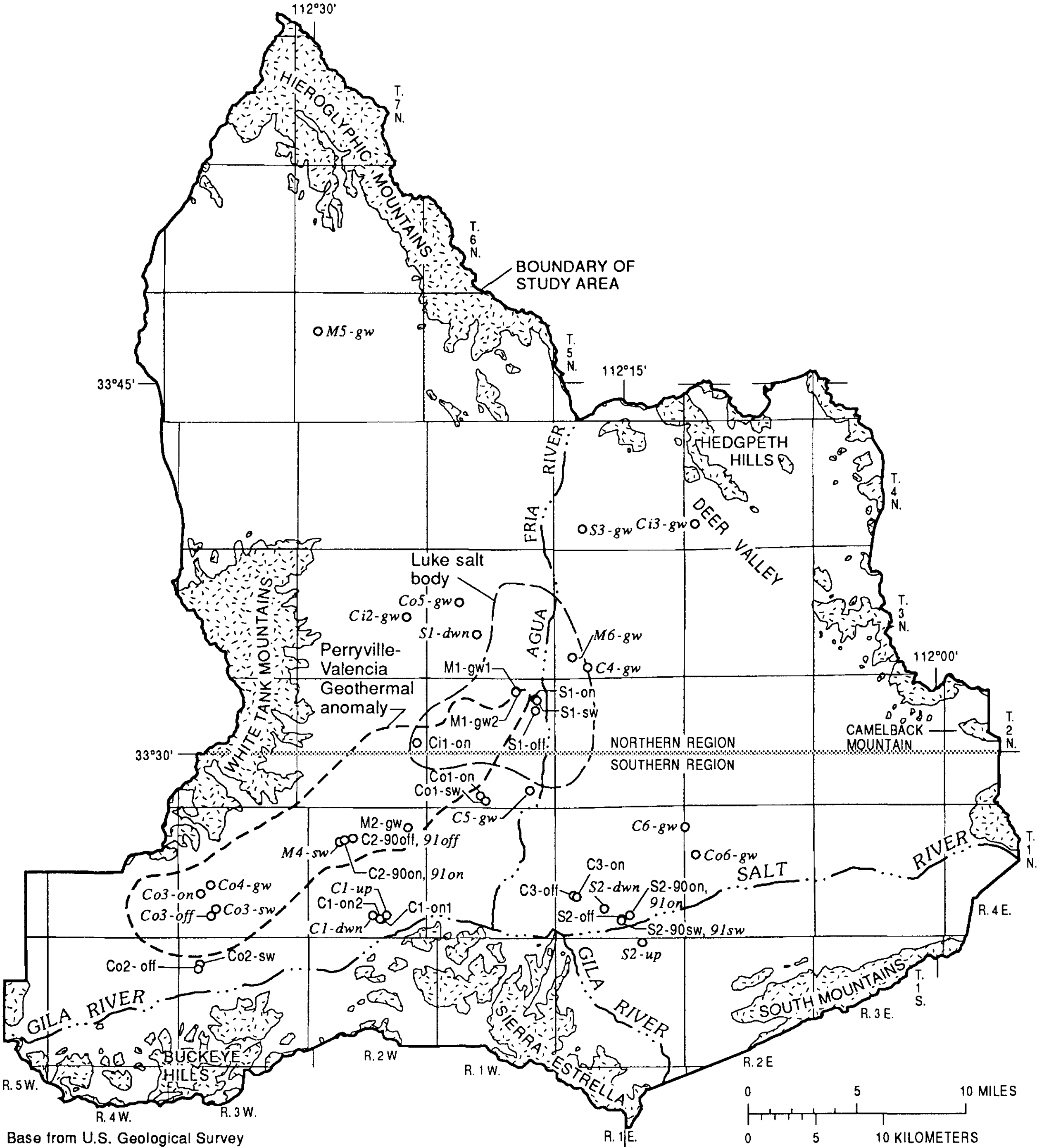
Sample locations selected for 1990 (fig. 2) were restricted to areas close to the suspected sources of nitrate listed above. Data from 1990 and review of historical nitrate information were used to select sample locations for 1991 (fig. 2). Sample locations selected for 1991 were selected downgradient and upgradient from the 1990 sites, in areas near possible sources of nitrate, and in areas where the source of nitrate was unknown. Site-specific ground-water flow directions were determined by measuring ground-water levels when possible (table 2). General ground-water flow directions were determined from ground-water gradients included in Brown and Pool (1989).

Ground-Water Sample Locations

Ground water was collected from existing wells used for irrigation or domestic purposes (table 2). Wells with casing openings specifically in the shallowest hydrogeologic unit were sampled unless wells that had longer intervals of open casing or casing openings in many hydrogeologic units were the only ones available (table 2).

In 1990 and 1991, ground-water samples were collected from 7 wells near cotton fields, 3 wells near citrus groves, 13 wells near dairies and feedlots, and 9 wells near STP's (table 2). Three sites, M6, M3, and M5, where the sources of nitrate were unknown also were sampled. At site M6, many sources of nitrate exist, and nitrate concentrations had been increasing in the ground water with time and had exceeded the MCL. Sites M3 and M5 were selected as sample locations because these sites represent areas that have little human activity. Site M3, in Rainbow Valley (T. 1 S., R. 4 W.), which is a basin adjacent to the south boundary of the study area, was sampled because nitrate concentrations in ground water at this site exceeded the MCL and no anthropogenic source of nitrate exists in the area. Site M5, which is in a sparsely populated area in the northwest corner of the study area, was considered to represent background ground-water conditions for the study area.

Some samples were collected in areas that had unique geologic or geochemical characteristics. Included in these samples were two wells at M1 near the Luke salt body (fig. 1) and one well at M2 completed in the Perryville-Valencia geothermal anomaly (fig. 1; A.L. Geldon and P.P. Ross, hydrologists, U.S. Geological Survey, written commun., 1981), which is more than 366 m below the land surface in the southwestern part of the study area. Several areas within the basin have been identified as geothermal anomalies, but only the Perryville-Valencia geothermal anomaly was sampled for this study.



Base from U.S. Geological Survey
State base map, 1:1,000,000, 1974

EXPLANATION

☐	ALLUVIAL DEPOSITS	S2-90sw, *91sw* ○	SAMPLING SITE—First site identifer is 1990 sample; second site identifer, in italic, is 1991 sample
▨	CONSOLIDATED ROCKS		

Figure 2. Location of sampling sites, western Salt River Valley, Arizona, 1990–91.

Surface-Water Sample Locations

Surface-water samples included outflow from STP's, irrigation return flow, and canal water. Nitrogen fertilizer also was collected at selected sites. Dip samples of irrigation return flow were taken from ditches that collect drainage from cotton fields at sites Co1, Co2, and Co3. Water also was collected from an irrigation canal at site M4, next to site C2. This sample was collected to evaluate the possible effects on the ground water from leakage through the bottom of the canal. A USDH–48 sampler and the equal-discharge-increment method was used for sample collection.

Outflow from STP's was collected at sites S1 and S2. Collection at S2 was done using a USDH–48 sampler and the equal-discharge-increment method. Surface water was collected at S2 during 1990 and 1991. Collection of the outflow at S1 was done in 1990 using a dip-sampling technique within a Parshall flume.

Nitrogen fertilizer (UN32), composed of 32 percent urea was collected at sites Co1, Co3, and Ci1. The fertilizer from sites Co1 and Co3 was collected from holding tanks at the cotton fields, and fertilizer from site Ci1 was obtained from a fertilizer distributor.

Manure Leachates

Manure samples represent end members from dairies and feedlots. All manure samples were collected from the holding pens at dairies and feedlots. Manure samples were collected in 1990 at C1, C2, and C3 and in 1991 at C1 and C3.

These solid samples were leached with distilled water at ratios of 20:1 by weight according to a published leaching procedure (Rhoades, 1982). The mixture of manure and distilled water was shaken by hand for 1 minute every 30 minutes for at least 2 hours. Leachates from manure samples collected in 1990 were centrifuged to remove any large material. Because filtering of this leachate through a 0.45-micron filter was not successful, analyses of $\delta^{15}N$ and $\delta^{34}S$ compositions for the leachates from 1990 were not possible. Leachates from manure samples collected in 1991 were not centrifuged but were successfully filtered through a 0.45-micron pressure-filter unit using helium gas.

Isotopic Nomenclature and Approach

Ratios of the isotope concentrations for an element usually are used as identifiers of the isotopic compositions of solid and liquid samples. Different sources of an element can have unique isotopic compositions that act as identification tools for that source.

All isotopic values listed in this report, excluding the strontium isotopic ratio and tritium concentration, are given in per mil units (‰). This value is calculated using the following equation

$$\delta\,(\text{delta}) = \frac{R\,(\text{sample}) - R\,(\text{reference})}{R\,(\text{reference})} \times 1000$$

where R = the ratio of isotope concentrations.

The delta symbol in this report is followed by the chemical symbol for the heavier isotope measured during isotopic analysis. Per mil values included in this report are presented relative to reference compounds. Vienna Standard Mean Ocean Water (V–SMOW) is the reference compound for $\delta^{18}O$ and δD analyses. The ^{2}H isotope commonly is referred to as deuterium, and the symbol used to represent this isotope is D. The reference compound for $\delta^{15}N$ analyses is air. Canyon Diablo Troilite (CDT) is the reference compound for $\delta^{34}S$ analyses. The reference compound for $\delta^{7}Li$ analyses is the L–SVEC standard. The reference compound for $\delta^{11}B$ analyses is from the National Bureau of Standards (NBS–951). Isotopic values in this report are described as lighter or heavier in relation to each other. Lighter isotopic values are smaller or more negative per mil values and heavier isotopic values are larger or more positive per mil values.

Compositions of $\delta^{18}O$ and δD can be used to trace water through its flow path if the source of the water has a unique isotopic signature. Isotopes of other elements are used to identify sources of the elements or various processes that involve these elements. The isotopic value of a solid material may be found in water when the solid has come into contact with water. Dissolution of the solid material into water may result in an isotopic composition in the water that is similar to that of the solid material.

The isotopic compositions of some elements can change as a result of physical, chemical, and biological processes that take place in a ground-water flow path. Some of these processes can alter the isotopic ratios by preferentially interacting with one isotope of an element. For example, water movement through fine-grained material can change the isotopic compositions of lithium. Physical interaction with the fine-grained material preferentially removes the lighter lithium isotope from solution resulting in a heavier isotopic composition of the water that moved through the fine-grained material relative to the water composition before it moved through the material. This change in isotopic composition is known as fractionation.

Fractionation of isotopic compositions can create difficulties in using isotope values as identification tools. If the isotopic systems and hydrologic systems are well understood, it is possible to evaluate the effects of fractionation on the isotopic compositions. If uncertainties exist, it is difficult to apply some isotopic methods to an investigation. Identifying sources of nitrate in water with nitrogen isotopic compositions can be difficult because biological processes can cause fractionation and change isotopic values. This study was designed to determine other methods to identify sources of nitrate in ground water, including additional isotopic systems and other chemical techniques.

The isotopic compositions used during this study are $\delta^{18}O$, δD, ^{3}H, $\delta^{15}N$, $\delta^{34}S$, $\delta^{11}B$, $\delta^{7}Li$, and $^{87}Sr/^{86}Sr$. The isotopes used in the per mil calculation are $^{18}O/^{16}O$, $^{2}H/^{1}H$, $^{15}N/^{14}N$, $^{34}S/^{32}S$, $^{11}B/^{10}B$, and $^{7}Li/^{6}Li$. Isotopes of nitrogen are the only true identifiers of nitrogen, but data from other isotopic systems may be used to identify ground water that has been affected by nitrate sources. Compositions of $\delta^{18}O$ and δD were used to trace the movement of water and identify sources of water. If the water can be traced to a nitrate source and the nitrogen can be linked to this source, these isotopes may be useful tools for nitrate-source identification.

Tritium, ^{3}H, was used to identify ground water that has received recent recharge from surface water. Fusion bomb testing in the 1950's and 1960's introduced a large amount of tritium to the atmosphere that was quickly converted to water molecules. Because the concentration of tritium in the atmosphere was high for a short period of time, its presence in ground water can identify water that has been in contact with the atmosphere in the last 40 years. If ground water can be identified as recently being in contact with the atmosphere (in the last 40 years), nitrate present in the ground water also could be identified as recently infiltrated.

Nitrogen isotopic compositions, $\delta^{15}N$, were used to identify nitrogen from different sources. These data can be used to identify the source of nitrogen, but its use is complicated by fractionation associated with biological processes. Sulfur isotopic compositions have been used to identify sources of sulfur or biological processes that involve sulfur. Fractionation processes complicate the use of these data; however, if sulfur isotopic compositions of nitrate sources vary sufficiently, the isotope data may be a useful tool if there is evidence that also links the nitrogen to that source. Isotopic compositions of boron, $\delta^{11}B$, have had little use in environmental studies, and isotopic compositions of lithium, $\delta^{7}Li$, have had no use in environmental studies before this investigation and were selected to identify sources of these elements. An advantage of using boron and lithium isotopes is the small number of fractionation processes that affect these isotopic compositions. Similar to applying sulfur isotopes to identify nitrate sources, the use of boron and lithium isotopic compositions also requires evidence that connects nitrogen to the same source.

If the isotopic compositions of sulfur, boron, and lithium varied sufficiently in different nitrate sources and nitrogen from the source could be traced, these isotopic systems could be used for identification. An example of this type of application is the boron composition related to STP outflow. Because wastewater entering STP's generally consists of domestic wastes, the predominant source of boron in this water is probably detergents. Borax is the source of boron in detergents, and this mineral has a specific boron isotopic composition. If this isotopic composition varies sufficiently from background values, it can be used to identify boron from STP outflow that has infiltrated to the ground water. If nitrogen from the STP also was identified in the ground water, the use of boron isotopes to identify the presence of nitrogen from the same source would be verified. Because boron and nitrogen do not have similar chemical or isotopic characteristics, it is necessary to justify the use of boron to identify nitrogen from a specific source. This same justification is necessary in order to use sulfur and lithium isotope data to identify nitrate sources.

Field and Laboratory Methods

Field and laboratory methods used during this study depended on the available equipment and components being analyzed. Some sites were sampled in 1990 and 1991 to ensure reproducibility of the results. Chemical analyses were completed according to standard procedures. Some isotopic analyses were made according to accepted procedures. Other isotopic analyses were unique, and the procedure is described here in detail.

Field Methods

Before a water sample was collected, pH, specific conductance, dissolved-oxygen concentration (DO), and temperature were monitored to determine that these properties were stable and ensure that a representative sample was being collected. These measurements were made in a flow-through chamber for ground-water samples whenever possible so that ambient conditions could not affect the water.

Samples collected for dissolved-constituent analyses were filtered on site through a 0.45-micron filter using a peristaltic pump, except for samples for dissolved organic carbon (DOC) that were filtered through a 0.45-micron silver filter in a stainless-steel cylinder pressurized with nitrogen gas. Preservation, if needed, was completed on site and included nitric acid to lower the pH to less than 2 in samples for analysis of metal, metalloid, and most common ions; mercuric chloride in samples for nutrient analyses; and potassium dichromate in samples for mercury analyses.

Unfiltered and untreated water was collected for analyses of $\delta^{18}O$, δD, and ^{3}H. $\delta^{18}O$ and δD analyses required 125 mL of water collected in a glass bottle with little or no air space and covered with a lid secured with tape to prevent evaporation during shipment. ^{3}H samples required 1 L of water collected in a polyethylene bottle. Water filtered through a 0.45-micron filter was used to analyze $\delta^{11}B$, $\delta^{15}N$, $\delta^{34}S$, $\delta^{7}Li$, and $^{87}Sr/^{86}Sr$ compositions. For $\delta^{11}B$ analyses, 1 L of filtered water was collected in a polyethylene bottle, and no preservation techniques were required. Samples collected for $\delta^{15}N$ analyses were 1 L of filtered water collected in a glass bottle and preserved with H_2SO_4. Samples collected for $\delta^{34}S$ analyses included 1 L of filtered water collected in a glass bottle and preserved with $HgCl_2$. For both nitrogen and sulfur isotopic analyses, the samples were chilled immediately after preservation until the analyses were performed. Lithium and strontium isotopic analyses required 1 L of sample collected in acid-rinsed polyethylene bottles and acidified to a pH of less than 2 with Ultrex HNO_3.

Laboratory Methods

In general, the USGS National Water Quality Laboratory (NWQL) in Arvada, Colorado, analyzed most of the constituents. Isotopic analyses were completed in laboratories associated with the NWQL. Laboratories not associated with the NWQL were used for analyses of $\delta^{7}Li$, $^{87}Sr/^{86}Sr$, and $\delta^{11}B$.

Chemical Analyses

Chemical analyses included inorganic and organic constituents (table 3; at end of the report). Inorganic constituents included dissolved forms of major ions, metals and metalloids, and dissolved and total forms of nutrients. Organic constituents included DOC and total organic carbon (TOC); DOC and TOC were determined to complete the characterization of the nutrient composition of the water.

Most of the chemical and physical constituents of water samples were analyzed by the National Water Quality Laboratory (NWQL). Fishman and Friedman (1989) discuss analytical methods used by the NWQL. Manure leachate and fertilizer samples were analyzed by ENSECO, Inc., of the Rocky Mountain Analytical Laboratories in Arvada, Colorado. ENSECO uses analytical methods established by the USEPA.

Isotopic Analyses

Isotopic compositions of oxygen, hydrogen, nitrogen, and sulfur were analyzed by laboratories contracted by the NWQL. Isotopic determinations of boron, lithium, and strontium were made by specific laboratories that were selected because of the uniqueness of the analytical technique. $\delta^{18}O$ and δD compositions were completed under the direction of Tyler Coplen, a research chemist with the USGS, Water Resources Division (WRD). ^{3}H analyses were performed at a lab operated by Robert Michel, a research chemist with the USGS, WRD. $\delta^{34}S$ analyses for samples collected in 1990 were performed at a laboratory operated by Patrick Shanks, USGS, Geologic Division (GD). $\delta^{34}S$ analyses for samples collected in 1991 were performed at a laboratory operated by Robert Rye, USGS, GD. $\delta^{15}N$ analyses of the NO_3 content in the samples were performed by Global-geochemistry, Incorporated.

$\delta^{11}B$ compositions were determined with a solid-source mass spectrometer by Randall L. Bassett, Department of Hydrology and Water Resources, University of Arizona. A description of the laboratory procedure is included because the analytical procedure is nonstandard. Before measuring the boron isotopic composition, a volume of sample containing 100 µg of boron was passed through a column containing a resin that preferentially removed boron from the sample at neutral to alkaline pH values. Elution of boron was completed by passing 0.1N HNO_3 through the resin. To ensure that all the boron was removed from the resin, 100 mL of 0.1N HNO_3 was passed through the resin after the pH of the eluent was less than 2. The eluent was collected and evaporated to approximately 3 mL. Methanol (approximately 50 mL) was added to the 3-milliliter sample and distilled into 50 mL of distilled water. This step removed the boron and methanol from the water and nitric acid, purifying the solution. The distillate was evaporated to dryness. The solid sample was loaded onto a tantalum filament by hydrating the solid with $NaCO_3$ and placing the solution onto the filament where it was heated to dryness. The solid sample was analyzed on a solid-source mass spectrometer to determine the boron isotopic composition. The precision of these values generally is less than 0.5‰ for most of the analyses.

Lithium isotopic determinations were made on a solid-source mass spectrometer by Thomas D. Bullen, USGS, Menlo Park, California. A description of the laboratory procedure is included because the analytical procedure is nonstandard. Before analysis, a volume of water containing approximately 2 µg of lithium was passed through a column packed with Biorad AG5OX8 cation resin. Lithium was stripped quantitatively from the resin using 2N HCl as eluent. This solution was evaporated to dryness, redissolved with 0.5N HNO_3, and loaded onto a second, larger column packed with AG5OX8 resin. Using 0.5N HNO_3 as eluent, lithium was stripped from the resin to the point of Na-breakthrough. This solution was evaporated to dryness and loaded with water onto one side of a double rhenium filament assembly and analyzed. The precision of $\delta^{7}Li$ values is better than 1‰.

GEOHYDROLOGIC SETTING OF WESTERN SALT RIVER VALLEY

The study area is in the Basin and Range Physiographic Province of the western United States (Fenneman, 1931). Mountains that surround the area and form the basin boundary range from Precambrian to middle Tertiary metamorphic and granitic rocks and Tertiary to Quaternary volcanics (Reynolds, 1988). The basin is filled with alluvial material, deposited during the Cenozoic Era, that is derived from the surrounding mountains. Surface water from anthropogenic sources and the Gila River and its tributaries that drain the study area are the primary sources for ground-water recharge. The basin-fill deposits form the water-bearing units that yield the primary ground-water supplies for the region. The occurrence and movement of ground water in the study area are controlled mainly by the lithologic and structural characteristics of the basin-fill deposits. Chemical characteristics of the ground water vary in different geographic parts of the study area and are affected by some distinct geologic features, such as the Luke salt body and a geothermal anomaly. Nitrate concentrations were higher than the MCL in almost half the ground-water samples collected for this study.

Lithologic and Water-Bearing Characteristics

The basin and range structure of the study area was developed during a period of high-angle block faulting that occurred 15 to 8 million years ago (Shafiqullah and others, 1980). Mountains that border the area were uplifted in relation to the floor of the basin. Alluvial material was deposited within the basin during faulting and successive subsidence of the basin.

Early to middle Proterozoic granitic, metamorphic, and metasedimentary and late Tertiary granitic rocks are exposed in the south boundary. Rocks exposed in the west boundary are Proterozoic metamorphics and Proterozoic and late Cretaceous to early Tertiary granites. Rocks exposed in the north boundary include Proterozoic granitic, metasedimentary, and metavolcanic rocks and middle Tertiary volcanics. Metamorphic and metavolcanic rocks of Proterozoic age and minor amounts of volcanic and sedimentary rocks of Tertiary age are exposed in the east boundary. (See Reynolds, 1988.)

Basin-fill material in the study area is derived primarily from the surrounding mountains. The basin fill ranges in thickness from less than 610 to more than 3,600 m. A possible fault within the crystalline rocks beneath the basin fill differentiates the structure of northeast and southwest sections of the study area (Brown and Pool, 1989). The northeast section contains northwest-trending crystalline block structures overlain by less than 610 m of basin fill. The southwest section contains a large structural graben overlain by more than 3,600 m of basin fill. A gravity low in the center of this graben indicates a structural depression.

Within the structural depression in the southwest section is a halite deposit that has been referred to in previous investigations as the "Luke salt body" (fig. 1; Eaton and others, 1972; Peirce, 1976; Eberly and Stanley, 1978; Brown and Pool, 1989). Eaton and others (1972) described the deposit as "an exceedingly thick, steep-sided sedimentary prism representing long-lived evaporite deposition in the center of a clastic sedimentary basin." The smallest depth to the top of the deposit, an anhydrite layer, is 241 m below the land surface approximately 2 km east of Luke Air Force Base (Eaton and others, 1972). The top of the halite was found at 268 m at the same location. The greatest depth to the top of the deposit was 716 m below the surface, where halite with no overlaying anhydrite was found in a well approximately 1.5 km southwest of Luke Air Force Base (Eaton and others, 1972). The bottom of this deposit is estimated to be more than 2,100 m below the surface. The volume is estimated to be between 63 and 125 km^3.

The basin-fill deposits that form the water-bearing units have been divided by Brown and Pool (1989) into four units: upper, middle, lower, and red. The lithology of these units depends on the depositional environments of these units. The red unit was deposited before the period of faulting in the basin (Laney and Hahn, 1986). The lower unit, which is divided into upper and lower parts, was deposited in a closed-basin system during high-angle normal faulting (Peirce, 1976). The middle unit was deposited as the drainage system through the area was developing (Brown and Pool, 1989). The upper unit was deposited after the surface-water drainage system developed (Brown and Pool, 1989).

The red unit consists of "well-cemented breccia, conglomerate, sandstone, and siltstone and contains granitic and rhyolitic detritus" (Laney and Hahn, 1986). Detritus from the red unit is found at the base of the lower unit in the southeastern part of the basin (Brown and Pool, 1989).

The lower unit "consists of playa, alluvial-fan, fluvial, and evaporite deposits" (Brown and Pool, 1989). The lower unit is divided into lower and upper parts differentiated by stratigraphy. The lower part of the unit is more consolidated and contains more homogeneous clast type and stratigraphy than the upper part. In general, the composition of sediments in the lower part is 20–80 percent sand and gravel. The thickness of the lower part ranges from 305 m at the margins of the basin to 3,048 m within the graben near the center of the basin (Brown and Pool, 1989). The halite deposit and other evaporite deposits of anhydrite, halite, and gypsum are found in the lower part of the lower unit (Brown and Pool, 1989). The upper part is characterized as 20–80 percent sand and gravel in most parts of the study area, but contains less than 10 percent sand and gravel "in a general arcuate pattern from northwest Phoenix to Tolleson and southeast of the White Tank Mountains" (Brown and Pool, 1989). The thickness of this part ranges from more than 305 m in a trough that is oriented in a north-south direction between the Luke salt body and the White Tank Mountains to less than 152 m in the Buckeye Valley. The upper part is not found along some of the mountain fronts (Brown and Pool, 1989).

The middle unit is composed of "playa, alluvial-fan, and fluvial deposits of silt, clay, siltstone, and silty sand and gravel" and is commonly cemented by calcium carbonate (Brown and Pool, 1989). This unit is not found near the mountain fronts but is as thick as 244 m in the center of the basin. More than 40 percent of the unit is sand and gravel in most of the study area. In localized areas near the cities of Glendale and Goodyear, the unit is composed of less than 20 percent sand and gravel (Brown and Pool, 1989).

The upper unit is characterized by Brown and Pool (1989) as "channel, flood plain, and alluvial-fan deposits." The sediments are mostly unconsolidated gravel, sand, and silt with some consolidation by caliche occurring near the mountain fronts and underlying terraces near major streams (Brown and Pool, 1989). The thickness of this unit varies from approximately 61 m near the margins of the basin to 122 m near the confluence of the Salt and Gila Rivers (Brown and Pool, 1989). These sediments include more than 80 percent sand and gravel in the northeastern region, along the Salt and Gila Rivers, and northwest of the halite deposit (Brown and Pool, 1989). Finer-grained deposits, containing less than 40 percent sand and gravel, are found in this unit southwest of Camelback Mountain, east of the White Tank Mountains, and along the southwest edge of the study area (Brown and Pool, 1989).

Volcanic material that is similar to volcanic material in the mountains is present in some parts of the alluvial deposits. Volcanic material older than middle Miocene occurs in well cuttings from the northern and northeastern parts of the study area (Brown and Pool, 1989). Late Miocene volcanics were identified in cuttings from wells near the center of the study area (Brown and Pool, 1989). Wells in the extreme southwestern region contain late Tertiary and Quaternary basalts that are interbedded with basin-fill materials (Brown and Pool, 1989).

Occurrence and Movement of Surface Water

Surface-water flow originates and is controlled by dams outside the study area for the major rivers that flow through the study area—the Salt, Gila, and Agua Fria Rivers. Small drainages within the study area also contribute flow to these rivers during or after storms. The total annual flow in the Salt River at 24th Street in Phoenix for water year 1990 was 18.1 m^3/s (U.S. Geological Survey, 1991). The total annual flow in the Gila River near Buckeye for water year 1991 was 1,250 m^3/s (U.S. Geological Survey, 1992); part of the flow recorded at this gage is outflow from the 91st Avenue STP, which is 32 km upstream (U.S. Geological Survey, 1991). Mean annual inflow to Lake Pleasant, approximately 10.5 km north of the north boundary of the study area on the Agua Fria River, was 0.3 m^3/s (U.S. Geological Survey, 1991). In the southern region of the study area, irrigation return flow and water deliveries from SRP to the Buckeye Irrigation Company are transported down the riverbed of the Agua Fria River (Jim Krause, hydrologist, SRP, oral commun., 1992). These data indicate that the amount of water available for recharge from the Salt River is greater than that from other rivers in the study area.

Anthropogenic sources of surface water in the study area include irrigation canals and outflow from STP's. SRP operates a canal system that delivers water throughout the study area. The canal system receives ground water and water that is diverted from the Salt and Verde Rivers in the eastern part of the valley. The Buckeye Irrigation Company and the Roosevelt Irrigation District operate irrigation canals that deliver water to the southern part of the study area. These canals receive water from STP outflow, the SRP system, and ground-water supplies. The Beardsley canal flows across the northern part of the study area and contains water from the Agua Fria River. The canal that transports water from the Colorado River for the Central Arizona Project (CAP) also is a source of surface water in the northern region. Irrigation return flow that is captured in basins at the downgradient edges of fields and outflow from STP's also can be considered sources of surface water in the study area.

Occurrence and Movement of Ground Water

Hydrologic conditions in the northeastern and southwestern regions are different because the structure of the basin-fill deposits is dissimilar. The lower unit is the primary water-bearing unit in the northeastern region because the thicknesses of the middle and upper units are small. In the southwestern region, all basin-fill units are significant water-bearing units. The fine-grained material within the basin-fill units controls the rate of ground-water flow in the aquifer in both regions. The hydraulic-conductivity values for each basin-fill unit of the aquifer depend on the material and structure of the deposits. Unconsolidated and coarser-grained sediments in the upper unit have the largest hydraulic conductivities—54.9 to 518.2 m/d. Fine-grained deposits in the middle unit limit the hydraulic conductivity to 1.2 to 18 m/d. The two parts of the lower unit have different hydraulic-conductivity values because of different lithologic characteristics of the deposits. The upper part of the lower unit has a hydraulic conductivity that ranges from 0.9 to 7.3 m/d, depending on the particle size of the sediments. The lower part of the lower unit has a hydraulic conductivity that ranges from 1.8 to 2.7 m/d and is controlled by fracturing and (or) cementation. (See Brown and Pool, 1989.)

Before major urban and agricultural development began, the general ground-water flow directions were from east to west in the southern region (fig. 2) and northeast to southwest from Deer Valley to the Agua Fria River (Anderson and others, 1992). Recent water levels indicate a change in ground-water flow directions in the southeastern part of the study area and in other areas in the northern region. Ground-water pumpage and recharge from human activities have changed the ground-water flow directions to the northwest near the Salt River in the eastern part of the study area and large depressions in the ground-water table have formed in areas north and west of Luke Air Force Base and in Deer Valley (Brown and Pool, 1989; SRP, 1982). Complete dewatering of the upper unit has been recorded by Brown and Pool (1989) in areas north and west of Luke Air Force Base and between Phoenix and Deer Valley.

The amount of ground-water recharge through the river beds depends on the amount of flow in the rivers. Significant ground-water recharge occurred along the Salt and Gila Rivers between large flows in February 1976 and June 1980; recharge was estimated to be 1.1 x 10^8 m^3 between a dam near the east boundary and a dam several kilometers southwest of the west boundary (Brown and Pool, 1989). As a result of these significant streamflow losses, ground-water levels stabilized or rose (Brown and Pool, 1989). Before this time period, depths to ground water in the study area were increasing rapidly.

GROUND-WATER CHEMISTRY

Chemical characteristics identify some large spatial variation of the ground water and localized effects from specific geologic occurrences in the study area. The chemistry of the ground water was used to distinguish (1) ground water from different geographic regions, (2) ground water affected by the Luke salt body, and (3) ground water from the geothermal anomaly. Nitrate concentrations in 16 of the 37 ground-water samples collected for this study were higher than or equal to the MCL set by the USEPA.

Chemical data differentiate ground water from northern and southern regions of the study area. To account for the differences, the study area was divided at 33°30' latitude (fig. 2). Trilinear diagrams (figs. 3 and 4) that include ground-water data for this study and data from the USGS water-quality database and other Federal, State, and private agencies for samples collected from 1986–91 display the different types of ground water in the northern and southern regions. Types of ground water are defined by the cations and anions that contribute more than 50 percent to the ions in solution.

Calcium and magnesium content generally is higher in the northern region than the southern region, but the anion content in both regions is dominated by chloride excluding some smaller areas that have significant contribution from bicarbonate. Some ground water contains more

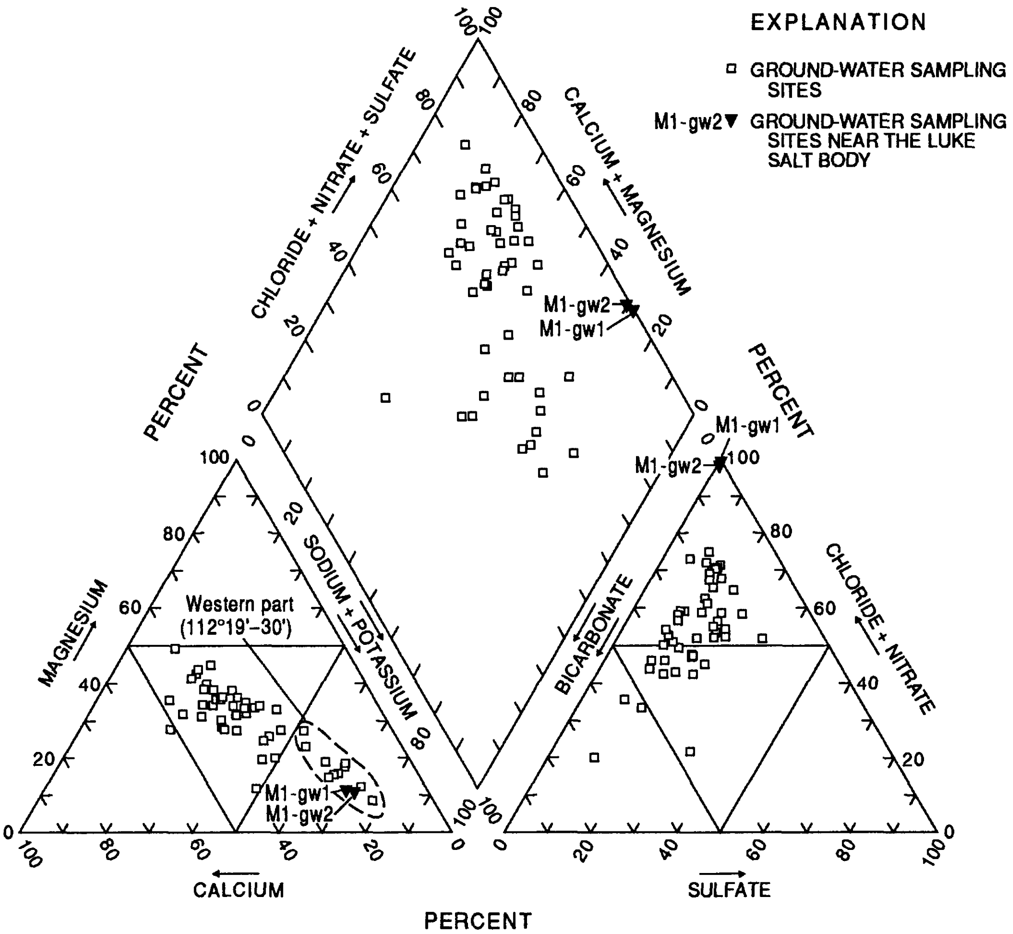


Figure 3. Relative compositions of ground water from the northern region, in percent, western Salt River Valley, Arizona, 1986–91. (See figure 2 for location of northern region, M1-gw1, and M1-gw2.)

than 50-percent sodium in the western part (112°19'–112°30') of the northern region; sodium concentrations in this area range from 67.6 to 471 mg/L. Ground water from the eastern part (112°00'–112°12') of the southern region contains more than 30-percent bicarbonate in the anion content; concentrations range from 256 to 714 mg/L as HCO_3. Significant amounts of sulfate (greater than 30 percent), and chloride (greater than 40 percent) are in the anion content of ground water from the western part (112°20'–112°38') of the southern region. The concentrations of chloride and sulfate in this area range from 326 to 1,400 mg/L and 300 to 2,600 mg/L, respectively. Sulfate, sodium, and chloride in the western part of the southern region have been attributed to irrigation activities (Maricopa Association of Governments, 1979; Brown and Pool, 1989). The linear trend in the cation diagrams identifies a change to more sodium-rich ground water in the western part of both the northern and southern regions. The explanation for this linear trend could be dissolution of sodium-rich minerals, cation exchange, or evaporation of surface water that infiltrates to the ground water. The specific reactions and sources of this trend are difficult to identify because of complications associated with the hydrologic system and anthropogenic activities.

Ground-water chemistry near the Luke salt body at sites M1-gw1 and M1-gw2 (table 2) indicates the effects of salt dissolution (fig. 3). Ground water from this area is distinctive because the anion content of the waters is primarily chloride. The depths to these wells are shallower than the depth to the salt body; therefore, chloride probably indirectly originates from halite in this geologic

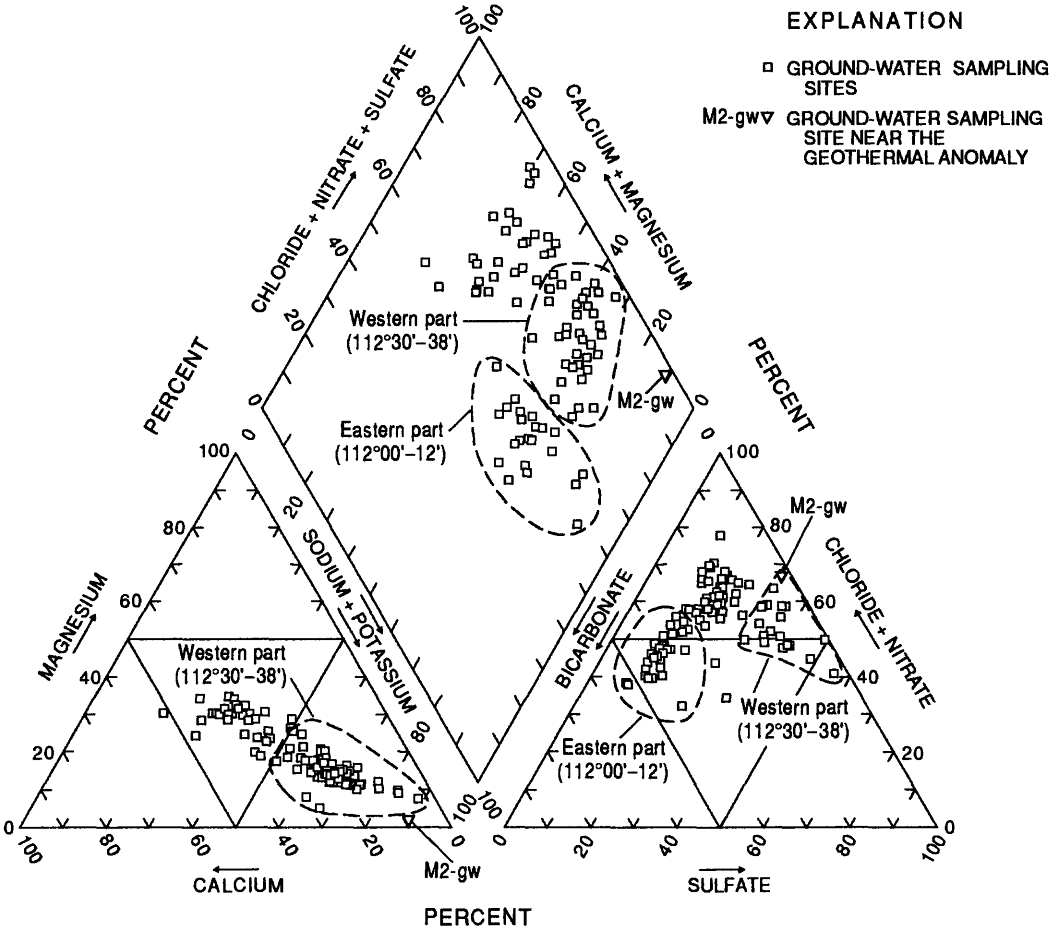


Figure 4. Relative compositions of ground water from the southern region, in percent, western Salt River Valley, Arizona, 1986–91. (See figure 2 for location of southern region and M2-gw.)

deposit. Similar chemical characteristics of ground water in this area have been identified in previous studies (Kister, 1974; Eaton and others, 1972; Brown and Pool, 1989).

In the southwestern part of the study area, the Perryville-Valencia geothermal anomaly (A.L. Geldon and P.P. Ross, hydrologists, U.S. Geological Survey, written commun., 1981) is characterized by ground water that has higher temperatures than ground water from other parts of the study area at equivalent depths. Chemical characteristics of ground water near the geothermal anomaly from site M2-gw (table 2) can be identified by the large sodium and chloride plus nitrate plus sulfate content (fig. 4). High concentrations of boron, 3,500 µg/L; lithium, 440 µg/L; arsenic, 120 µg/L; molybdenum, 280 µg/L; and vanadium, 140 µg/L also are unique to the ground water in this area (table 3).

The nitrogen species analyzed for this study included nitrate, ammonia, and nitrite. In the study area, nitrogen species occur primarily in the dissolved form, and nitrate is the largest contributor to the nitrogen content in ground water. Ground water collected during 1986–91 throughout the study area had nitrate concentrations that ranged from 0.3 to 43.1 mg/L as N. In general, ground water for this study contains ammonia and nitrite concentrations lower than the detection limit of the analyses (less than 0.01 mg/L; table 3). The highest concentration of dissolved ammonia and nitrite in ground water—1.7 mg/L NH_4 as N and 0.02 to 0.03 mg/L NO_2 as N—occurred near the Luke salt body at site M1.

Because land use surrounding the sample locations was well documented, the nitrate concentrations in ground water will be presented in relation to land use. Of the 37 ground-water samples collected in the study area, 16 had nitrate concentrations higher than or equal to the MCL set by the USEPA of 10 mg/L as N (U.S. Environmental Protection Agency, 1991; fig. 5, this report). Of these 16 samples, 9 were collected near dairies and feedlots. Of the other seven samples that exceeded the MCL, four samples were collected near cotton fields, and three samples were collected from areas with mixed land use.

The 21 samples that contained less than the MCL for nitrate were collected throughout the study area and in all types of land use. Six of the 21 samples were collected near STP's and have high concentrations of ammonia that could be transformed into nitrate. Five of the 21 samples were collected in areas of agricultural activities, and 3 of the 5 samples had concentrations higher than or equal to 8 mg/L. Three of the 21 samples were collected near dairies and feedlots. For 7 of the 21 samples that contained lower nitrate concentrations than the MCL, 1 was collected where little or no anthropogenic activity was present, 3 were collected where two or more land-use types were present, 2 were collected near the salt body, and 1 was collected near the geothermal anomaly.

ISOTOPIC COMPOSITIONS

Isotopic compositions of ground water and surface water identified some general variation within the study area and some local variation associated with the Luke salt body and a geothermal anomaly. Isotopes of hydrogen and oxygen display geographic variation of the ground water and evaporative effects from an average composition for global meteoric water. Sulfur isotopic compositions and sulfate concentrations show geographic variation of the ground-water compositions. Nitrogen isotopic compositions are affected locally by different nitrogen sources. Isotopic compositions of lithium and boron show a geographic variation in the study area and some local effects from the Luke salt body and a geothermal anomaly. Lithium isotopes also are distinctive near some specific sources of nitrate.

Hydrogen and Oxygen

Distributions of δD and $\delta^{18}O$ data for ground water show an evaporative trend from the global meteoric water line (GMWL) (fig. 6). The GMWL is the linear relation of δD and $\delta^{18}O$ values for precipitation data from throughout the world (Craig, 1961). At the present time, no local meteoric water line is available for the Salt River Valley basin; therefore, the GMWL developed by Craig (1961) is included as a possible model of the isotopic content of meteoric water in the study area. The equation for this relation is $\delta D = 8\delta^{18}O + 10‰$. The δD and $\delta^{18}O$ data for the Salt River near Roosevelt Lake (table 1) are included in this discussion to display the relation between surface water and ground water in the southern part of the study area.

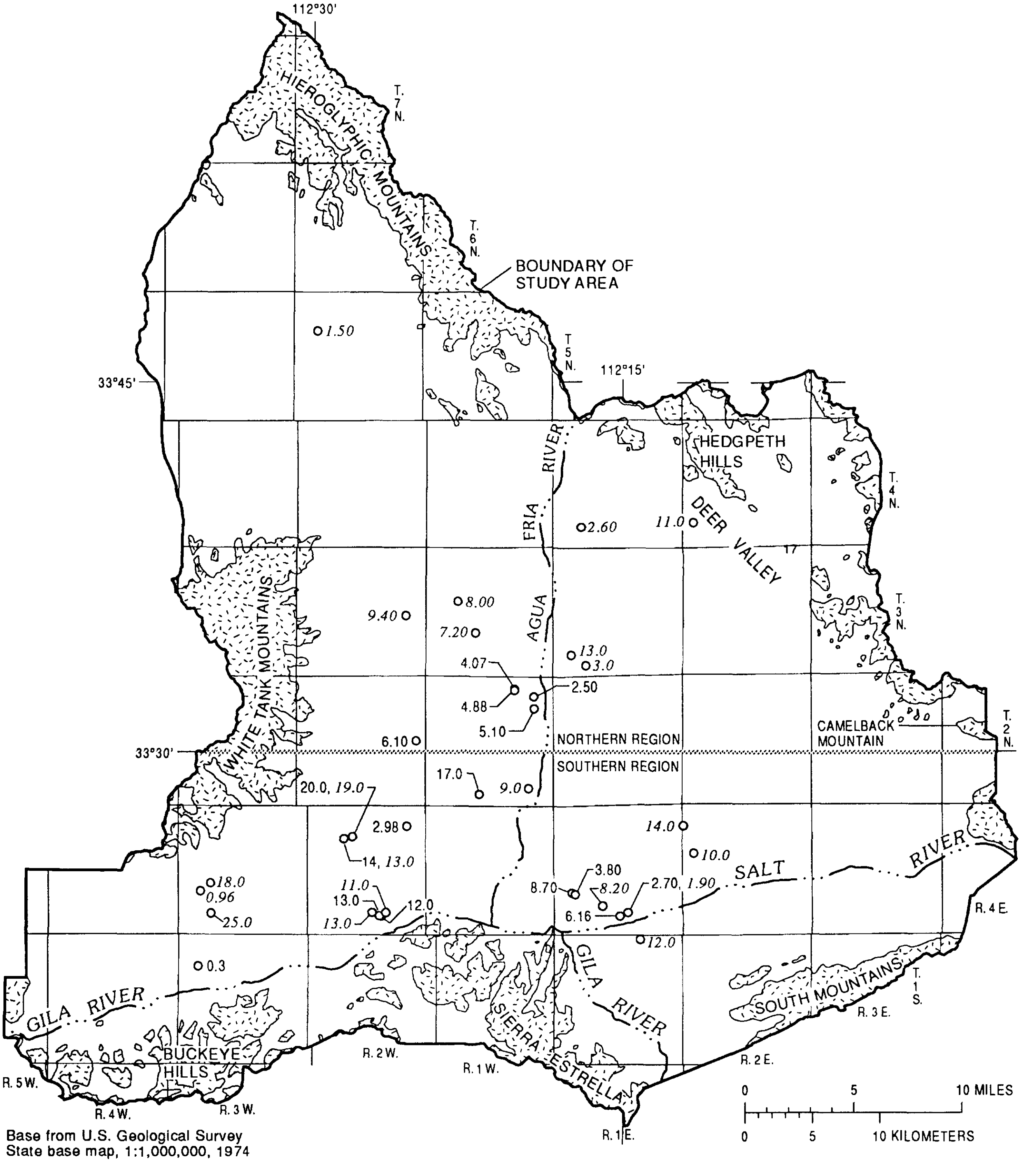
Table 1. $\delta^{18}O$ and δD data for the Salt River near Roosevelt Lake

[T.B. Coplen, research chemist, U.S. Geological Survey, oral commun., 1992]

Date	$\delta^{18}O$ (per mil)	δD (per mil)
12-30-86	-10.55	-73.0
02-24-87	-9.95	-72.0
08-18-87	-10.65	-75.0

The ranges of δD and $\delta^{18}O$ for ground water are -76.5 to -61.5‰ for δD and -10.45 to -8.15‰ for $\delta^{18}O$ (table 4; at end of the report). The lightest values were measured in ground water from site M2 and probably are the result of a geothermal system at depth. Most of the δD and $\delta^{18}O$ data lie to the right of the GMWL, which is the result of effects from evaporation (Gat and Gonfiantini, 1981).

In addition to evidence of evaporation, the data are divided into two groups by geographic location. This geographic differentiation identifies water from the northern and southern regions in the study area. The distribution of δD and $\delta^{18}O$ data for the two regions are both linear, but the groups are displaced. The separation of these data into two groups could indicate that different sources of ground water exist in the study area although determining these sources is difficult with these



EXPLANATION

☐	ALLUVIAL DEPOSITS
▨	CONSOLIDATED ROCKS

2.70, *1.90* ○ SAMPLING SITE—Concentrations are nitrate as nitrogen, in milligrams per liter. First number is 1990 sample, number in italics is 1991 sample

Figure 5. Nitrate concentrations as nitrogen in ground water, western Salt River Valley, Arizona,1990–91.

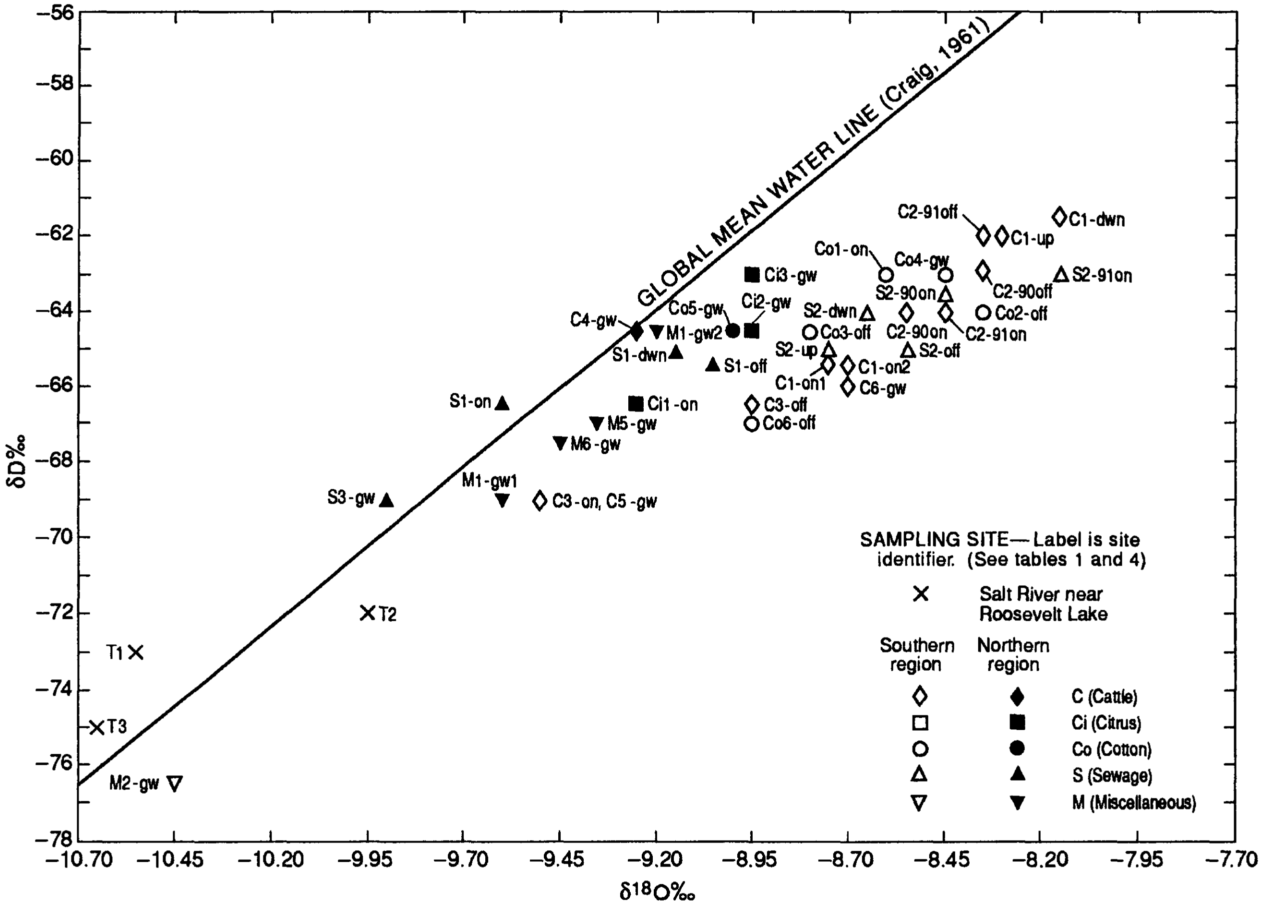


Figure 6. Relation between δD and $\delta^{18}O$ compositions in ground water and surface water, western Salt River Valley, Arizona, 1990–91. (See figure 2 for location of sampling sites.)

data alone. Possible ground-water sources include (1) rapid infiltration of local precipitation in mountain-front and streambed-recharge areas, (2) recharge of surface water from local rivers, (3) ground-water inflow from outside the study area, and (4) recharge from irrigation. The δD and $\delta^{18}O$ data for local precipitation are needed to determine if any of the ground-water data collected for this study represent direct recharge of local meteoric water. The amount of local rainfall recharging the ground water and effects from evaporation would be discernible with this additional information.

If recharge through riverbeds is a large source of ground water, the δD and $\delta^{18}O$ content in the ground water will be controlled by the rivers that have the larger flow amounts. Because most of the surface-water flow in the southern region originates in the Salt River drainage system, the δD and $\delta^{18}O$ content of ground-water recharge should reflect the isotopic composition of this surface water. The Agua Fria River is the major source of surface water in the northern region; therefore, any recharge through this river bottom should reflect the isotopic composition of this surface water. The headwaters for these two systems are in different parts of Arizona and are affected by different sources of water. This variation in the sources of surface water may cause the differences in the δD and $\delta^{18}O$ data.

The δD and $\delta^{18}O$ data for the Salt River near Roosevelt Lake plot near the GMWL. If the source of ground water in the study area was direct infiltration of unaltered river water, δD and $\delta^{18}O$ compositions of the ground water would be similar to values for the Salt River. Because this is not the case, the surface water must have been altered before infiltration. Evaporation of surface water could occur as water is transported through the study area in canals, by irrigation activities, or down the riverbeds before infiltrating into the ground-water system. Local precipitation, a recharge source to the ground water, also might be altered by evaporation in the atmosphere before infiltration. The effects of the surface-water transport mechanisms mentioned above would result in an evaporative trend similar to the distribution of data displayed between the Salt River and shallow ground water from the southern region. Because δD and $\delta^{18}O$ values for ground water from the northern region do not lie as far to the right of the GMWL, the source of ground water does not appear to be as greatly affected by evaporation as ground water from the southern region. This interpretation is restricted by the amount of δD and $\delta^{18}O$ data for precipitation that is available for the study area.

Most of the ground water collected for this study contained some ^{3}H, indicating that it was exposed to the atmosphere in the last 20 years (table 4). Ground water from 13 sites had concentrations of ^{3}H that were less than 4.5 pCi/L, which indicates that these ground waters have not been exposed to the atmosphere in the last 40 years (fig. 7). Twelve of the 13 sites with less than 4.5 pCi/L of ^{3}H are in the northern region. This geographical delineation of the data indicates that, in general, a significant volume, in percent, of ground water from the southern region was more recently recharged than ground water from the northern region. This difference in the age between ground water from different regions is due partially to the shallower depths to water and the larger amounts of irrigation water that have been and are currently being applied in the southern region. Both of these characteristics result in water being transported from the surface to the ground water more quickly and in larger amounts in the southern region. One outlier does exist within the geographical delineation of data. In the northern region, sample S1-off had 5.0 pCi/L of ^{3}H and could contain a large volume, in percent, of recent water that has drained downward through the annular space within the well or some other pathway from the surface.

Sulfur and Nitrogen

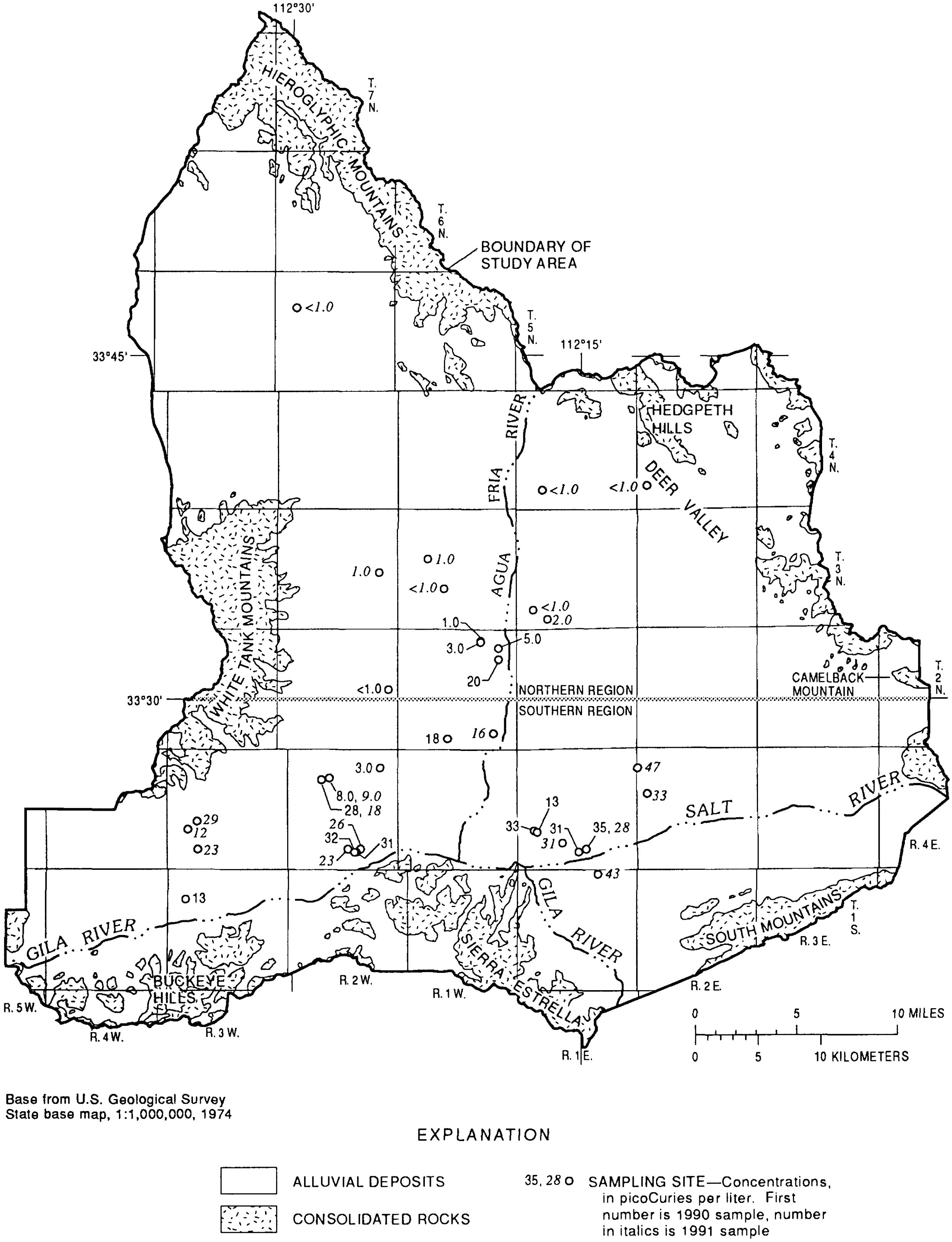
Chemical and isotopic distributions of sulfur and nitrogen are important characteristics of ground water in the study area. Sulfur isotopic compositions (table 4) are separated by geographical regions (fig. 8). Most water from the northern region has $\delta^{34}S$ values between +4.1 and +6.0‰. Most ground water from the eastern part of the southern region has $\delta^{34}S$ values between +8.1 and +9.2‰. Ground water in the western part of the southern region (112°26'–112°38') has $\delta^{34}S$ values between +6.0 and +8.5‰ (fig. 8), which are some of the heaviest $\delta^{34}S$ values in the study area; ground water from this area also has most of the higher sulfate concentrations.

The high sulfate concentrations and small range of $\delta^{34}S$ values in the western part of the southern region could indicate that an outside source is contributing sulfate to the ground water as it moves downgradient through this part of the study area. The source of the sulfate cannot be identified from ground-water analyses alone; analyses of the possible sources of sulfate are necessary for a distinct identification. Further discussion of the source and isotopic content of the sulfate is included in the section entitled "Sources of Nitrate."

$\delta^{15}N$ values for ground water in the study area were between +5.0 and +14.0‰ (fig. 9). The three heaviest $\delta^{15}N$ values—+13.1, +13.3, and +14.0‰—occurred in ground water at sites C1-dwn, S2-90on, and S2-91on, respectively (table 4). $\delta^{15}N$ values similar to these have been associated with nitrogen derived from animal-waste material (Kreitler, 1975; C.A. Cravotta, hydrologist, U.S. Geological Survey, written commun., 1991). The lighter $\delta^{15}N$ values could be affected by (1) nitrogen derived from other sources including fertilizers, STP outflow, and anthropogenic sources, (2) fractionation during biological and chemical reactions, and (or) (3) mixing of nitrogen from various sources. A site-specific discussion of the nitrogen isotopic content and nitrate concentrations is included in the section entitled "Sources of Nitrate."

Lithium

Isotopic compositions of lithium appear to be affected by the Luke salt body and specific types of nitrate sources in the study area. Some geographic delineation of the data also is observed. The ranges of $\delta^{7}Li$ values and lithium concentrations for



Base from U.S. Geological Survey
State base map, 1:1,000,000, 1974

Figure 7. Tritium concentrations in ground water, western Salt River Valley, Arizona, 1990–91.

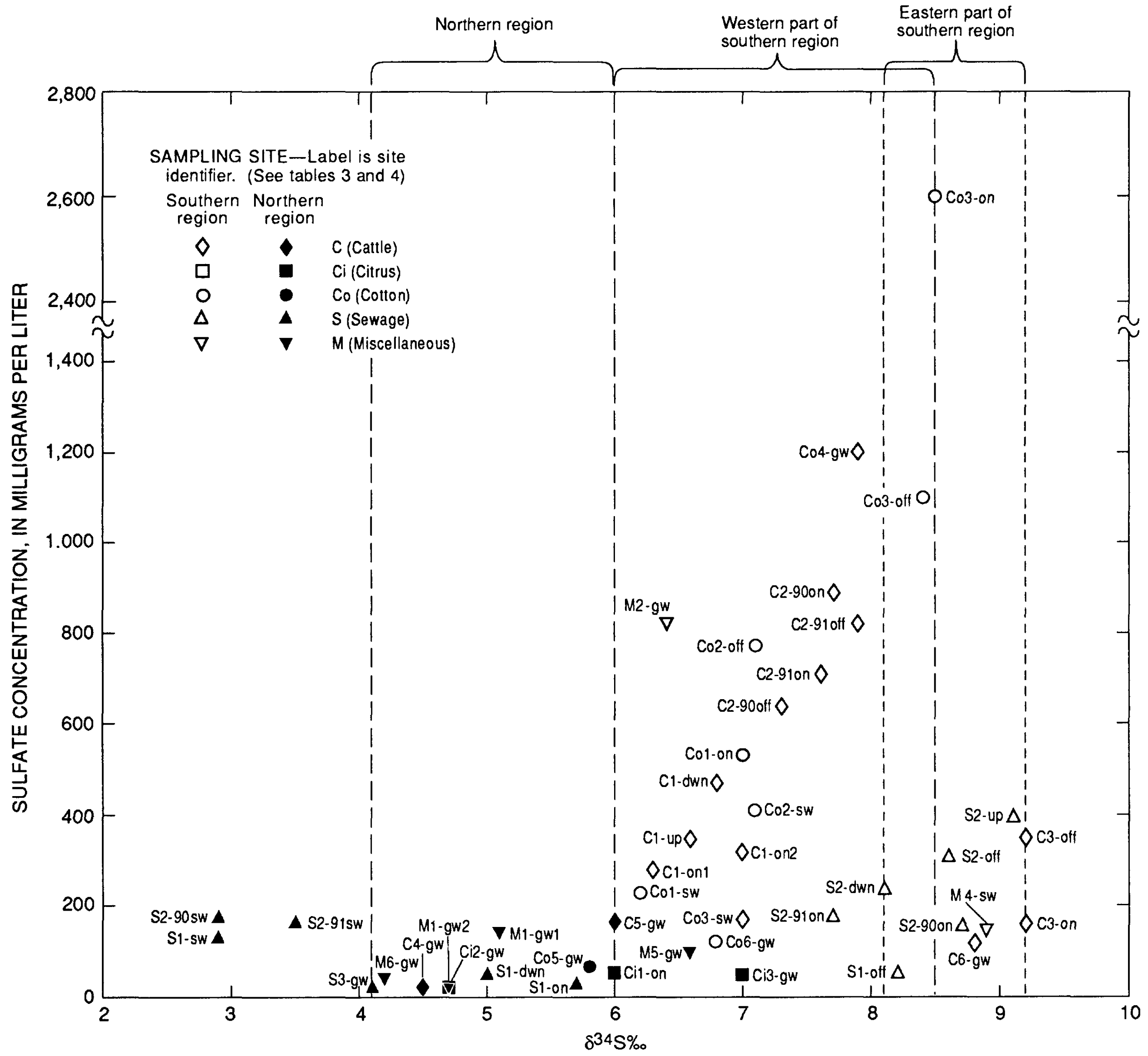


Figure 8. Relation between sulfate concentrations and $\delta^{34}S$ compositions in ground water and surface water, western Salt River Valley, Arizona, 1990–91. (See figure 2 for location of sampling sites.)

ground water are -2.8 to +18.0‰ (table 4) and 0.0 to 6,000 µg/L (table 3), respectively. The highest concentrations (6,000 µg/L) were analyzed in ground water collected near the salt body (M1-gw1, M1-gw2), but most of the ground water had concentrations less than 500 µg/L (fig. 10). In general, ground water from the northern region, excluding sites M1-gw1 and M1-gw2, contains lower concentrations of lithium and the range of δ^7Li values is smaller than ground water from the southern region (fig. 10).

Boron

Isotopic compositions of boron for ground water appear to be separated by geographical location and are affected by the Luke salt body (fig. 11). The ranges of $\delta^{11}B$ values and boron concentrations in ground water are -14.1 to +49.7‰ (table 4) and 50 to 5,800 µg/L (table 3).

In general, ground water from the northern region has lower concentrations of boron and lighter $\delta^{11}B$ values than ground water in the

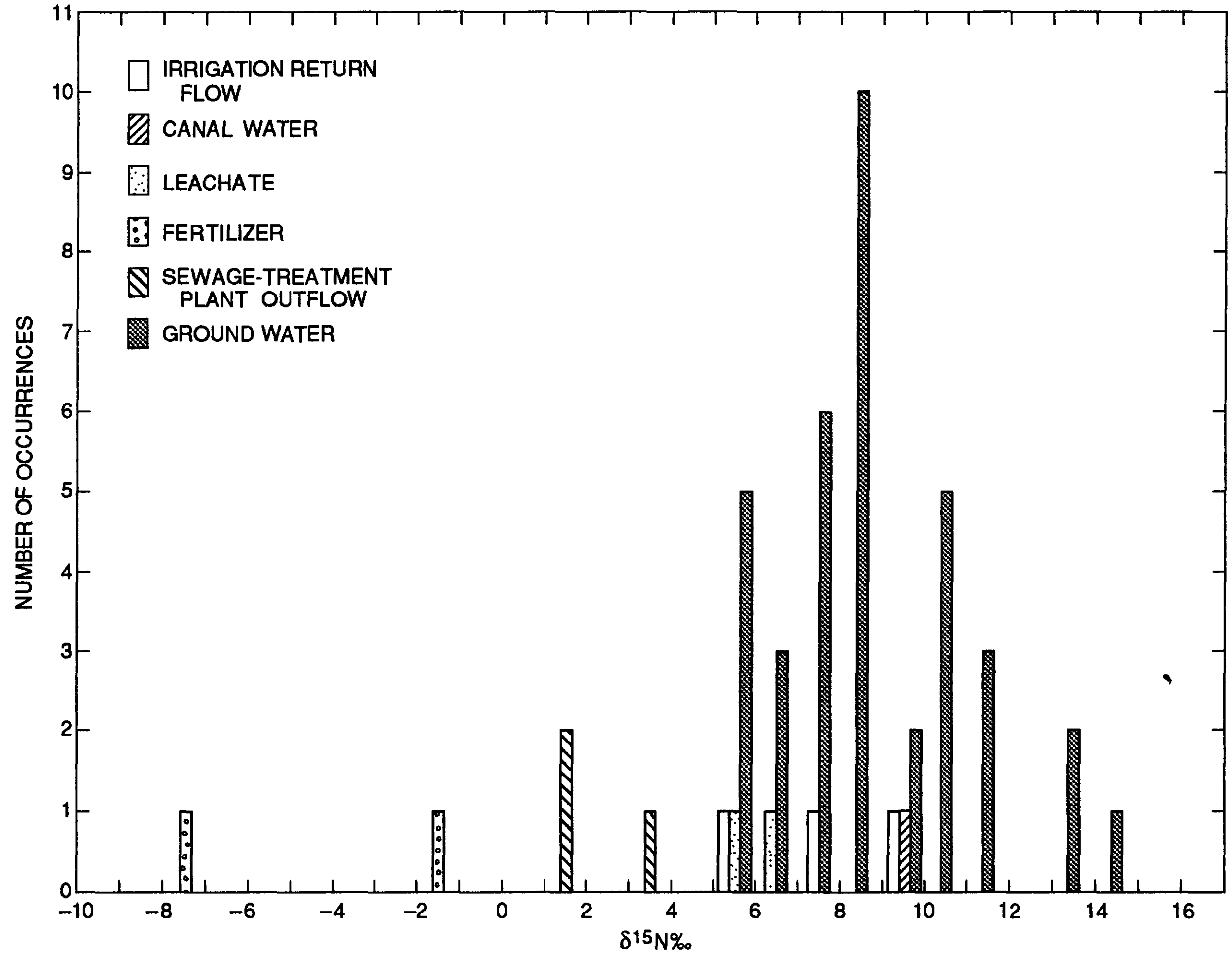


Figure 9. Values of $\delta^{15}N$ for all samples, western Salt River Valley, Arizona, 1990–91. (See table 4.)

southern region except ground water from C5-gw. C5-gw is near the boundary between the northern and southern regions, and the ground water might be more influenced by boron from the south than the north. The reason for the difference between the geographic regions is unclear; however, effects from the salt body might result in some of the lighter $\delta^{11}B$ values. Ground water collected near the salt body at sites M1-gw1 and M1-gw2 contained some of the lightest $\delta^{11}B$ values—0.7 and 1.2‰—in the northern region. These values could represent boron derived from the salt body. Because the salt body appears to have a distinctive $\delta^{11}B$ value in comparison with ground water in the northern region and the boron concentration is higher than in other ground water collected in this region, it seems possible that boron derived from the salt body could be affecting local ground water.

The lightest $\delta^{11}B$ value (-14.1‰) was measured in ground water near the geothermal anomaly (M2-gw) and is near the range of $\delta^{11}B$ values (-9.3 to +4.4‰) measured in thermal water from Yellowstone National Park (Palmer and Sturchio, 1990). The heaviest $\delta^{11}B$ values—47.3 and 49.7‰—were analyzed in ground water from sites C2-90off and C2-91off and are heavier than $\delta^{11}B$ values for sea water (Bassett, 1990). Although these data are anomalous within data for this study, Buska and others (1991) reported heavy $\delta^{11}B$ values (+44 ± 1.5‰) for native ground water near El Paso, Texas.

High boron concentrations were analyzed in ground water from the western part of the southern region, but $\delta^{11}B$ values do not indicate that a single source of boron exists. This area coincides with a fine-grained deposit in the middle unit of the

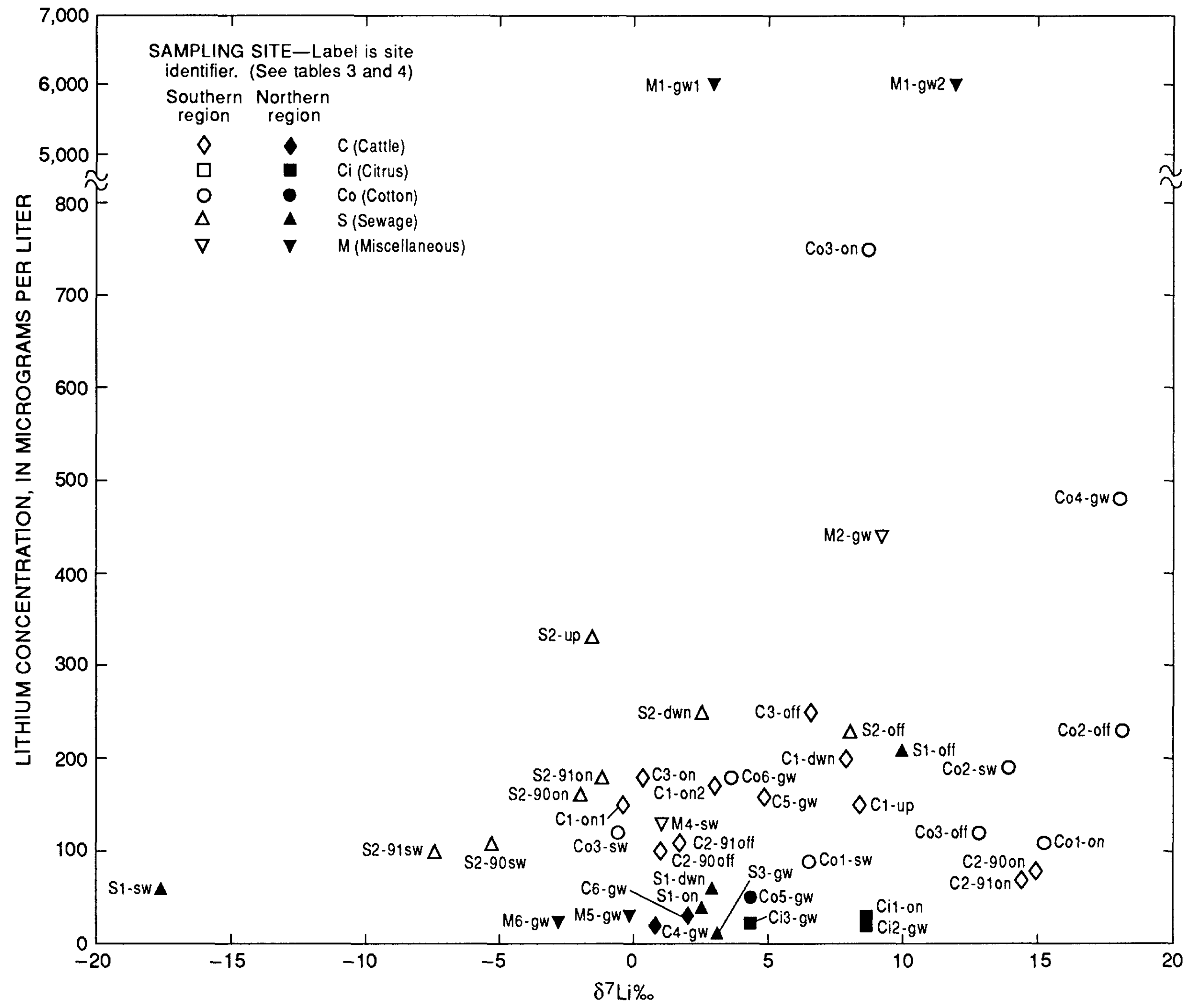


Figure 10. Relation between lithium concentrations and δ^7Li compositions in ground water and surface water, western Salt River Valley, Arizona, 1990–91. (See figure 2 for location of sampling sites.)

aquifer. These high values could be the result of dissolution of a boron-rich source in the alluvial material or infiltration of recharge water that has been concentrated after evaporation. Although concentrations in the ground water in this area are higher than most of the ground water collected for this study, the δ^{11}B values are not distinct. Ground water in this region that contains boron concentrations higher than 1,300 µg/L have δ^{11}B values from -0.3 to +49.7‰. This large range of isotopic values indicates that several sources probably are contributing to the high concentrations of boron in this area or that some water is affected by filtration through fine-grained material.

SOURCES OF NITRATE

The identification of nitrate sources was successful at specific sample locations and for some types of nitrate sources. At least one isotopic system and, in some cases, the chemical content uniquely identified the end member for each type of nitrate source. The end members were leachate from manure, STP outflow, and nitrogen fertilizer. Ground water from areas with little or no anthropogenic activity was collected to represent end members for natural nitrate sources. The isotopic characteristics for each end member were compared

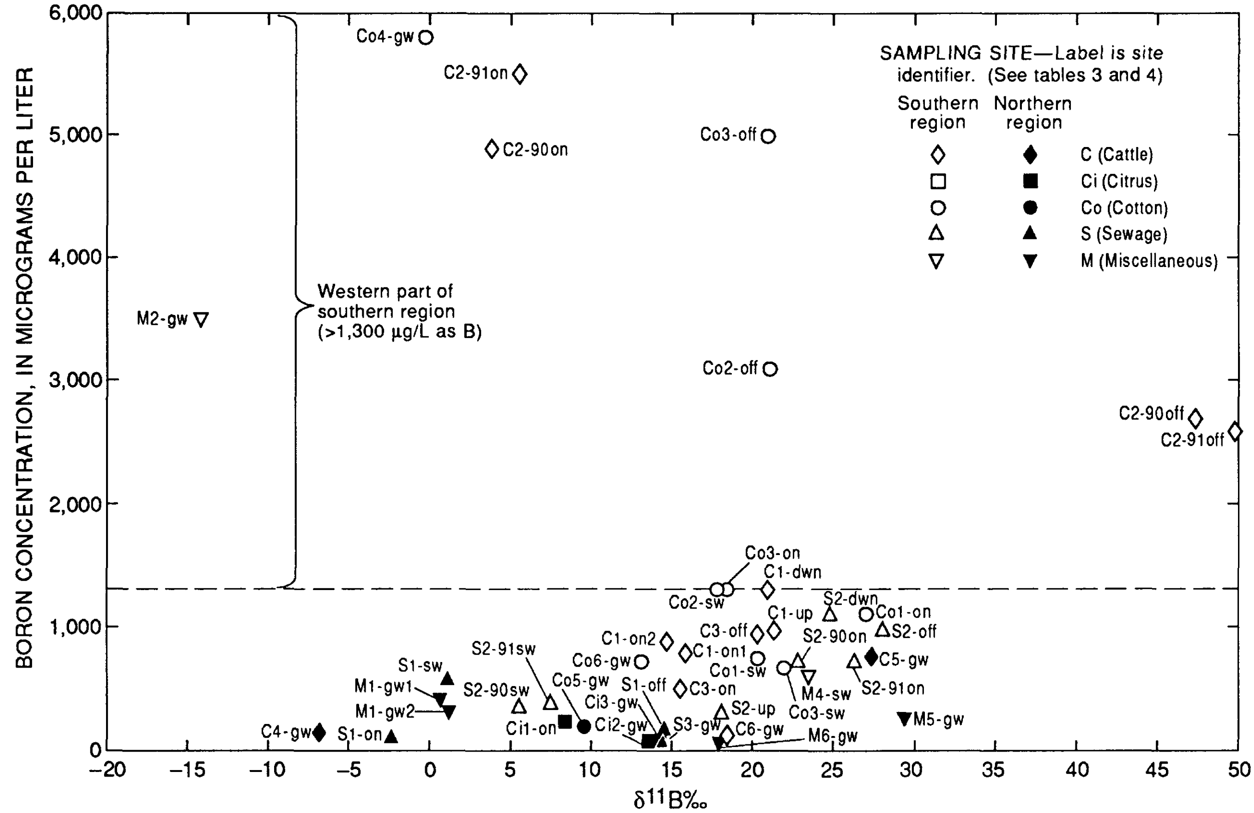


Figure 11. Relation between boron concentrations and $\delta^{11}B$ compositions in ground water and surface water, western Salt River Valley, Arizona, 1990–91. (See figure 2 for location of sampling sites.)

with the content of the ground water to identify the source of nitrate in the ground water.

Dairies and Feedlots

The most successful technique used during this study to identify ground-water nitrate derived from dairies and feedlots was $\delta^{15}N$ compositions of ground water. Nitrogen isotopic compositions of manure leachates were near an isotopic range presented by C.A. Cravotta (U.S. Geological Survey, written commun., 1991) for the same material. Comparison between the composition of manure leachates and ground water was difficult because fractionation processes alter the $\delta^{15}N$ values before, during, and after infiltration of water from the surface. To account for this complication, conclusions from previous studies were used to identify ground water affected by animal waste because of the unknown effects from these fractionation processes in the study area.

The $\delta^{15}N$ values measured in leachates from manure collected at sites C1 and C2 were +5.8 and +6.5‰, respectively. These values are within a range of values for runoff from manure, 0 to +6.4‰, presented by C.A. Cravotta (U.S. Geological Survey, written commun., 1991). Use of these data to identify ground water affected by nitrogen from manure is difficult because volatilization and other fractionation processes alter the $\delta^{15}N$ value as nitrogen is transported to the ground water. Previous studies have determined that $\delta^{15}N$ values greater than or equal to +9‰ represent nitrogen in ground water that is derived from animal waste (Kreitler, 1975; C.A. Cravotta, U.S. Geological Survey, written commun., 1991).

Nitrogen isotopic compositions in the range of +11 to +13‰ were measured in ground water from four wells at site C1 (table 4). These values are above +9‰, which Kreitler (1975) and C.A.

Cravotta (U.S. Geological Survey, written commun., 1991) identified as nitrogen present in ground water that is derived from "animal waste nitrate." In this area where many dairies are located, nitrogen could be transported to the ground water by either infiltration of water through manure piles, infiltration of liquid waste, or infiltration through irrigated fields that are fertilized with manure. The shallow depth to ground water near site C1 might cause rapid transport of nitrogen from the land surface to the ground water.

Sewage-Treatment Plants

Chemical constituents and isotopic compositions of nitrogen, sulfur, lithium, and boron characterize the outflow from STP's in the study area. Identification of this source of nitrogen is complicated by the evolution of nitrogen compounds, fractionation of nitrogen isotopes, and mixing of water from various sources. These processes could interfere with identification of nitrogen from STP's in ground water; however, isotopic compositions of lithium and boron are affected by fewer fractionation processes, which simplifies the use of these data.

Outflow from sites S1 and S2 contained concentrations of ammonia, nitrite, and phosphorus that were higher than concentrations measured in ground water. Ammonia concentrations were higher than 10 mg/L as N in the outflows, and the highest concentration in ground water, excluding site M1, was 0.18 mg/L as N (table 3). The average nitrite concentration in STP outflow was 2.1 mg/L as N. The highest nitrite concentration in ground water was 0.09 mg/L as N. The data indicate that most of the nitrogen in STP outflows occurred as ammonia (fig. 12). The distribution of nitrogen species indicates that nitrification is not a dominant process in the outflow at the point of collection.

Outflow from the STP's contained $\delta^{15}N$ values that ranged from +1.4 to +3.2‰, and are the lightest values analyzed in water for this study (fig. 9 and 12). These data are equivalent to values presented by C.A. Cravotta (U.S. Geological Survey, written commun., 1991) for dissolved nitrogen in sewage effluent. These light $\delta^{15}N$ values are the result of microorganisms and sewage-treatment processes that have fractionated nitrogen isotopes in the outflow (C.A. Cravotta, U.S. Geological Survey, written commun., 1991). The $\delta^{15}N$ compositions in sewage effluent are distinct in this data set and can be used as a signature of this nitrogen source if fractionation processes and other hydrologic characteristics are known.

Nitrogen derived from STP outflow can be traced from the surface to ground water at the STP's by analyzing the form of nitrogen and the isotopic content of nitrogen in outflow and in ground water along a flowpath at site S2. A 12‰ difference exists between $\delta^{15}N$ values for shallow ground water at S2-on (+13.3 and +14.0‰) and STP outflow from site S2 (+1.4 and +1.6‰). The $\delta^{15}N$ values in ground water at S2-on are within the range of values (above +9‰) that has been identified previously as water affected by human or animal wastes (Kreitler, 1975; C.A. Cravotta, U.S. Geological Survey, written commun., 1991). In addition to a variation in the $\delta^{15}N$ values, the major nitrogen compounds also are different in the outflow and the ground water. Most of the nitrogen in the outflow occurs in the form of ammonia, and most of the nitrogen in the ground water occurs in the form of nitrate (fig. 12). Ammonia volatilization might be occurring in the aquifer during percolation and infiltration of outflow that changes the dominant nitrogen compound in the water to nitrate. These processes have been found to preferentially remove ^{14}N from the solution resulting in a heavier nitrogen isotopic composition in solution (C.A. Cravotta, U.S. Geological Survey, written commun., 1991). A similar relation between isotopic compositions and nitrogen compounds in STP outflow and ground water also is displayed in water collected at site S1.

The $\delta^{15}N$ values for ground water downgradient from sites S1 and S2 (S1-off, S1-dwn, S2-off, S2-dwn) are within the range of most values for ground water in the study area. A gradual change in the $\delta^{15}N$ values is evident as the distance from each STP increases (figs. 9 and 12). At sites S1-off and S2-off, the $\delta^{15}N$ values are near 10‰, which is heavier than most values for ground water in the study area and within the range of $\delta^{15}N$ values that correspond with animal-waste material. At sites S1-dwn and S2-dwn, further downgradient from the STP's, the ground water contains nitrogen with $\delta^{15}N$ values that are lighter and that might indicate a small volume, in percent, of sewage in the

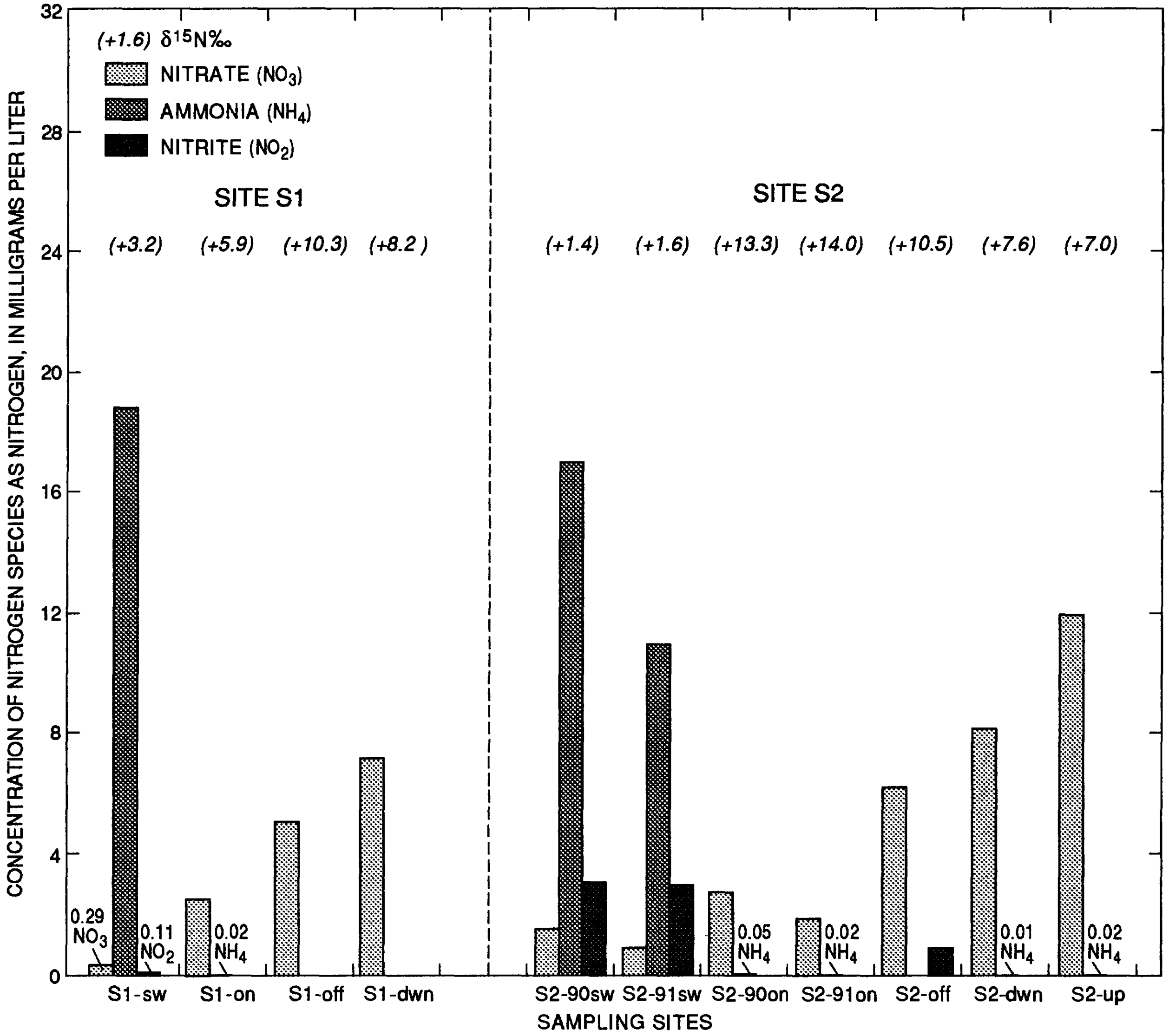


Figure 12. Distribution of concentration of nitrogen species as nitrogen and $\delta^{15}N$ compositions in samples collected near sewage-treatment plants, western Salt River Valley, Arizona, 1990–91. (See figure 2 for location of sampling sites.)

ground water or a return to background values. Site S2-up is considered to be upgradient from the STP and should represent ground water that is not affected by STP outflow. The $\delta^{15}N$ value from ground water at this location, +7.0‰, is similar to the $\delta^{15}N$ value, +7.6‰ from ground water downgradient of the STP at S2-dwn. This similarity is evidence that ground water at S2-dwn is only slightly affected by STP outflow. Mixing with other water probably is the cause of the lighter $\delta^{15}N$ values in ground water downgradient from the STP's.

Isotopic compositions of sulfur support the connection displayed in the nitrogen data between STP outflow and shallow ground water at site S2. Light $\delta^{34}S$ values were analyzed in the STP outflow at S1 and S2. The reasons for these values are unclear; however, the values are distinctive in the data set (fig. 8). At S1-sw, the value of +2.9‰ was lighter than the values for ground water collected at sites S1-on and S1-off. At sites S2-90sw and S2-91sw, $\delta^{34}S$ values of +2.9 and +3.5‰, respectively, were lighter than values of the ground water collected at sites S2-90on, S2-91on, and S2-off (table 4). Fractionation processes related to biological activity could account for the differences between these samples. These biological processes preferentially remove ^{32}S from solution resulting in an isotopically heavier water. The relation of these data supports the possibility that STP outflow and shallow ground water at site S2 are related.

The lightest δ^7Li values for this study were analyzed in outflows from STP's. The δ^7Li value of -17.6‰ for outflow from site S1 was the lightest analyzed and was lighter than the values of -5.3 and -7.4‰ measured in outflow from site S2 (fig. 10). The source of light δ^7Li values in STP outflow might be lithium that is present in the inflow to the plant or a treatment process that affects the lithium isotopic composition. For example, lithium that is present in lubricants and greases might contain light lithium that are inputs to the STP and might be present in outflow from the plant. Information about lithium isotopic behavior is not sufficient to hypothesize if these scenarios correctly identify the cause of the δ^7Li distribution in STP outflow; however, because the δ^7Li values of the STP outflow are significantly different, they may be useful for identification purposes.

Light δ^7Li values (-2.0 and -1.2‰) also were detected in shallow ground water collected at S2-on (fig. 10). Farther downgradient, at S2-dwn, the lithium isotopic values are no longer distinct from most ground water in the study area. Dilution of outflow and mixing probably occur in the aquifer and modify the distinct δ^7Li value of STP outflow. Flow through fine-grained material also might alter the lithium isotopic compositions. The light δ^7Li values in the STP outflow and the shallow ground water support the possibility that the sources of water at site S2 are related.

Some of the lightest $\delta^{11}B$ values—1.1, 5.5, and 7.5‰—were measured in outflow from STP's (fig. 11). The light $\delta^{11}B$ value in the outflow as compared with the bulk of the data might be the result of boron from detergents. Bassett (1990) reported five $\delta^{11}B$ values for borax, which is a mineral commonly used in detergents, that ranged from -0.9 to +6.5‰. These values are similar to values analyzed in the STP outflow for this study and might indicate that detergents are a source of boron in the outflow. The $\delta^{11}B$ values for STP outflow also are within a range of values that characterize various igneous rocks (Bassett, 1990) and could be the result of flow through igneous rocks. During treatment of the sewage, water may come into contact with these rock types, but it is more likely that borax from detergents is the source of the $\delta^{11}B$ values in the STP outflow because the source of the sewage is wastewater primarily from domestic sources. This wastewater should include a large amount of detergents. A small amount of $\delta^{11}B$ data is available at this time to compare with findings from other investigations.

Unlike nitrogen, sulfur, and lithium isotopic data, isotopic compositions of boron in STP outflow and ground water at site S2 do not support a relation between these sources of water. Fractionation of boron isotopes as the water flows through fine-grained material is possible and may explain the large difference between $\delta^{11}B$ values for STP outflow and ground water at S2 (fig. 11). Fine sediments are found at STP's in sedimentation ponds that could cause such a change in boron isotopic composition. If $\delta^{11}B$ values are to be used to identify STP outflow in ground water in this area, more knowledge is needed about fractionation of boron isotopes through fine-grained material that may help identify the effects of sewage on boron isotopes.

The change of the major nitrogen compounds and the change in nitrogen isotopic compositions from STP outflow to the shallow ground water at S2-on indicate that the nitrogen from these two sites could be related. Known fractionation processes associated with the change in the form of nitrogen explain the change in the nitrogen isotopic compositions. Sulfur isotopic compositions also are distinctive for water from site S2. Fractionation processes could explain the variation of $\delta^{34}S$ values between STP outflow and the ground water, thereby supporting the evidence suggested by the $\delta^{15}N$ compositions. The relation between the outflow and the shallow ground water also is supported by the light δ^7Li values in the STP outflow and the shallow ground water at site S2. The $\delta^{11}B$ values in STP outflow are distinctive and could be used with additional information about fractionation of boron isotopes to support the relation between STP outflow and shallow ground water at site S2.

Agricultural Activities

Chemical and isotopic characteristics of fertilizers and irrigation return flow were compared with chemical and isotopic characteristics of ground water to determine if nitrogen from agricultural activities could be identified in ground water. Some chemical and isotopic characteristics including values of $\delta^{15}N$ and $\delta^{34}S$ for fertilizers and irrigation return flow differ significantly from values for end members of other sources of nitrogen. Most of the irrigation return flow collected for this study had chemical and isotopic compositions that were similar to ground water and indicates that the influence of fertilizers present in the irrigation return flow is minimal.

Fertilizers used on cotton and citrus crops in the study area contain approximately 32 percent urea and generally are applied in liquid form with the irrigation water. Chemical constituents that had higher concentrations in fertilizers than in water samples were DOC, TOC, ammonia, nitrate, nitrite, fluoride, phosphorus, and some metals (table 3). Metal concentrations varied considerably between fertilizer samples and might be related to metal-storage facilities at fertilizer-distribution centers. The high concentrations of nutrients in these samples were useful as identification tools of nitrogen fertilizer.

Values of $\delta^{15}N$ measured in fertilizers were lighter (-1.4, -1.5, and -7.2‰) than values of $\delta^{15}N$ in water (table 4). The $\delta^{15}N$ values measured in the fertilizers are close to 0‰ because the manufacturing process includes reacting nitrogen gas from the air with hydrogen gas (C.A. Cravotta, U.S. Geological Survey, written commun., 1991), and nitrogen gas from the air is the reference material to determine $\delta^{15}N$ values in the laboratory. Sample Co1-F had a $\delta^{15}N$ value of -7.2‰, which was much lighter than 0‰ and might be a result of the manufacturing process (C.A. Cravotta, U.S. Geological Survey, written commun., 1991) or fractionation processes that occurred during storage of the fertilizer. These light $\delta^{15}N$ values are unique in this data set and might be useful identifiers of nitrogen fertilizer.

Chemical compositions of irrigation water, fertilizer, and irrigation return flow at sites Co1 and Co3 were used to determine the influence of fertilizers on the chemical and isotopic compositions of irrigation return flow and ground water. Irrigation return flow at Co2-sw was unique in this data set because no fertilizer is used in this part of the study area, and the source of irrigation water at the site was not sampled. Information received from local farmers at site Co2 indicates that the addition of fertilizer is not required because high concentrations of ammonia originate in the source of the irrigation water, which is canal water that is partially supplied with STP outflow.

Irrigation return flow at Co1-sw and Co3-sw had high concentrations of ammonia, phosphorus, and (or) orthophosphate and low concentrations in the source of irrigation water, Co1-on and M4-sw (table 3), and indicates that added fertilizer may increase the concentrations of these chemical constituents or that these elements are dissolved from the topsoil. Concentrations of nitrate in the sources of irrigation water at Co1-on and M4-sw are high enough to account for a considerable percentage of nitrate in the irrigation return flow samples at Co1-sw and Co3-sw, respectively. Irrigation return flows contained slightly higher concentrations of nitrate than the source of irrigation water, which indicates that a small amount of nitrogen from the fertilizers was present as nitrate in the irrigation return flow.

Values of $\delta^{15}N$ in the irrigation water and irrigation return flows also indicate that nitrogen fertilizer has a minor influence on the irrigation return flow. The $\delta^{15}N$ values at Co3-sw and Co1-sw, irrigation return flow samples, were +9.2 and +5.1‰, respectively. These values are similar to the $\delta^{15}N$ values at M4-sw (+9.4‰) and Co1-on (+7.7‰), which were the sources of the irrigation at Co3 and Co1, respectively. Although fertilizer was added to the irrigation water at both sites, the $\delta^{15}N$ values and concentrations of nitrate indicate that fertilizer is not a major source of nitrogen in the irrigation return flow. Mixing calculations indicate that less than 0.1 percent of the irrigation return flow samples was fertilizer. Fractionation of nitrogen isotopes may have altered the isotopic composition, but comparison of nitrate concentrations supports the idea that the fertilizer has a minor influence on the composition of the irrigation return flow.

Ground water collected in areas where agricultural activities were prevalent, excluding sites Co1, Co2, and Co3, generally had chemical and isotopic compositions that were similar to the irrigation return flow samples (tables 3 and 4; fig. 9). This similarity was expected because in general ground water is used as irrigation water in the study area.

Values of $\delta^{34}S$ for Co2-sw and Co2-off indicate that irrigation activities are affecting the ground water (fig. 13). At this cotton field, fertilizer is not added to the irrigation water, and the source of irrigation water is a canal that is partially supplied by STP outflow. Similar sulfur isotopic compositions (table 4) indicate that the irrigation return flow and ground water have similar sources of sulfur at site Co2. This connection would be supported by $\delta^{15}N$ values if ammonia volatilization affects the irrigation return flow as it percolates to the ground water. The $\delta^{15}N$ value of the ground water is heavier than the $\delta^{15}N$ value of irrigation return flow; therefore, if a source of the ground water is irrigation return flow, as the $\delta^{34}S$ data suggest, fractionation must occur to explain the $\delta^{15}N$ data in these samples. At site Co1, the $\delta^{34}S$ values of the irrigation return flow and the ground water are different and might indicate that agricultural activities are not affecting the local ground water (fig. 13). At site Co3, canal water (M4-sw) was used to irrigate the crop, and the $\delta^{15}N$ compositions of the canal water (+9.4‰) and the irrigation return flow (Co3-sw; +9.20‰) are similar. The $\delta^{34}S$

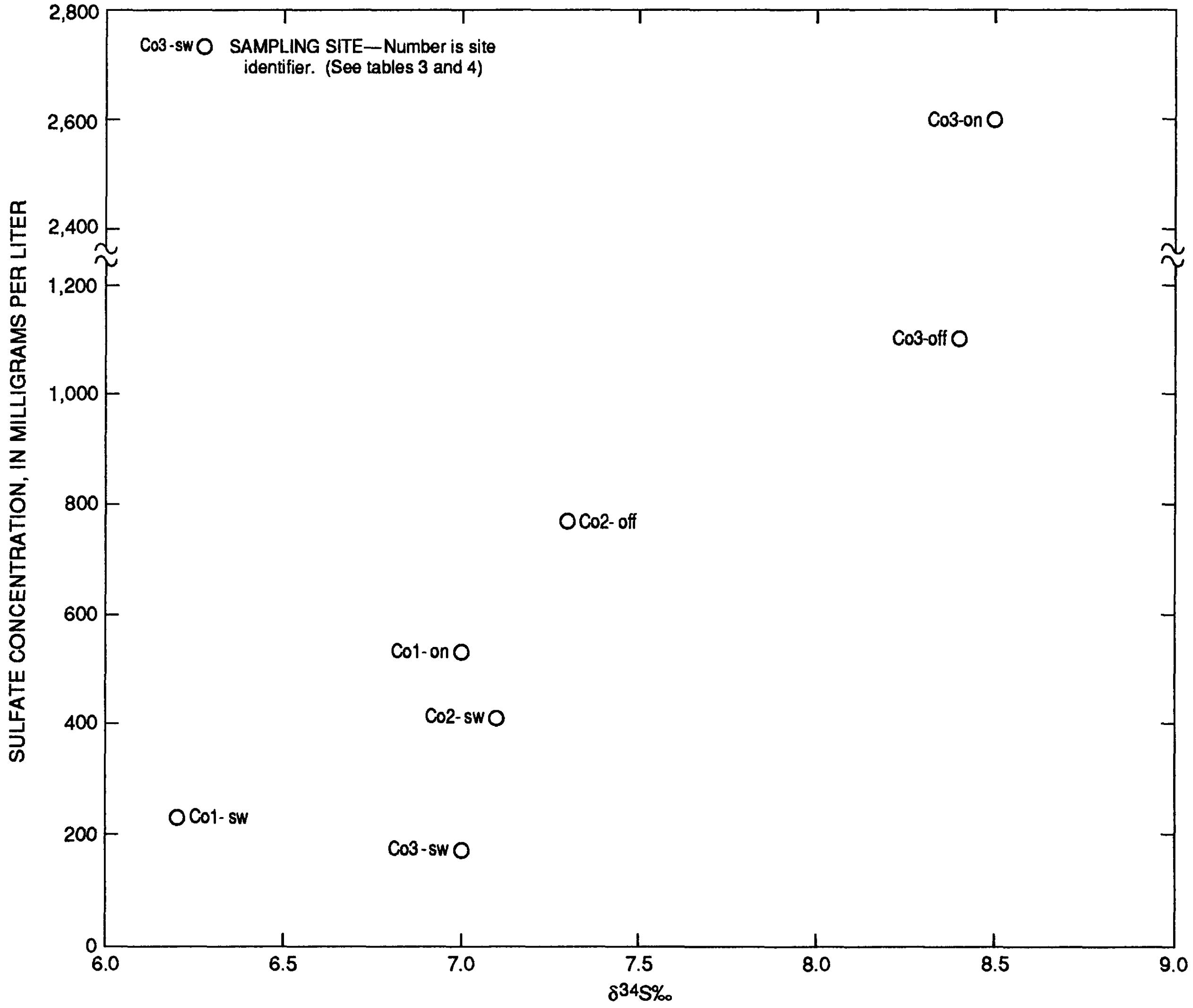


Figure 13. Relation between sulfate concentrations and $\delta^{34}S$ compositions at sites Co1, Co2, and Co3, western Salt Valley, Arizona, 1990–91. (See figure 2 for location of sampling sites.)

values for Co3-sw and ground water at the site, Co3-on and Co3-off, were not similar (fig. 13). This difference might indicate that irrigation return flow is not affecting ground water at site Co3.

High concentrations of ^3H in the southern region, where irrigation activities are prevalent and the depth to ground water is shallow, also are indicators of irrigation water affecting the shallow ground water (fig. 7). The recent exposure of the water to the atmosphere during irrigation increases the amount of ^3H in the water and creates a signature that could be used to identify irrigation water that has percolated to older ground water. Site Co2 is in an area where ^3H concentrations in ground water indicate recent exposure to the atmosphere.

For agricultural activities, $\delta^{15}N$ compositions were difficult to use as identification tools because the effects of the different $\delta^{15}N$ compositions from fertilizers in the irrigation return flow were minimal. At site Co2, where fertilizer is not used, $\delta^{34}S$ data display a connection between the irrigation return flow and the ground water. This relation could be supported by $\delta^{15}N$ data, if fractionation processes affect the nitrogen isotopic composition as the irrigation return flow percolates to the ground water. Tritium concentrations higher than 4.5 pCi/L also suggest that ground water at site Co2 is affected by irrigation return flow.

Natural Sources

Many chemical constituents and isotopic compositions in ground water from areas with little or no anthropogenic activity were similar to ground water collected in areas where anthropogenic nitrate sources were present. Ground water from sites M5 and M3 contained concentrations of chemical constituents that were within the limits of other ground-water values except for the concentrations of some metals in ground water from M3-gw that probably was from the steel casing in the well. The well had not been pumped recently, and the sample had visible evidence of iron precipitate in the water.

Most of the isotopic compositions for ground water from M5-gw and M3-gw were similar to other samples from the study area. Values of $\delta^{18}O$, δD, $\delta^{15}N$, δ^7Li, and $\delta^{11}B$ in ground water from sites M5 and M3 were within the limits for ground-water values in the study area. The suspected source of nitrate in ground water at these sites is natural soil nitrate derived from natural vegetation and nitrate formed during biological fixation on desert legume plants. Kreitler (1975) found that natural soil nitrate in areas not affected by anthropogenic nitrate sources ranged from about +2.0 to +8.0‰. The $\delta^{15}N$ values of ground water from sites M3 and M5 were within this range and might characterize the source of nitrate as natural in this ground water. These values also are within the $\delta^{15}N$ range for other ground water in the study area that is suspected to be affected by anthropogenic sources of nitrate. These $\delta^{15}N$ compositions indicate that natural soil nitrate could be a major source of nitrate in the study area.

CONSIDERATIONS FOR FURTHER STUDY

Additional data and research could improve the geochemical identification techniques for nitrate sources and the characterization of the ground-water chemistry in the study area. Techniques to identify nitrate sources could be improved by investigating smaller study areas and processes that affect some isotopic systems. A specific type of nitrate source could be investigated more thoroughly, and results from this study could be used to evaluate the effects on ground water. For example, constituents that uniquely identify STP outflow could be tested at many STP's to determine if the results obtained for this study are applicable to a variety of situations (for example, different climates, different sized STP's, and different stream chemistry). The identification of STP outflow by δ^7Li values could be validated if the fractionation processes and other chemical processes that affect this constituent could be determined. An evaluation of this constituent as an environmental indicator is necessary because a small amount of data is available. The cause of the $\delta^{11}B$ values in the STP outflow would also be useful in an evaluation of this component as an identification tool. The application of isotopic systems as indicators of different nitrate sources would be more successful if the hydrologic system was better understood.

Fractionation processes associated with some isotopic systems need to be predictable in order to better identify nitrate sources.

Geochemical reactions between the aquifer material and the ground water, including cation exchange and dissolution of minerals could be better identified if additional information about the composition of the aquifer material was available. For example, information about the chemical composition of the aquifer material would help to better characterize the distribution of calcium and magnesium in the ground water if the capacity for ion exchange was known.

Isotopic analyses of precipitation in the study area would provide a local meteoric water line that would result in better identification of ground-water sources. Without this information, only speculation about the ground-water distribution of $\delta^{18}O$ and δD is possible. Effects of the Luke salt body on the chemistry of ground water need to be better characterized to increase the understanding of the regional-flow system, and to better identify sources of nitrate.

Identification of nitrate derived from plant material in the soil or nitrate accumulated by biological fixation could be improved by evaluating areas in arid environments that contain high concentrations of ground-water nitrate and little or no anthropogenic activity. In this scenario, the chemical environment could be examined, and an identification technique might be developed.

SUMMARY AND CONCLUSIONS

The chemical and isotopic compositions of ground water were characterized and geochemical techniques were developed to identify sources of nitrate in ground water near Phoenix, Arizona. Nitrate concentrations in ground water from large parts of the study area exceeded the maximum contaminant level of 10 mg/L of nitrate as nitrogen set by the U.S. Environmental Protection Agency. Many sources of nitrate are present in the study area, but techniques to identify the source of nitrate in ground water at a particular location were needed. Four sources of nitrate were studied: dairies and feedlots, sewage-treatment plants, areas of agricultural activities, and areas of naturally occurring nitrate. In an attempt to identify the nitrate sources, chemical and isotopic analyses for end members representing three of the four nitrate sources were compared with chemical and isotopic compositions of the ground water. If compositions that were unique to one source also were found in the ground water, the source of nitrate in the ground water could be identified. A connection between nitrogen from the source and nitrogen in ground water must be established in conjunction with identification of other constituents from the source because other constituents may act different chemically than nitrogen between the source and the ground water. Without this connection, other constituents may indicate effects from a specific source, whereas the nitrogen could be from another source.

Successful geochemical-identification techniques depended on the type of nitrate source. Nitrate from dairies and feedlots was best identified by $\delta^{15}N$ compositions. The $\delta^{15}N$ values greater than +9‰ have been previously identified as indicators of nitrogen derived from animal waste in other studies, and similar values appeared to identify animal waste as a nitrate source in this study.

Nitrate from STP's was best identified by $\delta^{15}N$, $\delta^{34}S$, $\delta^{7}Li$, and $\delta^{11}B$ compositions. The distribution of nitrogen compounds in outflow from the STP's was different from ground water in the area because of chemical and biological processes that alter the distribution of nitrogen compounds. Light $\delta^{15}N$, $\delta^{34}S$, $\delta^{7}Li$, and $\delta^{11}B$ values were indicative of STP outflow. Fractionation processes that alter the isotopic compositions of nitrogen and sulfur during infiltration increased the difficulty of applying these data, although identification was successful. Few fractionation processes affect $\delta^{7}Li$ and $\delta^{11}B$ compositions, which makes these isotopes easier to use to identify effects from STP outflow. Light $\delta^{7}Li$ values that range from -17.6 to -5.3‰ were indicative of outflows from STP's. Light $\delta^{7}Li$ values also detected in shallow ground water near the STP's indicate that outflow is affecting shallow ground water near the plants. Light $\delta^{11}B$ values also were analyzed in sewage-treatment outflow. Heavier values were detected in shallow ground water near the STP's and could be a result of fractionation of boron isotopes during flow of water through fine-grained material.

Naturally occurring nitrate was difficult to identify because the chemical and isotopic compositions of ground water from areas with little or no anthropogenic activity were similar to chemical and isotopic compositions of ground water from areas with anthropogenic activity. Natural soil nitrate from decomposition of vegetation or nitrate formed during biological fixation on desert legume plants has been identified in other studies by a range of $\delta^{15}N$ values of +2.0 to +8.0‰. Many of the ground-water samples, which included samples from areas with little or no anthropogenic activity, had $\delta^{15}N$ values within this range. These data may indicate that much of the ground water in the study area is affected by nitrate from natural sources.

Identification of nitrate from agricultural activities was determined by the compositions of fertilizers and irrigation return flow. Nitrogen fertilizers used in the study area are composed of 32 percent urea; therefore, identification of this source depended primarily on the nitrogen composition. The fertilizer composition was greatly diluted in the irrigation return flow and made the identification of the effects of fertilizer difficult. The $\delta^{15}N$ compositions of the fertilizers ranged from -7.2 to -1.4‰ and were lighter than any $\delta^{15}N$ values from ground water collected for this study. The $\delta^{15}N$ values for irrigation return flow and ground water in agricultural areas were similar because, in most cases, the source of irrigation water was ground water and the fertilizer was greatly diluted in the irrigation return flow or removed by soil or vegetation. These similarities indicate that the effects from fertilizers are not discernible in the irrigation return flow and ground water. At one site, $\delta^{34}S$ values indicated that irrigation activities are affecting ground water in the area. The ^3H values indicated that recent ground-water recharge is affecting ground water in the western part of the southern region near Buckeye. These data could be supported by $\delta^{15}N$ data if specific fractionation processes occur.

During the analysis of geochemical-identification several characteristics of ground water in the study area were revealed. Geographic delineations of the ground water were observed in temperature; pH; concentrations of major ion, TDS, and lithium; ^3H, δD, and $\delta^{18}O$ data; and isotopic compositions and concentrations of boron. Cation exchange and evaporation were identified as possible controls on the ground-water chemistry specifically in the western part of the southern region near Buckeye where high concentrations of sulfate, chloride, and sodium occurred. Effects from the Luke salt body were identified in the total dissolved solids, major-ion, strontium, lithium, boron, and other metals concentrations for ground water near the salt body. The $\delta^{11}B$ values near 1.0‰ were analyzed in ground water collected near the salt body and were unique within the $\delta^{11}B$ data. These isotopic compositions could be used to identify ground water affected by the salt deposit. The δD, $\delta^{18}O$, $\delta^{11}B$, major-ion, and metals data uniquely identify ground water from a geothermal anomaly.

Nitrogen isotope values must be used carefully because of fractionation processes that might occur during infiltration and along ground-water flow paths. If the hydrologic system were better understood, $\delta^{15}N$ values could be used more effectively.

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TABLES 2-4

Table 2. Site information and well-construction data for sample locations, western Salt River Valley, Arizona

[Project identifier—First group of letters in identifier: S, sewage-treatment plants; C, dairies and feedlots; Co, cotton fields; Ci, citrus farms; M, miscellaneous: First number in identifier is sequential identifier for each type of nitrate source: Second number in identifier is the year that a sample was collected (only occurs if the location was sampled twice): Second group of letters in identifier: gw, ground water; on, onsite; off, offsite; dwn, downgradient; up, upgradient; sw, surface water; F, fertilizer; L, manure leachate. Sample type codes—GW, ground water; SW, surface water; F, fertilizer; M, manure. Hydrologic unit codes—Mi, Middle Unit; UL, Upper Part of Lower Unit; U, Upper Unit; LL, Lower Part of Lower Unit. Dashes indicate no data]

Project identifier	Latitude	Longitude	Local well number	Sample type	Collection point	Land-surface altitude (meters above sea level)	Depth of well (meters below land surface)	Open interval (meters below land surface)	Hydrologic unit	Date depth to ground water measured	Depth to ground water (meters below land surface)
Sewage-treatment plants											
S1-on	33°32'13"	112°19'20"	(B-02-01) 01ccc2	GW	Well	326	182	110-179	Mi	01-01-60	62
S1-off	33°31'45"	112°19'18"	(B-02-01) 12bcc	GW	Well	322	293	91-290 291-193	Mi, UL	08-30-73 06-15-87	70 [1]138
S1-dwn	33°34'48"	112°22'09"	(B-03-01) 28baa2	GW	Well	349	335	---------	--------	06-01-82	[2]183
S1-sw	33°32'12"	112°19'15"	---------	SW	Outflow	----	-----	---------	---------	----------	--------
S2-90on S2-91on	33°23'30"	112°14'49"	(A-01-01) 34bbb	GW	Well	295	43	27-43	U	07-24-87	[2]6
S2-off	33°23'23"	112°15'13"	(A-01-01) 33aad	GW	Well	294	152	46-76	U	----------	--------
S2-up	33°22'25"	112°14'11"	(D-01-01) 02bbc	GW	Well	297	104	49-99	U, Mi	12-11-58	11.0
S2-dwn	33°23'45"	112°16'00"	(A-01-01) 28cac	GW	Well	294	46	15-43	U	07-10-92	[1]14.2
S2-90sw S2-91sw	33°23'20"	112°15'13"	---------	SW	Outflow	----	-----	--------	---------	----------	--------
S3-gw	33°39'08"	112°17'02"	(A-04-01) 32bab	GW	Well	373	369	55-240 245-246 247-357	U, UL	07-23-91	[2]134
Dairies and feedlots											
C1-on1	33°23'25"	112°26'45"	(B-01-02) 34aaa	GW	Well	272	54	50-54	U	----------	--------
C1-on2	33°23'25"	112°26'47"	(B-01-02) 34aab	GW	Well	272	59	45-59	U	----------	--------
C1-up	33°23'31"	112°26'28"	(B-01-02) 26ccc	GW	Well	272	44	12-29 36-39	U	06-26-91	[1]12.6
C1-dwn	33°23'29"	112°27'06"	(B-01-02) 34abb	GW	Well	271	186	18-46 55-180	U, Mi, UL	06-26-91	[1]10.4
C1-90L C1-91L	33°23'25"	112°26'43"	---------	M	Holding pen	----	----	---------	--------	----------	-------
C2-90on C2-91on	33°26'30"	112°28'28"	(B-01-02) 09cbd	GW	Well	305	91	0-91	U, Mi	04-25-91 06-25-91	27 [1]52.9

See footnotes at end of table

Table 2. Site information and well-construction data for sample locations, western Salt River Valley, Arizona—Continued

Project identifier	Latitude	Longitude	Local well number	Sample type	Collection point	Land-surface altitude (meters above sea level)	Depth of well (meters below land surface)	Open interval (meters below land surface)	Hydrologic unit	Date depth to ground water measured	Depth to ground water (meters below land surface)
					Dairies and feedlots—Continued						
C2-90off C2-91off	33°26'35"	112°28'07"	(B-01-02) 09acc	GW	Well	305	92	49-87	U, Mi	06-25-91	^{1}64
C2-90L C2-91L	33°26'32"	112°28'25"	---------	M	Holding pen	----	----	---------	--------	-----------	-------
C3-on	33°24'14"	112°17'21"	(A-01-01) 30aad	GW	Well	297	195	183-195	Mi, UL	-----------	-------
C3-off	33°24'18"	112°17'29"	(A-01-01) 30aab	GW	Well	297	118	61-118	U	-----------	-------
C3-L	33°24'08"	112°17'27"	---------	M	Holding pen	----	----	---------	--------	-----------	-------
C4-gw	33°33'30"	112°16'48"	(A-03-01) 32dbb	GW	Well	333	213	115-206	Mi, UL	01-10-91	^{1}95
C5-gw	33°28'32"	112°19'38"	(B-02-01) 35abd	GW	Well	302	183	---------	--------	08-30-62	^{1}80
C6-gw	33°27'03"	112°12'07"	(A-01-02) 07bbb	GW	Well	318	241	24-236	U, Mi, UL	07-22-91	^{1}34.5
					Agricultural areas						
Co1-on	33°28'19"	112°22'00"	(B-02-01) 33bdd2	GW	Well	304	282	59-278	U, Mi, UL	08-02-85	^{1}53
Co1-sw	33°28'06"	112°21'44"	---------	SW	Irrigation return flow	----	----	---------	--------	-----------	-------
Co1-F	33°28'38"	112°22'27"	---------	F	Holding tank	----	----	---------	--------	-----------	-------
Co2-off	33°21'22"	112°35'31"	(C-01-03) 07add2	GW	Well	255	255	---------	--------	-----------	-------
Co2-sw	33°21'35"	112°35'27"	---------	SW	Irrigation return flow	----	----	---------	--------	-----------	-------
Co3-on	33°24'45"	112°34'55"	(B-01-03) 20caa	GW	Well	302	----	---------	--------	06-28-91	^{1}61.5
Co3-off	33°23'31"	112°34'55"	(B-01-03) 32baa	GW	Well	282	63	23-58	U	06-28-91	^{1}28.0
Co3-sw	33°23'44"	112°34'38"	---------	SW	Irrigation return flow	----	----	---------	--------	-----------	-------
Co3-F	33°23'40"	112°34'40"	---------	F	Holding tank	----	----	---------	--------	-----------	-------
Co4-gw	33°24'22"	112°35'25"	(B-01-03) 30aaa	GW	Well	296	125	30-125	U, Mi, UL	-----------	-------
Co5-gw	33°36'07"	112°23'01"	(B-03-01) 17dbb2	GW	Well	363	427	249-427	UL	07-19-85	^{1}185

See footnotes at end of table

Table 2. Site information and well-construction data for sample locations, western Salt River Valley, Arizona—Continued

Project identifier	Latitude	Longitude	Local well number	Sample type	Collection point	Land-surface altitude (meters above sea level)	Depth of well (meters below land surface)	Open interval (meters below land surface)	Hydrologic unit	Date depth to ground water measured	Depth to ground water (meters below land surface)
					Agricultural areas—Continued						
Co6-gw	33°25'57"	112°11'39"	(A-01-02) 18acb	GW	Well	313	91	17-88	U	08-30-89 08-02-91	[1]29.6 [1]29.8
Ci1-on	33°30'29"	112°25'04"	(B-02-02) 24baa	GW	Well	327	281	71-277	Mi, UL	08-01-85 07-02-87	[1]144 [1]134
Ci1-F	33°34'01"	112°25'36"	---------	F	Distribution facility	----	----	---------	--------	----------	-------
Ci2-gw	33°35'30"	112°25'32"	(B-03-02) 24bbc	GW	Well	373	201	91-196	Mi, UL	----------	-------
Ci3-gw	33°39'21"	112°11'39"	(A-04-02) 30cdd	GW	Well	383	305	54-194 194-295 295-305	UL, LL	----------	-------
					Miscellaneous sites						
M1-gw1	33°32'33"	112°20'18"	(B-02-01) 02ccb2	GW	Well—Luke salt body	331	195	107-244	Mi, UL	----------	-------
M1-gw2	33°32'36"	112°20'18"	(B-02-01) 02cbb	GW	Well—Luke salt body	331	196	107-196	Mi, UL	----------	-------
M2-gw	33°27'04"	112°25'31"	(B-01-02) 01ccc	GW	Well—Geothermal anomaly	302	579	372-457 494-579	LL	09-02-86	[1]97
M3-gw	33°01'47"	112°23'02"	(C-04-01) 32cdd	GW	Well—Natural source-outside the study area	436	189	158-189	--------	09-19-87 09-19-87	170 [1]175
M4-sw	33°26'25"	112°28'42"	---------	SW	Canal	----	----	---------	--------	----------	-------
M5-gw	33°47'06"	112°29'52"	(B-05-02) 08ccb	GW	Well—Natural source—inside the study area	519	305	171-305	--------	06-27-91	[1]168
M6-gw	33°33'55"	112°17'35"	(A-03-01) 31aab1	GW	Well—Many nitrate sources	340	274	61-177 186-174	Mi, UL	04-23-91	[1,2]77

[1] Depth to ground water measured during pumping.

[2] Data from well owner.

Table 3. Physical and chemical data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona

[°C, degrees Celsius; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; <, less than; µg/L, micrograms per liter; dashes indicate no data]

Project identifier[1]	Date	Time	Specific conductance (µS/cm)	pH (standard units)	Temperature, water (°C)	Oxygen, dissolved (mg/L)	Alkalinity, dissolved (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)
Sewage-treatment plants								
S1-on	07-24-90	1316	684	7.6	29.0	8.1	129	23
S1-off	07-31-90	1600	326	7.1	26.0	6.2	202	61
S1-dwn	07-11-91	1500	630	8.0	31.0	5.4	121	23
S1-sw	07-25-90	1930	938	7.3	32.0	3.4	202	25
S2-90on	07-26-90	1030	1,820	7.1	22.5	0.6	254	72
S2-91on	07-30-91	1500	2,150	7.0	23.5	0.3	241	81
S2-off	08-02-90	0844	3,100	6.8	24.0	1.0	302	160
S2-up	07-11-91	1140	3,850	7.0	23.0	4.8	283	150
S2-dwn	07-10-91	1105	2,480	7.0	22.5	1.6	338	76
S2-90sw	07-26-90	1815	1,730	7.0	32.0	4.7	192	57
S2-91sw	07-31-91	1655	1,750	7.2	28.0	4.8	191	57
S3-gw	07-23-91	1255	420	7.7	26.0	----	153	38
Dairies and feedlots								
C1-on1	08-03-90	0900	2,790	6.5	22.5	0.6	298	230
C1-on2	08-02-90	1243	1,430	6.7	23.5	1.2	314	230
C1-up	06-26-91	0940	3,520	6.9	23.0	2.4	261	200
C1-dwn	06-26-91	1250	4,270	6.8	24.5	2.3	296	200
C1-90L	09-01-90	1030	978	7.8	-----	----	270	24.2
C1-91L	01-17-92	1600	958	8.1	-----	----	312	39
C2-90on	08-03-90	1111	3,250	7.2	26.0	6.2	286	220
C2-91on	06-25-91	0945	4,420	7.3	25.5	5.6	271	180
C2-90off	08-07-90	1319	3,840	6.7	28.0	6.2	127	350
C2-91off	06-25-91	1215	4,040	6.9	28.0	6.1	133	340
C2-90L	09-01-90	1130	893	7.3	-----	----	434	53.2
C2-91L	01-22-92	1700	3,890	----	-----	----	----	130
C3-on	08-09-90	1530	2,720	7.0	25.5	2.0	163	120
C3-off	08-29-90	1230	4,700	7.1	24.0	----	294	190
C3-L	09-01-90	0930	725	7.5	----	----	219	31.2

See footnotes at end of table

Table 3. Physical and chemical data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona—Continued

Project identifier[1]	Date	Time	Specific conductance (µS/cm)	pH (standard units)	Temperature, water (°C)	Oxygen, dissolved (mg/L)	Alkalinity, dissolved (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)
				Dairies and feedlots—Continued				
C4-gw	07-24-91	1707	510	7.6	28.0	9.3	120	23
C5-gw	07-22-91	1415	1,380	7.3	23.0	----	175	77
C6-gw	07-22-91	0940	2,350	7.2	23.5	6.5	360	140
				Agricultural areas				
Co1-on	08-01-90	1130	3,080	6.0	29.5	5.6	238	260
Co1-sw	07-31-90	1115	2,150	7.7	35.5	7.3	164	120
Co1-F	09-08-90	1000	129,000	6.8	-----	----	2,890	<100
Co2-off	08-20-90	1815	5,180	7.1	24.0	7.6	285	210
Co2-sw	08-29-90	1000	3,910	7.9	31.5	6.1	264	180
Co3-on	06-28-91	1250	8,310	6.9	28.5	6.1	156	510
Co3-off	06-28-91	1000	5,760	7.1	25.0	7.0	210	260
Co3-sw	07-02-91	1450	1,800	8.2	35.0	----	244	90
Co3-F	07-02-91	1000	114,000	6.5	-----	----	1,640	115
Co4-gw	07-12-91	1405	6,000	7.4	24.0	----	22	130
Co5-gw	07-24-91	1115	650	8.1	32.5	5.6	113	26
Co6-gw	08-02-91	1205	1,810	7.2	21.5	3.3	345	54
Ci1-on	08-09-90	1145	5,650	7.9	33.0	4.1	93	16
Ci1-F	07-31-91	1200	121,000	7.3	-----	----	928	56.7
Ci2-gw	07-25-91	1020	450	8.3	31.0	7.4	92	12
Ci3-gw	08-01-91	1545	680	7.7	29.5	----	117	52
				Miscellaneous sites				
M1-gw1	08-21-90	0920	73,800	7.3	32.0	4.3	34	2,300
M1-gw2	08-21-90	1115	55,200	7.4	32.5	6.8	39	3,300
M2-gw	08-09-90	0930	288	7.8	45.5	0.6	69	99
M3-gw	09-05-90	1145	1,480	6.6	29.5	0.2	100	78
M4-sw	06-25-91	1430	1,870	7.8	25.0	9.7	260	89
M5-gw	06-27-91	1444	617	7.5	31.5	4.9	142	38
M6-gw	08-01-91	1025	790	7.7	25.5	7.7	112	59

See footnotes at end of table

Table 3. *Physical and chemical data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona—Continued*

Project identifier[1]	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate, dissolved (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)
				Sewage-treatment plants				
S1-on	11	86	2.3	157	32	84	1.5	0.17
S1-off	28	52	2.8	246	56	80	0.30	0.32
S1-dwn	12	93	3.4	148	54	77	1.2	0.35
S1-sw	10	120	10	246	110	130	2.3	0.24
S2-90on	31	270	5.2	310	160	360	0.30	0.30
S2-91on	36	290	5.5	300	180	420	0.40	0.35
S2-off	61	440	7.7	369	310	690	0.10	0.66
S2-up	63	610	5.6	345	400	780	0.50	0.55
S2-dwn	35	420	5.8	412	240	460	0.70	0.42
S2-90sw	24	240	14	234	150	340	2.0	0.12
S2-91sw	24	240	17	229	140	340	1.5	0.11
S3-gw	17	26	2.2	187	23	25	0.20	0.16
				Dairies and feedlots				
C1-on1	76	350	6.2	364	280	640	1.2	0.82
C1-on2	78	420	7.1	383	320	780	0.50	1.3
C1-up	79	420	6.2	318	350	830	0.60	0.89
C1-dwn	93	580	5.6	361	470	1,000	1.0	1.1
C1-90L	32.2	34.7	137	329	35.9	134	<0.5	0.28
C1-91L	37	28	99	381	130	460	4.2	3.6
C2-90on	120	580	6.2	349	890	1,200	1.3	1.8
C2-91on	110	610	6.2	331	710	980	1.4	1.1
C2-90off	160	290	9.3	155	640	930	0.30	1.4
C2-91off	160	310	9.5	162	820	950	0.40	1.3
C2-90L	47.5	9.3	39.8	529	5.5	43.8	2.0	0.24
C2-91L	110	110	200	----	130	460	4.2	3.6
C3-on	59	400	5.7	199	160	810	0.10	0.50
C3-off	72	540	6.0	359	350	930	<0.10	0.78
C3-L	28.8	32.6	86.8	267	17.5	87.6	0.59	0.50

See footnotes at end of table

Table 3. Physical and chemical data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona—Continued

Project Identifier[1]	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate, dissolved (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Bromide, dissolved (mg/L as Br)
Dairies and feedlots—Continued								
C4-gw	15	46	3.3	150	22	50	0.30	0.15
C5-gw	39	350	4.3	210	160	410	0.50	0.41
C6-gw	50	55	3.2	440	89	240	0.20	0.49
Agricultural areas								
Co1-on	110	330	6.8	290	530	620	<0.10	1.8
Co1-sw	56	240	12	200	230	440	0.70	1.6
Co1-F	12.7	127	18.6	3,526	707	2,020	315	69
Co2-off	110	920	5.2	348	770	1,100	4.6	1.6
Co2-sw	78	530	13	322	410	880	0.70	0.83
Co3-on	57	1,400	17	190	2,600	1,400	1.6	2.4
Co3-off	130	820	7.7	256	1,100	1,300	2.0	2.3
Co3-sw	44	240	6.2	298	170	360	0.30	0.39
Co3-F	3.9	47.2	22.6	2,001	122	<50	226	<0.5
Co4-gw	70	1,000	8.2	27	1,200	850	3.3	1.3
Co5-gw	11	89	2.8	136	68	76	0.90	0.33
Co6-gw	24	290	5.0	414	120	270	0.50	0.28
Ci1-on	5.8	100	1.9	114	54	79	1.4	0.39
Ci1-F	0.36	6.3	<5.0	1,132	66	<50	206	<0.5
Ci2-gw	6.0	66	2.6	110	22	45	0.80	0.32
Ci3-gw	23	47	5.0	140	49	88	0.30	0.36
Miscellaneous sites								
M1-gw1	880	11,000	340	41	140	24,000	2.2	1.2
M1-gw2	1,200	14,000	42	48	20	2,800	8.8	1.8
M2-gw	11	1,100	4.4	84	820	1,300	15	0.27
M3-gw	7.7	200	7.6	121	100	330	2.4	1.1
M4-sw	43	230	5.2	316	150	340	0.30	0.40
M5-gw	15	68	2.2	173	95	44	1.0	0.14
M6-gw	36	39	4.0	136	40	110	0.20	0.56

See footnotes at end of table

Table 3. Physical and chemical data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona—Continued

Project identifier[1]	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)
			Sewage-treatment plants				
S1-on	<0.010	<0.010	[2]2.50	2.50	2.50	0.010	0.020
S1-off	<0.010	<0.010	[2]5.10	4.90	5.10	<0.010	<0.010
S1-dwn	<0.010	<0.010	[2]7.20	7.20	7.20	<0.010	0.020
S1-sw	0.110	0.110	0.29	0.40	0.40	10.0	19.0
S2-90on	<0.010	<0.010	[2]2.70	2.70	2.70	0.090	0.050
S2-91on	0.020	<0.010	[2]1.90	3.80	1.90	0.020	0.020
S2-off	--------	0.940	6.16	-------	7.10	--------	--------
S2-up	<0.010	<0.010	[2]12.0	12.0	12.0	0.010	0.020
S2-dwn	<0.010	<0.010	[2]8.20	8.20	8.20	<0.010	0.010
S2-90sw	3.20	3.10	1.50	4.60	4.60	16.0	17.0
S2-91sw	2.90	3.00	0.90	3.80	3.90	11.0	11.0
S3-gw	<0.010	<0.010	[2]2.60	2.60	2.60	<0.010	0.010
			Dairies and feedlots				
C1-on1	<0.010	<0.010	[2]12.0	13.0	12.0	0.020	0.010
C1-on2	<0.010	<0.010	[2]13.0	13.0	13.0	<0.010	<0.010
C1-up	<0.010	<0.010	[2]11.0	11.0	11.0	0.030	0.020
C1-dwn	<0.010	<0.010	[2]13.0	13.0	13.0	0.030	0.010
C1-90L	--------	<0.010	<0.5	0.15	0.058	11.8	10.3
C1-91L	--------	0.08	[2]0.06	-------	0.14	--------	16.0
C2-90on	<0.010	<0.010	[2]14.0	14.0	14.0	<0.010	<0.010
C2-91on	<0.010	0.010	13.0	14.0	13.0	0.020	0.020
C2-90off	<0.010	<0.010	[2]20.0	21.0	20.0	0.020	0.020
C2-91off	<0.010	<0.010	[2]19.0	20.0	19.0	0.030	0.020
C2-90L	--------	<0.010	<0.50	<0.50	<0.050	40.4	38.7
C2-91L	--------	0.06	[2]70.9	-------	0.068	--------	66.0
C3-on	<0.010	<0.010	[2]3.80	3.60	3.80	0.020	0.010
C3-off	<0.010	<0.010	[2]8.70	8.90	8.70	0.010	0.010
C3-L	--------	0.013	<0.50	<0.05	<0.05	5.8	5.7

See footnotes at end of table

Table 3. Physical and chemical data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona—Continued

Project identifier[1]	Nitrogen, nitrite, total (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, NO_2+ NO_3, total (mg/L as N)	Nitrogen, NO_2+ NO_3, dissolved (mg/L as N)	Nitrogen, ammonia, total (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)
Dairies and feedlots—Continued							
C4-gw	<0.010	<0.010	[2]3.00	0.23	3.00	<0.010	0.010
C5-gw	<0.010	<0.010	[2]9.00	1.40	9.00	<0.010	0.010
C6-gw	<0.010	<0.010	[2]14.0	9.10	14.0	<0.010	0.010
Agricultural areas							
Col-on	<0.010	0.020	17.0	18.0	17.0	0.05	0.040
Col-sw	1.20	1.20	23.8	21.0	25.0	6.20	5.30
Col-F	--------	0.10	97,200	95,300	111,000	96,000	117,000
Co2-off	<0.010	<0.010	[2]0.3	21.0	0.30	0.040	0.010
Co2-sw	0.260	1.00	7.30	9.20	8.30	6.40	4.60
Co3-on	<0.010	<0.010	[2]0.96	27.0	0.96	0.070	0.070
Co3-off	<0.010	<0.010	[2]25.0	25.0	25.0	0.030	0.020
Co3-sw	0.050	0.040	8.96	8.90	9.00	0.270	0.240
Co3-F	--------	0.44	102,000	136,000	252,000	134,000	182,000
Co4-gw	<0.010	<0.010	[2]18.0	18.0	18.0	<0.010	0.020
Co5-gw	<0.010	<0.010	[2]8.00	8.10	8.00	<0.010	0.010
Co6-gw	0.010	<0.010	[2]10.0	9.70	10.0	0.010	<0.010
Cil-on	<0.010	<0.010	[2]6.10	6.20	6.10	0.020	<0.010
Cil-F	--------	0.43	99,600	150,000	118,000	145,000	122,000
Ci2-gw	<0.010	<0.010	[2]9.40	9.10	9.40	<0.010	0.010
Ci3-gw	0.020	<0.010	[2]11.0	10.0	11.0	0.010	<0.010
Miscellaneous sites							
M1-gw1	0.030	0.030	4.07	4.20	4.10	0.960	0.900
M1-gw2	0.030	0.020	4.88	5.70	4.90	1.00	1.70
M2-gw	0.020	0.020	2.98	2.90	3.00	<0.010	0.030
M3-gw	0.090	0.090	12.9	12.0	13.0	0.180	0.180
M4-sw	0.020	<0.020	[2]8.40	8.60	8.40	0.030	0.010
M5-gw	<0.010	<0.010	[2]1.50	1.50	1.50	0.020	<0.010
M6-gw	0.010	<0.010	[2]13.0	14.0	13.0	<0.010	<0.010

See footnotes at end of table

Table 3. Physical and chemical data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona—Continued

Project identifier[1]	Nitrogen, ammonia + organic, total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Arsenic, dissolved (μg/L as As)	Boron, dissolved (μg/L as B)
			Sewage-treatment plants				
S1-on	0.40	<0.010	0.020	<0.010	0.030	15	100
S1-off	0.40	<0.010	<0.010	<0.010	<0.010	5	170
S1-dwn	0.70	0.010	<0.010	0.010	<0.010	12	210
S1-sw	27	2.40	1.10	2.00	1.00	12	570
S2-90on	0.90	0.040	0.040	0.020	0.030	6	720
S2-91on	0.40	0.030	0.040	0.020	0.020	6	720
S2-off	-------	---------	--------	--------	0.060	8	990
S2-up	0.50	0.020	0.020	0.020	<0.010	5	310
S2-dwn	0.50	0.040	0.060	0.050	0.030	12	1,100
S2-90sw	20	5.30	0.040	4.70	<0.550	4	350
S2-91sw	17	5.40	5.40	5.50	4.70	3	390
S3-gw	0.40	0.020	<0.010	<0.010	<0.010	4	70
			Dairies and feedlots				
C1-on1	0.90	<0.010	<0.010	<0.010	<0.010	6	790
C1-on2	0.70	0.010	<0.010	<0.010	<0.010	7	880
C1-up	0.50	0.030	0.020	0.030	<0.010	4	960
C1-dwn	1.4	0.010	0.010	0.010	<0.010	5	1,300
C1-90L	-------	23.9	10.9	11.2	9.8	5	350
C1-91L	-------	---------	9.1	---------	7.7	-----	230
C2-90on	0.80	<0.010	<0.010	<0.010	<0.010	2	4,900
C2-91on	0.60	<0.010	<0.010	<0.010	<0.010	2	5,500
C2-90off	1.0	<0.010	<0.010	<0.010	<0.010	2	2,700
C2-91off	0.50	<0.010	<0.010	<0.010	<0.010	2	2,600
C2-90L	------	28.4	174	12.8	9.1	2.5	260
C2-91L	-------	---------	71	---------	65	-----	1,500
C3-on	0.80	0.020	0.020	0.010	<0.010	2	500
C3-off	0.50	<0.010	0.010	0.020	0.010	3	930
C3-L	------	19.0	14.2	11.6	10.1	4.6	100

See footnotes at end of table

Table 3. Physical and chemical data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona—Continued

Project identifier[1]	Nitrogen, ammonia + organic, total (mg/L as N)	Phosphorus, total (mg/L as P)	Phosphorus, dissolved (mg/L as P)	Phosphorus, ortho, total (mg/L as P)	Phosphorus, ortho, dissolved (mg/L as P)	Arsenic, dissolved (µg/L as As)	Boron, dissolved (µg/L as B)
			Dairies and feedlots—Continued				
C4-gw	0.60	<0.010	<0.010	<0.010	<0.010	7	140
C5-gw	0.60	<0.010	<0.010	<0.010	<0.010	4	760
C6-gw	0.60	0.040	0.030	<0.010	<0.010	3	100
			Agricultural areas				
Co1-on	0.70	0.040	0.020	0.030	0.040	2	1,100
Co1-sw	23	2.90	2.90	2.90	1.20	8	730
Co1-F	-------	2,010	1,060	1,100	1,140	72	<1,000
Co2-off	0.70	0.020	0.030	0.020	<0.010	11	3,100
Co2-sw	6.6	3.20	2.80	3.10	2.20	8	1,300
Co3-on	1.1	<0.010	0.010	<0.010	<0.010	5	1,300
Co3-off	0.50	<0.010	0.010	<0.010	<0.010	3	5,000
Co3-sw	1.0	0.240	0.010	0.040	0.020	5	660
Co3-F	-------	1,300	1,090	813	677	<100	1,400
Co4-gw	0.50	0.020	0.020	<0.010	<0.010	11	5,800
Co5-gw	0.70	<0.010	<0.010	<0.010	<0.010	11	190
Co6-gw	0.70	0.040	0.030	0.020	<0.010	8	710
Ci1-on	1.1	<0.010	<0.010	<0.010	<0.010	23	220
Ci1-F	-------	6.3	9.0	<50.0	<50.0	<100	630
Ci2-gw	0.90	0.010	<0.010	<0.010	<0.010	7	70
Ci3-gw	0.50	<0.010	<0.010	<0.010	0.090	4	70
			Miscellaneous sites				
M1-gw1	0.30	0.020	0.010	<0.010	<0.010	6	390
M1-gw2	0.50	0.010	0.010	<0.010	<0.010	2	300
M2-gw	0.90	<0.010	<0.010	<0.010	<0.010	120	3,500
M3-gw	0.60	0.100	<0.010	0.010	<0.010	<1	480
M4-sw	0.70	0.040	0.020	0.020	<0.010	4	600
M5-gw	<0.20	<0.010	0.020	0.010	<0.010	4	250
M6-gw	0.70	<0.010	<0.010	<0.010	<0.010	4	50

See footnotes at end of table

Table 3. Physical and chemical data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona—Continued

Project identifier[1]	Lithium, dissolved (µg/L as Li)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Carbon, organic, total (mg/L as C)	Carbon, organic, dissolved (mg/L as C)
			Sewage-treatment plants				
S1-on	40	<0.1	5	370	27	<0.1	0.3
S1-off	210	0.1	<1	880	12	0.3	0.4
S1-dwn	60	<0.1	8	630	22	0.2	0.3
S1-sw	60	<0.1	45	370	18	20	10
S2-90on	160	0.1	1	690	12	1.1	1.1
S2-91on	180	<0.1	2	920	13	0.9	1.0
S2-off	230	0.3	<1	1,500	20	1.2	1.2
S2-up	330	<0.1	1	1,500	21	0.6	1.3
S2-dwn	250	<0.1	3	800	18	1.0	1.1
S2-90sw	110	0.2	17	690	10	13	10
S2-91sw	100	<0.1	15	630	9	15	11
S3-gw	10	<0.1	1	350	11	<0.1	0.3
			Dairies and feedlots				
C1-on1	150	0.2	2	3,700	21	0.8	0.8
C1-on2	170	0.4	1	4,100	26	1.0	1.0
C1-up	150	<0.1	2	2,600	28	0.8	2.9
C1-dwn	200	<0.1	4	3,400	40	0.7	1.2
C1-90L	21	<0.2	2.5	520	5.1	367	143
C1-91L	22	<0.1	<10	880	<6	------	-------
C2-90on	80	1.2	36	5,400	21	1.4	1.3
C2-91on	70	<0.1	36	5,500	47	0.9	1.3
C2-90off	100	<0.1	<1	8,100	33	0.9	0.9
C2-91off	110	<0.1	<30	7,700	<18	-------	-------
C2-90L	7.4	<0.2	2.3	1,000	9.2	748	417
C2-91L	26	<0.1	<30	1,100	<18	-------	------
C3-on	180	0.1	1	3,500	22	0.2	0.3
C3-off	250	0.1	<1	1,900	33	0.8	0.7
C3-L	15	<0.2	6.4	530	3.8	249	237

See footnotes at end of table

Table 3. Physical and chemical data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona—Continued

Project identifier[1]	Lithium, dissolved (µg/L as Li)	Mercury, dissolved (µg/L as Hg)	Molybdenum, dissolved (µg/L as Mo)	Strontium, dissolved (µg/L as Sr)	Vanadium, dissolved (µg/L as V)	Carbon, organic, total (mg/L as C)	Carbon, organic, dissolved (mg/L as C)
Dairies and feedlots—Continued							
C4-gw	20	<0.1	7	460	24	<0.1	0.3
C5-gw	160	<0.1	2	1,400	21	0.4	0.7
C6-gw	30	<0.1	2	1,500	13	0.3	0.4
Agricultural areas							
Co1-on	110	1.7	<1	3,800	27	0.8	0.8
Co1-sw	90	<0.1	2	2,200	34	11	9.8
Co1-F	<100	<1.0	78	1,100	1,900	86,000	86,800
Co2-off	230	<0.1	10	4,100	430	1.4	0.5
Co2-sw	190	<0.1	8	2,500	38	6.7	5.7
Co3-on	750	<0.1	8	12,000	61	------------	-----------
Co3-off	120	<0.1	17	6,000	48	0.8	1.4
Co3-sw	120	<0.1	<10	1,500	11	4.2	1.5
Co3-F	<200	<0.4	100	160	1,500	102,000	108,000
Co4-gw	480	0.1	61	5,300	58	0.8	1.5
Co5-gw	50	<0.1	4	520	25	0.1	0.3
Co6-gw	180	<0.1	2	660	12	0.6	0.8
Ci1-on	30	0.1	6	410	40	0.2	0.3
Ci1-F	<200	<0.4	<100	<100	<100	99,000	98,000
Ci2-gw	20	<0.1	3	390	25	0.1	0.4
Ci3-gw	22	<0.1	<10	730	16	0.2	0.5
Miscellaneous sites							
M1-gw1	6,000	0.7	4	74,000	310	0.6	0.3
M1-gw2	6,000	1.0	<1	130,000	430	0.5	1.2
M2-gw	440	<0.1	280	4,700	140	0.4	0.4
M3-gw	100	<0.1	5	680	8	0.3	0.4
M4-sw	130	<0.1	2	1,500	14	0.8	1.5
M5-gw	30	<0.1	14	540	17	0.2	0.4
M6-gw	23	<0.1	<10	1,100	12	0.3	0.4

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[1] See table 2 for notation descriptions.

[2] Computed value.

Table 4. Isotopic data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona

[pCi/L, picoCuries per liter; dashes indicate no data; <, value is known to be less than the value shown]

Project identifier[1]	Date	$\delta^{18}O$ (per mil)	δD (per mil)	^{3}H (pCi/L)	$\delta^{15}N$ (per mil)	$\delta^{34}S$ (per mil)	$\delta^{7}Li$ (per mil)	$\delta^{11}B$ (per mil)
Sewage-treatment plants								
S1-on	07-24-90	-9.60	-66.5	5.0	5.90	5.70	2.5	-2.4
S1-off	07-31-90	-9.05	-65.4	20	10.30	8.20	10.0	14.5
S1-dwn	07-11-91	-9.15	-65.0	<1.0	8.20	5.00	2.9	------
S1-sw	07-25-90	-8.85	-63.4	10	3.20	2.90	-17.6	1.1
S2-90on	07-26-90	-8.45	-63.5	35	13.30	8.70	-2.0	22.8
S2-91on	07-30-91	-8.15	-63.0	28	14.00	7.70	-1.2	26.3
S2-off	08-02-90	-8.55	-65.0	31	10.50	8.60	8.0	28.0
S2-up	07-11-91	-8.75	-65.0	43	7.00	9.10	-1.6	18.1
S2-up[2]	07-11-91	-8.75	-65.0	——	6.80	9.20	——	——
S2-dwn	07-10-91	-8.65	-64.0	31	7.60	8.10	2.5	24.8
S2-90sw	07-26-90	-8.15	-63.5	27	1.40	2.90	-5.3	5.5
S2-91sw	07-31-91	-8.50	-65.5	31	1.60	3.50	-7.4	7.5
S3-gw	07-23-91	-9.90	-69.0	<1.0	5.10	4.10	3.1	14.4
Dairies and feedlots								
C1-on1	08-03-90	-8.75	-65.4	31	10.40	6.30	-0.4	15.8
C1-on2	08-02-90	-8.70	-65.4	32	11.20	7.00	3.0	14.7
C1-up	06-26-91	-8.30	-62.0	26	11.30	6.60	8.4	21.4
C1-dwn	06-26-91	-8.15	-61.5	23	13.10	6.80	7.9	20.9
C1-90L	09-01-90	------	-------	------	-------	------	8.9	------
C1-91L	01-17-92	------	-------	------	6.50	------	10.5	------
C2-90on	08-03-90	-8.55	-64.0	28	6.50	7.70	14.9	3.8
C2-91on	06-25-91	-8.45	-64.0	18	7.10	7.60	14.4	5.5
C2-90off	08-07-90	-8.35	-62.9	8.0	8.20	7.30	1.0	47.3
C2-91off	06-25-91	-8.35	-62.0	9.0	8.40	7.90	1.7	49.7
C2-90L	09-01-90	------	-------	------	-------	------	19.2	------
C2-91L	01-22-92	------	-------	------	5.80	------	18.2	------
C3-on	08-09-90	-9.50	-69.0	13	10.90	9.20	0.3	15.5
C3-off	08-29-90	-8.95	-66.5	33	8.70	9.20	6.6	20.3
C3-L	09-01-90	------	-------	------	-------	------	13.8	------

See footnotes at end of table

Table 4. Isotopic data for ground water, surface water, fertilizer, and manure leachates, western Salt River Valley, Arizona—Continued

Project identifier[1]	Date	$\delta^{18}O$ (per mil)	δD (per mil)	^{3}H (pCi/L)	$\delta^{15}N$ (per mil)	$\delta^{34}S$ (per mil)	$\delta^{7}Li$ (per mil)	$\delta^{11}B$ (per mil)
Dairies and feedlots—Continued								
C4-gw	07-24-91	-9.25	-64.5	2.0	5.90	4.50	0.8	-6.8
C5-gw	07-22-91	-9.50	-69.0	16	6.20	6.00	4.8	27.4
C6-gw	07-22-91	-8.70	-66.0	47	8.30	8.80	2.0	18.4
Agricultural areas								
Co1-on	08-01-90	-8.60	-63.0	18	7.70	7.00	15.2	27.0
Co1-sw	07-31-90	-7.85	-59.4	14	5.10	6.20	6.5	20.3
Co1-F	09-08-90	------	-------	<1.0	-------	-----	-4.5	------
Co2-off	08-20-90	-8.35	-64.0	13	10.20	7.30	18.1	21.1
Co2-sw	08-29-90	-8.40	-66.5	7.0	7.10	7.10	13.9	17.8
Co3-on	06-28-91	------	-------	12	8.10	8.50	8.7	18.4
Co3-off	06-28-91	-8.80	-64.5	23	7.80	8.40	12.8	21.0
Co3-sw	07-02-91	-8.25	-62.5	30	9.20	7.00	-0.6	22.0
Co3-F	07-02-91	------	-------	------	-1.40	------	3.5	------
Co4-gw	07-12-91	-8.45	-63.0	29	8.10	7.90	18.0	-0.3
Co5-gw	07-24-91	-9.00	-64.5	1.0	8.30	5.80	4.3	9.6
Co6-gw	08-02-91	-8.95	-67.0	33	8.80	6.80	3.6	13.2
Ci1-on	08-09-90	-9.25	-66.5	<1.0	8.90	6.00	8.6	8.4
Ci1-F	07-31-91	------	-------	——	-7.20	-----	3.8	------
Ci2-gw	07-25-91	-8.95	-64.5	1.0	7.90	4.70	8.6	13.6
Ci3-gw	08-01-91	-8.95	-63.0	<1.0	5.80	7.00	4.3	14.3
Miscellaneous sites								
M1-gw1	08-21-90	-9.60	-69.0	1.0	11.10	5.10	2.9	0.7
M1-gw2	08-21-90	-9.20	-64.5	3.0	9.70	4.70	11.9	1.2
M2-gw	08-09-90	-10.45	-76.5	3.0	9.00	6.40	9.2	-14.1
M3-gw	09-05-90	-8.95	-65.5	1.0	8.10	8.30	1.0	21.6
M4-sw	06-25-91	------	-64.0	28	9.40	8.90	1.0	23.5
M5-gw	06-27-91	-9.35	-67.0	<1.0	5.70	6.60	-0.2	29.4
M6-gw	08-01-91	-9.45	-67.5	<1.0	6.40	4.20	-2.8	18.0

[1] See table 2 for notation descriptions.

[2] Duplicate sample for isotopic analyses.