Ground-Water Quality Assessment of the Carson River Basin, Nevada and California—Results of Investigations, 1987–91

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Ground-Water Quality Assessment of the Carson River Basin, Nevada and California—Results of Investigations, 1987-91

By ALAN H. WELCH, STEPHEN J. LAWRENCE,
MICHAEL S. LICO, JAMES M. THOMAS, and
DONALD H. SCHAEFER

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FOREWORD

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

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

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

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

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

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

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

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

Robert M. Hirsch

Robert M Hirsch
Chief Hydrologist

CONTENTS

PLATE

[Plate is in pocket]

FIGURES

TABLES

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

Multiply	By	To obtain
acre	0 4047	square hectometer
acre-foot (acre-ft)	0 001233	cubic hectometer
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
cubic foot per second (ft^3/s)	0 02832	cubic meter per second
foot (ft)	0 3048	meter
gallon (gal)	0 003785	cubic meter
inch (in)	25 4	millimeter
inch per year (in/yr)	25 4	millimeter per year
mile (mi)	1 609	kilometer
square mile (mi^2)	2 590	square kilometer

Temperature: Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the formula °F = [1 8(°C)]+32
Degrees Fahrenheit can be converted to degrees Celsius by using the formula °C = (°F - 32)/1 8

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

Abbreviated Water-Quality Units Used in this Report

mg/kg (milligram per kilogram)	µg/L (microgram per liter)
mg/L (milligram per liter)	pCi/L (picocurie per liter)

Ground-Water Quality Assessment of the Carson River Basin, Nevada and California—Results of Investigations, 1987-91

By Alan H Welch, Stephen J. Lawrence, Michael S Lico, James M Thomas, *and* Donald H Schaefer

Abstract

The Carson River Basin is an area of dramatic contrasts The Carson River drains pristine wilderness of the forested Sierra Nevada, which provides much of the basin's water The chemical composition of the Carson River changes from that of a fresh, untamed white-water river in the Headwaters Area to that of stagnant saline sloughs and alkali lakes in the Carson Desert The ground-water quality, particularly in shallow aquifers, broadly mirrors the chemical changes in the river—a major source of recharge to basin-fill aquifers Contrasts in ground-water quality within the Carson River Basin are evident across the basin, among the different aquifers, and, to a lesser extent, between shallow ground water beneath urban and agricultural land.

Using current drinking-water standards as a measure of overall water quality, ground-water quality in principal aquifers in the upper basin generally is good Principal aquifers in the upper basin are a major source of supply for municipal systems that provide water to the communities of Minden, Gardnerville, and Carson City Precipitation falling on the Sierra Nevada, along with recharge from the Carson River in areas of heavy ground-water pumping, is the major source of recharge to principal aquifers Except for locally high concentrations of nitrate and presence of synthetic organic compounds, water quality in principal aquifers generally results from chemical reactions with aquifer materials Some ground water in and adjacent to the Sierra Nevada contains uranium concentrations greater than the proposed drinking-water standard Radon activities in the Sierra Nevada locally exceed 10,000 pCi/L and are highest in the Carson River Basin

Shallow aquifers in Carson Valley contain higher concentrations of most major constituents and, compared to water in principal aquifers, more commonly contain concentrations of some minor constituents that exceed drinking-water standards Manganese exceeds the secondary maximum contaminant level at more than 25 percent of the sampled sites Minor constituents that exceed drinking-water standards at less than 10 percent of sampled sites are arsenic, fluoride, nitrate, and iron Water from shallow aquifers more commonly contains concentrations of arsenic, fluoride, iron, and manganese in excess of the drinking-water standards than does water from the principal aquifers.

Shallow aquifers beneath the upper basin locally contain herbicides, pesticides, and volatile organic compounds Beneath the urban part of Carson City, prometone, trichloroethylene, and tetrachloroethylene were found at concentrations well above the laboratory minimum reporting level Trichloroethylene was found at concentrations above the drinking-water standard With a few exceptions, ground water beneath agricultural land in Carson Valley contained, at most, low concentrations of synthetic organic compounds

Principal aquifers beneath the sparsely populated middle Carson River Basin are recharged by precipitation falling on the uplands and, locally, by

the Carson River. Concentrations of major constituents in water from principal aquifers in the lower basin generally are higher than in water from the principal aquifers of the upper basin. Concentrations of dissolved solids, iron, manganese, and sulfate more commonly exceed drinking-water standards in principal aquifers of the middle than the upper basin.

Carson Desert, at the distal end of the Carson River Basin, is a closed basin that loses water only by evapotranspiration. Analyses of ground water indicate a wide range in concentrations of major and minor inorganic constituents, with dissolved solids reaching maximum concentrations greater than seawater. Concentrations of sodium, chloride, bicarbonate, and dissolved solids generally are higher in shallow and principal aquifers of Carson Desert than in the upper and middle parts of the basin. More than 10 percent of sampled ground water from shallow and principal aquifers contains concentrations of arsenic, dissolved solids, and manganese greater than the drinking-water standards.

Several minor constituents reach unusually high concentrations in shallow aquifers of Carson Desert. Notable are arsenic, iron, manganese, and uranium. Among these four elements, all except uranium reach concentrations greater than 1 milligram per liter. Processes leading to the high concentrations include evapotranspiration and reactions of sedimentary organic matter with metal oxides. Locally, these reactions appear to be an indirect result of a rise in the water table in response to application of irrigation water for agricultural activities.

INTRODUCTION

Background

This report summarizes results of one of seven pilot NAWQA projects selected to represent diverse hydrologic environments and water-quality conditions. The seven pilot projects include three concerned with ground water and four concerned with surface water. Ground-water project areas are the Carson River Basin in Nevada and California, the Central Oklahoma aquifer in Oklahoma, and the Delmarva Peninsula in Delaware, Maryland, and Virginia. Surface-water project areas are the Yakima River Basin in Washington, the lower Kansas River Basin in Kansas and Nebraska, the upper Illinois River Basin in Illinois, Indiana, and Wisconsin, and the Kentucky River Basin in Kentucky.

The Carson River Basin pilot project included several studies, some of which were discussed in reports on three subareas of the basin, and topics of special interest. Reports describing the geochemistry and water-quality characteristics of ground water are available for Carson and Eagle Valleys (Welch, 1994, Thodal, 1989), Dayton and Churchill Valleys (Thomas and Lawrence, 1994), and Carson Desert (Lico and Seiler, 1994). Data assembled during the project are reported by Whitney (1994). Topics of special interest include the effects of urbanization on water quality (Lawrence, 1996), radionuclides in ground water (Thomas and others, 1990, 1993, Welch and others, 1990), minor inorganic constituents (A.H. Welch and M.S. Lico, U.S. Geological Survey, written commun., 1995), the chemistry of shallow sediments (Tidball and others, 1991), and fluorocarbon compounds as indicators of ground-water age (Sertic, 1992). These reports complement and update geochemical and hydrologic data available through 1987, as summarized by Welch and others (1989). This report summarizes the interpretations given in the reports cited above.

Purpose and Scope

The primary purpose of this report is to describe the chemical quality of ground water in the Carson River Basin, with an emphasis on ground water in aquifers used for municipal and domestic water supply. Included are discussions of the general water-quality characteristics and the physical and chemical processes producing the observed quality. The hydrology of the area is discussed because water quality is affected by processes occurring as water flows through the basin.

Unlike most of the earlier reports listed above, this report includes comparisons of water-quality characteristics throughout the basin. Evaluation of isotope data complements hydrologic analyses based on geologic, hydrologic, and geophysical information. Data collected during 1987-90 (Whitney, 1994) as part of the Carson River Basin NAWQA project are the principal basis for this report. The discussion of ground-water quality includes statistical descriptions of the concentrations of major and minor inorganic constituents, radionuclides, and synthetic organic compounds For more in-depth explanations of the processes responsible for the observed water quality, sections describing processes that affect constituent concentrations, a description of the mineralogic composition of the sediments, and a discussion of the principles of isotope hydrology are included

Location System for Wells

Locations of ground-water sampling sites are identified using a "site identification" expressed in terms of local well numbers Local well numbers are based on the rectangular subdivision of public lands relative to the Mount Diablo base line and meridian A complete designation of a site consists of (1) the township number north of the base line, (2) the range east of the meridian, (3) the section number, (4) letters designating the quarter section, quarter-quarter section, and so-on (the letters "A," "B," "C," and "D" indicate northeast, northwest, southwest, and southeast quarters, respectively), and (5) a number distinguishing wells in the same tract within the section For example, well N17 E28 30 DBA 1 is the first recorded in the NE 1/4 NW 1/4 SE 1/4 of section 30, township 17 north, range 28 east Township and range numbers are shown along the margins of well-location maps

Acknowledgment

Appreciation is extended to residents and water purveyors in the Carson River Basin for permitting access to wells

DESCRIPTION OF THE STUDY AREA

***By* Donald H Schaefer**

Location and Physiography

Located within the western Great Basin and eastern Sierra Nevada, the Carson River Basin encompasses an area of about 3,980 mi^2 The area is mostly in western Nevada, but includes a small part in eastern California (fig 1) The basin is divided into six areas generally corresponding to hydrographic areas delineated by the Nevada Division of Water Resources (Rush, 1968) and California Department of Water Resources for management and allocation of water resources In downstream order through the basin, the areas consist of the mountainous Headwaters Area, Carson Valley, Eagle Valley, Dayton Valley, Churchill Valley, and Carson Desert Dayton Valley includes two subbasins known as Carson Plains and Stagecoach Valley Water quality is discussed for upper, middle, and lower Carson River Basin, corresponding to the Headwaters, Carson Valley and Eagle Valley areas (upper basin), the Dayton Valley and Churchill Valley areas (middle basin), and the Carson Desert area (lower basin) The boundary between the Headwaters and the Carson Valley areas is defined on the basis of surface-water drainage rather than the Nevada-California boundary used by Rush (1968) for Carson Valley An area to the west of the Carson River and east of Eagle Valley is included in the discussion of the upper Carson River Basin This area, which is formally part of the Dayton Valley hydrographic area, receives flow from Eagle Valley and probably contributes little ground-water flow to Dayton Valley

The Headwaters Area is composed of drainage basins of the East and West Forks of the Carson River and contains no areally extensive alluvial aquifers Steep local topography with mountain peaks reaching altitudes greater than 10,000 ft above sea level form this scenically spectacular area

Valley floors of the Carson River Basin generally are level and surrounded by high mountains Altitudes of valley floors range from nearly 5,000 ft in Carson Valley to about 3,800 ft in Carson Desert Altitudes of adjacent mountains range from 6,000 to 8,700 ft along divides in the middle and lower basin and from 9,000 to 11,000 ft in the upper basin

Major hydrographic features of the Carson River Basin (fig 1) include the East and West Forks of the Carson River in the Headwaters Area and southwestern Carson Valley, the main stem of the Carson River, Lahontan Reservoir on the lower Carson River, and the Truckee Canal, which transports water from the Truckee River to Lahontan Reservoir Other features include distributary channels, marshes, shallow intermittent lakes, and salt flats in Carson Desert, as well as the Carson Sink and Carson Lake, the terminal sinks of the Carson River Many small tributary streams enter the Carson River from adjacent mountains Some of these streams are perennial in valleys as far downstream as Eagle Valley, but with few exceptions are ephemeral to the east Most of the flow in the Carson River and its perennial tributaries comes from springtime melting of snow Some reaches of the river are dry

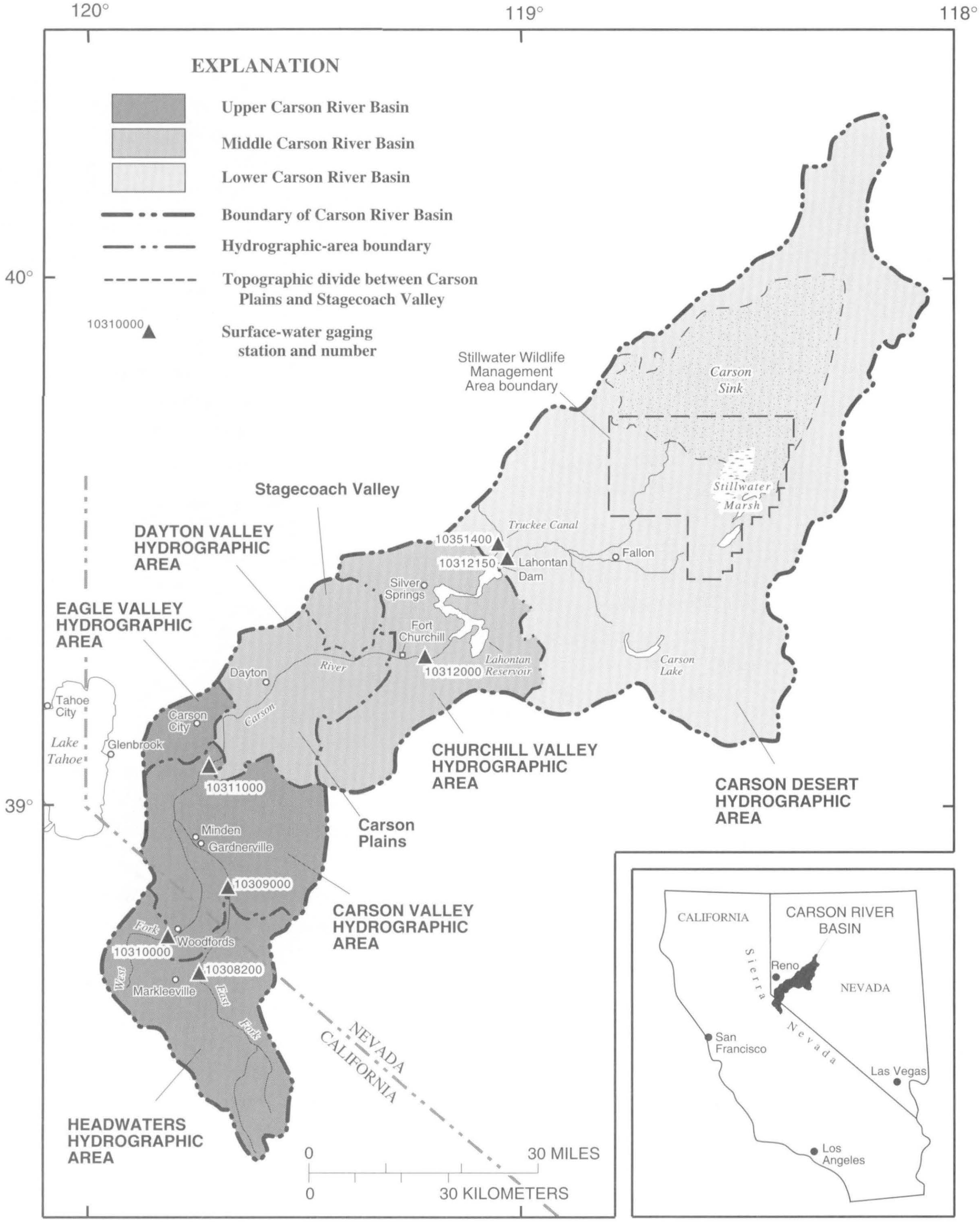


Figure 1. Location and hydrographic features of Carson River Basin.

during extended periods of drought. Carson Valley and Carson Desert have extensive networks of ditches, drains, and sloughs.

Climate

Climate of the Carson River Basin is dominated by the Sierra Nevada, which receives as much as 25-50 in/yr of precipitation at higher altitudes (Twiss and others, 1971, p. 3). The region to the east, however, is distinctly drier because much of the moisture carried by winter storms from the Pacific Ocean falls as snow or rain in the Sierra Nevada. This eastern region, including most of the Carson River Basin, lies in the rain shadow of the Sierra Nevada (Houghton and others, 1975, p. 6). Climatic zones in the Carson River Basin vary from alpine in the Headwaters Area and the Carson Range of the Sierra Nevada in Carson Valley to arid in Carson Desert.

Precipitation in the Carson River Basin falls as winter snow at high altitudes, as winter snow and rain at lower altitudes, and as summer thundershowers throughout the area. Uplands, including much of the Headwaters Area, can receive 25 in/yr or more in an average year. Valley floors and other low areas receive 3 to 11 in/yr (National Climatic Center, 1986, p. 3). The effect of the Sierra Nevada rain shadow is apparent when comparing long-term precipitation totals at Virginia City to those at Glenbrook (along the east shore of Lake Tahoe), Markleeville, and Woodfords (Glancy and Katzer, 1976, p. 18). The altitude at the Virginia City station is nearly the same as at the Glenbrook station and is higher than the Markleeville and Woodfords stations. In spite of this, the Virginia City station, about 30 mi east of the Sierra coast, receives from 11 to 13 in/yr less precipitation than any of the other three stations in the headwaters.

Land and Water Use

Agriculture and mining are historically the major land uses in the Carson River Basin. Decline of mining in the basin in the 1880's was followed by an increase in irrigated acreage in Carson Desert due to the Newlands Project.

In the upstream part of the study area, barren land is primarily exposed bedrock, whereas in the downstream part of the basin, barren land is primarily dry salt flats and other sandy areas. Nearly 10,000 acres of land along the crest of the Sierra Nevada in the Headwaters Area and Carson Valley are classified as tundra. The Headwaters Area remains largely undeveloped and sparsely populated. More than 70 percent of the area is forested land.

Carson Valley has been a major agricultural area in Nevada since the 1850's and contained about 47,000 irrigated acres in 1985 (Douglas K. Maurer, U.S. Geological Survey, oral commun., 1986). The urban area in Carson Valley, primarily in Minden and Gardnerville, has increased considerably since the 1973-80 inventory shown in table 1. Eagle Valley, which contains Carson City, is largely urban and has only a small amount of agricultural land (about 1,000 acres in 1973).

Dayton and Churchill Valleys, which have the smallest populations of the hydrographic areas in the Nevada part of the basin, are primarily rangeland. The valleys include agricultural areas along the Carson River.

Carson Desert has the largest percentage of barren land because it contains the Carson Sink and other alkali flats. During 1980-87, the estimated irrigated acreage in Carson Desert ranged from 61,000 to 67,000 acres (Bureau of Reclamation, 1987a). Urban land in Carson Desert consists of the city of Fallon and the Fallon Naval Air Station. Construction of a 31-mi-long canal to divert Truckee River water to the Carson River was completed in 1905. Construction of Lahontan Dam on the Carson River, to store the diverted water and water from the Carson River, was completed in 1915 (Katzer, 1971). Since 1914, irrigated acreage in the Newlands Project area, which includes land along the Truckee Canal, has ranged from as little as 39,449 acres in 1916 to as much as 67,294 acres in 1979. The Fallon National Wildlife Refuge was established in 1931 and the Stillwater Wildlife Management Area and Stillwater National Wildlife Refuge were established in 1948.

Other than changes associated with the Newlands Project, land use and population in the Carson River Basin were relatively stable from the 1890's until about 1950. Urban and suburban development began to increase during the 1950's and has been increasing rapidly since the 1960's. Minden, Gardnerville, Carson City, and Fallon have grown considerably, as have rural populations throughout much of the basin. Most of the urban and suburban development has been on land previously used for agriculture (either irrigated cropland or rangeland).

Land uses in the basin, by acreage and as a percent of the total basin, are listed in table 1. Because of rapid urban and suburban growth since the compilation

Table 1 Land use and land cover in Carson River Basin, Nevada and California, by hydrographic area, 1973-80 [1]

[Upper number is area, in acres Number in parentheses is percentage of total acreage for each hydrographic area Land-use areas that constitute more than 25 percent of a hydrographic area are shown in **bold** type Due to rounding, sum of individual percentages may not be 100 percent Symbol <, less than]

Hydrographic area (years for which data apply)	Urban	Agricultural	Range	Forest	Water	Wetland	Barren	Tundra	Total (rounded)	
									Acres	Percent of Carson River Basin
Headwaters Area	49	0	62,000	**190,000**	410	300	2,500	8,800	270,000	11
(1973-79)	(<0 1)	(0)	(23)	**(72)**	(0 2)	(0 1)	(0 9)	(3 3)		
Carson Valley	3,400	47,000	**98,000**	**130,000**	470	5,300	1,400	1,600	280,000	11
(1973-79)	(1 2)	(16)	**(34)**	**(45)**	(2)	(1 9)	(5)	(6)		
Eagle Valley	[2]4,800	1,100	**28,000**	**12,000**	0	0	450	0	47,000	2
(1973)	(10)	(2 3)	**(60)**	**(26)**	(0)	(0)	(1 0)	(0)		
Dayton Valley	950	4,800	**150,000**	**70,000**	9	1,600	4,700	0	230,000	9
(1973)	(4)	(2 0)	**(65)**	**(30)**	(<0 1)	(7)	(2 0)	(0)		
Churchill Valley	720	1,700	**250,000**	21,000	7,500	7,000	28,000	0	320,000	12
(1973)	(2)	(5)	**(79)**	(6 7)	(2 4)	(2 2)	(8 8)	(0)		
Carson Desert	[2]5,600	79,000	**580,000**	30,000	23,000	62,000	**600,000**	0	1,400,000	55
(1973, 1980)	(4)	(5 7)	**(42)**	(2 1)	(1 6)	(4 4)	**(44)**	(0)		
Carson River Basin	15,000	130,000	**1,200,000**	450,000	31,000	76,000	**640,000**	10,000	2,500,000	
totals (rounded)	(6)	(5 2)	**(46.1)**	(17 9)	(1 2)	(3 0)	**(25.2)**	(4)		100

[1] Data sources U S Geological Survey, 1979, 1980, 1983 (maps interpreted from photographs taken during 1973-79 for areas south of 39 degrees latitude, in 1973 for areas between 39 and 40 degrees latitude, and in 1980 for areas north of 40 degrees latitude)

[2] Carson Desert has less than one-half the population of Eagle Valley, but it has more urban land because Fallon Naval Air Station is classified as urban land

period (1973-80), the distribution and percentage of urban land are now different, although the numbers in the table represent the most current information available for the basin as a whole Carson Valley and the Carson Desert contain more than 90 percent of the agricultural land in the basin Forest land predominates in the Headwaters Area and in Carson Valley, and decreases markedly toward the downstream part of the study area Rangeland increases eastward from Dayton Valley to Churchill Valley to Carson Desert

Areal extent of water bodies and wetlands is highly variable, both seasonally and from year to year This is especially true in Carson Desert For example, between July 1984 and February 1985, following three unusually wet years, the surface-water area of the Carson Sink was about 200,000 acres (Rowe and Hoffman, 1990) By April 1988 (during a second consecutive drought year), the sink was dry (Rowe and Hoffman, 1990) Major water bodies in the basin are the Lahontan Reservoir in Churchill Valley and ephemeral lakes, reservoirs, and alkali flats in Carson Desert

Demand for water in the Carson River Basin exceeded supply soon after the area was settled Historically, court suits regarding water rights in the basin follow drought years (Dangberg, 1975, p 134-135 and unnumbered plate) In the 1980's, major water-management issues in the Carson River Basin included distributing available water and finding new sources of water to support urban and suburban growth, farming interests, and wildlife management Many water-use and water-allocation disputes in the Carson River Basin and between the Truckee River and Carson River Basins await decision by the courts and negotiations as of 1990

Basinwide estimates of water use in 1969, 1975, and 1988 are listed in table 2 Trends (1969-88) in ground-water use are shown in figure 2 and include estimates for 1985 from Welch and others (1989, table 19) The significant decline in surface-water use between 1985 and 1988 is due to a combination of changes in operation of the large Newlands Irrigation Project in the lower Carson River Basin and effects of relative drought in 1987 and 1988 Withdrawals of ground water for public water supply (combined with self-supplied domestic use and labeled as domestic use in fig 2) increased from 3,900 acre-ft in 1969 to about 21,000 acre-ft in 1988 The estimated ground-water withdrawal for self-supplied domestic use has more than tripled

Table 2 Estimated basinwide water use in Carson River Basin, Nevada and California, 1969, 1975, and 1988

[Estimated withdrawals, in acre-feet, are significant to no more than two figures, columns may not cross-total because of independent rounding Abbreviations GW, ground water, RS, reclaimed sewage, SW, surface water, --, no data]

Type of water use	1969 [1]				1975 [2]				1988 [3]			
	GW	SW	RS	Total	GW	SW	RS	Total	GW	SW	RS	Total
Public supply	2,700	1,200	0	3,900	5,900	480	0	6,400	16,900	1,600	0	18,500
Self-supplied domestic	1,200	40	0	1,200	1,700	50	0	1,800	4,100	40	0	4,100
Livestock (non-irrigated agriculture)	120	440	0	560	[4]2,200	870	0	3,100	[5]2,600	1,800	0	4,400
Irrigation	6,000	[6]670,000	[7]--	680,000	8,800	650,000	[8]900	660,000	18,600	260,000	5,400	280,000
Thermoelectric power	0	0	0	0	0	0	0	0	0	0	0	0
Self-supplied commercial, industrial, and mining	1,200	430	0	1,600	[4]1,300	[9]300	[8]--	1,600	1,300	100	0	1,400
Total withdrawal (rounded)	11,000	670,000	[7]--	690,000	20,000	650,000	900	670,000	44,000	260,000	5,400	310,000

[1] Smales and Harrill (1971, p 17, 29, and 30)

[2] James R Harrill and Jon O Nowlin (U S Geological Survey written commun 1976)

[3] U S Geological Survey files, 1990

[4] For 1975, estimate of self-supplied industrial water use includes 2,200 acre-feet of ground water withdrawn by the Lahontan Fish Hatchery For consistency with 1988 categories of water use, those 2,200 acre-feet are included in nonirrigated agriculture A very small percentage of this water is lost from the system

[5] Includes 1,900 acre-feet of ground water withdrawn by the Lahontan Fish Hatchery A very small percentage of this water is lost from the system

[6] Includes 114,000 acre-feet diverted from Truckee River into Derby Canal

[7] In 1969, 2,900 acre-feet of treated sewage effluent from the Lake Tahoe Basin was imported to the Carson River Basin, but the amount used for irrigation was not recorded (Glancy and Katzer, 1976, p 53)

[8] In 1975, the estimate of self-supplied industrial water use included 500 acre-feet of reclaimed sewage applied to the Carson City Golf Course For consistency with 1988 categories of water use, that 500 acre-feet is included as irrigation

[9] In 1975, the estimate of self-supplied industrial water use included 2,000 acre-feet of surface water withdrawal by Huck Salt Company in Carson Desert Water on the salt flats flows naturally and is not diverted or withdrawn Salt-mining operations do not affect natural evaporation rates For consistency with 1988 estimates, the 2,000 acre-feet included in the original 1975 estimates is not included in above table

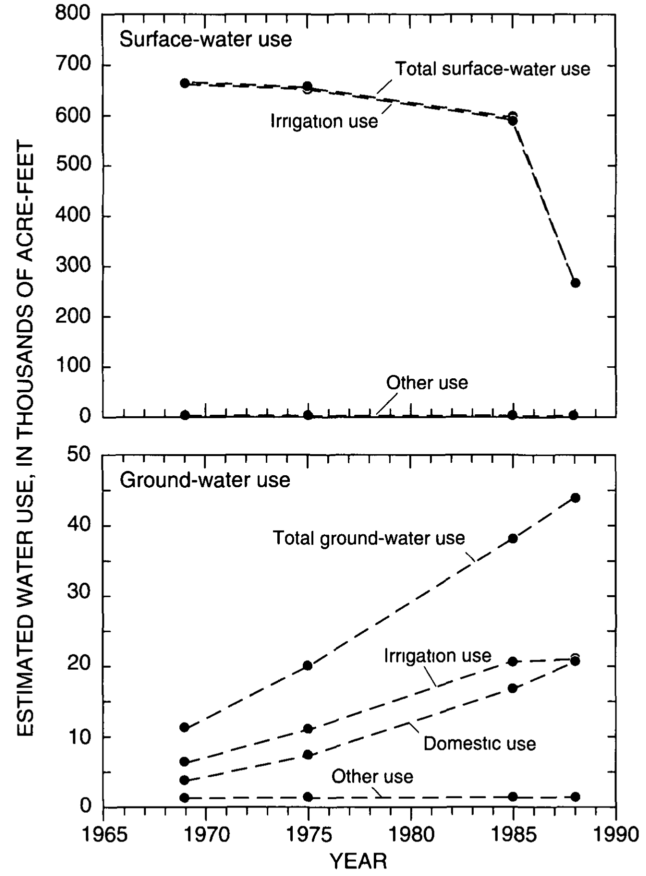


Figure 2 Estimated water use in Carson River Basin, Nevada and California, 1969-88

Total water use in the Carson River Basin for 1988 is estimated to be 310,000 acre-ft, more than 80 percent was surface water diverted for irrigation (table 2) Although ground water accounts for only 14 percent of the total water use, it supplies 93 percent of the amount withdrawn for domestic use

Sewage effluent returned to ground-water and surface-water systems of the study area has the potential to degrade regional ground-water quality Estimates of effluent discharged in each hydrographic area in 1985 are detailed by Welch and others (1989, table 6) Four sewage-treatment facilities within the Lake Tahoe Basin began exporting effluent to the Carson River Basin between 1968 and 1971 (Glancy and Katzer, 1976, p 50-53), for more than 10 years (as of 1988), all effluent from the Lake Tahoe Basin has been exported to the upper Carson River Basin Treated sewage effluent is used for irrigation in Carson Valley and Eagle Valley Similar applications are made on 20 acres in Carson Desert

HYDROGEOLOGIC SETTING

Geologic Framework

***By* Donald H Schaefer**

Alluvial valleys in the Carson River Basin are located in structural basins formed by extensional faulting during the Tertiary and Quaternary periods of geologic time These basins are bounded laterally by consolidated rocks of adjacent mountain ranges and at depth by consolidated rocks of the down-faulted valley blocks, and contain basin-fill deposits that range in thickness from 2,000 to 12,000 ft Aquifers in the Carson River Basin are mostly these basin-fill deposits

Differences in lithology and rock chemistry allow grouping of the consolidated rocks into five hydrogeologic units (pl 1, Welch and others, 1989) (1) Metasedimentary and metavolcanic rocks of Triassic and Jurassic age, (2) basic igneous rocks consisting of diorite, gabbro, and marine volcanic rock of Jurassic age, (3) granodiorite and quartz monzonite of Jurassic to Tertiary age, (4) silicic volcanic rocks consisting of rhyolite, latite, and dacite of Tertiary and Quaternary age, and (5) basic volcanic rocks consisting of basalt, andesite, and trachyte of Tertiary and Quaternary age Except for Jurassic basic igneous rocks, which are found only in the West Humboldt and Stillwater Ranges, each of these units is widespread in the basin

Basin-fill deposits include sediments of Tertiary and Quaternary age Tertiary sediments consist of clays, silts, sands, and gravels In former times, these deposits were more extensive than in the modern basins These older deposits are exposed in mountain blocks and along basin margins and presumably make up the deeper part of the basin-fill deposits in each basin For purposes of this report, Tertiary sediments are considered part of the basin-fill deposits

Younger deposits are at and near the land surface in each basin and include poorly sorted to unsorted clay, silt, sand, and gravel of alluvial fans, pediments, and basin lowlands Some of these deposits are associated with Pleistocene Lake Lahontan, ancient Carson River deltas, and past and present flood plains of the river Lake Lahontan was a Late Pleistocene pluvial lake that covered much of the eastern half of the basin during its highest stand (fig 3) Fine-grained deposits accumulated mostly as lacustrine and deltaic sediments of Lake Lahontan and, depending on the level of the lake, as fluvial sediments of the Carson River flood plain Locally, basin-fill deposits are interbedded with

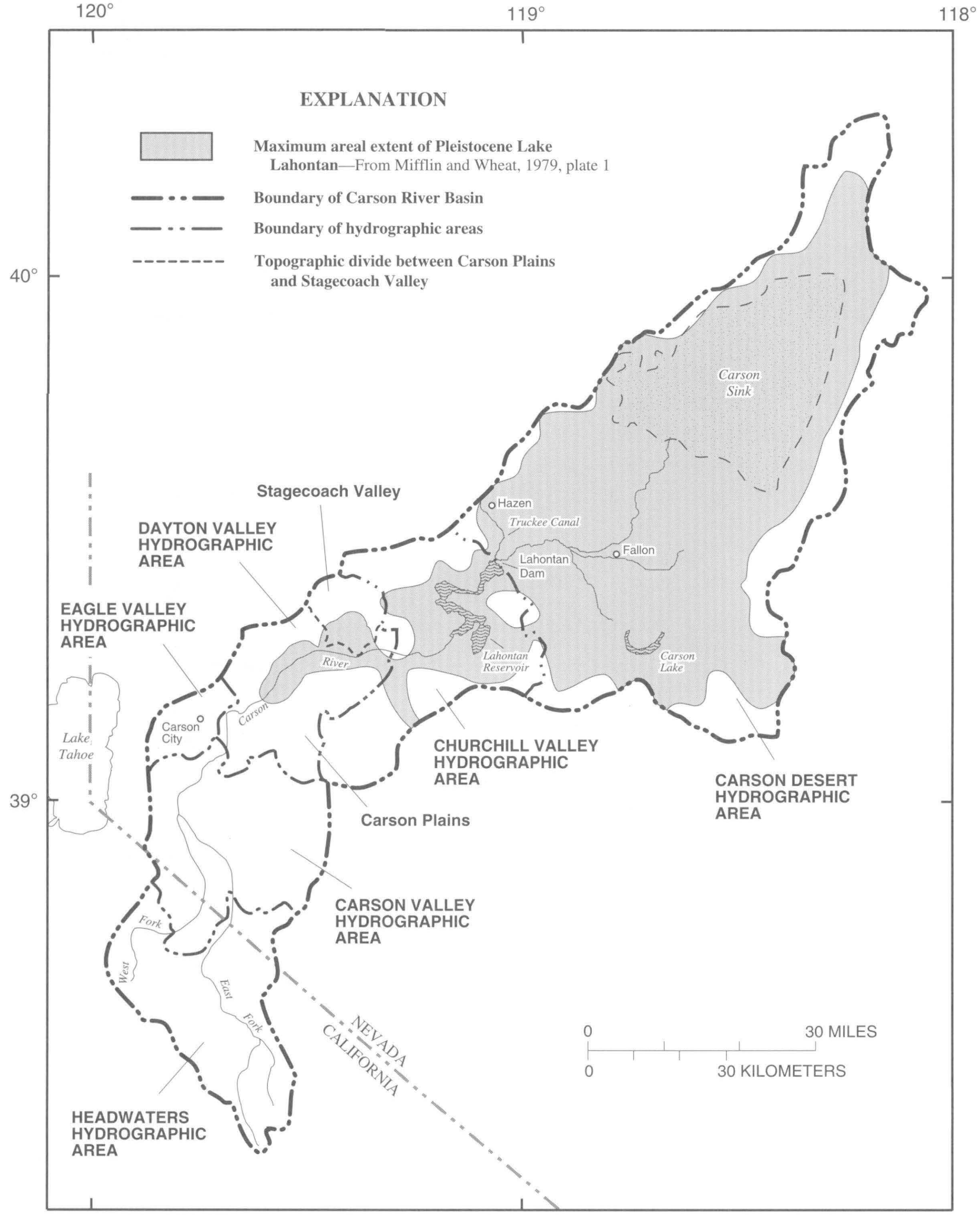


Figure 3. Maximum extent of Pleistocene Lake Lahontan in Carson River Basin.

volcanic rocks These volcanic rocks are considered part of the basin-fill deposits One important aquifer in southern Carson Desert is composed of basalt and is exposed at Rattlesnake Hill This basalt aquifer is the source of public supply for the city of Fallon and the Fallon Naval Air Station

A dominant hydrologic feature of the Carson River Basin is the Carson River, which provides a connection between the valleys of the basin The river flows through and physically connects the Headwaters Area, Carson Valley, Dayton Valley, Churchill Valley, and Carson Desert Shallow aquifers are hydraulically connected to the river in these valleys Depending on flow, reach of the river, and local irrigation practices, the river either can be a source of ground-water recharge or can receive discharge The Carson River does not enter Eagle Valley or Stagecoach Valley, although both are hydraulically connected to the river, either by tributary streams in Eagle Valley or by ground-water underflow in Stagecoach Valley

Mineralogic Composition of the Aquifers

By **Michael S Lico**

Knowledge of an aquifer's mineralogic composition can lead to an understanding of reactions affecting constituent concentrations in ground water of the Carson River Basin It is important to determine whether precipitation or dissolution of mineral phases has occurred In some mineral samples, distinguishing whether features were formed in place or at another location and transported to a present location is difficult The mineralogic composition of parts of Carson Desert is described by Lico and others (1986, 1987) and Lico (1992)

Igneous rocks form the bulk of the bedrock uplands (table 3) As a result, minerals forming the basin-fill sediment reflect the igneous origin of upland areas The Sierra Nevada batholith, which is composed mostly of silicic rocks including granodiorite and quartz monzonite, has been a major source of sediment transported by the Carson River since the Late Tertiary

Table 3 Area of shallow or exposed bedrock of Carson River Basin, Nevada and California, by hydrographic area

[Upper number is area, in square miles Number in parentheses is percentage of total bedrock outcrop area for each hydrographic area Bedrock areas that constitute more than 25 percent of a hydrographic area are in **bold** type Due to rounding, sum of individual percentages may not be 100 percent Silicic rocks are sum of QTsv and TJsi Abbreviations QTbv, basic volcanic rocks, QTsv, silicic volcanic rocks, TJsi, intrusive igneous rocks, Jm, Jurassic igneous rocks, JTRm, metasedimentary and metavolcanic rocks, mi^2, square miles]

Hydrographic area	Total area (mi^2)	QTbv	QTsv	TJsi	Jm	JTRm	QTsv+TJsi
Upper Carson River Basin							
Headwaters area	365	**210** **(58)**	21 (6)	**123** **(34)**	0 (0)	11 (3)	144 (39)
Carson Valley	169	42 (25)	2 (1)	**75** **(44)**	1 (1)	**49** **(29)**	77 (46)
Eagle Valley	58	5 (8)	2 (3)	**31** **(53)**	0 (0)	**21** **(35)**	33 (57)
Subtotal	592	**257** **(43)**	25 (4)	**229** **(39)**	1 (0)	81 (14)	254 (43)
Middle Carson River Basin							
Dayton Valley[1]	244	**176** **(72)**	5 (6)	24 (10)	0 (0)	30 (12)	38 (16)
Churchill Valley	268	**197** **(73)**	46 (17)	14 (5)	0 (0)	11 (4)	60 (22)
Subtotal	513	**373** **(73)**	61 (12)	38 (7)	0 (0)	41 (8)	99 (19)
Lower Carson River Basin							
Carson Desert	463	**254** **(55)**	98 (21)	21 (5)	28 (6)	62 (13)	119 (26)
Carson River Basin total	1568	**883** **(56)**	184 (12)	288 (18)	29 (2)	184 (12)	472 (30)

[1] Dayton Valley includes Carson Plains and Stagecoach Valley

Table 4 Minerals and alteration products in shallow sediment of Carson River Basin, Nevada and California

[Due to rounding, sum of individual percentages may not be 100 percent Abbreviations C, chlorite, D, dissolution, H, hematite, I, illite, K, kaolinite, M, montmorillonite (beidellite), N, no alteration, S, sericite **Bold** letters indicate strong alteration Symbol --, mineral not detected]

Component	Percentage of total (alteration)		
	Carson Valley (27 samples)	Dayton and Churchill Valleys (5 samples)	Carson Desert (27 samples)
Quartz	20 (N)	18 (N)	22 (N)
Plagioclase feldspar	26 (C,I,K)	19 (C,S)	26 (C,S)
Potassium feldspar	9 (C,K)	4 (C,S)	6 (C,S)
Volcanic lithic fragments	34 (C,H,I,S)	29 (C,H,I,S)	23 (C,H,I,S)
Sedimentary lithic fragments	8 (**C**)	27 (C,H,I,K,M,S)	18 (C,H,I,M,S)
Biotite	1 (**C, D**)	1 (**C**)	2 (**C**)
Hornblende	trace (C)	--	trace (C,D)
Pyroxene (augite)	1 (C)	1 (C,D)	1 (C,D)
Opaque minerals	1 (H)	1 (H)	1 (H)
Total (all components)	100	100	99

Silicic rocks are most commonly found in the upper basin and constitute about 40 percent of the exposed bedrock

Volcanic rocks formed mountain ranges within the basin and also are major sources of sediment for the basin-fill deposits In the upper basin, basic volcanic rocks are exposed throughout much of the Headwaters Area (table 3) Volcanic rocks are more common in the middle and lower basin than in the uplands of Carson and Eagle Valleys Almost three-quarters of the bedrock in the middle basin is volcanic As a result, volcanic-rock fragments constitute a major part of the basin-fill sediment Coarse-grained granodiorite and quartz monzonite commonly break down to grains consisting of single minerals Consequently, few granodiorite or quartz monzonite rock fragments are found in the basin-fill sediment In contrast, volcanic rocks are typically fine grained and more commonly survive transport as rock fragments

Minerals from 59 sediment samples were identified by electron microscopy, X-ray diffraction, and visually from thin sections and hand specimens (table 4) The most commonly identified phases are those included in geochemical models discussed later in this report Plagioclase feldspar generally has a more calcium-rich composition with increasing distance from the Sierra Nevada (fig 4) Increasing dominance of basalt in the middle compared to the upper basin is a likely source for the more calcium-rich plagioclase An alternative explanation is preferential weathering of sodium relative to calcium in the feldspar

Calcite is a common secondary mineral in basin-fill deposits of dry climates Although calcite was not found in sediment samples from Carson or Eagle Valleys, its presence in these sediment deposits is likely Calcite constitutes a small amount of the basin-fill sediment in Churchill Valley and Carson Desert as shell fragments and tufa in the Pleistocene lacustrine deposits of Lake Lahontan Secondary calcite also is present as coatings on shell fragments and cavity-filling cement (Lico, 1992) in basin-fill deposits of Carson Desert (fig 5) Calcite also forms in the unsaturated zone of Carson Desert (Lico and others, 1987)

Gypsum is commonly found in desert soils Triassic to Jurassic evaporite deposits (mostly gypsum) are present in northwestern Dayton Valley and the West Humboldt Range of northern Carson Desert These deposits release gypsum into the basin-fill sediment However, no gypsum was seen in the five sediment samples from Dayton Valley Gypsum was found in shallow sediment near the Stillwater Wildlife Management area (Lico, 1992)

Most basin-fill sediment is altered (table 4) Typically, volcanic lithic fragments are highly altered Chlorite, the most abundant alteration product, probably formed before the sediment was transported to its current location rather than being a product of reactions in the aquifers Alteration of minerals to chlorite usually occurs in low-grade metamorphic or hydrothermal conditions These conditions are rare in the aquifers of the Carson River Basin except in active geothermal

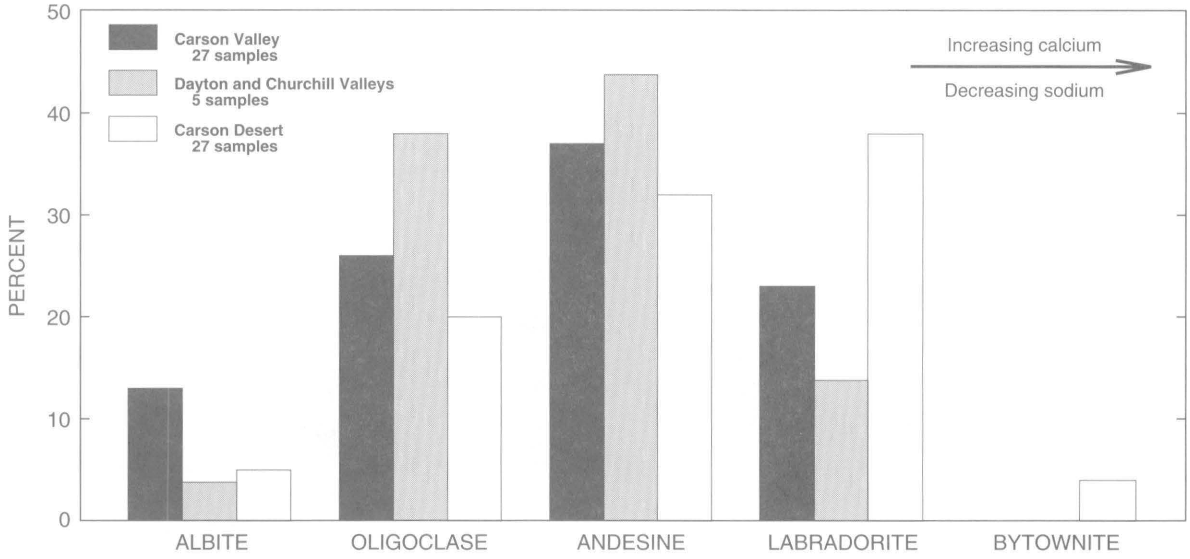


Figure 4. Composition of plagioclase feldspar in shallow sediments of Carson River Basin, Nevada and California, by hydrographic area.

areas. Plagioclase feldspar is altered to chlorite, sericite, illite, or kaolinite along cleavage planes and fracture surfaces. Sericite is increasingly abundant with distance from the Sierra Nevada. Kaolinite, an alteration product of plagioclase and potassium feldspars, was found mostly in samples collected near the Sierra Nevada. Hematite commonly forms on volcanic and sedimentary lithic fragments throughout the Carson River Basin (fig. 6). In a few samples throughout the basin, pyroxene (augite), biotite, and hornblende grains have dissolution features.

Plagioclase feldspar, potassium feldspar, and augite are the principal minerals that compose the basalt aquifer in Carson Desert. Minerals formed after initial cooling of basalt include calcite (with about 2.5 mole percent magnesium), phillipsite (a potassium-calcium zeolite), and an unidentified clay mineral. Pyroxene in the basalt aquifer has been slightly altered to chlorite. Plagioclase feldspar laths have minor illitic or sericitic alteration along cleavage planes. Edges of the iron-bearing minerals magnetite and ilmenite have been commonly altered to hematite.

General Principles of Isotope Hydrology

***By* Alan H. Welch**

Isotopes provide information on a variety of hydrologic processes, including sources of recharge and age of ground water. Information presented in this section provides the basis for interpretation of isotopic data in unraveling hydrologic processes in the Carson River Basin.

Commonly measured stable isotopes of water are the hydrogen isotopes with atomic masses of 1 and 2 (deuterium) and oxygen isotopes with atomic masses of 16 and 18. Isotopes of these two elements are expressed as ratios and related to comparable ratios for a standard called "Vienna Standard Mean Ocean Water" or V-SMOW (Fritz and Fontes, 1980, p. 11-14). Differences from the standard are expressed as delta deuterium (δD) and delta oxygen-18 ($\delta^{18}O$); the units are expressed as "permil" (o/oo). Because of the convention adopted for calculating delta values, more negative delta values are isotopically lighter than less negative values (Fritz and Fontes, 1980, p. 4-5).

Isotopic compositions of nonthermal ground water generally are different from those of local meteoric water because the compositions are affected by processes occurring during recharge and discharge. Evaporation in the near-surface environment during recharge and discharge is a major factor affecting the isotopic composition of ground water and surface water in the Carson River Basin. Rock-water interaction at temperatures greater than about 150°C also can affect the isotopic composition of oxygen. Important mechanisms affecting the stable-isotope composition of ground water in the Basin and Range Province are discussed below.

Figure 5. Calcite overgrowth in shallow sediment from southern Carson Desert, Nevada. Photomicrograph by William Carothers, U.S. Geological Survey, May 1986.

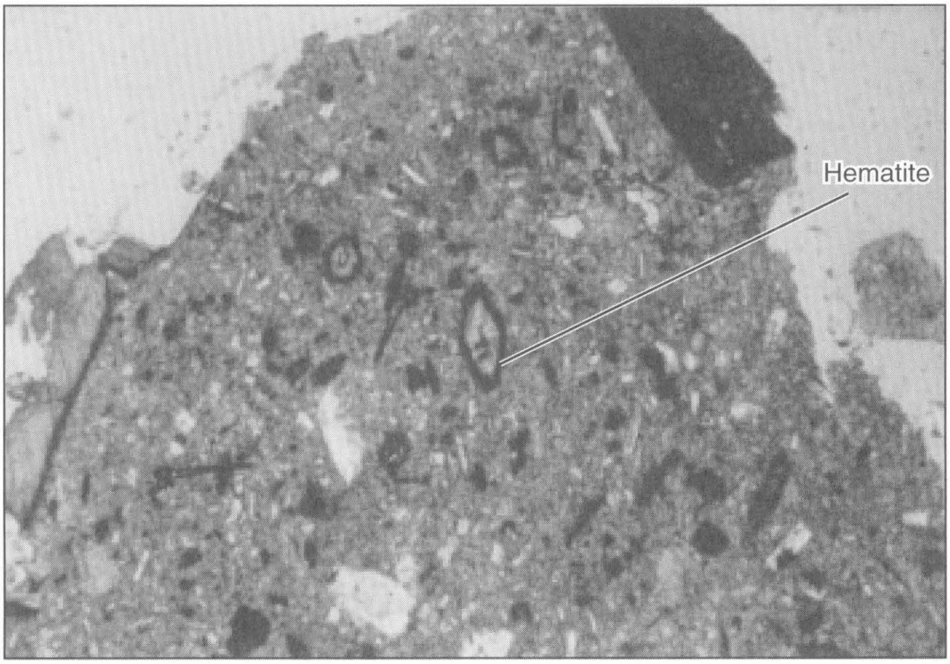


Figure 6. Hematite rims on pyroxene in shallow sediment from Carson Valley, Nevada. Photomicrograph by Patrick Goldstrand, U.S. Geological Survey, November 1990.

Although the isotopic composition of precipitation commonly varies widely from storm to storm (Gat, 1980, p 37-39), the average composition at a site commonly lies along a regression line called the "meteoric-water line " The slope of the regression is

$$\delta D = 8\delta^{18}O \tag{2}$$

Precipitation in dry climates is heavier in deuterium (δD), compared with oxygen-18 (^{18}O), than suggested by the simple relation of equation 1 Thus, the meteoric-water line is displaced upward from the lower regression line, labeled "ground-water recharge," shown in figure 7 This displacement is commonly called the "deuterium excess parameter" (Dansgaard, 1964), or "deuterium excess" (*d*) The general equation of the meteoric-water line is

$$\delta D = 8\delta^{18}O + d \tag{3}$$

A widely used "*d*-value" is 10 permil for atmospheric precipitation, on the basis of a study by Craig (1961) of many places in the world (see upper meteoric-water line in fig 7) The isotopic composition of ground-water recharge from precipitation in northern Nevada may be estimated from measurements of nongeothermal ground water with chloride concentrations less than 25 mg/L Low chloride concentrations indicate evaporation has not greatly affected the stable-isotope composition of the water The linear relation between the oxygen and hydrogen-isotope composition in ground water of northern Nevada with deuterium concentrations ranging from -130 to -100 is

$$\delta D = 6\ 94\delta^{18}O - 10\ 6 \tag{4}$$

This equation compares favorably with a regression equation for rain in southeastern California that has a slope of 6 5 and a *d*-value equal to -9 7 (Friedman and others, 1992, fig 9) Data for 206 sites north of 38 degrees north latitude in Nevada were used for the regression A linear regression for ground water with chloride concentrations less than or equal to 10 mg/L yields a slope of 6 60, deuterium excess of -14 2, and a correlation coefficient of 0 84 for 127 analyses This line, although not shown in figure 7, would plot near the "ground-water recharge" line Similar regression equations suggest evaporation has not greatly affected the isotope composition because the chloride concentrations increased from 10 to 25 mg/L Within this range of chloride concentration, the increase may come from aquifer materials rather than evaporative concentration

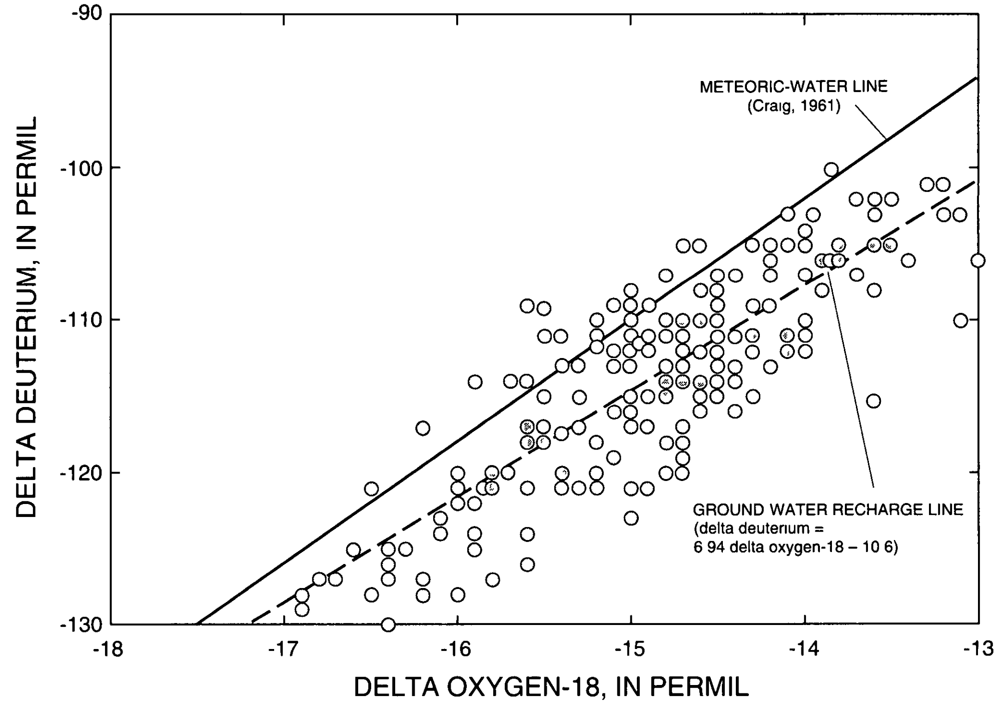


Figure 7 Relation between stable isotopes of hydrogen (delta deuterium) and oxygen in ground water of northern Nevada

In general, the stable-isotope composition of precipitation becomes progressively lighter with increasing distance east of the Sierra Nevada (Ingram and Taylor, 1991) Conversely, water subject to evaporation becomes progressively heavier with increasing evaporation because of the loss of the lighter fraction as water vapor

Surface water also is a source of ground-water recharge in the Carson River Basin Among the different sources of surface water analyzed, streams draining the Carson Range of the Sierra Nevada on the west side of Carson Valley have the lightest stable-isotope composition (fig 8) Carson River water generally had hydrogen-isotope compositions ranging from about -110 to -100 permil in the reach from above Carson Valley (at gages 10309000 and 10308200, fig 1) to above Lahontan Reservoir (gage 10312000) Lahontan Reservoir receives water from both the Carson River and, through the Truckee Canal, from the Truckee River The Truckee River at Tahoe City, which is the outflow from Lake Tahoe, had a distinctly heavier isotopic composition than any other surface water sampled at a higher altitude than Lahontan Reservoir (fig 8) The isotopic composition of water from Lake Tahoe and the Truckee River about 500 ft downstream from Lake Tahoe (gage 10337000, Bostic and others, 1991) is similar Truckee River water near Farad (gage 10346000, Bostic and others, 1991, fig 10) appears to have an isotopic composition largely controlled by the amount of water from Lake Tahoe compared to contributions from other drainages Release of ground water from bank storage also may alter the isotopic composition of Truckee River water (McKenna, 1990)

Tritium is a useful indicator of the "age" of ground water (the time since the water has been out of contact with the atmosphere), which provides information on the hydrogeology of the area Tritium, a radioactive isotope of hydrogen with a half-life of 12 33 years (Friedlander and others, 1981), is part of the water molecule forming precipitation and provides recharge to ground water The tritium content of precipitation is derived from atmospheric releases generated by above-ground thermonuclear explosions beginning in 1952 and cosmic-ray bombardment in the upper atmosphere

Tritium present in precipitation before thermonuclear testing of atomic weapons generally is believed to result (in 1990) in activities less than about 25 pCi/L (picocuries per liter, Fontes, 1980, p 81) If tritium activities in precipitation before 1952 were at a constant value of 25 pCi/L, ground water older than 57 years would have present-day (1990) activities less than about 1 pCi/L Major releases from above-ground testing caused tritium activities in 1990 of more than 10 pCi/L in precipitation since 1952 High tritium activities in ground water (greater than 100 pCi/L) are a result of precipitation in 1958-59 and 1962-69 These periods of high tritium activities are supported by estimated activities in precipitation on the Sierra Nevada in the Lake Tahoe Basin (fig 9, Carl Thodal, U S Geological Survey, written commun , 1991, and on the basis of the tritium deposition model developed by Michel, 1989) Mixing of water with different activities of tritium can produce intermediate values Ages for ground water based on tritium data are interpreted using the following general guidelines

Tritium activities (pCi/L)	Period of recharge		Comments
	Years	Number of years before 1990	
Less than 1	pre-1933	more than 57	--
1 to 10	1933 to 1952	57 to 38	Can be mixture of pre- and post-1952 water
11-100	after 1952	fewer than 38	--
Greater than 100	1958-59, 1962-69	32-31, 28-21	--

Hydrogeology of the Upper Carson River Basin

By **Donald H Schaefer** *and* **Alan H. Welch**

The Headwaters Area and the Carson Range are rugged, with extremes of altitude and relief Drainages are typically narrow with steep sides and, in the Headwaters Area, the canyons are more than 1,000 ft deep Main hydrologic features of the Headwaters Area are the East and West Forks of the Carson River and their many tributaries Average annual flow of the West Fork is about 80,000 acre-ft, based on records collected during 59 years between 1900 and 1990 (gaging station 10310000, Bostic and others, 1991, p 137) For the East Fork, average annual flow is about 270,000 acre-ft, based on records collected during 64 years between 1891 and 1990 (gaging station 10309000, Bostic and others, 1991, p 131)

Canyon bottoms of the Headwaters Area are underlain by lenses of stream-deposited boulders, cobbles, and gravel probably no more than a few tens of

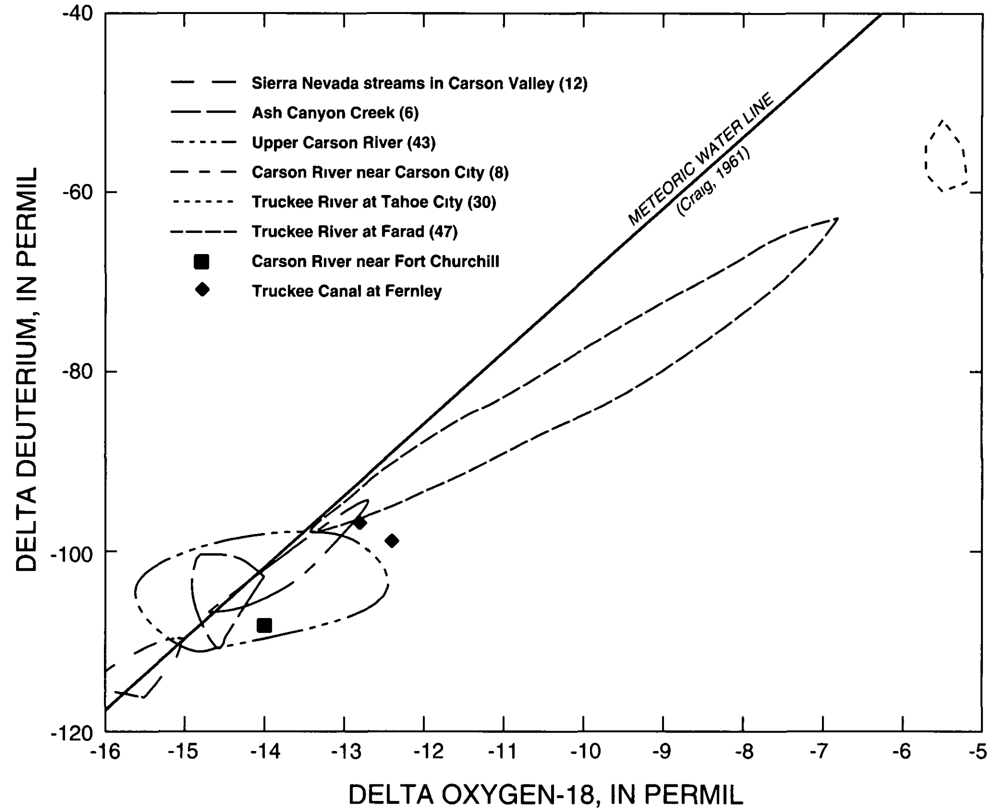


Figure 8. Relation between stable isotopes of hydrogen (deuterium) and oxygen in surface water of Carson and Truckee River Basins, Nevada and California. Value in parentheses is number of analyses enclosed by envelope. Data are from U.S. Geological Survey, except for Ash Canyon Creek (Szecsody and others, 1983).

feet thick and generally no more than a few hundred feet wide. Ground-water levels in these deposits are controlled by the stage of the adjacent stream.

In upland areas, the presence of ground water depends on the permeability of consolidated rocks. Permeability is related mostly to the depth of weathering and, beneath the weathered zone, to the degree to which the rocks are fractured. Both factors probably differ throughout the area, and the degree to which consolidated rocks are saturated with water and will yield water to wells differs accordingly.

Carson Valley is a north-trending basin bounded to the west by the Carson Range, to the east by the Pine Nut Mountains, and to the north by an alluvial divide separating Carson Valley from Eagle Valley. The valley floor is underlain by a structural basin as much as 5,000 ft deep along the west side that becomes progressively more shallow to the east (Maurer, 1985, p. 5).

The East and West Forks of the Carson River enter Carson Valley at its south end and join near the west margin of the valley floor about 3 mi northwest of Minden. Just downstream from this confluence, the river bends and exits the valley at its northeast corner. Average annual flow, measured at a gage near Carson City, has been about 290,000 acre-ft during the years from 1939 through 1990 (gaging station 10311000, Bostic and others, 1991, p. 143). Other surface-water features include several small streams in the Carson Range and the Pine Nut Mountains, sloughs and abandoned channels of the river, and a network of irrigation ditches and drains.

Older, Tertiary-age basin-fill deposits in Carson Valley reach thicknesses of 1,000 ft or more on the east side of the valley (Moore, 1969, p. 12; Maurer, 1986, p. 12). Dipping westward beneath younger deposits, the older deposits underlie the central valley. Younger deposits are mostly fluvial gravels that attain thicknesses up to 50 ft (Moore, 1969, p. 14, 15). These younger deposits overlie the older deposits along the east side of the valley. Youngest deposits form alluvial fans next to mountains and extensive areas in the Carson River flood plain (Moore, 1969, pl. 1).

The ground-water basin in Carson Valley contains two discontinuous confined alluvial aquifers (Maurer, 1985) and a shallow water-table aquifer Aquifers are confined in alluvial fans along the west margin of the valley and in basin-fill deposits beneath the central part of the valley Contours show the altitude of the water table (pl 1) Contours indicate ground-water movement is toward the Carson River from both sides of the valley, and then generally northward through sediments beneath the river A water-table aquifer is hydraulically connected to the river throughout most, if not all, of the valley Water moves between the river and aquifer in either direction, depending mostly on the stage of the river

Many features of the ground-water system in Carson Valley can be visualized by examining ground-water flow along an east-west line at the latitude of Gardnerville (fig 10), derived from a description by Welch (1994) Precipitation on the Carson Range is an important source of recharge to upland aquifers Ground-water flow in the upland areas is largely restricted to fractures in the shallow subsurface and faults Flow from upland aquifers in the Carson Range recharges the basin-fill sediments and then flows north and east

Basin-fill sediments include lacustrine clays, deposits formed by through-flowing river water, and alluvial fan deposits Fan deposits generally form at the mouths of canyons at the base of the Carson Range Much, if not all, surface water flowing across these fans recharges the basin-fill sediments Away from canyons, the bedrock sides of basin-bounding faults are exposed and fans are small or absent This setting is shown in figure 10 Through-flowing rivers formed both permeable channel sediments (sand and gravel) and less-permeable flood-plain deposits (clay and silt) Structural tilting of the basin to the west has probably displaced rivers to the west As a result of tilting, a greater proportion of the channel deposits is in the western than in the eastern basin-fill sediments

Laterally extensive clay deposits restrict vertical movement of ground water in the basin-fill sediments The lateral extent of the clay deposits is consistent with deposition of lacustrine sediments These deposits are not continuous (Douglas K Maurer, U S Geological Survey, oral commun ,1992) The lack of lateral continuity may be a result of erosion by through-flowing surface water after deposition Replacement of clay deposits by more permeable fluvial sediments allows much of the vertical movement of water between zones above and below the clay deposits (inset *B* of fig 10)

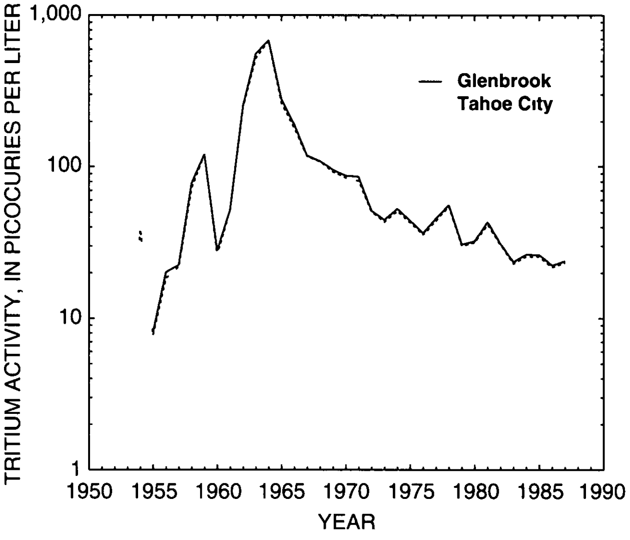


Figure 9 Estimated 1990 tritium activities in 1953-86 precipitation on uplands of Truckee River Basin, Nevada and California

Shallow basin-fill aquifers are recharged by flow from upland aquifers, surface water diverted for irrigation, and the Carson River Most irrigation water returns to the Carson River either as ground-water discharge or by way of drainage ditches (inset *A* of fig 10) Recharge of deeper aquifers through shallow basin-fill sediments is enhanced by hydraulic gradients created by pumping and by flow through breaches in laterally extensive clay deposits (inset *B* of fig 10)

The structural basin beneath Eagle Valley consists of several north-northeast-trending fault blocks (Arteaga, 1982, p 26) Fault scarps in the basin-fill deposits approximately coincide with margins of these fault blocks The basin has a maximum depth of about 2,800 ft beneath the eastern part of the valley (Arteaga, 1982, p 26)

Eagle Valley has a shallow water-table aquifer and one or more deeper alluvial aquifers (Arteaga, 1982, p 8) Confining beds are composed of discontinuous clay lenses at different depths Confined conditions are most pronounced where ground-water flow paths from the north, northwest, and southwest converge Water-level altitudes shown on plate 1 are based on measurements at shallow wells in some areas, and at deeper wells in others Therefore, the altitudes shown do not necessarily represent the water table, instead, they are a composite potentiometric surface that represents confined conditions in some areas

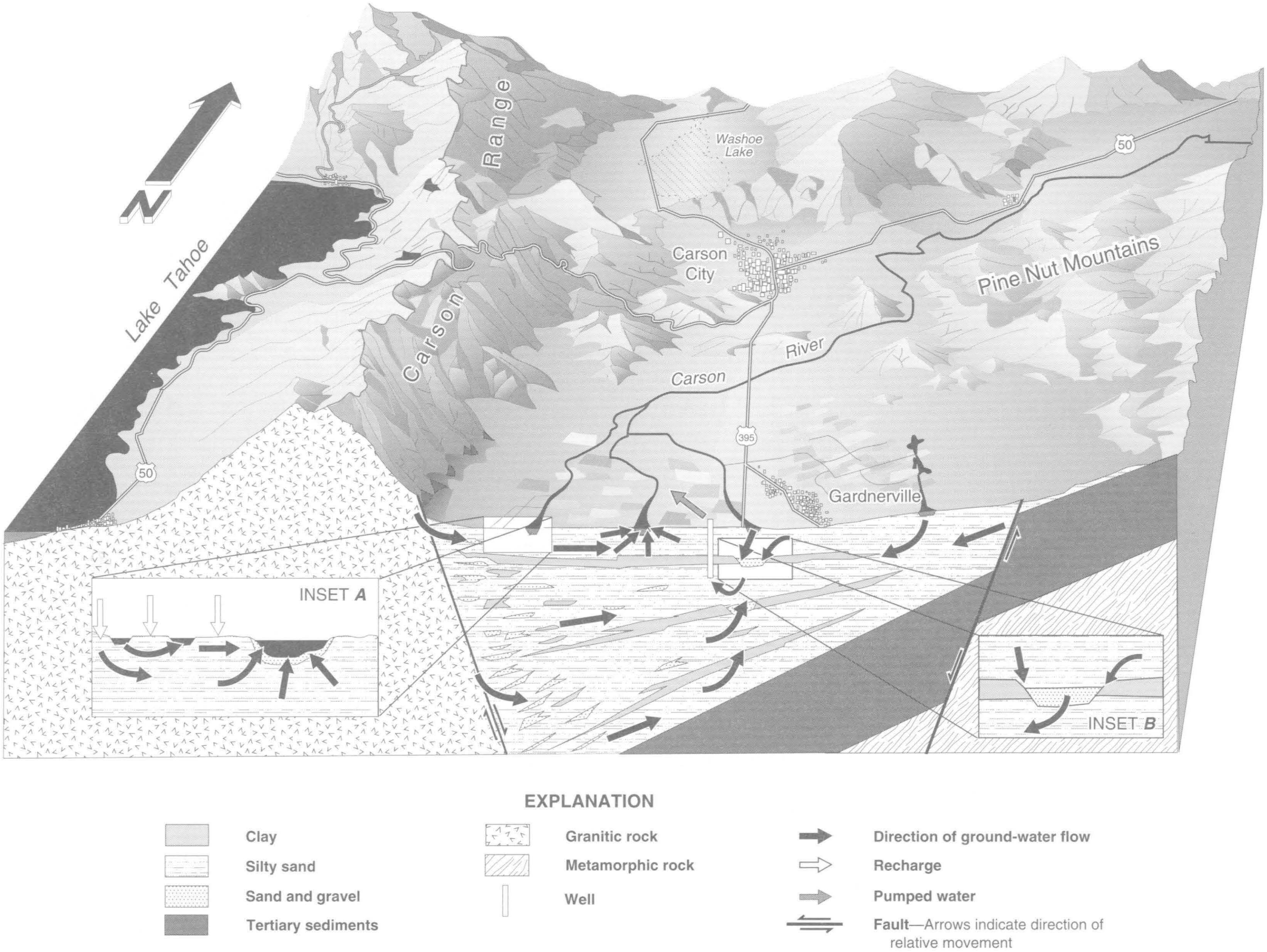


Figure 10. Schematic three-dimensional "block diagram" showing geology and ground-water flow in Carson Valley, Nevada and California. Inset *A* shows shallow ground-water recharge and discharge; inset *B* shows downward movement through buried channel deposits.

Though ground-water movement is complex because of several consolidated-rock barriers, the movement is generally toward the Carson River

Most recharge to principal aquifers in Eagle Valley comes from runoff and underflow along the west side of the valley and infiltration of streamflow and irrigation water elsewhere Ground water discharges from the basin as evapotranspiration, by pumping, and as subsurface underflow to Carson Valley and the Carson River The easternmost part of Eagle Valley is along the flood plain of the Carson River Although this part of the valley is formally part of the Dayton Valley hydrographic area, it is hydrologically connected to Eagle Valley and discussed as part of the upper Carson River Basin in this report This area is a small structural basin filled with sediment as much as 800 ft thick (Arteaga, 1982, p 26) Sediments in this small basin consist of poorly sorted silty gravels and sands of alluvial fans and pediments along basin margins and silt and sands of the Carson River flood plain (Bingler, 1977)

Recharge to this small basin is provided by underflow eastward from Eagle Valley Ground water is discharged by wells, seepage into the Carson River, and by evapotranspiration The Carson River gains about 1,500 acre-ft/yr of ground-water discharge in its reach through this area (Arteaga and Durbin, 1978, p 32), much of which is from the west In contrast, the river probably acts as a source of recharge during high flow Pumping of municipal wells next to the river, beginning in the late 1980's, may be inducing recharge from the river

A major control on the stable-isotope composition of ground water in basin-fill sediments of Carson and Eagle Valleys is the composition of recharge In Carson Valley, hydrogen-isotope compositions of the major sources of recharge are -110 to -98 permil for the Carson River, -118 to -98 permil for precipitation and precipitation runoff in the Carson Range of the Sierra Nevada (fig 11), and -128 to -122 permil for precipitation and precipitation runoff in the Pine Nut Mountains (estimated by Welch, 1994)

The source of recharge to shallow and principal aquifers in Carson Valley may be inferred from relations between the hydrogen-isotope composition of the ground water and of recharge Water from shallow wells (water levels less than 50 ft below the land surface) in agricultural areas generally has an isotope composition within the range of Carson River water, which is the source of most water used for irrigation This similarity in the hydrogen-isotope composition indicates the Carson River is an important source of recharge to shallow aquifers Local exceptions may be caused by infiltration of treated sewage water imported from the Lake Tahoe Basin or upward flow from principal aquifers

Most ground-water samples from Carson Valley contain at least some water recharged since about 1952, as indicated by tritium activities equal to or greater than 10 pCi/L Ground water in principal aquifers in the Minden-Gardnerville area is withdrawn by large-capacity wells used for irrigation and municipal supply Water in this area has stable hydrogen-isotope compositions within the range found for the Carson River and tritium activities equal to or greater than 10 pCi/L (fig 12) Taken together, the stable hydrogen-isotope composition and tritium data for this area indicates that the Carson River is a major source of recharge to principal aquifers Pumping of the large-capacity wells has created a downward component of flow, recharging principal aquifers in this area

Ground water beneath northwest Carson Valley generally has tritium activities less than 10 pCi/L and hydrogen-isotope compositions lighter than -110 permil (fig 12) These values suggest precipitation in the Carson Range entered the ground-water system more than 38 years before present (1990)

Stable-isotope composition of ground water in principal aquifers beneath much of Eagle Valley generally is similar to the composition of water in upland aquifers of the mountains to the west Water in Ash Canyon Creek and the upland aquifers is considered representative of water in the mountains Wells tapping principal aquifers along surface-water drainages and beneath an irrigated park yield water with slightly heavier hydrogen-isotope compositions Heavier compositions are most likely caused by evaporation affecting the water before recharge Isotope composition of ground water in northeastern Eagle Valley also is lighter than Ash Canyon Creek This lighter composition is due to a lighter stable-isotope composition in precipitation in the recharge area to the northeast than in precipitation in the Carson Range Tritium activities in principal aquifers of Eagle Valley of generally less than 1 pCi/L, except along the margins of the basin-fill deposits (fig 13), indicate the water was recharged at least 57 years ago

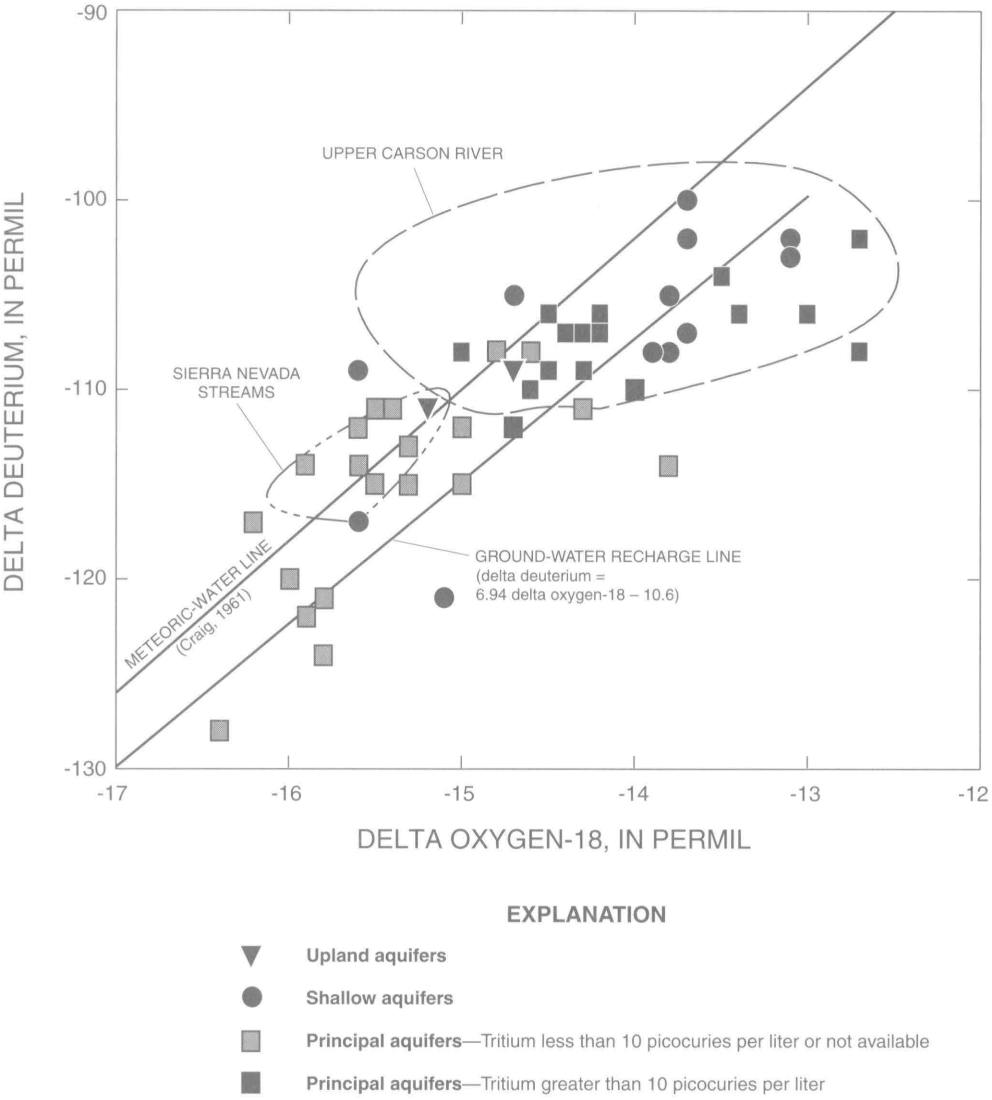


Figure 11. Relation between stable isotopes of hydrogen (delta deuterium) and oxygen in ground water of Carson Valley, Nevada and California.

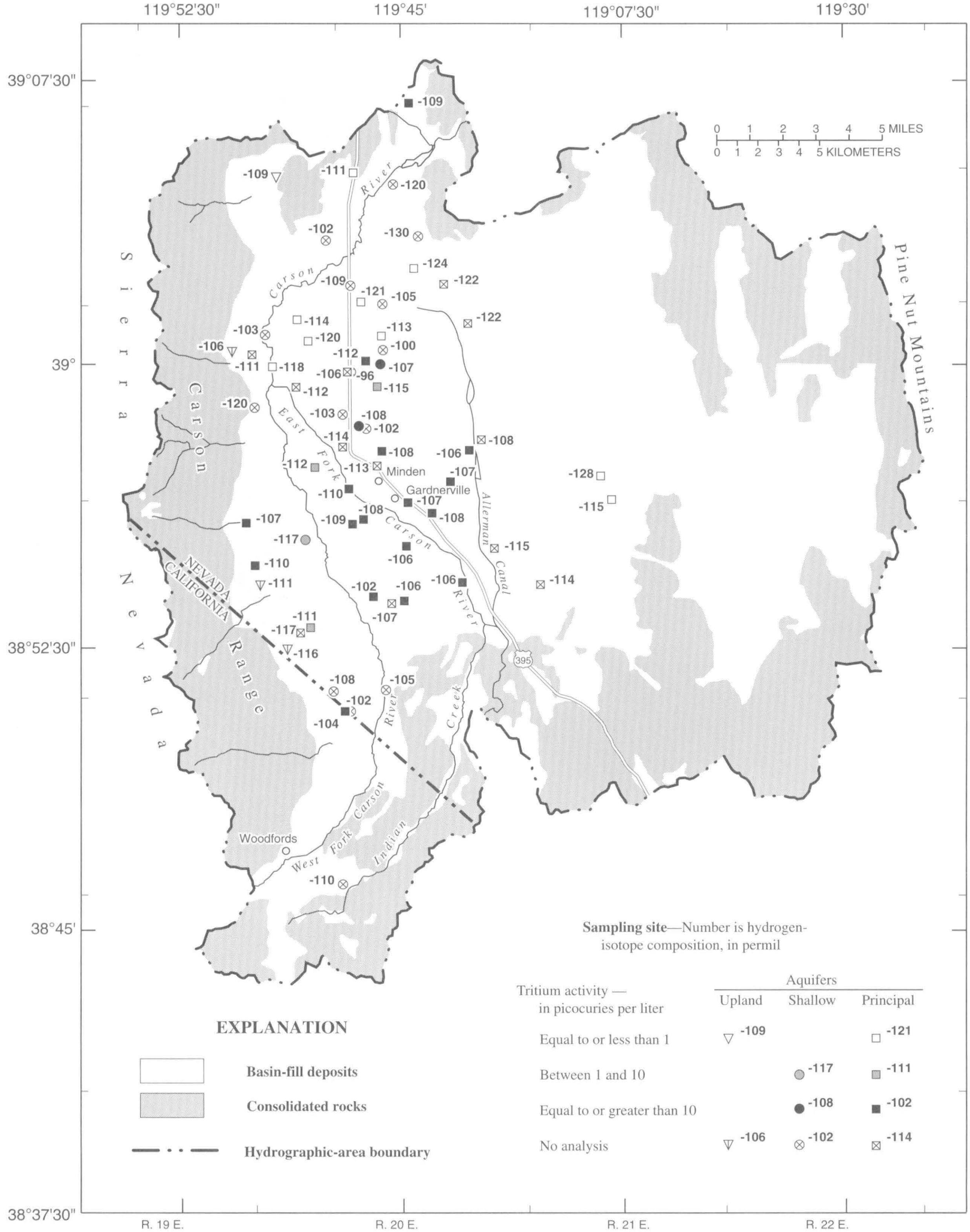
Hydrogeology of the Middle Carson River Basin

By **Donald H. Schaefer** *and* **James M. Thomas**

The Dayton Valley hydrographic area includes several basins extending from Eagle Valley to Churchill Valley (pl. 1). One of these is Carson Plains, a valley east of the town of Dayton. Carson Plains also includes a narrow strip of river flood plain and uplands of the Pine Nut Mountains south of Stagecoach Valley. Maximum thickness of basin-fill deposits, on the basis of geophysical modeling, is about 3,000 ft (Schaefer and Whitney, 1992).

A structural basin underlying Stagecoach Valley contains as much as 3,000 ft thickness of fill on the east side and as much as 1,000 ft on the west side (Schaefer and Whitney, 1992). Basin-fill deposits in Stagecoach Valley consist of poorly sorted deposits of alluvial fans and pediments extending from mountain fronts toward valley lowlands. Valley lowlands are underlain by fine playa deposits formed, at least in part, by lacustrine sediments of Pleistocene Lake Lahontan. Flood-plain deposits are restricted to a narrow strip south of and along the south bank of the Carson River.

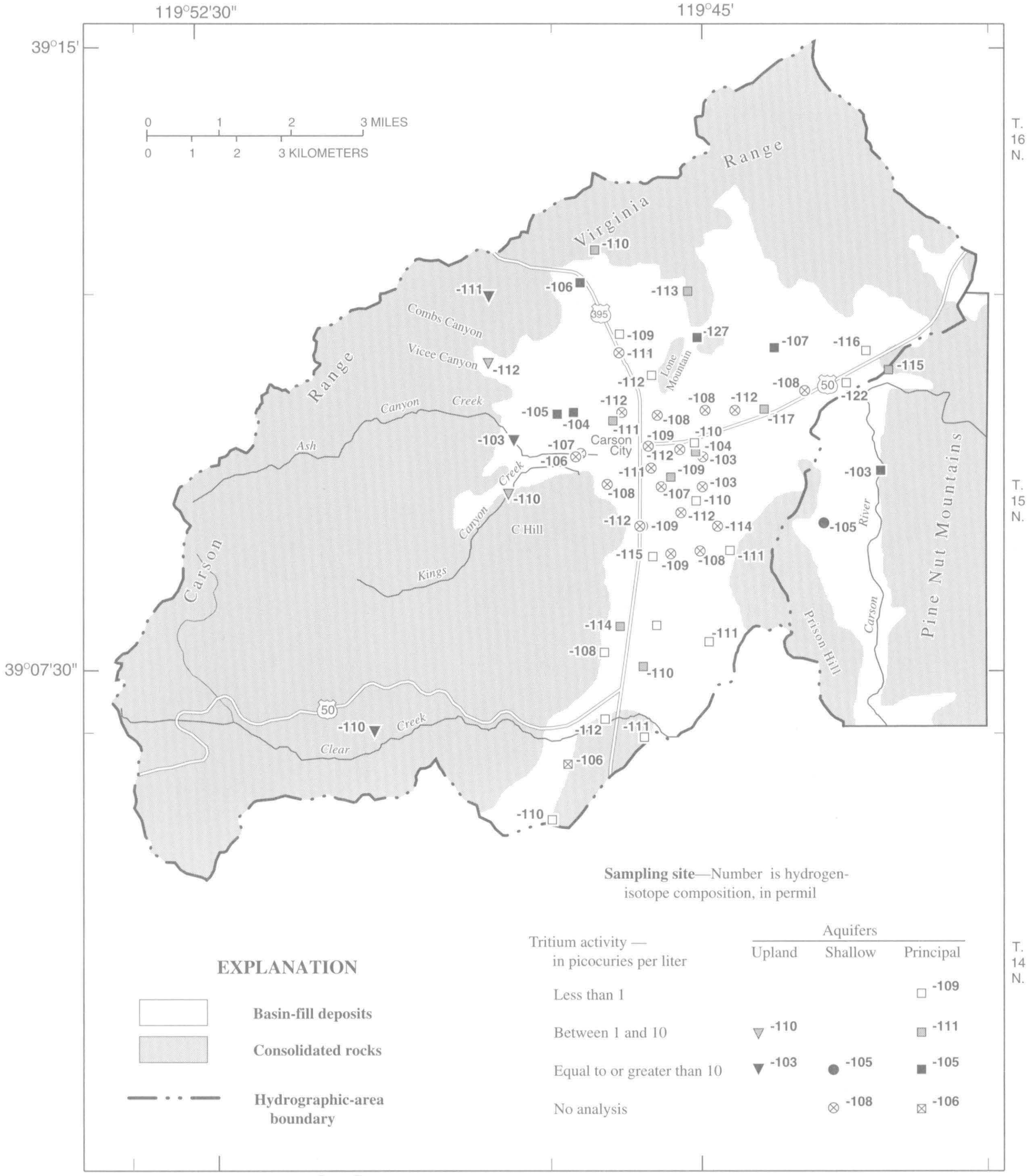
Depths to water in Carson Plains range from less than 20 ft near the Carson River to 100-200 ft on fan slopes away from the river (Glancy and Katzer, 1976,



Base from U.S. Geological Survey digital data, 1:100,000, 1985
Local Mercator projection
Central meridian -119°10', latitude of true scale 39°20'

Geology modified from Stewart and others (1982), and Greene and others (1991)

Figure 12. Hydrogen-isotope composition of ground water in Carson Valley, Nevada.



Base from U.S. Geological Survey digital data, 1:100,000, 1985
Local Mercator projection
Central meridian -119°10', latitude of true scale 39°20'

Geology modified from Greene and others (1991)

Figure 13. Hydrogen-isotope composition of ground water in Eagle Valley, Nevada.

p 104) Average depth to water is about 60 ft (Schaefer and Whitney, 1992) Ground water generally moves eastward through the valley, as shown by water-level contours (pl 1) Aquifers are recharged by precipitation in the Virginia Range and Pine Nut Mountains, and discharged by withdrawals from wells and evapotranspiration Shallow aquifers near the Carson River are recharged by diversions from the Carson River During high flow, the river also can be a source of recharge Discharge from shallow aquifers to the river probably occurs during some periods of low flow in the Carson River

Water levels in Stagecoach Valley indicate shallow ground water moves eastward and southward through basin-fill deposits (pl 1) Precipitation provides recharge in the Virginia Range to the north and by inflow from the Carson River flood plain in the east part of the Carson Plains Evidence for inflow is supported not only by contours of water-level altitudes in Stagecoach Valley, but also by stable-isotope composition of the ground water (Harrill and Preissler, 1994) Aquifers in Stagecoach Valley are discharged by pumping, evapotranspiration on the valley floor, outflow to the river through basin fill, and possible outflow to Churchill Valley through the alluvial divide separating the two valleys

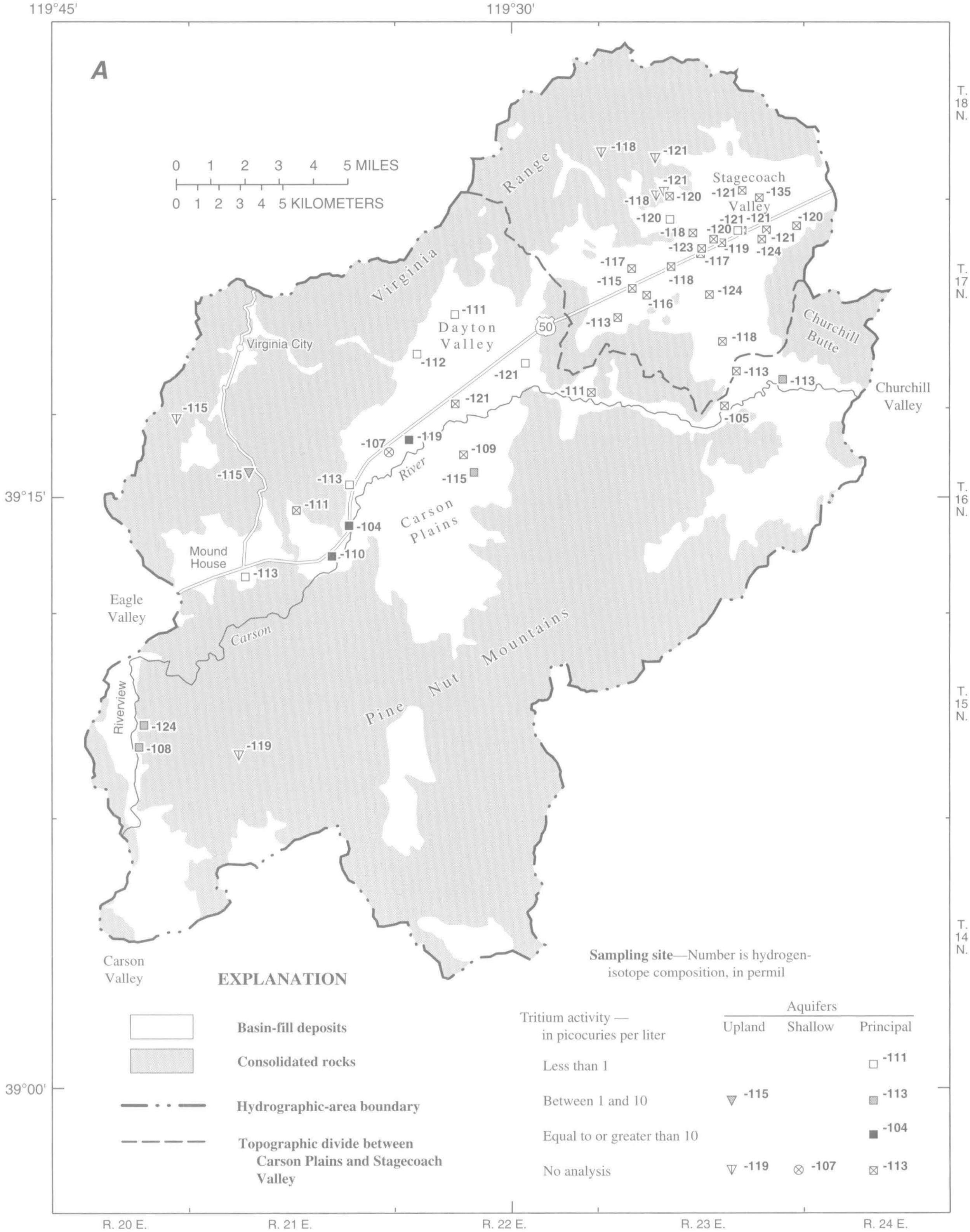
Churchill Valley trends northeast and is bounded by mountains (pl 1) The Carson River enters the west side of the valley south of Churchill Butte (fig 14*A*) Before the construction of Lahontan Dam, the river flowed out of the valley through a canyon, now buried, in the Dead Camel Mountains (fig 14*B*) Average annual flow of the Carson River into the valley was about 268,000 acre-ft/yr for 1911-90 (gaging station 10312000, Bostic and others, 1991, p 150) Another 145,000 acre-ft/yr was diverted into Lahontan Reservoir from the Truckee River by way of the Truckee Canal during 1966-90 (gaging station 10351400, Bostic and others, 1991, p 275)

Thicknesses of basin-fill deposits in Churchill Valley reach a maximum of about 2,900 ft, as shown by gravity and magnetic data (Schaefer and Whitney, 1992) Logs for two domestic wells in the northwest and north-central parts of the valley show depths to consolidated rock of 300 ft and 210 ft, respectively In addition, andesite crops out near the center of the valley On the basis of geophysical data, the andesite appears to cap metavolcanic and sedimentary rocks extending from Churchill Butte (Schaefer and Whitney, 1992)

Ground-water levels beneath Churchill Valley range from 20-50 ft or less below land surface near the shores of Lahontan Reservoir and the Carson River flood plain to more than 200 ft near the margins of the alley (Glancy and Katzer, 1976, p 105) Directions of ground-water movement are southward toward the river flood plain and eastward toward Lahontan Reservoir (pl 1, Schaefer and Whitney, 1992) that now covers much of an earlier flood plain Ground-water recharge to the valley is an estimated 1,300 acre-ft/yr (Glancy and Katzer, 1976, p 48) and comes from precipitation in surrounding mountains and infiltration from the river and reservoir Discharge of ground water is primarily by withdrawal from wells and evapotranspiration

On the basis of geographic location, stable hydrogen-isotope composition, and limited tritium analyses, ground water in principal aquifers of Dayton and Churchill Valleys can be separated into two groups One group consists of ground water in principal aquifers of Dayton and Churchill Valleys away from the river Ground water in this group has stable hydrogen-isotope compositions similar to ground water in adjacent mountains Tritium activities in ground-water samples were less than 1 pCi/L, except in a sample from one well in an alluvial fan in Dayton Valley (fig 14*A*) The other group, which has hydrogen-isotope compositions heavier than ground water in the adjacent principal aquifers (fig 15) and tritium activities greater than 1 pCi/L, is near the Carson River (fig 14) Because the hydrogen-isotope composition in this group is similar to the Carson River, or is between that of the Carson River and ground water in the adjacent principal aquifer, and because of the apparent relatively young age, a major source of recharge probably is the river This recharge can be either directly from the river, especially during high streamflow, or from diversions for irrigation Local subsurface flow of river water into principal aquifers in southwestern Stagecoach Valley also is indicated by general ground-water quality, water-level contours, and a water-budget imbalance (Harrill and others, 1992)

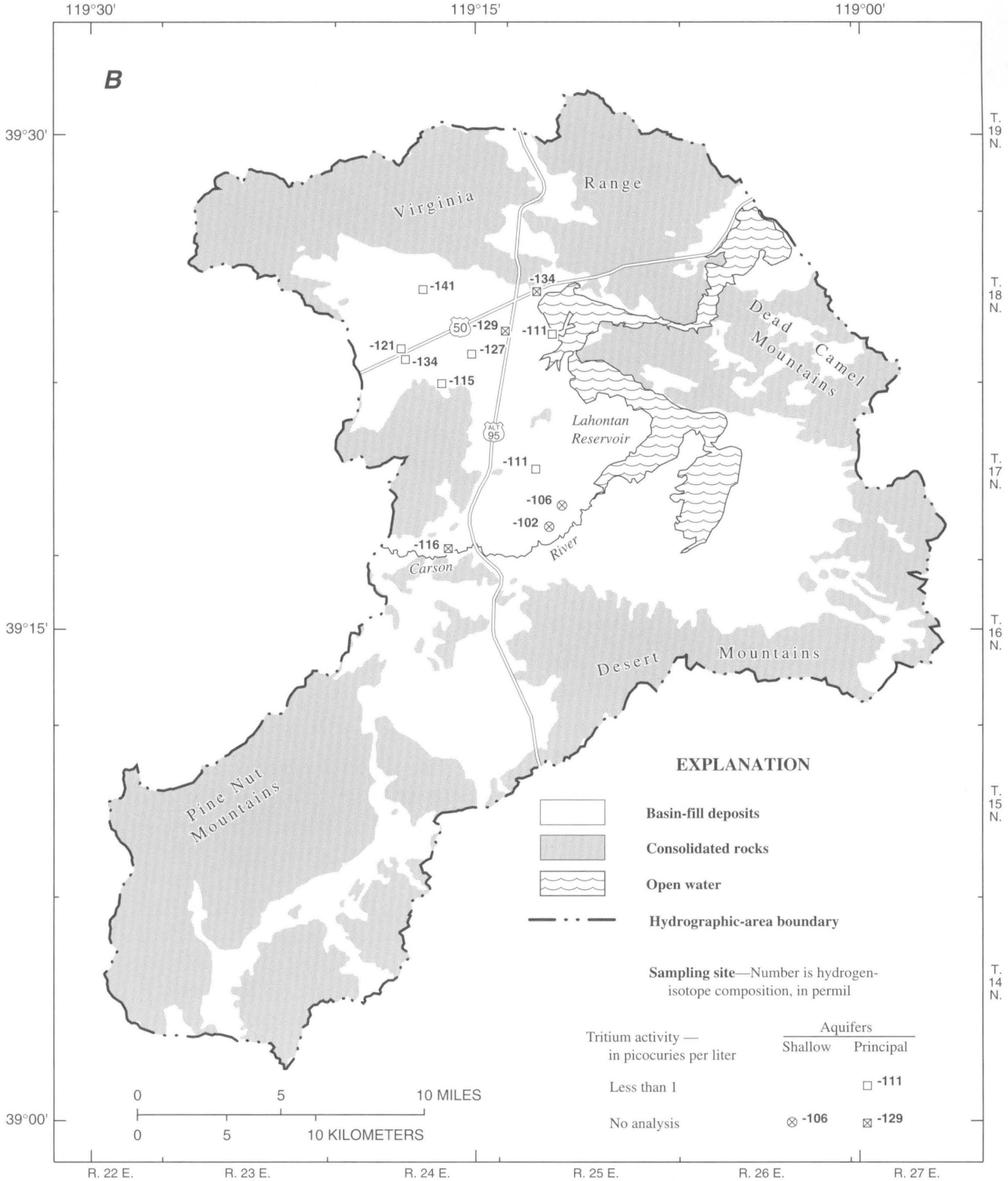
The hydrogen-isotope composition of ground water in principal aquifers away from the Carson River in Dayton and Churchill Valleys becomes distinctly heavier proceeding west (fig 16) Deuterium content of



Base from U.S. Geological Survey digital data, 1:100,000, 1985
Local Mercator projection
Central meridian -119°10', latitude of true scale 39°20'

Geology modified from Greene and others (1991)

Figure 14. Hydrogen-isotope composition of ground water in (*A*) Dayton and (*B*) Churchill Valleys, Nevada.



Base from U.S. Geological Survey digital data, 1:100,000, 1985
Local Mercator projection
Central meridian -119°10', latitude of true scale 39°20'

Geology modified from Greene and others (1991)

Figure 14. Continued.

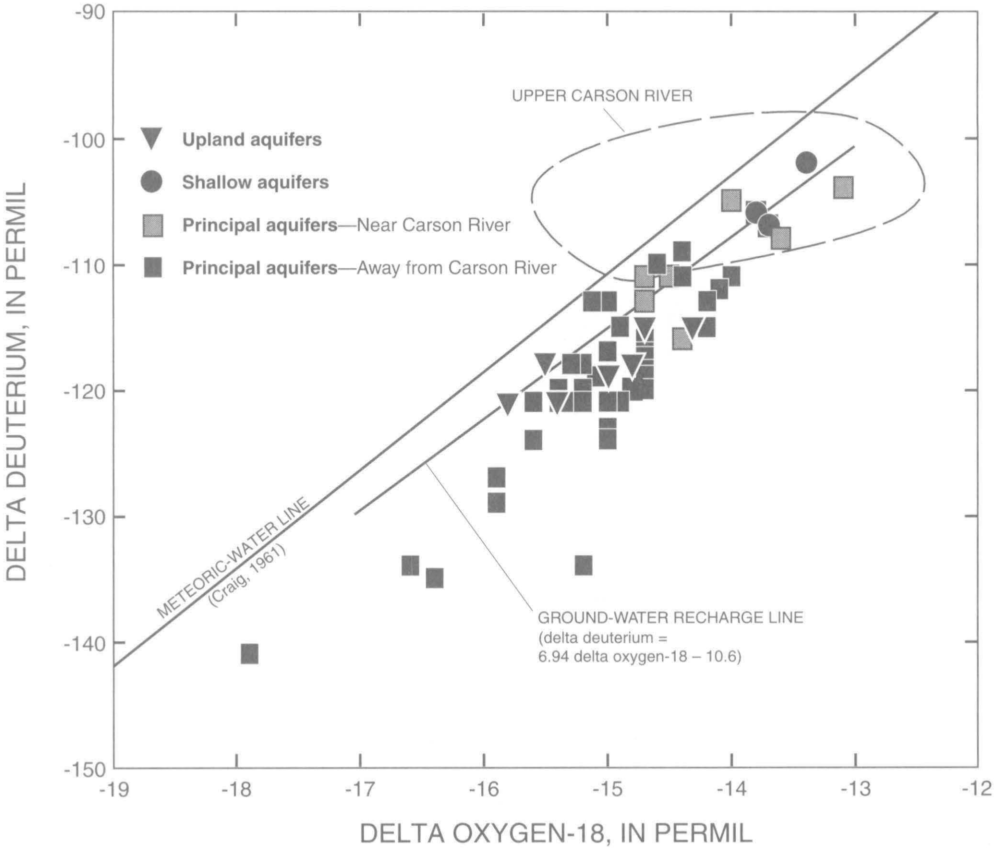


Figure 15. Relation between stable isotopes of hydrogen (delta deuterium) and oxygen in ground water of Dayton and Churchill Valleys, Nevada.

ground water in principal aquifers of Dayton and Stagecoach Valleys generally is similar to ground water in the adjacent Virginia Range and Pine Nut Mountains (fig. 14*A*). Due to a lack of available sampling sites, the stable-isotope composition of water in upland aquifers in Churchill Valley is not known. Primary sources of ground water in Churchill Valley north of the Carson River are precipitation on the Flowery Range to the north along with ground-water flow from Stagecoach Valley. Absence of tritium in wells in basin-fill aquifers away from the Carson River, suggests that the water was recharged more than 57 years ago. This conclusion is supported by the absence of irrigation away from the river, except limited irrigation by ground water in Stagecoach Valley (Welch and others, 1989).

Hydrogeology of the Lower Carson River Basin

By **Donald H. Schaefer** *and* **Michael S. Lico**

Carson Desert, the largest valley in the Carson River Basin, is elongate northeastward, and has a maximum length of about 70 mi and a maximum width of about 25 mi (pl. 1). The basin is the terminus of the Carson River, which enters the basin just below Lahontan Dam. Average flow of the river below the dam, including Truckee River water diverted to Lahontan Reservoir by way of the Truckee Canal, was about 390,000 acre-ft/yr for 1966-90 (gaging station 10312150; Bostic and others, 1991, p. 154). Most of the Carson River flow is diverted for irrigation in the Fallon area. The rest, along with irrigation returns, flows to sinks and lakes in the Desert. Carson Sink is a large salt flat during years of average or below-average precipitation, but during wet years it becomes a large shallow lake that receives water from the Carson River, from irrigation runoff, and by occasional overflow from the Humboldt River Basin north of the sink.

Carson Desert consists of several smaller structural basins, some of which are oriented along regional structural trends. Northern Carson Desert is underlain by a northeast-trending structural basin along the West Humboldt Range that is 6,000 ft deep, and by a north-trending trough along the Stillwater Range that is 12,000 ft deep. A northeast-trending bedrock high

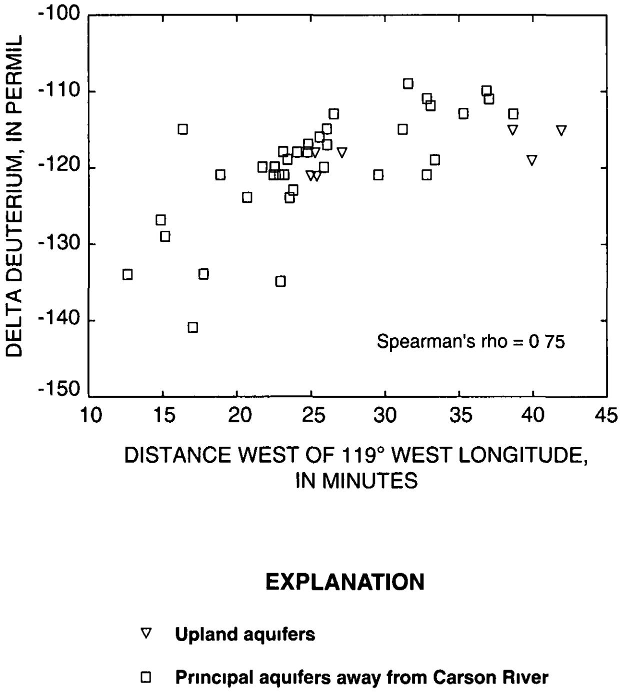


Figure 16. Relation between the hydrogen-isotope (delta deuterium) composition of ground water and longitude in Dayton and Churchill Valleys, Nevada

at a depth of about 2,000 ft separates the two smaller basins (Hastings, 1979, p 518) Unpublished gravity data indicate a deep basin underlying the southern part of the desert, where an exploration hole penetrated more than 8,000 ft of basin-fill deposits without reaching bedrock (Garside and others, 1988)

Lacustrine, fluvial, and wind-blown sediments and interbedded volcanic rocks form the basin-fill deposits beneath the desert. The upper 2,000-3,000 ft of the basin-fill deposits are mostly sediments and include lesser amounts of volcanic rocks Deeper parts of the basin-fill deposits have increasingly greater proportions of volcanic rocks (Franklin H Olmsted, U S Geological Survey, written commun , 1987)

The ground-water system in Carson Desert is the most complex in the Carson River Basin It has been investigated in the southern Carson Desert (Glancy, 1986) and in geothermal areas (Morgan, 1982, Olmsted and others, 1984, Olmsted, 1985) Shallow, intermediate, and deep alluvial aquifers and a basalt aquifer underlie the southern area (Glancy, 1986) The basalt aquifer is the source of water for the municipal water supply for Fallon and the Fallon Naval Air Station, shallow and intermediate aquifers provide water to domestic wells and to some irrigation wells

Discussion of the ground-water quality in Carson Desert is based on the aquifer designations of Glancy (1986) The shallow aquifer system includes ground water at depths less than 50 ft below land surface The intermediate aquifer system includes ground water in sediments at depths between 50 and about 320 ft below land surface The basalt aquifer crops out at Rattlesnake Hill The term "principal aquifers," when applied to the Carson Desert, refers to the intermediate and the basalt aquifer systems

Directions of ground-water flow in shallow aquifers generally are northeastward and eastward toward the Carson Sink (pl 1) Directions of movement in intermediate basin-fill aquifers are similar Flow directions in the basalt aquifer are uncertain because gradients are nearly horizontal (Glancy, 1986, p 15-16) Vertical gradients between the different aquifers indicate upward movement of ground water in some parts of the Carson Desert and downward movement in other parts (Glancy, 1986, p 27, 55) In addition, short-term reversals of vertical gradients in shallow aquifers have been documented (Olmsted, 1985, p 15-19)

Some important features of the ground-water system in southern Carson Desert are shown (view is to the north) in figure 17 Recharge under current conditions is supplied largely by seepage from irrigation canals, the Carson River and its distributary channels, and flood irrigation (Glancy, 1986, p 39) Other sources include locally ponded precipitation in low-lying areas after intense storms (Olmsted, 1985, p 25) and precipitation in mountains surrounding the basin Before irrigation, most recharge probably was supplied by subsurface flow from the Carson River At that time, the depth to the water table was greater in areas away from the river and in low-lying areas, such as Carson Lake Pre-irrigation measurements of depth to water (Stabler, 1904) and the altitude of water in Soda Lake (Rush, 1972) are consistent with this description

Ground-water flow in the basin-fill sediments is affected by laterally extensive lake deposits Fine-grained lake sediments retard vertical movement, except where subsequent erosion has cut through the deposits Channel deposits of the ancestral Carson River generally are more permeable than the enclosing sediments Greater permeability leads to greater ground-water flow, both vertical (fig 17) and horizontal, in these sediments Horizontal movement of ground water is greater in the basalt aquifer than in equivalent thicknesses of the surrounding sediments because of its greater hydraulic conductivity In general, hydraulic

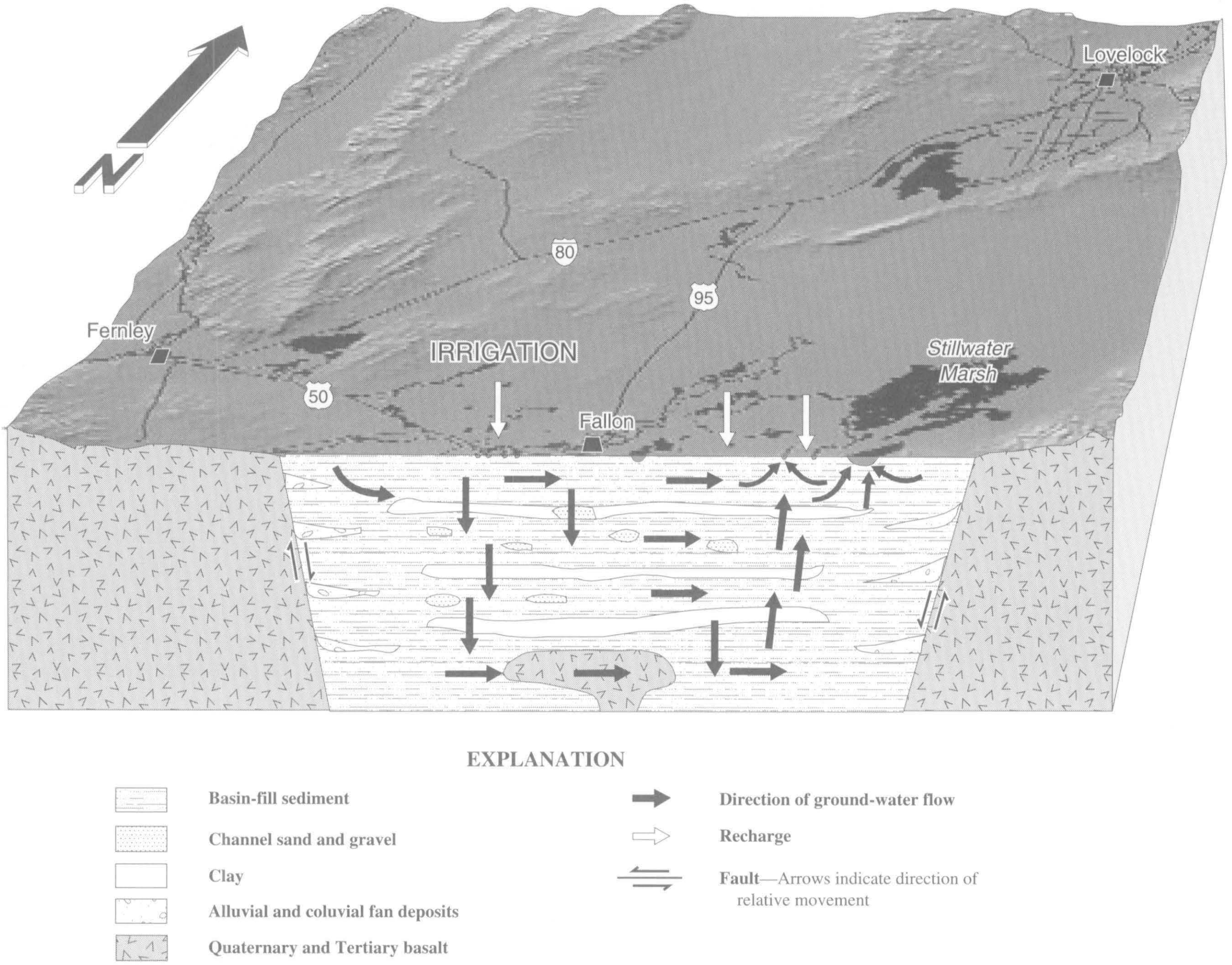


Figure 17. Schematic three-dimensional "block diagram" showing geology and ground-water flow in southern Carson Desert, Nevada.

heads decrease with depth in the recharge area to the west resulting in downward movement of ground water. In discharge areas, on the east side of the southern Carson Desert, ground water tends to move upward (fig. 17).

Irrigation drains and unlined canals control movement of ground water in shallow aquifers beneath irrigated areas (fig. 18). Flood irrigation and leakage from irrigation canals provide water to shallow aquifers. Water levels can rise to land surface during flood irrigation, then decline as water flows into drains that direct the water to Carson Pasture and Stillwater Marsh. Ground water in shallow aquifers is largely from surface sources, except in the low areas of intense evapotranspiration, such as Carson Lake and Stillwater Point Reservoir. Shallow aquifers beneath low areas receive flow from the underlying intermediate aquifers (fig. 17).

The stable-isotope composition of water in shallow aquifers is a result of the water's origin and subsequent isotopic fractionation caused by evaporation. The areal distribution of deuterium shows that less negative values (heavier water) correspond to areas where ground water discharges from shallow aquifers (fig. 19). The composition of this water (fig. 20) is a result of evaporation at the water table of water that moved upward from intermediate aquifers.

The diverse origins of the water result in different stable-isotope compositions. The water from the Carson and Truckee Rivers and water rising from

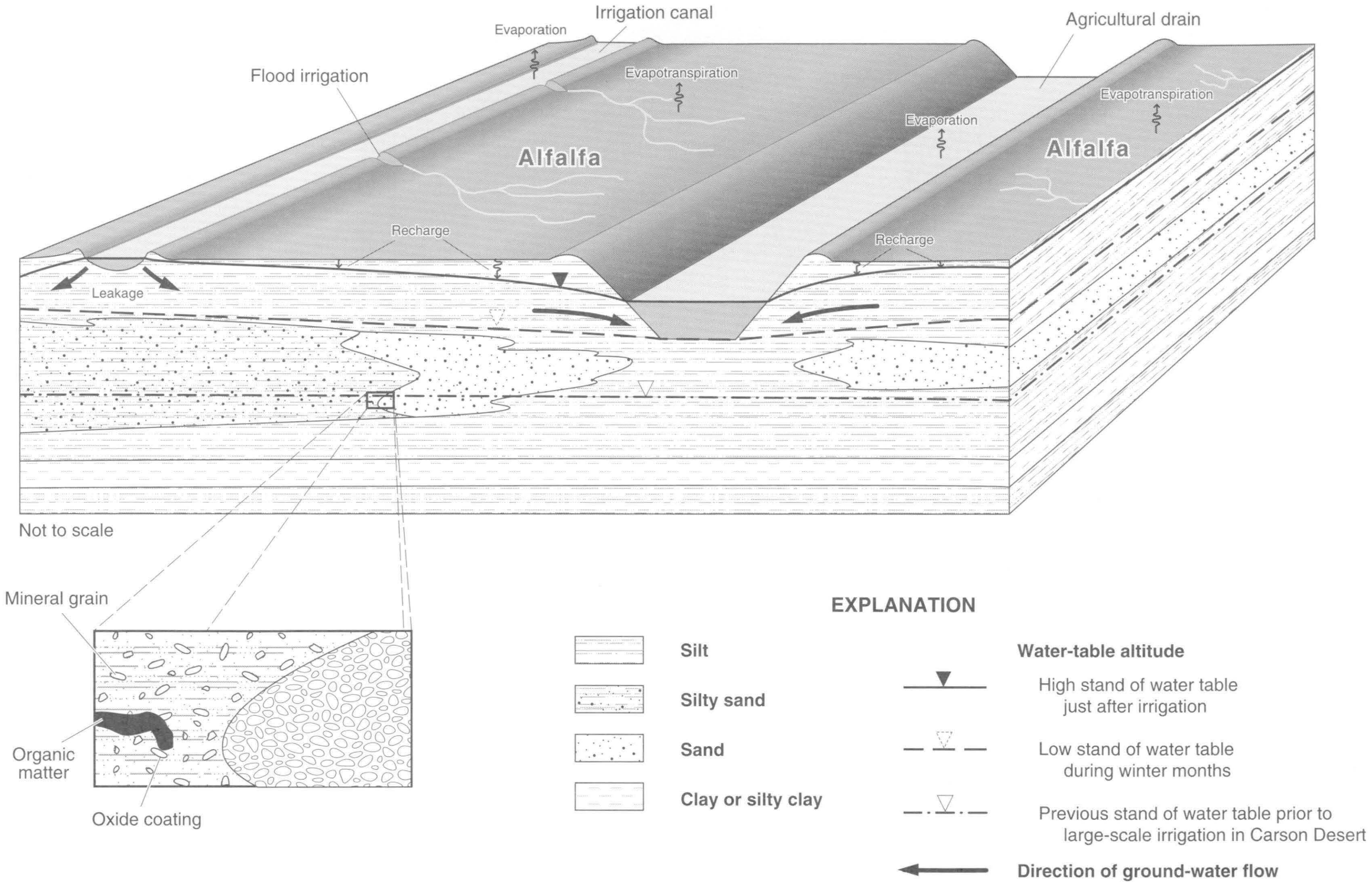


Figure 18. Schematic three-dimensional "block diagram" showing generalized hydrology and hydrogeologic processes affecting the chemistry of water in shallow aquifers of southern Carson Desert, Nevada.

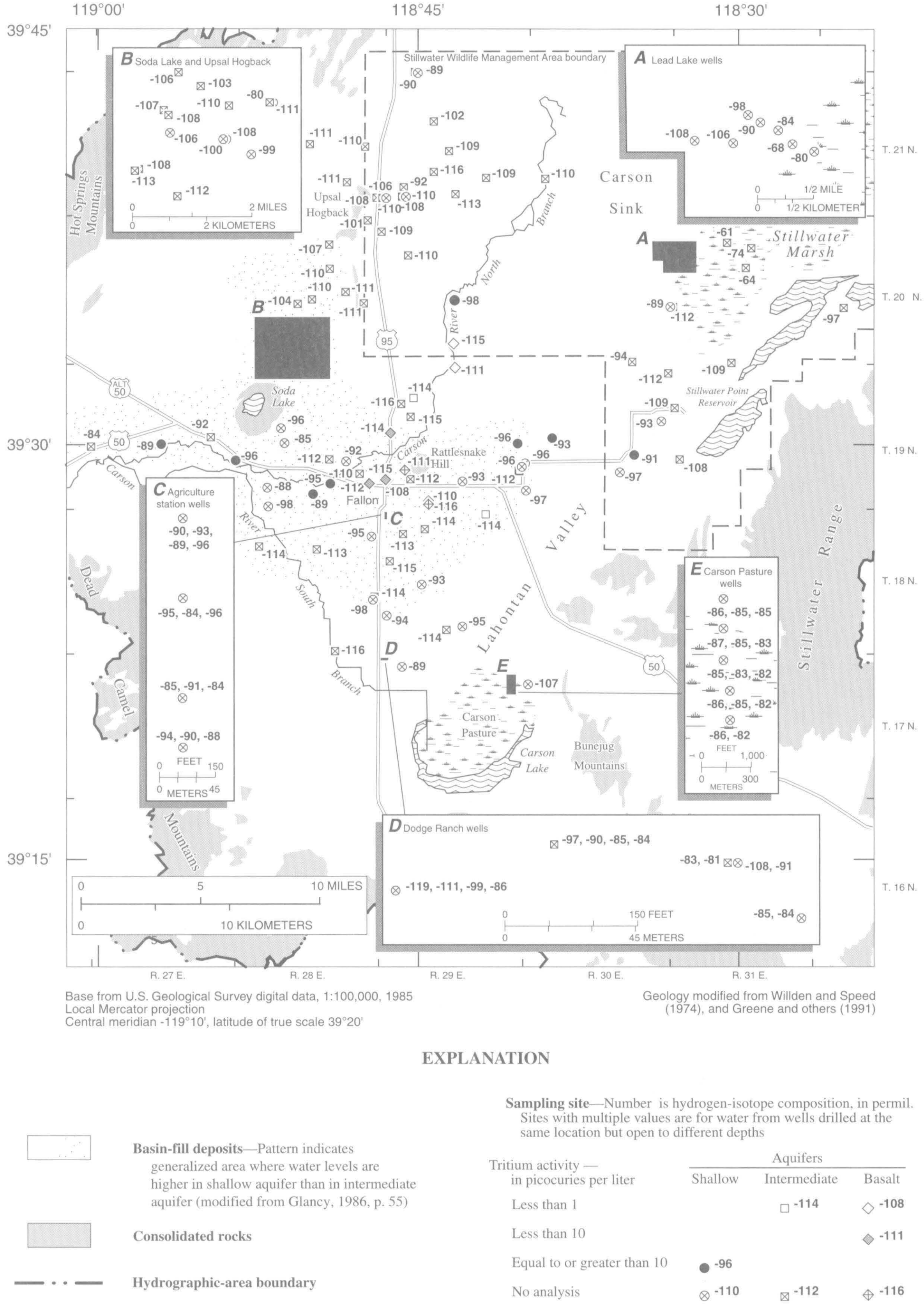


Figure 19. Hydrogen-isotope composition of ground water in southern Carson Desert, Nevada.

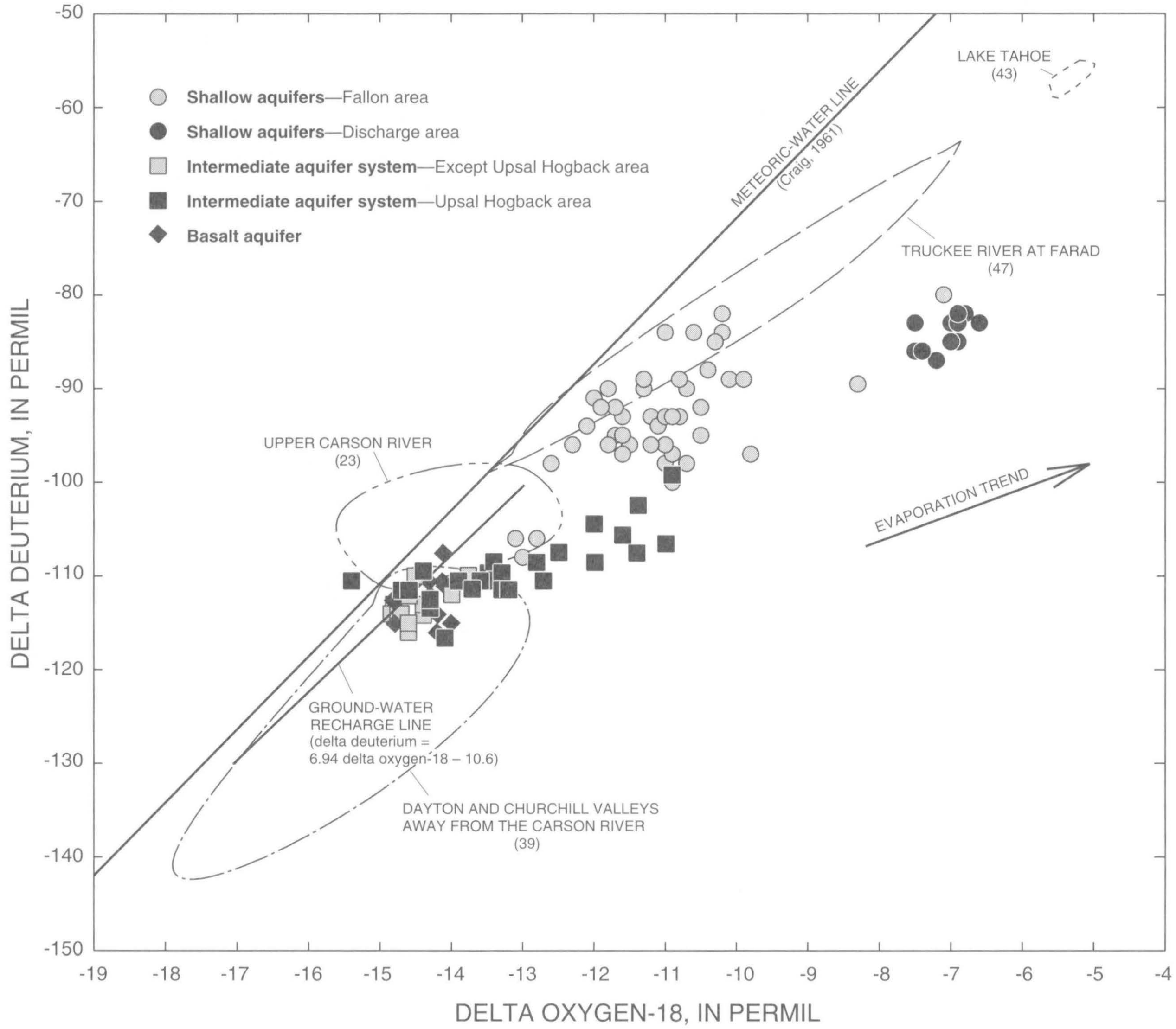


Figure 20. Relation between stable isotopes of hydrogen (delta deuterium) and oxygen in ground water of southern Carson Desert, Nevada. Value in parentheses is number of analyses enclosed by envelope.

intermediate aquifers is subsequently affected by evaporation. The composition of the irrigation water is not constant because it includes varying amounts and compositions of water diverted from the Carson and Truckee Rivers and undergoes varying degrees of evaporation before recharge. The measured range in composition of Carson and Truckee River water is shown in figure 20. Water in shallow aquifers beneath irrigated areas had tritium activities ranging from 39 to 93 pCi/L (table 5). These concentrations suggest recent recharge of surface water.

Most water in basalt and intermediate aquifers near Fallon is isotopically lighter than present-day Carson and Truckee Rivers. Thus, present-day river water alone cannot be the source of water in these aquifers. Recharge for the basalt and intermediate aquifers can be from several sources. Mixing of Carson River water with water having a lighter composition could produce the observed ground water. An isotopically lighter source of water is in Churchill Valley, where a hydrogen-isotope composition as light as -141 permil was measured in ground water (fig. 15). A mixture consisting of about 84 percent river water (with a hydrogen-isotope composition of -110 permil) and about 16 percent ground water (the lightest water measured in Churchill Valley) would have an isotopic composition of -115 permil. This is the approximate average composition of water in the basalt and intermediate aquifers.

Another possible source for water in the basalt and intermediate aquifers could be recharge during the Pleistocene age when Lake Lahontan last was present (about 4,000-7,000 years ago). Carbon-14 ages for water from some wells are old enough to support this origin, however, water in some wells is too young for this to be a realistic hypothesis. Water in the basalt and intermediate aquifers could be the result of recharge several hundred years ago when Carson River water was isotopically lighter. Several observations, including Pyramid Lake levels and cirque glacier reformation in the Sierra Nevada, suggest that the climate in the western United States was wetter and dominated by winter precipitation from 600 to 50 years ago (Davis, 1982, p. 68). Presumably, precipitation during this time was isotopically lighter and recharge rates higher than during the present because of large unrestricted flows in the Carson River. Carbon-14 ages for water in some wells suggest that the basalt and intermediate aquifers were recharged within the last several hundred years.

Unlike water in the basalt and intermediate aquifers near Fallon, water in intermediate aquifers near the Upsal Hogback area has been affected by evaporation (fig. 20). Prior to evaporation, the water probably had a stable-isotope composition similar to basalt aquifer water.

Six samples from wells tapping intermediate aquifers analyzed for tritium had activities less than 16 pCi/L, except for samples from two wells in the western Carson Desert (table 5). These two wells yield water that probably was recently recharged from shallow aquifers. Glancy (1986, p. 32) reported tritium activities of less than 0.3 pCi/L for samples from three wells tapping the intermediate aquifers near Fallon. The water from these three wells apparently was recharged more than 57 years ago.

Most samples from wells tapping the basalt aquifer analyzed for tritium had activities greater than 10 pCi/L, indicating ages of less than 38 years. Water from the basalt aquifer near the center of Fallon and at the Naval Air Station had tritium concentrations greater than 20 pCi/L (Glancy, 1986). For the basalt aquifer, this suggests recharge may be taking place near the center of Fallon and near Rattlesnake Hill, the only area where the basalt is exposed. Surface water from irrigation canals is the most likely source of recharge in this area. Recharge may be increased by pumping of wells completed in the basalt aquifer near Rattlesnake Hill. The pumping causes lower hydraulic heads in the basalt, which results in greater ground-water flow into the basalt aquifer.

WATER QUALITY AND AQUEOUS GEOCHEMISTRY

This section describes water quality of principal aquifers and the processes that produce the observed quality. Other aquifers, the Carson River, and the West Fork Carson River, are discussed primarily because they affect water quality in principal aquifers. For example, shallow and upland aquifers are described because they recharge principal aquifers.

Nevada State drinking-water standards (table 6) provide an appropriate reference for evaluating the quality of ground water. The standards, which apply to public water supplies, include primary maximum contaminant levels (MCL), secondary preferred standards (SPS), and secondary maximum contaminant levels (SMCL). MCL's were established because of human health concerns and specify enforceable maximum permissible levels of constituents in water delivered to the user of a public water-supply system. SPS's relate to the aesthetic quality of water and are intended to be guidelines within the State, they are not enforceable. The SPS's may be applied if levels are locally attainable—if not, SMCL's apply (Nevada Administrative Code, 1992, p. 3). The primary and secondary maximum contaminant levels were adopted, with the addition of a SMCL of 2 mg/L (milligrams per liter) for fluoride, by the State of Nevada from the U.S. Environmental Protection Agency's National Drinking Water Regulations (Nevada Administrative Code, 1992). Although a drinking-water standard has not been established for radon, the U.S. Environmental Protection Agency (1991) has proposed a MCL of 300 pCi/L. The proposed MCL for uranium is 20 µg/L and radium-226 and -228 each have a proposed standard of 20 pCi/L (U.S. Environmental Protection Agency, 1991).

Differences between MCL's and SMCL's can be illustrated by a comparison of arsenic, which has an MCL, with iron and manganese, which have SMCL's. The standard for arsenic was established because of scientific evidence that human health can be adversely affected by concentrations greater than the standard. In contrast, iron and manganese can stain clothes and plumbing fixtures when present in concentrations greater than the standards, but do not generally affect

Table 5 Carbon-13, carbon-14, and tritium in ground water of Carson Desert, Nevada

[Carbon-13 values relative to Peedee belemnite standard. Abbreviations: PMC, percent modern carbon, pCi/L, picocuries per liter, <, less than, --, no data, NA, not applicable]

Local number	Date	Carbon-13 (permil)	Carbon-14 (PMC)	Tritium (pCi/L)	Laboratory[1]
		Shallow aquifers			
N17 E29 05BCBB1	03-08-89	-14.0	--	70	DRI
N18 E28 30BDBA1	03-07-89	-11.6	--	51	DRI
N19 E28 23DCDB1	03-09-89	-11.3	--	42	DRI
N19 E28 30ADBC1	02-23-89	-12.0	--	93	DRI
N19 E29 25AADA1	04-19-89	-14.1	--	39	USGS
N19 E30 23DBCD1	08-30-89	--	--	44	USGS
N19 E30 30BBBA1	04-19-89	-13.4	--	55	USGS
		Intermediate aquifers			
N18 E29 02BADA1	04-28-89	-8.3	--	5	USGS
N18 E28 10CAAA1	01-27-89	-13.2	61	--	NA
N18 E28 23ADAA1	04-20-89	-8.5	41	--	NA
N18 E28 35CDBD1	04-18-89	-6.3	18	--	NA
N18 E29 05CCCB1	04-20-89	-10.7	62	--	NA
N18 E29 05DDAB1	03-08-89	-8.5	35	--	NA
N18 E29 18BAAD1	04-20-89	-8.8	40	--	NA
N18 E29 28DDCD1	04-21-89	-10.1	13	--	NA
N19 E27 13CCCB1	02-28-89	-11.0	90	67	DRI
N19 E27 19BCB 1	02-28-89	-12.2	85	90	DRI
N19 E28 24ADCC1	03-08-78	-11.0	62	< 3	USGS
N19 E28 24DABB1	03-08-78	-10.7	87	3	USGS
N19 E28 25BCDD1	03-07-89	-12.2	89	--	NA
N19 E29 07DAAD1	03-01-89	-11.4	69	--	NA
N19 E29 08DABC1	04-25-89	-9.9	18	< 3	USGS
N19 E29 17BABD1	05-31-89	-11.6	73	--	NA
N19 E29 29CACA1	02-22-89	-12.1	77	--	NA
		Basalt aquifer			
N19 E28 36AABC1	10-06-78	-10.0	40	8.4	USGS
N19 E29 18DCBB1	03-02-89	-8.4	36	--	NA
N19 E29 29BACB1	03-01-89	-9.1	43	14	DRI
N19 E29 30CBAD1	01-25-89	-9.5	51	15	USGS
N19 E29 30CDBC1	08-10-78	-9.4	53	26	USGS
N19 E29 30CDBC2	01-25-89	-9.6	52	15	USGS
N19 E29 33CBBC1	01-26-89	-9.2	45	14	USGS
N19 E29 33CBBB2	02-22-78	-8.9	51	22	USGS
N20 E29 34BBAC1	06-01-89	-8.2	15	--	NA
N20 E29 34CCDC1	07-19-78	-6.9	30	6	USGS

[1] Laboratories performing tritium analysis: DRI, Desert Research Institute, Reno, Nevada, USGS, U.S. Geological Survey, Arvada, Colorado

human health. Sources and possible effects, either health related or aesthetic, for several constituents in ground water of the Carson River Basin are listed in table 7. These constituents consistently exceed established or proposed drinking-water standards in ground water of the basin.

Some dissolved constituents reach concentrations that may impair use of the water, but do not have established or proposed drinking-water standards. Four minor constituents in this category within the Carson River Basin are boron, lithium, molybdenum, and vanadium. Concentration guidelines established for these elements in water for irrigation and livestock use are boron, 750 µg/L (U.S. Environmental Protection Agency, 1976), lithium, 100 µg/L (Hem, 1985, p. 134 and 216), molybdenum, 10 µg/L (Committee on Water Quality Criteria, 1973, p. 344), and vanadium, 100 µg/L (Committee on Water Quality Criteria, 1973, p. 345).

Table 6 Nevada State drinking-water standards for public water systems

[Unit of measure milligrams per liter, except as noted, --, standard does not exist for indicated constituent or property]

Constituent or property	Primary maximum contaminant level (MCL)[1]	Secondary maximum contaminant level (SMCL)[2]	Secondary preferred standard (SPS)[3]
Inorganic constituents and properties			
Arsenic	0 05	--	--
Barium	1 0	--	--
Cadmium	01	--	--
Chloride	--	400	250
Chromium	05	--	--
Copper	--	--	1 0
Fluoride	4 0	2 0	--
Iron	--	6	3
Lead	05	--	--
Magnesium	--	150	125
Manganese	--	1	05
Mercury	002	--	--
Nitrate (as N)	10	--	--
Selenium	01	--	--
Silver	05	--	--
Sulfate	--	500	250
Dissolved solids	--	1,000	500
Zinc	--	--	5 0
pH (units)	--	--	6 5-8 5
Organic compounds			
Benzene	0 005	--	--
Carbon tetrachloride	005	--	--
Endrin	0002	--	--
Lindane	004	--	--
Methoxychlor	1	--	--
Trichloroethylene	005	--	--
Toxaphene	005	--	--
Trihalomethanes (total)	1	--	--
Vinyl chloride	002	--	--
1,2-Dichloroethane	005	--	--
1,1-Dichloroethylene	007	--	--
1,4-Dichlorobenzene	075	--	--
1,1,1-Trichloroethane	2	--	--
2,4-Dichlorophenoxyacetic acid (2,4-D)	1	--	--
2,4,5-Trichlorophenoxypropionic acid (2,4,5-T)	01	--	--
Radionuclides			
Adjusted gross alpha (excluding radium-226, radon, and uranium), in picocuries per liter[4]	15	--	--
Gross beta, in millirems per year	4	--	--
Radium-226 and -228 (combined), in picocuries per liter	5	--	--
Radium-226, in picocuries per liter[4]	20	--	--
Radium-228, in picocuries per liter[4]	20	--	--
Radon-222, in picocuries per liter[4]	300	--	--
Uranium' in milligrams per liter[4]	02	--	--

[1] Primary maximum contaminant level (MCL's) are health related and State and Federally mandated Best available technology as determined by U S Environmental Protection Agency must be utilized to achieve these levels (JeffreyA Fontaine, Nevada Bureau of Consumer Health Protection Services, oral commun , 1989) MCL's are adopted by the Nevada Administrative code (1992) from the National Drinking Water Regulations (U S Environmental Protection Agency, 1986a, b)

[2] Secondary maximum contaminant levels (SMCL's) are based on aesthetic qualities and are enforceable by the State of Nevada (Nevada Administrative Code, 1992) Best available technology is determined by the State of Nevada (Jeffrey A Fontaine, Nevada Bureau of Consumer Health Protection Services, oral commun , 1989) SMCL's, except that for magnesium, are adopted from National Drinking Water Regulations (U S Environmental Protection Agency, 1986c, p 587–590) SMCL's have not been established by the State of Nevada for copper, pH, and zinc

[3] Secondary preferred standards (SPS's) must be met unless water of that quality is not attainable, in which case existing SMCL's must be met (Nevada Administrative Code, 1992)

[4] Standard has been proposed but not adopted as of 1993 (U S Environmental Protection Agency, 1991)

Table 7 Source and significance of selected constituents in ground water of Carson River Basin, Nevada and California

[Constituents having maximum contaminant levels (MCL's) are in **bold** letters and listed first, constituents and properties having secondary maximum contaminant levels (SMCL's) are nonbold, constituents having proposed U S Environmental Protection Agency MCL's are in *italics* (Contaminant levels for individual constituents and properties are listed in table 6) Modified from Nowlin (1982, table 2) and Garcia (1989, table 1) Abbreviation mg/L, milligrams per liter]

Constituent or property	Major source	Significance
Arsenic	Common in basin-fill aquifers derived from weathering of intermediate and acidic volcanic rocks (Welch and others, 1988, p 334)	Two chemical forms trivalent (arsenite) and pentavalent (arsenate) The former is more toxic Epidemiologic studies have shown that arsenic can cause a variety of chronic and acute health problems, including skin cancer
Fluoride	Dissolved in small amounts from most rocks and soils Also common to most thermal water Concentrations commonly exceed 2 mg/L in ground water having low concentrations of calcium Added to many public water supplies to inhibit dental caries	Concentrations between 0 6 and 1 7 mg/L may have beneficial effects on structure and resistance to decay of children's teeth Concentrations in excess of 4 mg/L may cause mottling and pitting of teeth
Nitrate	Sources include fixation of atmospheric nitrogen by plants, leaching of decaying organic matter, fertilizers, or industrial, agricultural, or domestic wastes	Concentrations exceeding 10 mg/L may cause infant methemoglobinemia (blue-baby syndrome) High concentrations may indicate contamination from one or more human sources
Chloride	Dissolved in differing amounts from all rocks and soils High concentrations may be derived from marine and desert evaporite minerals such as halite May be derived from salts used for control of ice on streets and highways May be concentrated by evapotranspiration	May make water corrosive Imparts salty taste at concentrations as low as 100 mg/L Chloride ion is very stable in ground water and is often used as a tracer of movement of wastes in aquifers
Dissolved solids	Sum of all minerals dissolved from rocks and soils High dissolved-solids concentration generally is a result of dissolution of evaporite minerals (such as halite or gypsum) or concentration by evaporation	General indicator of overall chemical concentration of water Imparts unpleasant taste to water when concentrations exceed standards Additional effects on water uses depend on concentrations of individual constituents
Iron	Dissolved from iron minerals present in most rocks and soils Found in some industrial wastes, and can be corroded from pipes, well casings, pumps, and other equipment Also can be concentrated in wells and springs by certain bacteria	Oxidizes to a reddish-brown precipitate Stains utensils, enamelware, clothing, and plumbing fixtures May be objectionable for food and beverage processing because of taste and odor problems
Manganese	Dissolved from rocks, soils, and lake-bottom sediments Generally associated with iron	Oxidizes to form a dark brown or black precipitate Problems similar to those cause by iron
Sulfate	Dissolution of sulfate minerals such as gypsum, and sulfide minerals such as pyrite May be concentrated by evapotranspiration	Forms boiler scale in combination with calcium Causes bitter taste when combined in high concentrations with other ions, and may have laxative effects when first ingested in higher concentrations than those to which an individual is accustomed
Uranium	Dissolution of acidic plutonic rocks, sedimentary organic matter, and iron oxide	Chemical toxicity can cause kidney failure
Radon-222	Natural radionuclide in the uranium-decay chain	Rapidly volatilizes from ground water when it is exposed to atmosphere Inhalation may cause lung cancer

Water-Quality Data and Statistical Analysis

By **Alan H Welch**

The general chemical ionic composition, discharge or pH, and dissolved-solid concentrations of the Carson River are displayed in a five-field diagram in figure 21 One use of this diagram is to examine where data points tend to group in each of five individual triangular and rectangular areas Each chemical analysis is plotted as five points on the diagram and together they provide a broad visualization of the chemical composition of the water Relative proportions of major cations (calcium, magnesium, and sodium plus potassium) and major anions (carbonate plus bicarbonate, sulfate, and chloride) are shown on the left and upper triangles, respectively Dissolved-solids concentrations and discharge are plotted in the right and bottom rectangles, respectively Arrows in figure 21 show how cation and anion points for a single

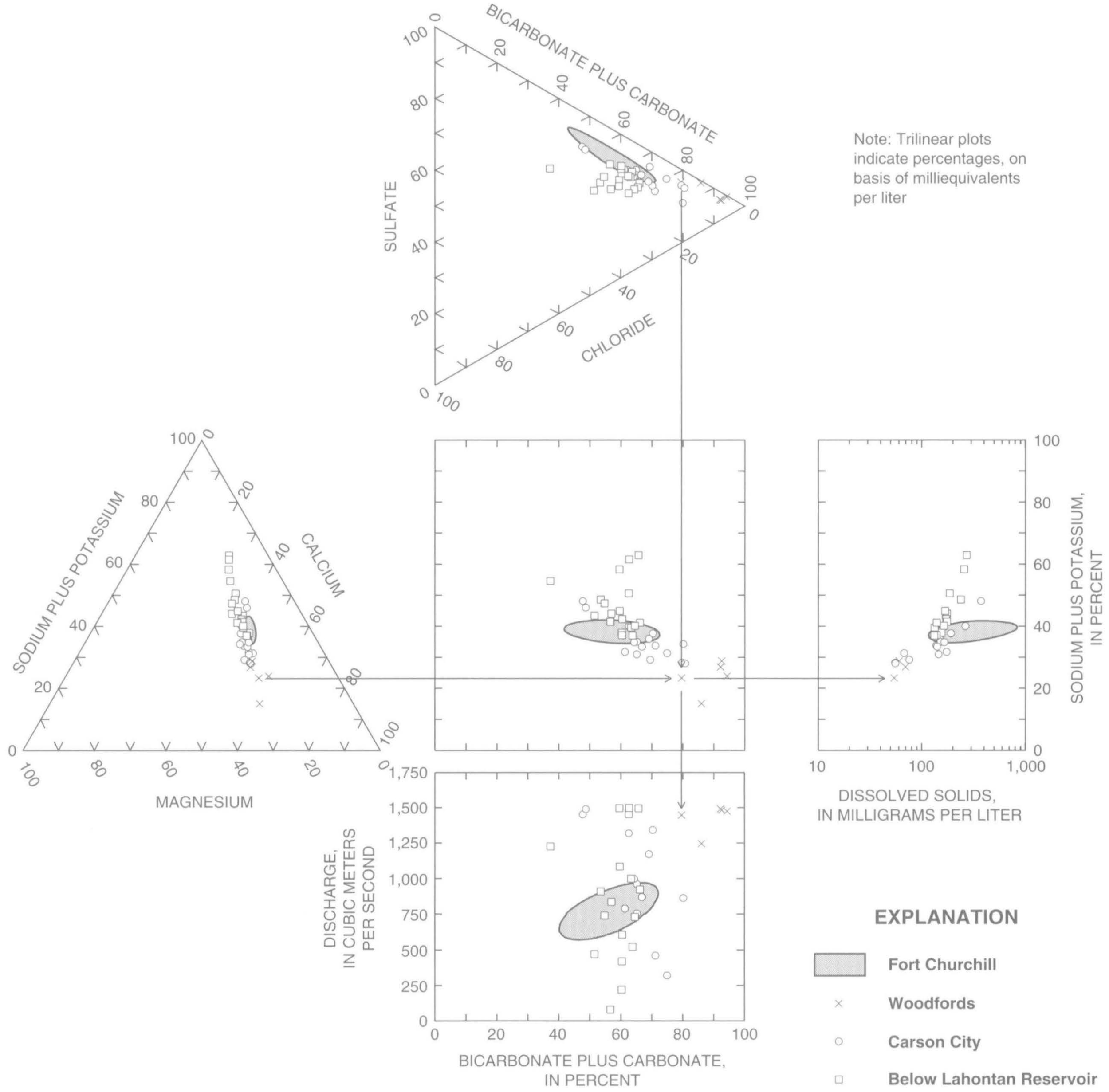


Figure 21. General chemical composition and discharge of Carson River and West Fork Carson River, Nevada and California. Envelope boundaries are derived by polar smoothing routines and encompass 50 percent of data. Arrows show projection scheme for individual chemical analysis.

analysis are projected from triangles to a central square and two rectangles. The central square functions primarily as a transitional area to connect the four outside plots. Where abundant data results in crowding, distinguishing the individual symbols is difficult. Where crowding is a problem, fields enclosing either 50 or 75 percent of the data are shown. These "envelopes" are defined by using polar-smoothing routines (Dennis Helsel, U.S. Geological Survey, written commun., 1992).

Boxplots, like those in figure 22, are used to display summary statistics regarding the distribution of reported concentrations for selected constituents. Statistical components are represented visually by features known as "boxes" and "whiskers," the box defines the spread of the middle 50 percent of the data (concentrations that lie between the 25th and 75th percentiles). A median value (the 50th percentile) is shown by a horizontal line within the box. Whiskers are vertical lines that extend from the ends of the box to the maximum and minimum values. Modified trilinear diagrams and boxplots are used to display a large number of data points in this report.

Bar graphs, such as figure 29, show frequencies with which data for selected constituents exceed primary and secondary drinking-water standards. Generally, constituents are shown only when more than 2 percent of the data exceed a standard.

Nonparametric statistics are included in this report because water quality and other environmental data commonly do not (or cannot be proved to) fit some common distribution. Additionally, extreme values are common, distorting the true central tendency of the data and making parametric statistics invalid. Nonparametric approaches use data ranks rather than actual values. Nonparametric approaches are only slightly less efficient than parametric tests when data are normally distributed and are more efficient when data are not normally distributed (Hollander and Wolfe, 1973, p. 1).

For a comparison of ranks, the Mann-Whitney test (Conover, 1980, p. 216) is used. The statistical difference between mean ranks of selected constituents is estimated by this method for (1) the different aquifers, (2) the upper, middle, and lower Carson River Basin, and (3) shallow ground water beneath agricultural and urban land.

A chi-square test for differences in probabilities (Conover, 1980, p. 145) is used to evaluate whether a significant proportion of samples from an aquifer have concentrations above a drinking-water standard. The test also is used to determine whether minor constituents are more commonly above laboratory reporting limits in one group of samples than in another.

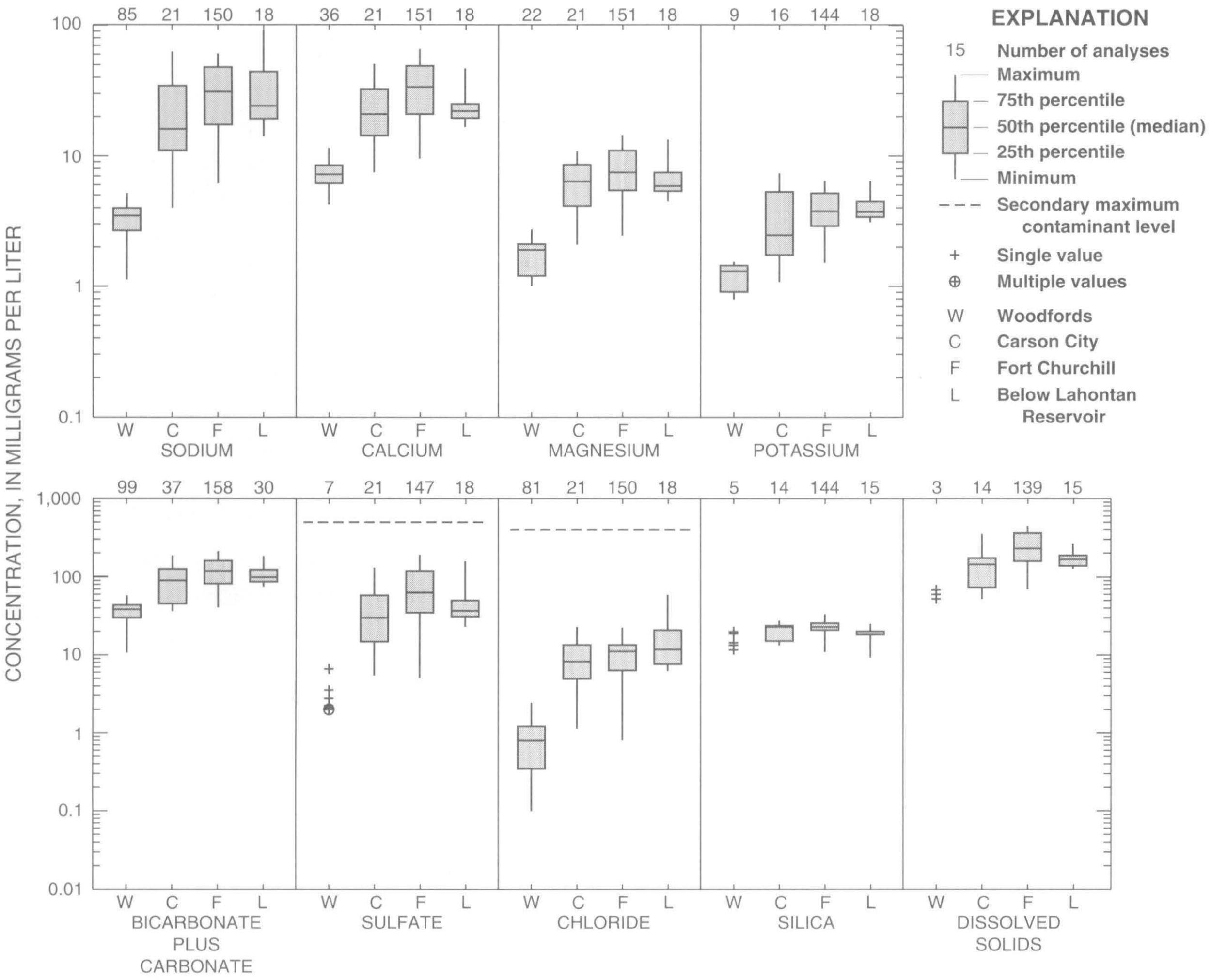


Figure 22. Summary statistics for major constituents at four Carson River and West Fork Carson River sites, Nevada and California.

The Mann-Whitney and chi-square tests yield a test statistic called a "p-value " For purposes of this report, the following terms describe significance for a range in the p-value highly significant, p less than or equal to 0 01, significant, p greater than 0 01 and less than or equal to 0 05, and not significant, p greater than 0 05 A confidence level is equal to 1 00 minus the p-value and is expressed as a percent For example, a p-value of 0 05 is equal to a 95-percent confidence level

A tendency for the concentration of one constituent to correspond to an increase or decrease in the concentration of another is evaluated using a statistic called "Spearman's rho" (Iman and Conover, 1983, p 126-129) For purposes of this report, the following terms describe the correlation between two constituents based on a range in absolute magnitude of Spearman's rho very strongly correlated, greater than or equal to 0 90, strongly correlated, 0 75 to less than 0 90, moderately correlated, 0 50 to less than 0 75, weakly correlated, 0 25 to less than 0 50, and not correlated, less than 0 25 For example, a Spearman's rho of 0 55 describes a moderate correlation Negative values indicate that one variable tends to decrease as a second variable increases A Spearman's rho is reported only for relations valid at the 95th-percent confidence level or greater (p-value less than or equal to 0 05)

Surface-Water Quality

***By* James M Thomas**

This section describes water quality of the main stem and West Fork of the Carson River The quality of this water is important because it is a source of recharge to the ground-water flow system Data collection sites with major-ion analyses used to describe water quality of the river are the West Fork at Woodfords near Carson City (where the river exits Carson Valley) above Lahontan Reservoir in Churchill Valley, and the Carson River and below Lahontan Reservoir (where it enters Carson Desert, fig 1) Comparisons of median concentrations (fig 22) and ranks (table 8) of major constituents show changes along the river Ranks also were compared after removing data for samples collected during periods of highest and lowest flow (the upper and lower 10-percent durations) Relations suggested by table 8, with the few exceptions noted in the table, are similar when data collected during periods of highest and lowest flow are excluded

Calcium and bicarbonate are the dominant ions in the dilute water of the West Fork Carson River at Woodfords (fig 21), where relative proportions of major ions generally are independent of flow Concentrations of the major constituents increase downstream from Woodfords (fig 22, table 8) The West and East Forks are the principal sources of irrigation water in Carson Valley Consequently, the river system is an important source of recharge to shallow aquifers Proportions of sodium, sulfate, and chloride are greater where the main stem passes Carson City (fig 21) Major constituents, except for chloride and silica, become even more concentrated as the river flows past Fort Churchill Sulfate contributes an increased proportion of the total anion concentration beyond Fort Churchill These changes in the water quality are

Table 8 Statistical comparison of ranked concentrations of major constituents in samples from the Carson River and West Fork Carson River, Nevada and California

[Constituents in **bold** and nonbold have, respectively, higher and lower ranked concentrations in more downstream part of basin, p-values determined by Mann-Whitney method (Conover, 1980, p 216) Symbol --, no constituent]

Location	Highly significant (p less than 0 01)	Significant (p less than or equal to 0 05 and greater than 0 01)	Not significant (p greater than 0 05)
Woodfords compared with Carson City	**Calcium, magnesium, sodium, potassium, chloride, sulfate, bicarbonate**	**Silica**[1]**, dissolved solids** [2]	--
Carson City compared with Fort Churchill	**Calcium, sulfate, bicarbonate, dissolved solids** [3]	**Magnesium, sodium**[1]**, potassium**[3]	Chloride, silica
Fort Churchill compared with below Lahontan Reservoir	Calcium, silica	Magnesium, **chloride**, sulfate[1], dissolved solids[1]	Sodium, potassium[1], bicarbonate

[1] Highly significant with data for highest and lowest flows (upper and lower 10-percent durations) removed

[2] Not significant with data for highest and lowest flows (upper and lower 10-percent durations) removed

[3] Significant with data for highest and lowest flows (upper and lower 10-percent durations) removed

most likely caused by return of irrigation water diverted from the river, evapotranspiration, and inflow of ground water

For most major constituents, the trend toward increasing concentration reverses at the site below Lahontan Reservoir Except chloride, all major constituents have median values lower than or similar to those for the river near Fort Churchill, and the spread of the middle 50 percent of the data is less (fig 22) This reversal probably is due to contributions of Truckee River water to Lahontan Reservoir by way of the Truckee Canal Much of the water passing Lahontan Dam is used for irrigation that recharges shallow aquifers in Carson Desert

Ground-Water Quality

***By* Alan H Welch**

This section includes discussions of the major inorganic constituents, minor inorganic constituents, radionuclides, and synthetic organic compounds in the ground water, and processes producing concentrations of the different constituents In this report, the major inorganic constituents are those that make up 98 percent or more of the total solute mass Minor inorganic constituents generally are present at concentrations less than 1 mg/L

Most data used to describe ground-water quality were collected as part of the NAWQA pilot program Other sources of data include inorganic chemical analyses of water from springs in the Carson Range (Feth and others, 1964), and inorganic chemical and tritium analyses of ground water in Eagle Valley (Szecsody and others, 1983) Data collected for monitoring ground-water quality in Carson Valley (Garcia, 1989, Thodal, 1992), for a study of irrigation drainage in Carson Desert (Rowe and others, 1991, Lico, 1992), and for a study of ground water beneath the southern Carson Desert (Glancy, 1986) also are used

A comprehensive description of regional ground-water quality can be made only if an adequate number and distribution, both areally and vertically, of chemical analyses are available General characterization of regional ground-water quality is usually constrained by the areal and vertical distribution of the sample sites Limited access for sampling, however, commonly results in an uneven distribution of sampled sites In the Carson River Basin, samples from only 39 upland aquifer sites were collected In contrast, analyses of water from shallow and principal aquifers are available for about 160 and 230 sites, respectively

A second constraint results from the water uses Wells tapping principal aquifers generally are used for drinking water or irrigation The selection of these wells may result in a biased sample population because wells drilled for public water supply that yield poor-quality water commonly are abandoned Consequently, the selection may result in a greater percentage of samples that meet the drinking-water standards than is truly representative of the entire aquifer system

Wells tapping principal aquifers also have variable open intervals or an annulus filled with gravel Different well construction means that some wells can produce water from an interval of 100 ft or more and others may produce water from an interval of 30 ft or less Most wells tapping principal aquifers are water-supply wells used primarily for domestic, municipal, and irrigation purposes Generally, these wells have open intervals within the most productive parts of the aquifer Consequently, the water quality of finer grained, less productive parts of principal aquifers, is probably not well represented The wells available for sampling tap only the upper part of the principal aquifer and generally are less than 400 ft deep, whereas the basin-fill deposits locally have thicknesses of 5,000 ft or more Because of these limitations, the data for principal aquifers are more representative of ground water used for public supply than of all ground water in the basin

Methods of Sample Collection and Data Compilation

***By* Alan H Welch**

Data collection required site selection, well pumping, sample collection, and measurement of unstable constituents Laboratory analyses were for a wide range of organic and inorganic constituents and isotopes Field and laboratory data, along with basic information on the wells, is included in a report by Whitney (1994) Surface-water samples were analyzed by U S Geological Survey laboratories Methods of sample collection are described by Garcia and others (1992)

About 30 wells tapping principal and upland aquifers in four areas were sampled as part of the NAWQA pilot project These areas are Carson Valley, Eagle Valley, the middle basin (Dayton and Churchill Valleys), and Carson Desert The wells are located throughout the valleys from which most of the ground water is withdrawn

Shallow wells were drilled for sampling the upper part of shallow aquifers using protocols described by Hardy and others (1989). Most shallow wells were drilled to depths less than 30 ft and completed within 20 ft beneath the shallow water table. Because agriculture is a major land use, 30 wells were drilled in agricultural areas throughout the basin. The wells were sited using a program written by Scott (1990) to ensure random distribution and geographic coverage of the basin. Closely spaced, shallow wells also were drilled in three agricultural areas and in the urban part of Carson City.

Most wells were drilled with a hollow-stem auger using a nationally consistent NAWQA quality-assurance plan (Mattraw and others, 1989). Cores of aquifer material were collected at the depth of screen placement for analysis of the solid phase. Minerals forming shallow sediments were identified using a petrographic microscope and X-ray diffraction. A total of 372 shallow soil samples was collected at the drilled sites and other sites throughout Carson Desert. Chemical analyses of these samples are reported by Tidball and others (1991).

Ground-water samples were collected using methods and protocols described by Hardy and others (1989). The procedures specify that wells be pumped with a positive-displacement pump until several monitored properties (pH, specific conductance, temperature, and dissolved oxygen) are constant before the sample is collected. Most constituents were analyzed by the U.S. Geological Survey National Water Quality Laboratory (NWQL) in Arvada, Colo. Radionuclides (except radon-222) and stable isotopes of carbon and sulfur were analyzed by a contractor to the NWQL, and stable isotopes of water were analyzed by the U.S. Geological Survey laboratory in Menlo Park, Calif. Tritium was analyzed at two different laboratories (Desert Research Institute laboratory in Reno, Nev., and the University of Miami through a contract to the U.S. Geological Survey). Methods of analysis are described by Fishman and Friedman (1985), Thatcher and others (1977), and Wershaw and others (1987).

Compiled water-quality data for the Carson River Basin include multiple analyses of some wells and springs. To avoid bias toward repeatedly sampled sites, only the most recent analyses are used in the spatial description of ground-water quality. The most recent analyses (most of which are for samples collected since 1985) are used because analytical precision and accuracy generally are improved in comparison to older analyses.

Major-ion analyses were eliminated from the data set if the absolute value of the difference between the milliequivalents of the cations and anions divided by the sum of the two is greater than 10 percent.

Different aspects of ground-water quality in the area are displayed on graphic plots. Depending on the hydrographic area, the illustrations include (1) maps that show all sampling sites and highlight those where concentrations of selected constituents exceed the Nevada State drinking-water standards, (2) a diagram showing the general chemical composition of the water, (3) a bar graph showing percentages of samples that exceed selected Nevada State drinking-water standards, and (4) boxplots showing the statistical distribution of concentrations or activities.

Concentrations of Major Constituents

By Michael S. Lico

This section describes the concentrations of major constituents in ground water of the Carson River Basin. Comparisons between median concentrations of major constituents in individual valleys and aquifer systems are given. The quality of ground water also is compared to current Nevada State drinking water standards.

The chemical composition of ground water in principal aquifers beneath Carson and Eagle Valleys is dominated by calcium, sodium plus potassium, and bicarbonate (fig. 23*A*). Dissolved-solids concentrations generally are less than 300 mg/L and pH values generally are between 7 and 8. Chloride concentrations typically are less than 10 mg/L, corresponding to the relatively dilute composition of the water (fig. 24*A*).

All major constituents except potassium have lower median and ranked concentrations in water from upland aquifers than from principal aquifers (table 9, fig. 24*A*). Lower concentrations are consistent with the upland aquifers as a source of recharge to principal aquifers. Additionally, many samples were collected in areas underlain by granitic rocks, which generally yield water with lower dissolved-solids concentrations.

Ground water in shallow aquifers beneath Carson and Eagle Valleys has a wider range of dissolved solids and ionic compositions than water in principal aquifers. Most water in shallow aquifers is dominated by sodium plus potassium, calcium, and bicarbonate (fig. 23*B*). Dissolved-solids concentrations generally range from 300 to 600 mg/L and pH values generally are near 7. Much of the shallow ground water in Carson Valley is recharged by irrigation. Carson River is the

Table 9. Statistical comparison of ranked concentrations of major constituents in water from principal aquifers and water from upland and shallow aquifers of Carson River Basin, Nevada and California

[Constituents in **bold** and nonbold have, respectively, higher and lower ranked concentrations in principal aquifers; p-values determined by Mann-Whitney method (Conover, 1980, p. 216). Symbol: --, no constituent]

Location	Aquifer system	Highly significant (p less than 0.01)	Significant (p greater than 0.01 and less than or equal to 0.05)	Not significant (p greater than 0.05)
Carson and Eagle Valleys	Upland	**Sodium, chloride, sulfate, silica, dissolved solids**	**Bicarbonate, calcium, magnesium**	Potassium
	Shallow	Calcium, magnesium, sodium, chloride, sulfate, bicarbonate, dissolved solids	Potassium, silica	--
Carson Desert	Shallow	Calcium, magnesium, sulfate	Bicarbonate	Sodium, potassium, silica, chloride, dissolved solids

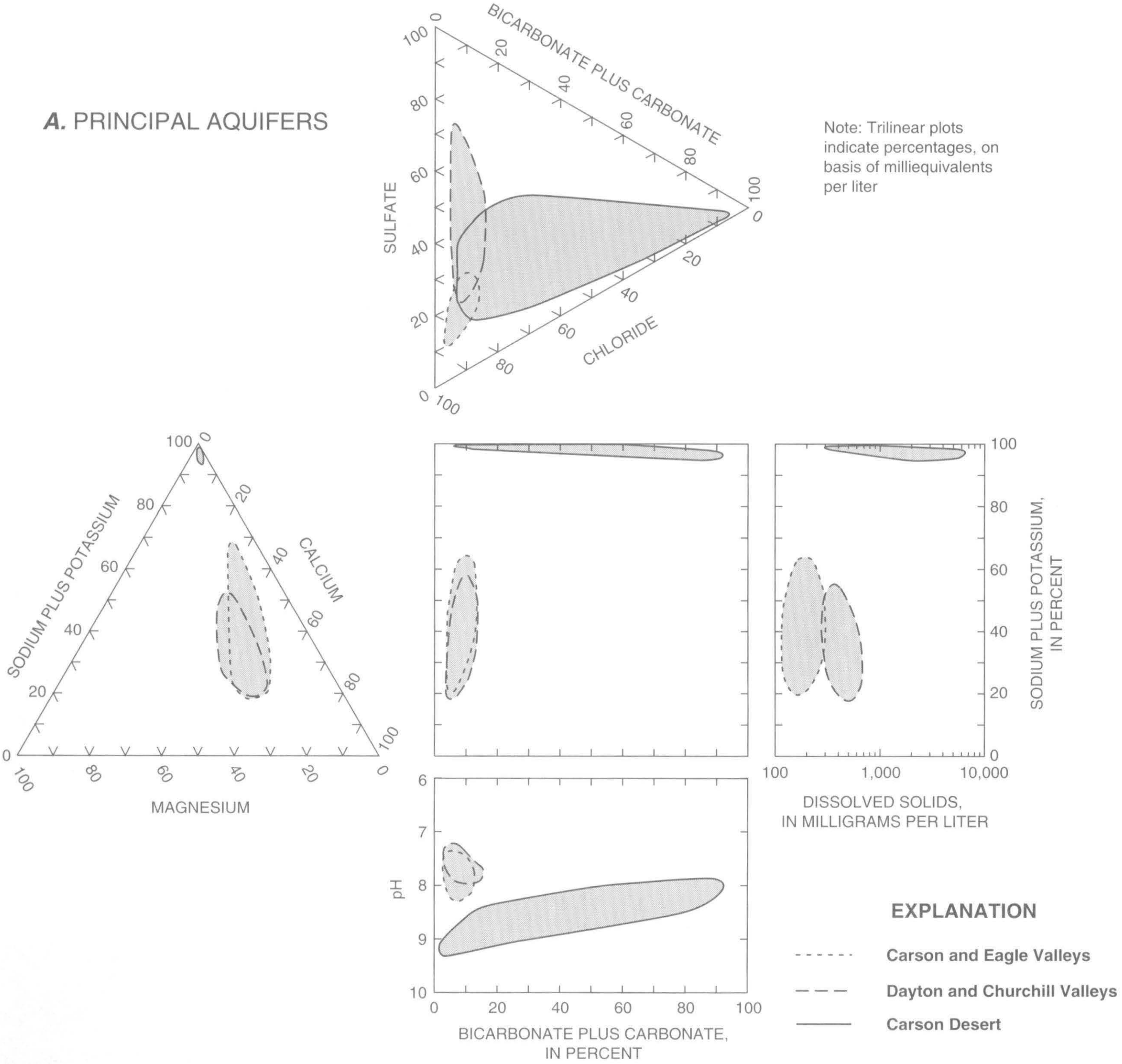


Figure 23. General chemical composition of ground water in Carson River Basin, Nevada and California. Envelope boundaries are derived by polar smoothing routines and encompass 50 percent of data for each area. *A*, Water from principal aquifers; and *B*, Water from shallow aquifers.

primary source of irrigation water. The generally higher concentrations of major constituents in water in shallow aquifers than in water in principal aquifers (table 9, fig. 24*A*) are consistent with concentrations in much of the shallow water discharging to the river. Except for areas near major pumping of ground water, such as near Gardnerville and along the Carson River east of Carson City, the river probably is not a major source of recharge to principal aquifers.

In Dayton and Churchill Valleys, ground-water quality in principal aquifers is dominated by the cations sodium plus potassium and calcium; bicarbonate and sulfate are the dominant anions (fig. 23*A*). Dissolved-solids concentrations in water from principal aquifers of Dayton and Churchill Valleys generally are greater than in water from principal aquifers of Carson and Eagle Valleys. Greater dissolved-solids concentrations result from higher concentrations of most major constituents (table 10; fig. 25), most notably from sulfate. Median concentrations of sulfate in principal aquifers increase from less than 20 mg/L in the upper Carson River Basin to more than 80 mg/L in the middle and lower basin (fig. 25).

Water from principal aquifers of Carson Desert generally is dominated by sodium plus potassium, and bicarbonate or chloride ions (fig. 23*A*). As dissolved-solids concentrations increase, chloride becomes more dominant. Sulfate also is a major part of the total anion

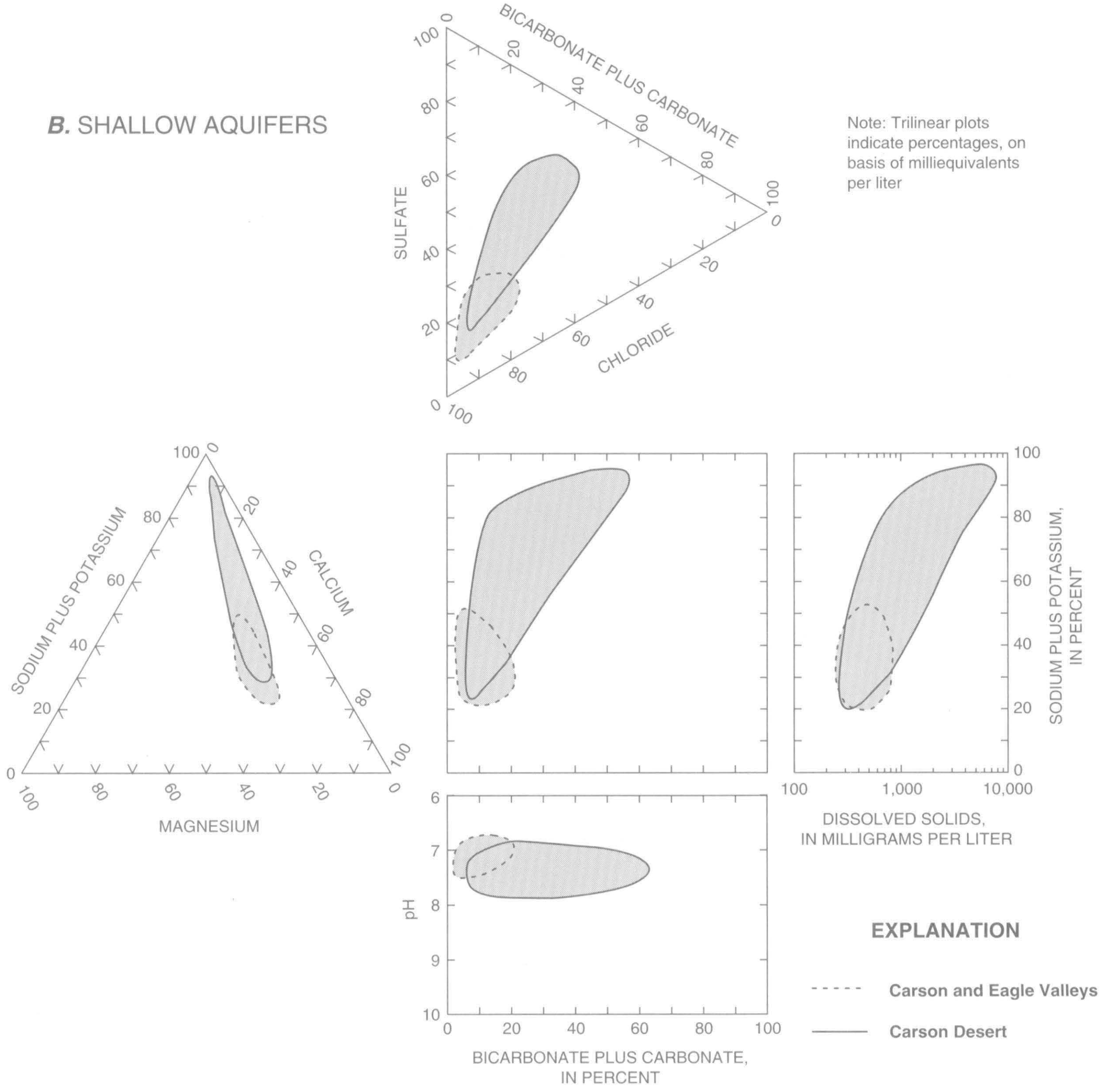

B. SHALLOW AQUIFERS

Figure 23. Continued.

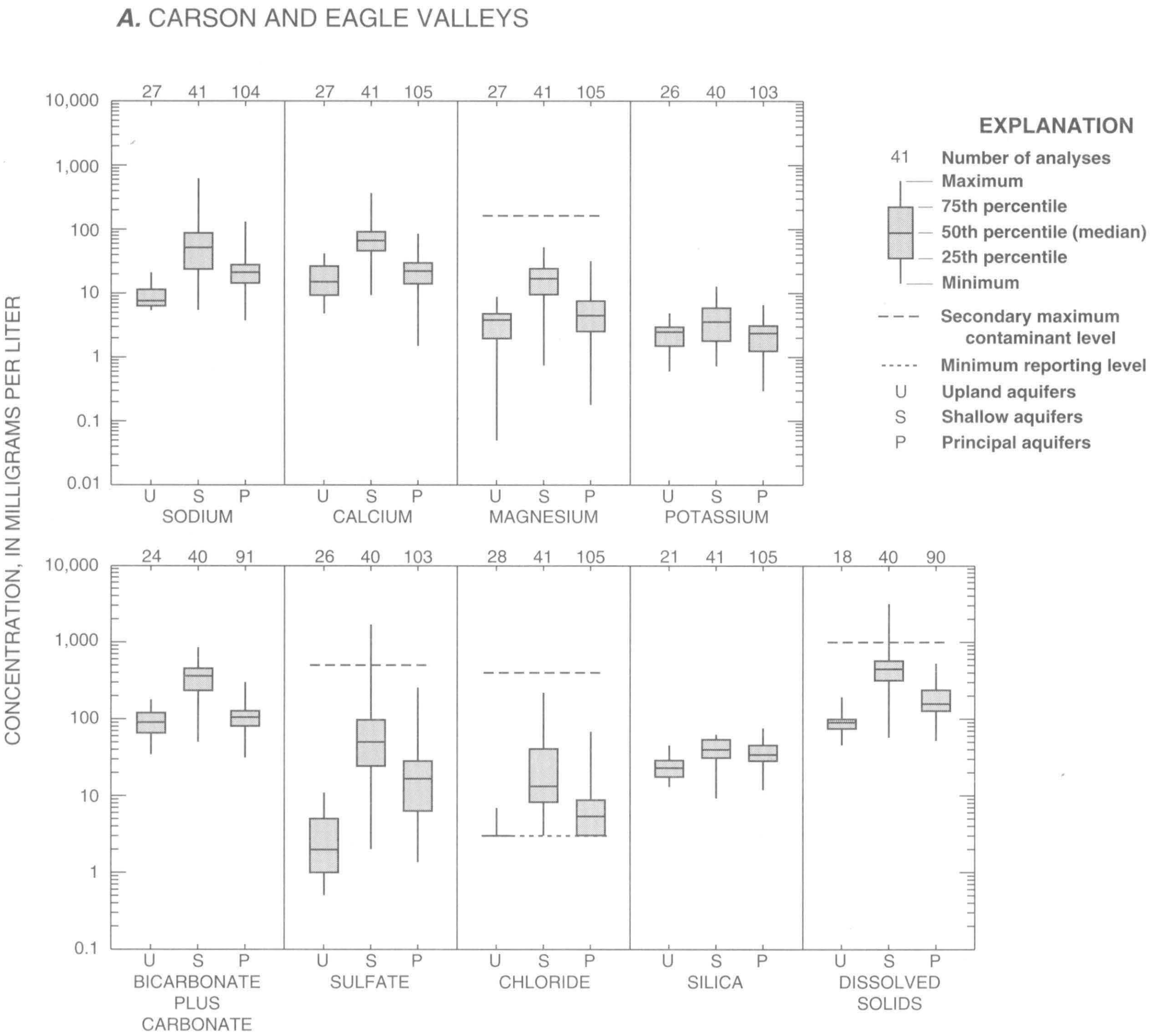


Figure 24. Summary statistics for major constituents in the different aquifer systems of Carson River Basin, Nevada and California. *A*, Carson and Eagle Valleys; and *B*, Carson Desert.

composition in some ground water. Dissolved-solids concentrations in water from principal aquifers in Carson Desert generally are greater than in ground-water from other parts of the Carson River Basin (fig. 25). The Carson Desert ground water also is more alkaline, with pH values generally ranging from 8 to 9. Concentrations of sodium, potassium, chloride, and bicarbonate are all distinctly higher in ground water from Carson Desert than in ground water from the upper and middle basin (table 10, fig. 25). The median chloride concentration for Carson Desert (about 260 mg/L) is more than 10 times greater than the median for the middle Carson River Basin (about 15 mg/L). Median concentrations in the basin (lower compared to the middle basin) are greater by factors of about 8 and 1.7 for sodium and bicarbonate, respectively (fig. 25). In contrast, medians and ranked concentrations of magnesium and calcium are lower in Carson Desert than in the upper and middle basin. As discussed in the following section, these lower concentrations are probably caused by exchange of calcium and magnesium in the water for sodium on clay-mineral surfaces.

Shallow aquifers beneath Carson Desert contain water with a wide range in composition and dissolved-solids concentration (fig. 23*B*). Much of the water is dominated by bicarbonate, sodium plus potassium, and calcium (or just sodium). In general, increases of dissolved-solids concentrations correspond to increasing dominance of sodium and chloride (fig. 23*B*). Water with the higher dissolved-solids concentrations

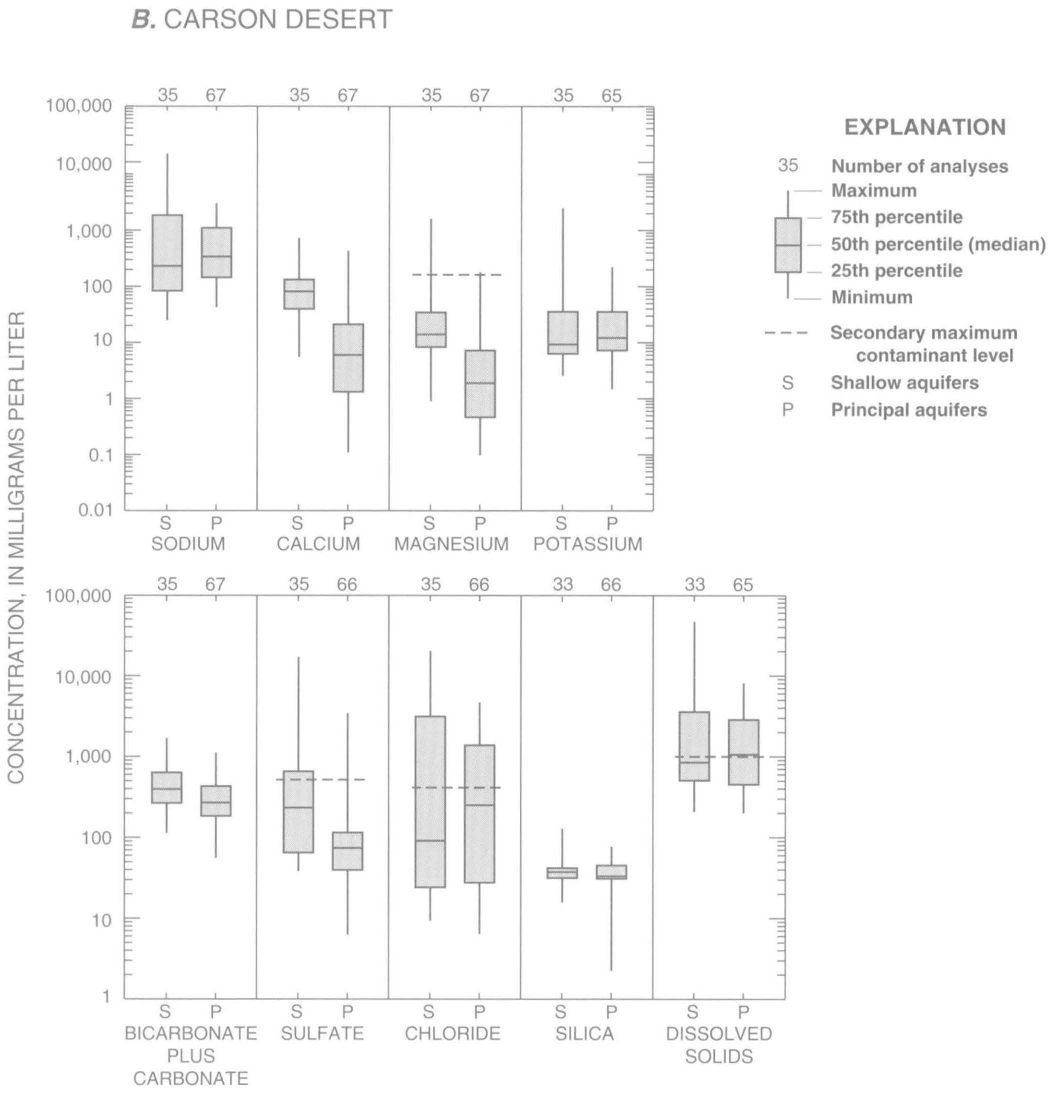


Figure 24. Continued.

is found in areas of intense evapotranspiration from the shallow subsurface. Most samples had dissolved-solids concentrations less than 10,000 mg/L, but the maximum measured concentration was 41,000 mg/L.

Secondary maximum contaminant levels (SMCL's) have been established for sulfate, chloride, magnesium, and dissolved solids (table 6). Where the concentration of one of these constituents exceeds the SMCL, the dissolved-solids concentration also exceeds the SMCL. Most samples with high dissolved-solids concentrations are from topographically low areas in the Carson Desert—Stillwater Marsh, Carson Sink, and Carson Lake areas (fig. 26). Intense evapotranspiration accompanied by dissolution of salts, such as halite and gypsum, are the most likely causes of the high dissolved-solids concentrations. Ground water with high dissolved-solids concentrations in the middle basin generally also has high sulfate concentrations. Water with high dissolved-solids and sulfate concentrations is in principal aquifers of Dayton Valley. Water with high dissolved-solids content in the upper Carson River Basin is limited to shallow aquifers—two sites are in the Carson City urban part of Eagle Valley and one site is in northern Carson Valley.

Processes Producing Concentrations of Major Constituents

***By* Michael S. Lico**

The purpose of this section is to describe the physical and chemical processes resulting in observed concentrations of major constituents in ground water of

Table 10. Statistical comparison of ranked concentrations of major constituents in ground water from upper, middle, and lower Carson River Basin, Nevada and California

[Constituents in **bold** and nonbold have, respectively, higher and lower ranked concentrations in more downstream part of basin; p-values determined by Mann-Whitney method (Conover, 1980, p. 216). Symbol: --, no constituent]

Area	Highly significant (p less than 0.01)	Significant (p greater than 0.01 and less than or equal to 0.05)	Not significant (p greater than 0.05)
	Principal aquifers		
Carson and Eagle Valleys compared with Dayton and Churchill Valleys	**Calcium, magnesium, sodium, potassium, chloride, sulfate, bicarbonate, silica, dissolved solids**	--	--
Dayton and Churchill Valleys compared with Carson Desert	Calcium, magnesium, **sodium**, **potassium**, **chloride**, **bicarbonate**, silica, **dissolved solids**	Sulfate	--
Carson and Eagle Valleys compared with Carson Desert	Calcium, magnesium, **sodium**, **potassium**, **chloride**, **sulfate**, **bicarbonate**, **dissolved solids**	--	Silica
	Shallow aquifers		
Carson and Eagle Valleys compared with Carson Desert	**Sodium**, **potassium**, chloride, **sulfate**, **dissolved solids**	Bicarbonate	Calcium, silica, magnesium

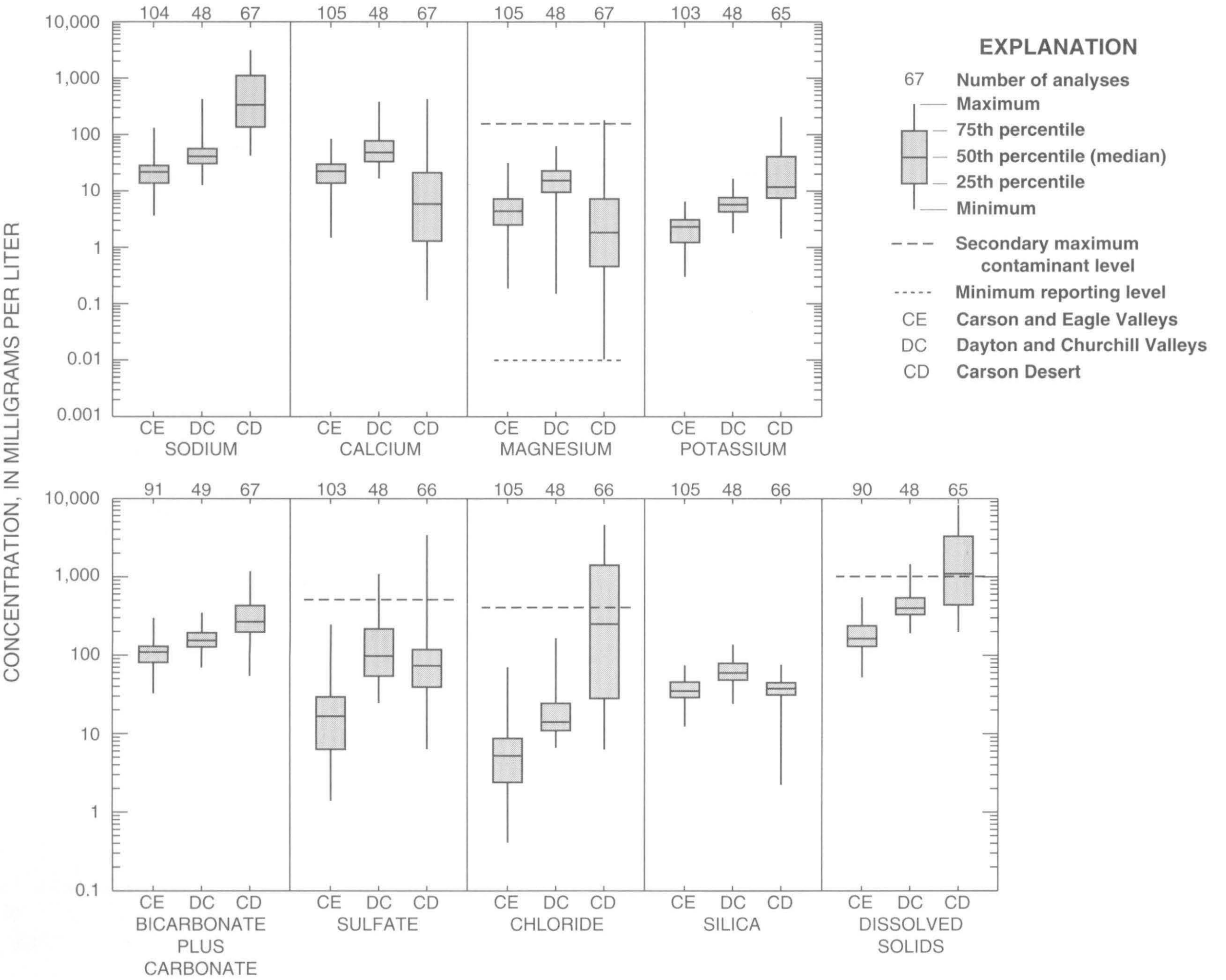
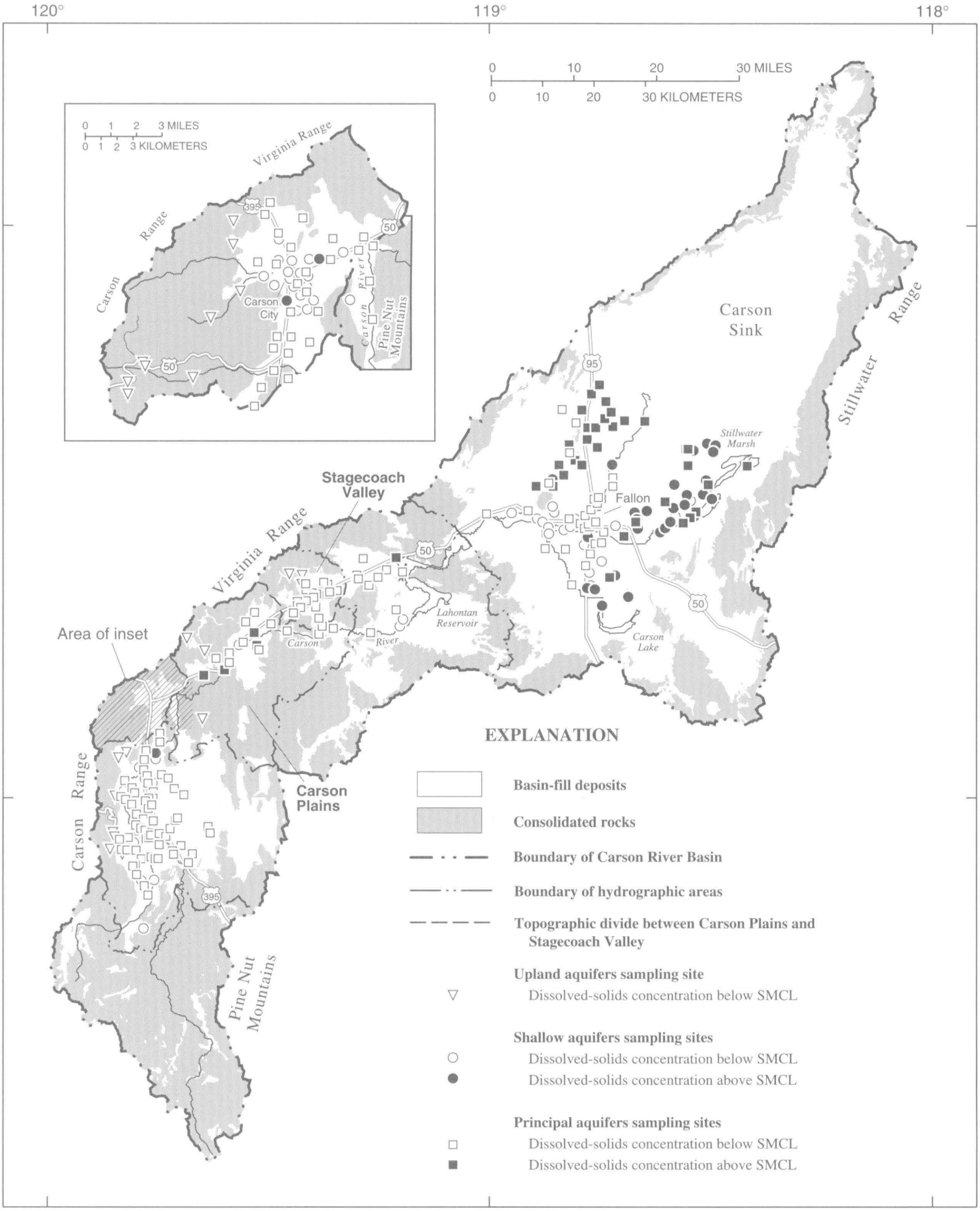


Figure 25. Summary statistics for major constituents in principal aquifers of Carson River Basin, Nevada and California.



Base from U.S. Geological Survey digital data, 1:100,000, 1985
Local Mercator projection
Central meridian -119°10', latitude of true scale 39°20'

Geology modified from Johnson (1977),
Stewart and others (1982), and
Greene and others (1991)

Figure 26. Ground-water sampling sites in Carson River Basin, Nevada and California, where concentrations of dissolved solids exceed Nevada State secondary maximum contaminant levels (1,000 milligrams per liter). SMCL, secondary maximum contaminant level.

the Carson River Basin. Some introductory explanations of processes that commonly control ground-water quality of inorganic constituents are included. These processes can be important controls on major and minor inorganic constituents and radionuclides. A discussion of the use of thermodynamic and isotope data in determining processes also is included.

Concentrations of inorganic constituents in ground water are controlled by a variety of geochemical processes including reaction kinetics, mineral solubility, adsorption, and ion exchange. Application of laboratory-derived reaction rates requires information unavailable for the Carson River Basin and, therefore, is considered only generally. Radioactive isotopes produced by radioactive decay, such as radon, are controlled by the concentration of the parent and half-lives of intermediate progeny products in the decay chain. Additionally, some constituents are present in only small amounts within aquifer materials.

Mineral solubility as a control on concentrations generally is evaluated using computer programs that calculate the state of saturation with respect to minerals and other solid phases. The program WATEQ4 (Ball and others, 1987) was used to estimate a measure of saturation termed a "saturation index," which is the log of the activity product divided by the equilibrium constant. For example, a saturation index for the calcium sulfate mineral gypsum is

$$\text{saturation index} = \text{Log}\ \{[Ca^{2+}]\ [SO_4^{2-}]\ /\ (\text{equilibrium constant for gypsum})\},$$

where values in square brackets are chemical activities of calcium and sulfate (Hem, 1985, p. 19). Positive values for the saturation index indicate oversaturation with respect to a solid phase, whereas negative values indicate undersaturation. For purposes of discussion, saturation index values between -0.5 and 0.5 are considered to indicate equilibrium. Greater and lesser values indicate oversaturation and undersaturation, respectively. One limitation of the WATEQ4 program is that chemical-activity coefficients for dissolved species are calculated using the extended Debye-Huckel equation, which becomes increasingly inaccurate for ionic strengths greater than about 0.1 (Stumm and Morgan, 1970, p. 83). Some ground water in Carson Desert has ionic strengths greater than 0.1; accordingly, chemical activities and saturation indexes are reported only for ground water with ionic strengths less than 0.5.

Stable isotopes of dissolved inorganic sulfur and carbon can aid in understanding reactions in ground water. Differences in stable-isotope compositions can be caused by (1) differences in the isotope composition of recharge water, (2) variations in the isotopic composition of minerals dissolved by ground water, (3) the amount of a mineral that is dissolved, (4) mineral precipitation, (5) concentration by evapotranspiration, or (6) microbial processes, such as sulfate reduction.

The stable-isotope composition of sulfur (as dissolved sulfate) is highly variable in ground water throughout the Carson River Basin (fig. 27). In the upper Carson River Basin, sulfate has at least three isotopically distinct sources (Welch, 1994). (1) Lighter (more negative) sulfur is derived from dissolution of sulfide minerals in granitic rocks of the Sierra Nevada. Therefore ground water in upland areas generally has a lighter sulfate-isotope composition. (2) To the east (downgradient) of metavolcanic rocks in the Carson Range, the sulfate in ground water is isotopically heavier. Apparently, these rocks have a source of heavier sulfur than granitic rocks. Ground water with the heaviest sulfur-isotope composition in the Carson River Basin is in northeastern Eagle Valley. (3) Dissolved sulfate also is derived from Triassic and Jurassic evaporite deposits containing gypsum and gypsum-rich detritus in the basin-fill sediment. All common sulfur-bearing minerals are undersaturated in ground water of Carson and Eagle Valleys. This suggests precipitation of sulfur-containing minerals does not modify the stable-isotope composition of dissolved sulfur.

In Dayton and Churchill Valleys, sulfate concentrations in ground water generally are higher than in Carson and Eagle Valleys (fig. 25). The stable-isotope composition of dissolved sulfate is similar to that of ground water from Carson and Eagle Valleys (fig. 27; Thomas and Lawrence, 1994). Sources of dissolved sulfate include dissolution of gypsum deposits; in volcanic rocks and granite, some sulfate may be microbially reduced, as indicated by the lighter sulfur-isotope composition in one water sample than in rock sources. Evidence of precipitation of sulfur-bearing minerals in the middle Carson River Basin has not been observed.

The sulfur-isotope composition is highly variable in ground water of Carson Desert (fig. 27). Sources of dissolved sulfate in ground water include dissolution of pyrite from volcanic and granitic rocks and dissolution of gypsum from desert sediments. Lighter sulfur-isotope compositions are similar to those for granitic rocks of the Sierra Nevada (fig. 27), indicating the granitic rocks and their sedimentary derivatives are sources of dissolved sulfate. Ground water in intermediate aquifers commonly has lower sulfate concentrations and heavier sulfur-isotope compositions than

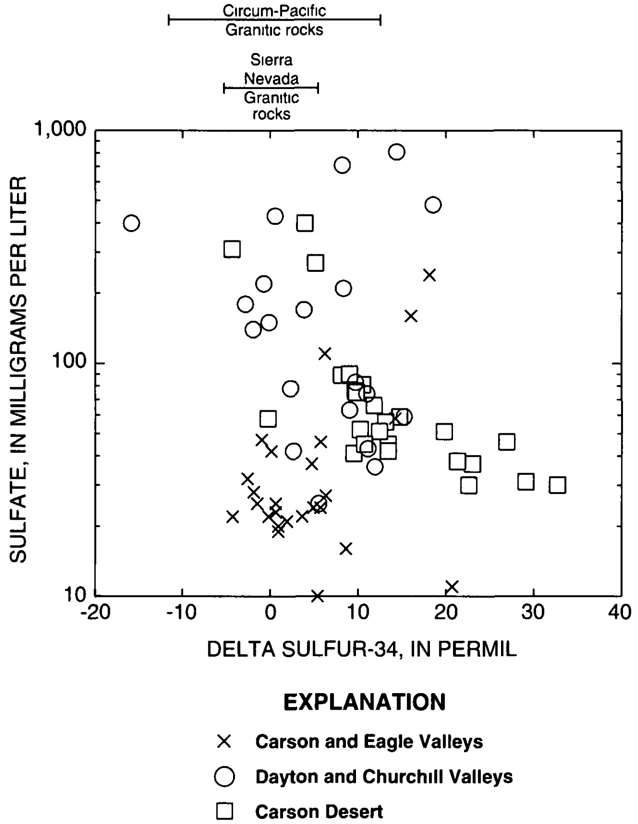


Figure 27. Relation between stable isotopes of sulfur and sulfate concentrations in ground water of Carson River Basin, Nevada and California.

ground water in shallow aquifers. If sulfate in both aquifers is from the same source, microbial reduction of sulfate (Krouse, 1980, p. 458-461) probably is the cause of heavier sulfate and lower concentrations in intermediate aquifers. Precipitation of sulfur-bearing minerals also can alter the sulfur-isotope composition. However, precipitation of sulfur-bearing minerals from ground water in the Carson River Basin has not been documented, except in shallow aquifers near Stillwater Wildlife Management Area (Lico, 1992).

The stable-isotope composition of dissolved inorganic carbon is variable in ground water of the Carson River Basin (fig. 28). Concentrations of dissolved inorganic carbon generally increase eastward in the basin. Sources of carbon in ground water include the atmosphere and the soil zone as carbon dioxide, calcite, and organic carbon. Soil-zone carbon dioxide dissolves in ground water, resulting in a weak carbonic acid solution that dissolves calcite in granitic rock or basin-fill sediment in Carson and Eagle Valleys. Oxidation of organic carbon probably adds a small amount of carbon to the dissolved inorganic carbon in ground water.

In Dayton and Churchill Valleys, dissolved-inorganic-carbon concentrations and carbon stable-isotope compositions are primarily the result of dissolution of soil-zone carbon dioxide in ground water in recharge areas. Subsequent precipitation of calcite preferentially removes heavier carbon from the ground water, leaving a lighter dissolved-inorganic-carbon composition. Oxidation of organic matter with an isotope composition similar to soil-zone carbon dioxide may contribute a small amount of carbon to the dissolved inorganic carbon in ground water.

In Carson Desert, concentrations of dissolved inorganic carbon in ground water are much greater than concentrations in ground water in the middle and upper Carson River Basin. Evapotranspiration has a major affect by concentrating the dissolved inorganic carbon, especially in shallow aquifers near Carson Lake and Stillwater Wildlife Management Area. Ground water with the highest dissolved-inorganic-carbon concentrations also has the heaviest carbon-isotope composition, indicating the most likely source of heavy carbon is calcite present in the basin-fill sediment. Calcite in shallow aquifers (8 samples) has a carbon-isotope composition between -6.8 and 0.9 permil, which is heavy enough to cause the observed values; organic carbon, with a range of -25.2 to -22.9 permil in 14 samples, has a carbon-isotope composition too light to cause the observed values.

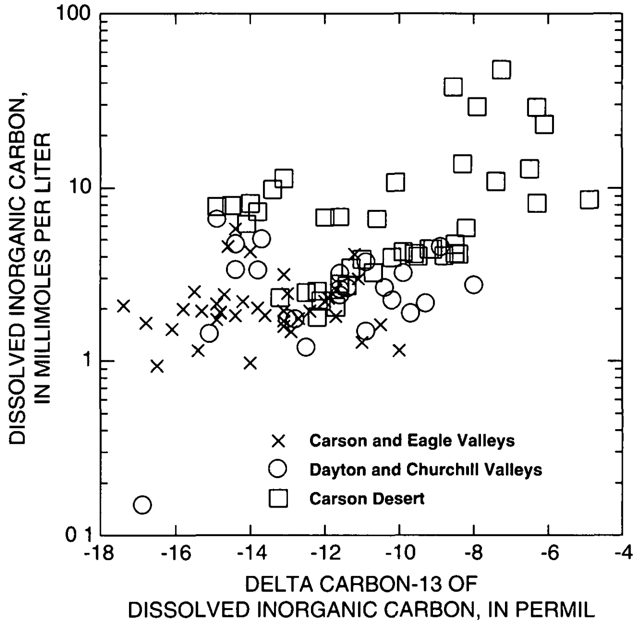


Figure 28. Relation between stable isotopes of carbon and inorganic-carbon concentrations in ground water of Carson River Basin, Nevada and California.

Most ground water in the Carson River Basin is at equilibrium with calcite and amorphous silica (fig 29) Thus, solubility of calcite limits concentrations of calcium and dissolved inorganic carbon Similarly, solubility of amorphous silica limits concentrations of dissolved silica

Interpretation of activity diagrams, such as those shown in figures 30*A-G*, indicate that clay minerals are an important control on the cation composition of ground water in the basin Chemical activity ratios for ground water generally plot along slopes consistent with cation exchange reactions Specifically, if concentrations of a divalent cation (such as calcium) and a monovalent cation (such as sodium) are controlled by exchange, then a slope of 2 will result (figs 30*A* and *C*) Similarly, exchange of two cations with the same valence will result in a slope of 1 (fig 30*B*)

Most ground-water data for the Carson River Basin lie along trend lines consistent with cation exchange Some data, mostly for samples from the shallow aquifers in Carson Desert, do not indicate that exchange controls the relation between sodium and calcium A different process may be removing calcium from solution as concentrations of sodium plus calcium increase A likely explanation for the decrease in calcium is precipitation of calcite The presence of secondary calcite (overgrowth) in sediment from Carson Desert (fig 5) and Stillwater Wildlife Management Area (Lico, 1992) is consistent with the precipitation of calcite

Relations between activities of cations and silica are shown in figures 30*D-G* Fields in these plots indicate relations between ground-water compositions and mineral stability The clay minerals, kaolinite and beidellite, may be stable in aquifers of the Carson River Basin Ground water in Carson and Eagle Valleys typically is in the stability field for kaolinite In the middle and lower Carson River Basin, beidellite is more commonly the stable clay mineral For some ground water, mostly from Carson Desert, chlorite may be a stable mineral Also shown in figures 30*D-G* is a line representing saturation of amorphous silica Few samples have silica concentrations greater than saturation, probably because amorphous silica is the major control on dissolved silica concentrations

Three general models were evaluated to determine reaction paths for ground water in western Carson and Eagle Valleys "silicate," "closed system," and "open system" models (Welch, 1994, p 42-57) Each model started with the average chemical composition of atmospheric precipitation and ended with the composition of water samples from principal aquifers The "silicate" model did not contain calcite as a mineral phase and did not explain observed water chemistry in principal aquifers The "open" and "closed" system models have broadly similar results In both models, plagioclase feldspar is the major source of dissolved solids, calcite, carbon dioxide, pyrite, sodium chloride, and silica contribute a small amount of the dissolved solids content Kaolinite and sodium beidellite are major products formed by reactions within aquifers Cation-exchange processes also modify cation ratios in ground water

In Dayton Valley, water chemistry can result from dissolution of plagioclase feldspar, sodium chloride, gypsum, and small amounts of potassium feldspar, biotite, and chlorite (Thomas and Lawrence, 1994, p 24-32) Products formed by reactions in aquifers are calcite, kaolinite, sodium beidellite, and carbon dioxide gas Exchange processes caused the observed cation concentrations in ground water Water chemistry in Churchill and Stagecoach Valleys can be explained using a model similar to that for Dayton Valley, except that chlorite and potassium feldspar are not involved

Three reaction paths were modeled for aquifer systems in Carson Desert (Lico and Seiler, 1994, p 40-55) These reactions cause changes in water chemistry as water flows from shallow aquifers to the intermediate aquifers, from shallow aquifers to the basalt aquifer, and from intermediate aquifers to the basalt aquifer In general, dissolution of plagioclase feldspar, formation of sodium beidellite, cation exchange, and evapotranspiration are major processes controlling the composition of ground water Most models constructed for these reaction paths included solution and precipitation of small amounts of calcite and silica along with minor amounts of other minerals

Concentrations of Minor Constituents

***By* Stephen J Lawrence**

Minor inorganic constituents (arsenic, boron, fluoride, iron, lithium, manganese, molybdenum, nitrate, and vanadium) reach concentrations that can affect use of ground water in the Carson River Basin, particularly in Carson Desert Large differences in concentration are found in water from the different aquifers in the three parts of the basin Some differences are shown by comparing shallow ground water beneath agricultural and urban settings Concentrations of minor

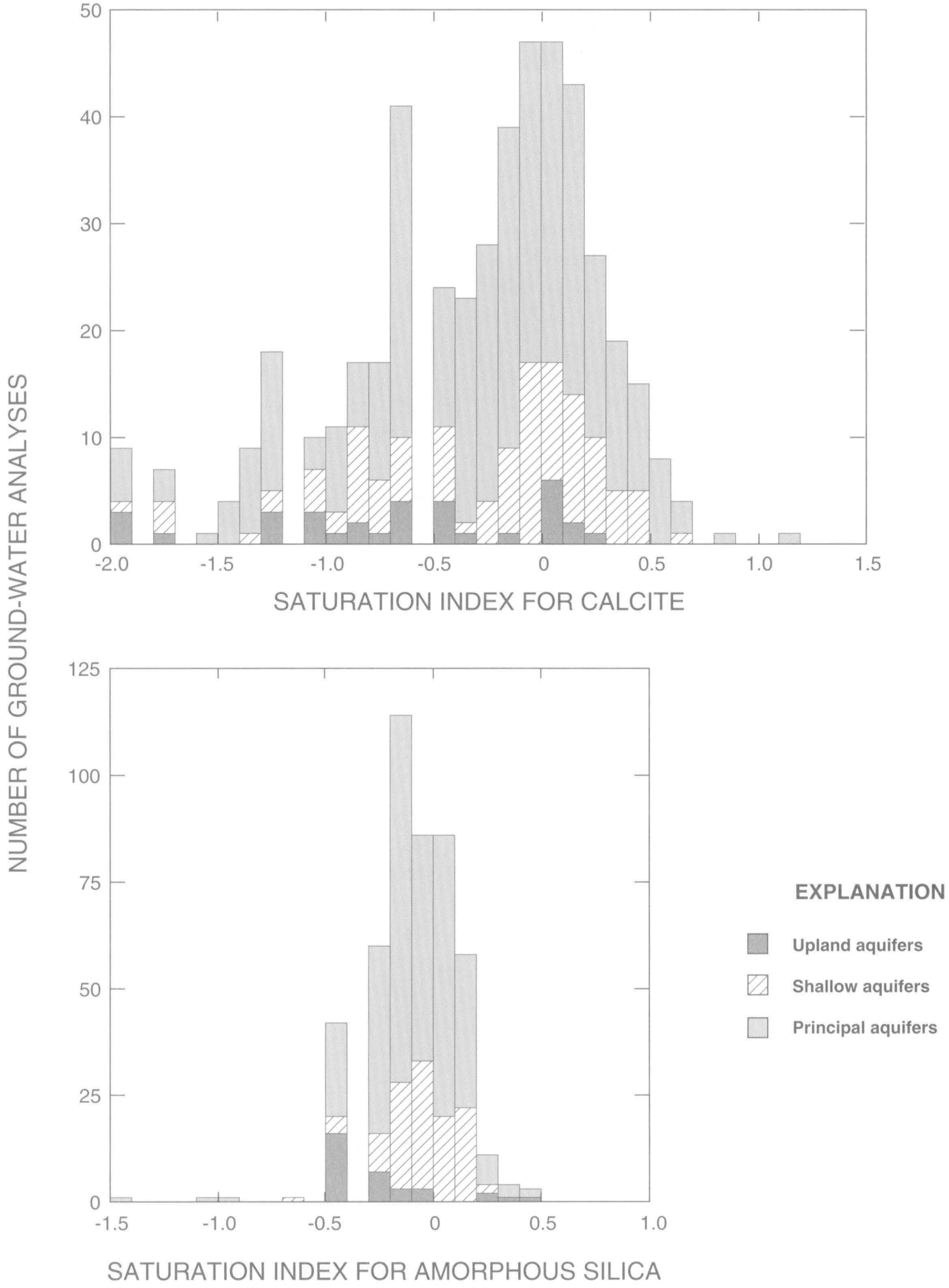


Figure 29. Saturation indexes for calcite and amorphous silica in ground water of Carson River Basin, Nevada and California.

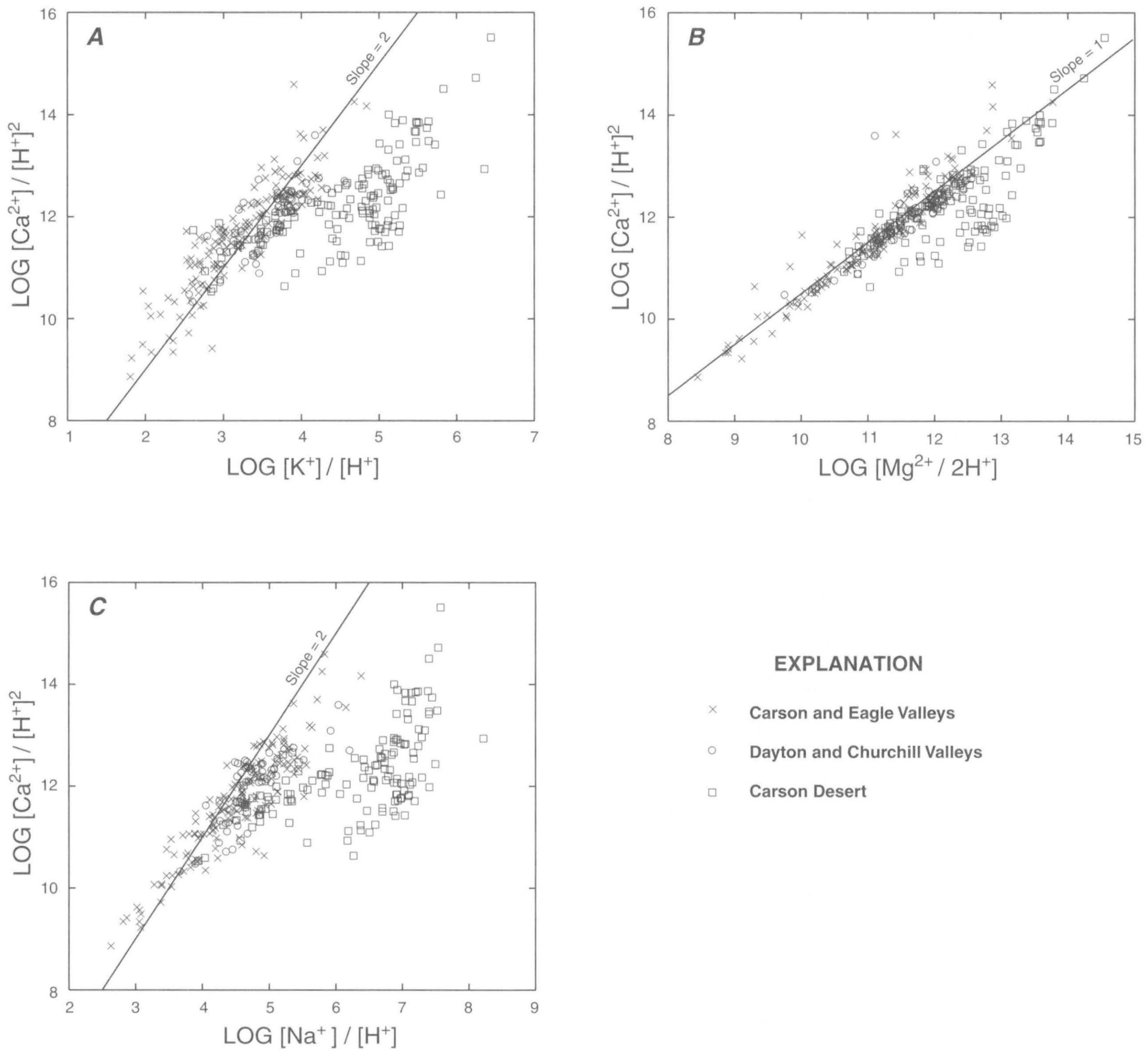


Figure 30. Relation between activities of selected major constituents in ground water of Carson River Basin, Nevada and California. *A*, Calcium and potassium; *B*, Calcium and magnesium; *C*, Calcium and sodium; *D*, Calcium and silica; *E*, Potassium and silica; *F*, Magnesium and silica; and *G*, Sodium and silica.

constituents can differ greatly over small vertical and horizontal distances, particularly in shallow aquifers of Carson Desert. Nitrate, although not always considered a minor constituent, is included in this section because its concentrations generally are less than 1 mg/L, expressed as nitrogen.

Except for manganese in shallow aquifers, ground water of Carson and Eagle Valleys has low concentrations of minor constituents compared to drinking-water standards and the guidelines previously discussed (fig. 31). Water in principal aquifers has significantly higher ranked concentrations of boron and fluoride compared to water in the upland aquifers (table 11). Although ranked iron concentrations are significantly higher in water from the upland aquifers than from principal aquifers, the median concentrations are similar (11 and 7 µg/L, respectively). Among the minor constituents with significantly higher ranked concentrations in water from shallow aquifers than from principal aquifers, only manganese concentrations exceed the SMCL in more than 25 percent of the samples (fig. 31*A*).

Ground water beneath agricultural land in Carson Valley and the urban part of Carson City has been analyzed for chloride and minor constituents. Chloride is included in this comparison because of possible

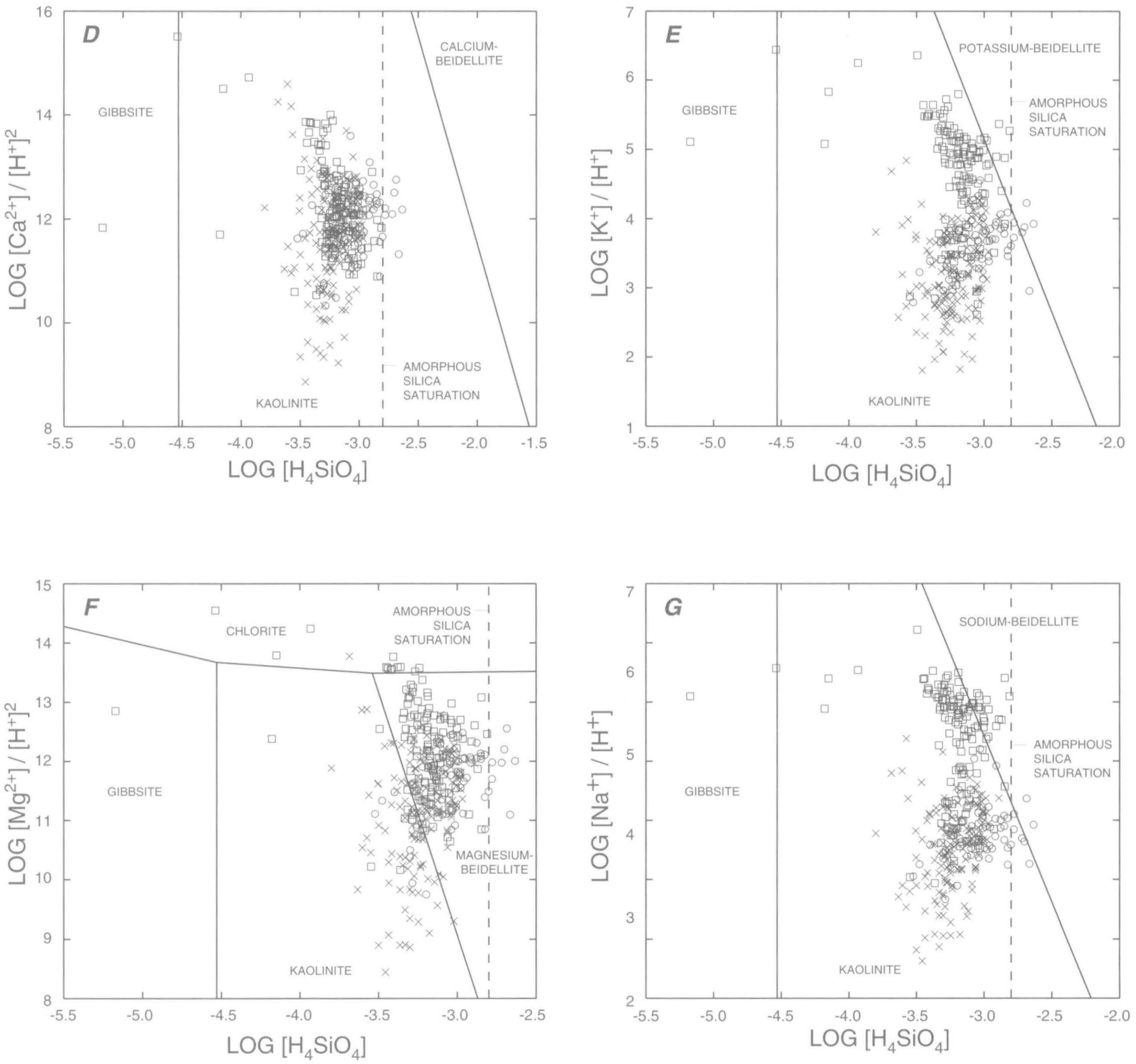


Figure 30. Continued.

relation to human activities. A comparison of ranked concentrations shows some significant differences between these two land-use groups (table 12, fig. 32). Ground water beneath agricultural areas has significantly higher ranked concentrations of arsenic, boron, fluoride, and molybdenum than ground water from urban areas. In contrast, ranked chloride, iron, lithium, and nitrate concentrations in ground water beneath urban land are significantly higher.

Differences in ground-water quality between the agricultural and urban areas may be caused by human activities. Shallow ground water beneath both areas is largely recharged by surface irrigation. Higher chloride, nitrate, and iron beneath the urban areas could be a result of human activities common in urban environments. For example, higher chloride concentrations could result from winter application of salt on roads. Higher nitrate could result from fertilizers and sewage. Higher iron concentrations can be an indirect result of release of synthetic organic compounds to the ground water. Synthetic organic compounds released to the shallow subsurface can react with oxygen, producing anoxic conditions. As discussed in the following section, a rise in the water table from landscape and agricultural irrigation can cause reaction of

Table 11. Statistical comparison of ranked concentrations of minor constituents and dissolved oxygen in water from principal aquifers and water from upland and shallow aquifers of Carson River Basin, Nevada and California

[Constituents in **bold** and nonbold have, respectively, higher and lower ranked concentrations in principal aquifers; p-values determined by Mann-Whitney method (Conover, 1980, p. 216)]

Aquifer system	Highly significant (p less than 0.01)	Significant (p greater than 0.01 and less than or equal to 0.05)	Not significant (p greater than 0.05)
Carson and Eagle Valleys			
Upland	**Boron**, **fluoride**	Iron	Arsenic, lithium, manganese, molybdenum, nitrate, vanadium, dissolved oxygen
Shallow	Iron, manganese, lithium	Boron	Arsenic, fluoride, molybdenum, nitrate, vanadium, dissolved oxygen
Carson Desert			
Shallow	**Iron**, manganese, nitrate,molybdenum	Lithium, dissolved oxygen	Arsenic, boron, fluoride, vanadium

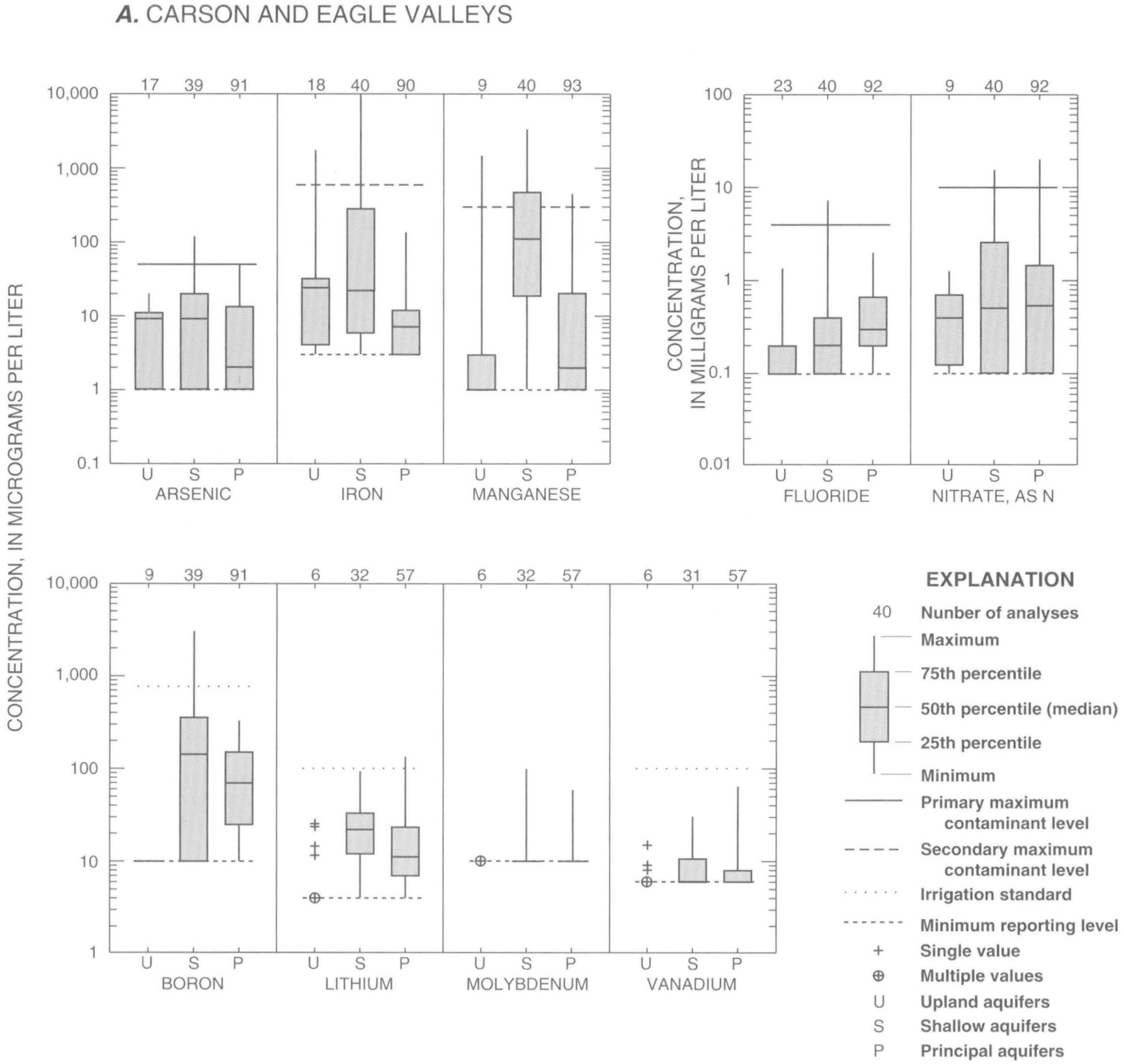


Figure 31. Boxplots showing summary statistics for minor constituents in aquifer systems of Carson River Basin, Nevada and California. *A*, Carson and Eagle Valley; and *B*, Carson Desert.

Table 12. Statistical comparison of ranked concentrations of minor constituents and chloride beneath agricultural and urban land of upper Carson River Basin, Nevada and California

[Constituents in **bold** and nonbold have, respectively, higher and lower ranked concentrations in ground water beneath urban land; p-values determined by Mann-Whitney method (Conover, 1980, p. 216)]

Highly significant (p less than 0.01)	Significant (p greater than 0.01 and less than or equal to 0.05)	Not significant (p greater than 0.05)
Arsenic, boron, **chloride, iron**	Fluoride, **lithium,** molybdenum, **nitrate**	Manganese, vanadium

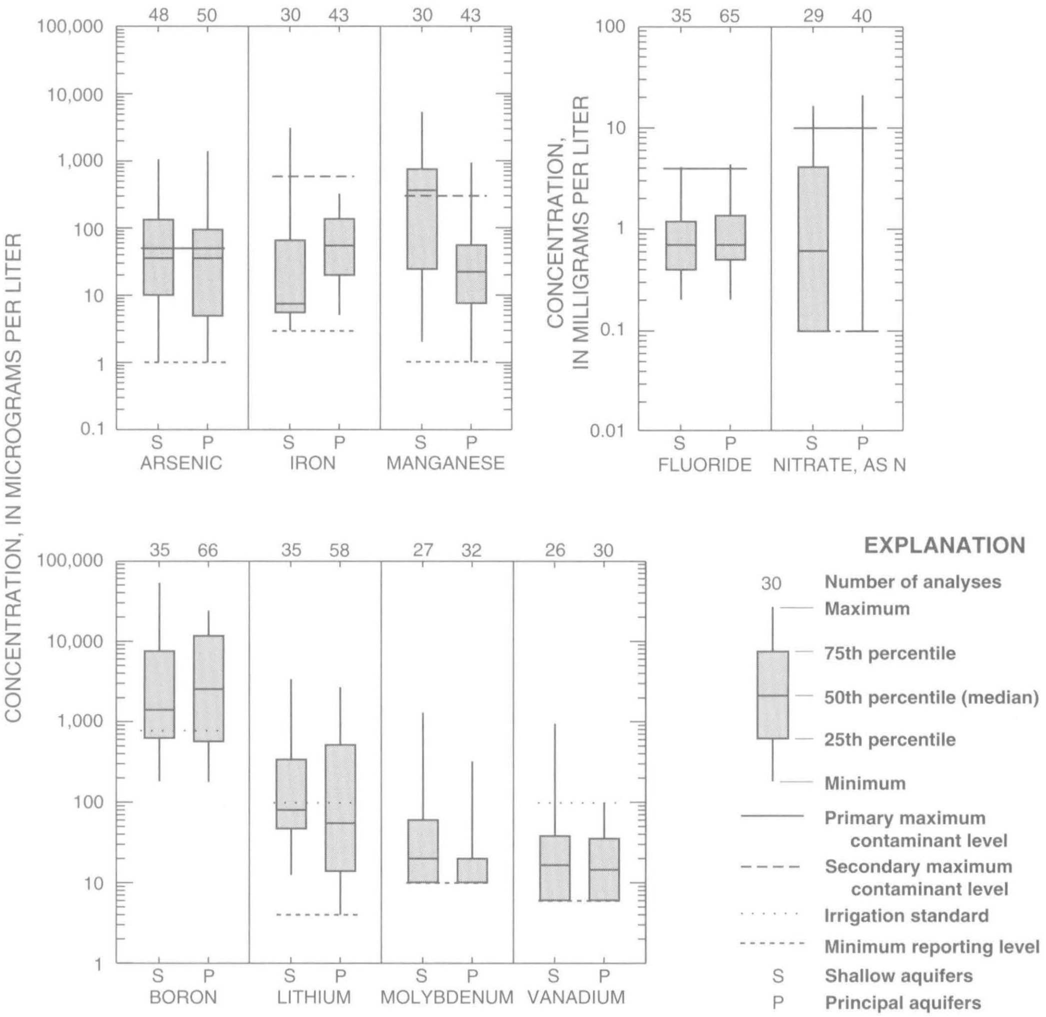

B. CARSON DESERT

Figure 31. Continued.

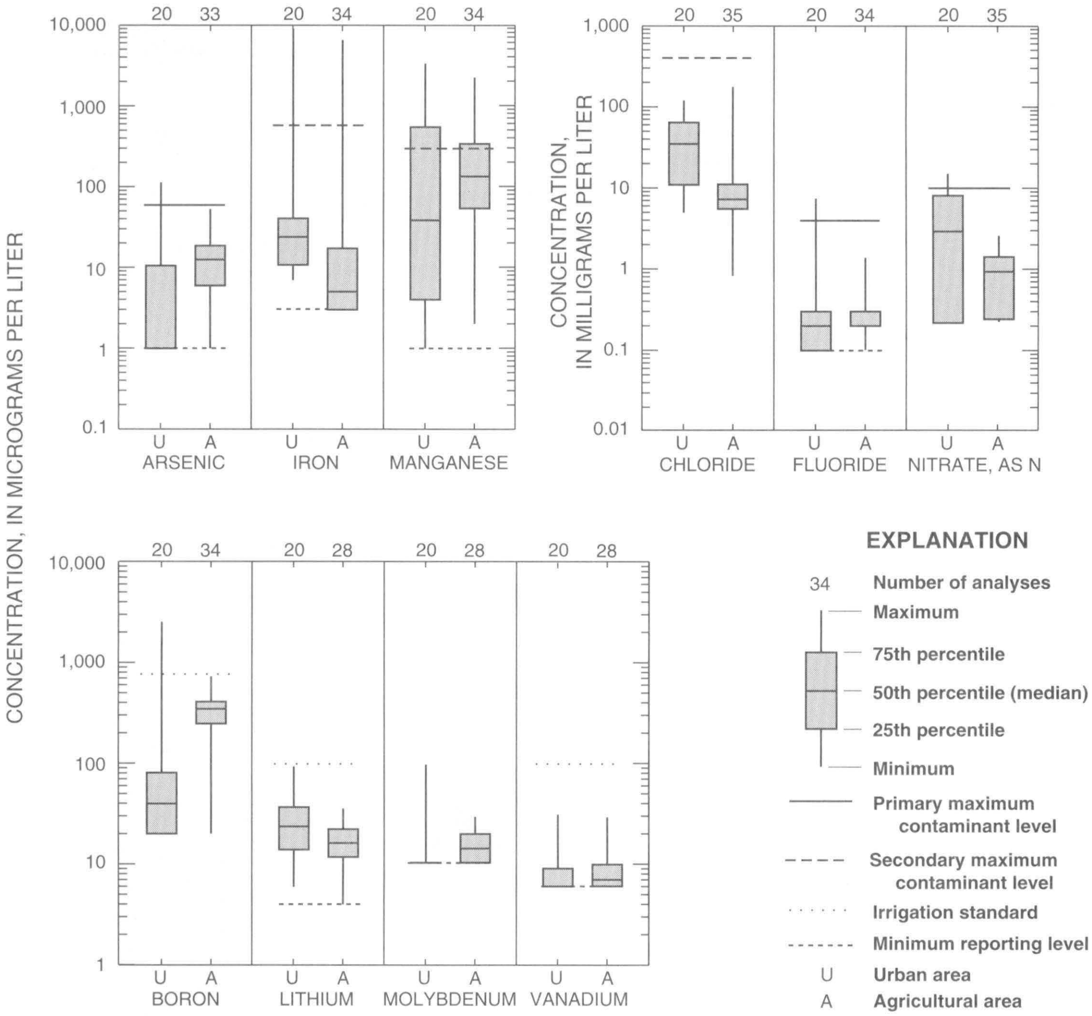


Figure 32. Summary statistics for minor constituents and chloride in shallow aquifers beneath agricultural and urban land of the upper Carson River Basin, Nevada and California.

sedimentary organic matter, producing water that contains little or no dissolved oxygen. Iron is much more soluble in water without dissolved oxygen.

The differences in ground-water quality may be due to factors unrelated to human activities. One complicating factor is that the urban samples are located only in Eagle Valley whereas the agricultural samples are from wells in Carson Valley. The lack of analyses of samples collected prior to urban and agricultural land use prevents an evaluation of whether the differences are related to land use or other factors.

Water in principal aquifers of the upper and middle Carson River Basin generally contains lower concentrations of minor constituents than in the lower basin (Carson Desert), as shown in figure 33. Although some constituents have significantly higher ranked concentrations in ground water from the middle than from the upper basin (table 13), concentrations generally are below standards and guidelines (fig. 33).

Several minor constituents in ground water of Carson Desert commonly are highly concentrated, both relative to upstream parts of the basin and compared to standards and guidelines (table 13, fig. 33). Arsenic, boron, lithium, and molybdenum concentrations exceed standards and guidelines in more than 25 percent of samples from aquifers in Carson Desert. The sole source of drinking water for Fallon and the Fallon Naval Air Station is a basalt aquifer containing arsenic concentrations slightly higher than the 50 µg/L standard. Ranked concentrations of arsenic, boron, fluoride, iron, lithium, manganese, molybdenum, and nitrate are significantly higher in ground water in Carson Desert than in the upper and middle basin (table 13).

Table 13. Statistical comparison of ranked concentrations of minor constituents in ground water from upper, middle, and lower Carson River Basin, Nevada and California

[Constituents in **bold** and nonbold have, respectively, higher and lower ranked concentrations in more downstream part of basin; p-values determined by Mann-Whitney method (Conover, 1980, p. 261). Symbol: --, no constituent]

Area	Highly significant (p less than 0.01)	Significant (p greater than 0.01 and less than or equal to 0.05)	Not significant (p greater than 0.05)
	Principal aquifers		
Carson and Eagle Valleys compared with Dayton and Churchill Valleys	**Boron, iron, vanadium**	**Lithium, manganese, dissolved oxygen**	Arsenic, fluoride, molybdenum, nitrate
Dayton and Churchill Valleys compared with Carson Desert	**Arsenic, boron, fluoride, iron, lithium, molybdenum, nitrate**	**Manganese**	Vanadium, dissolved oxygen
Carson and Eagle Valleys compared with Carson Desert	**Arsenic, boron, fluoride, iron, lithium, manganese, molybdenum, nitrate, vanadium**, dissolved oxygen	--	--
	Shallow aquifers		
Carson and Eagle Valleys compared with Carson Desert	**Arsenic, boron, fluoride, lithium, molybdenum, vanadium**, dissolved oxygen	--	Iron, manganese, nitrate

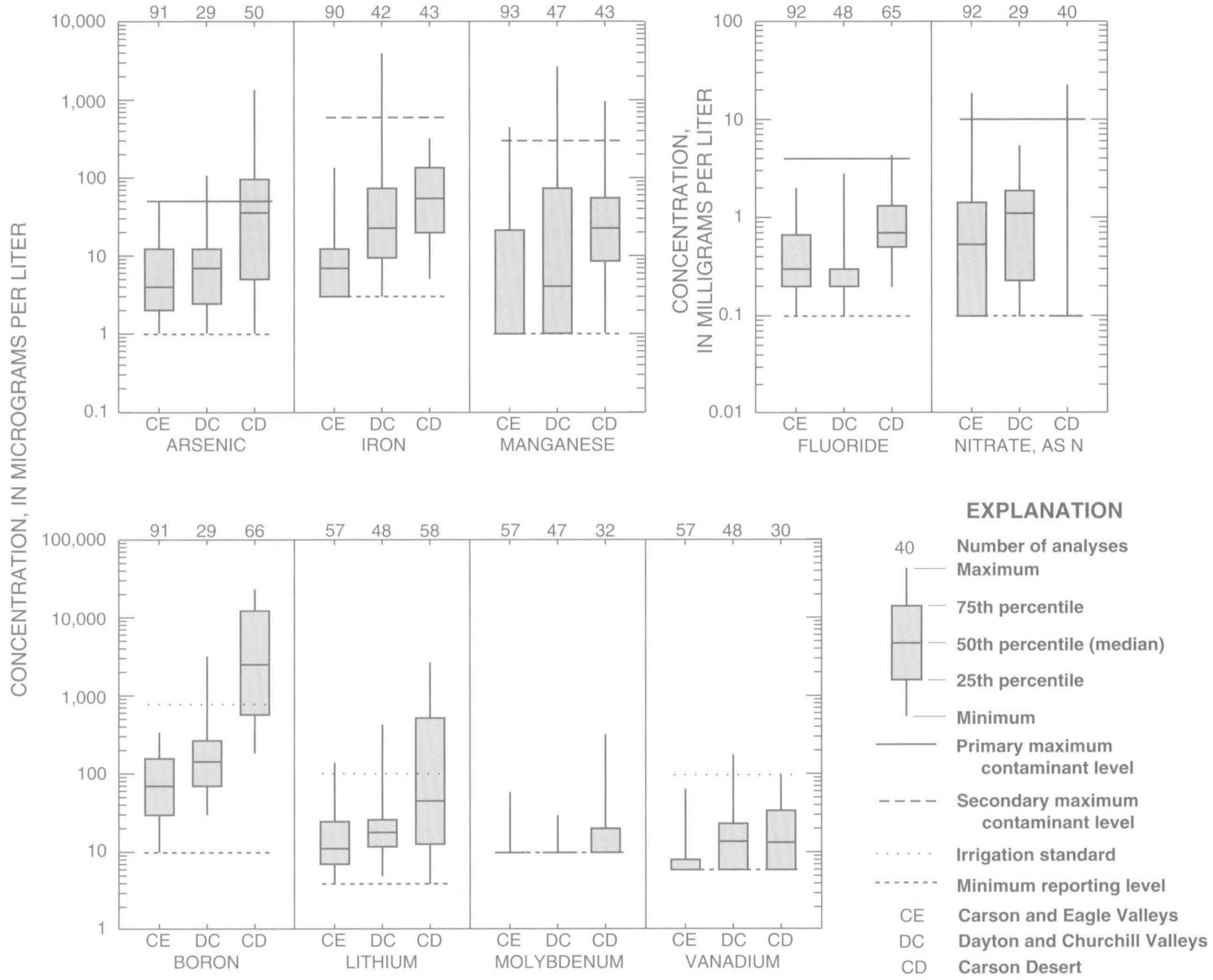


Figure 33. Summary statistics for minor constituents in principal aquifers in Carson River Basin, Nevada and California.

In Carson Desert, shallow aquifers have significantly higher ranked concentrations of manganese, nitrate, molybdenum, and lithium than those found in principal aquifers (fig 31*B*, table 11) Iron, fluoride, nitrate, and vanadium concentrations do not exceed standards and guidelines in principal and shallow aquifers (fig 31*B*)

Among constituents with MCL's, arsenic most commonly exceeds the standard in ground water of the Carson River Basin Most constituents that exceed MCL's in the basin are in shallow aquifers of Carson Desert (fig 34) Concentrations of dissolved arsenic in shallow aquifers locally differ greatly over short vertical and horizontal distances Differences are greatest in irrigated areas in Carson Desert For example, measured arsenic concentrations at Dodge Ranch increase from about 10 µg/L in irrigation water recharging the shallow aquifer to more than 2,000 µg/L in water at depths less than 20 ft below land surface (fig 35*A*) In areas of upward flow from intermediate to shallow aquifers, such as near Lead Lake, arsenic concentrations also are high (fig 35*B*), but the range is somewhat less In this area, measured arsenic concentrations differ by a factor of 2 9 and range from 480 to 1,400 µg/L

Manganese concentrations greater than the SMCL are found in ground water throughout much of the Carson River Basin (fig 36) Water with concentrations in excess of the drinking-water standards is most common in shallow aquifers of the upper and lower basin (fig 31) Shallow aquifers beneath urban and agricultural land in the upper basin contain high manganese concentrations (fig 32)

During the late 1800's to early 1900's, 7,000 tons of mercury was released to the environment during milling and amalgamation of gold and silver ore from the Comstock Lode in the Virginia City and Gold Hill areas (Smith, 1943, p 257) Much of this mercury and associated mine tailings were washed into the Carson River, resulting in contaminated river sediments downstream from the Comstock As a result of this contamination, a public health warning for human consumption of fish caught in Lahontan Reservoir was issued in 1986 by the Nevada Bureau of Health Protection Services A public health warning also was issued in March 1989 for consumption of shoveler duck muscle from the Carson Lake area High concentrations of mercury in sediment samples from Lahontan Reservoir and the Carson River have been documented by Van Denburgh (1973), and from Carson Lake and depositional areas of the Carson River in Carson Desert by Hoffman and others (1990) Surficial soil samples from Carson Desert contained high concentrations of mercury, especially along former channels of the Carson River (Tidball and others, 1991) Despite this documented contamination, only very low concentrations of mercury have been found in ground-water samples from Carson Desert (Hoffman and others, 1990, Lico and Seiler, 1994) and from Dayton and Churchill Valleys (Thomas and Lawrence, 1994) A recent summary of ground-water data in the Carson River Basin (Welch and others, 1989) showed that mercury concentrations did not exceed or closely approach established MCL's

Analyses of ground water compiled for this study generally show low selenium concentrations A few samples collected in Carson Desert during studies of irrigation drainage (Hoffman and others, 1990, p 36, Rowe and others, 1991, table 33) had selenium concentrations greater than the 10 µg/L MCL However, these samples were from monitoring wells in shallow aquifers near Stillwater Wildlife Management Area where ground water is not used for human consumption The Bureau of Reclamation studied selenium in shallow ground water and surface drains in the Fallon Indian Reservation and found high concentrations very localized (Bureau of Reclamation, 1987b) Extensive studies of surface-water quality, particularly with respect to selenium, have been completed in Carson Desert (Hoffman and others, 1990, Rowe and others, 1991, Lico, 1992) These studies show a possible link between selenium and wildlife mortalities or deformities in Carson Desert No apparent relation between selenium concentrations in ground water and in water from a nearby surface drain was observed in Carson Desert (Hoffman and others, 1990)

Processes Producing Concentrations of Minor Constituents

***By* Alan H Welch**

Chemical reduction caused by reaction with sedimentary organic matter can lead to dissolution of metal oxides and conversion of nitrate to less oxidized species Organic matter is microbially oxidized, resulting in electrons being accepted by some oxidized species that are thereby reduced The reduction of both dissolved chemical species and solid phases typically present in alluvial aquifers can proceed in an order estimated by thermodynamics A commonly described sequence involving closed-system reactions in the presence of sedimentary organic matter from a more

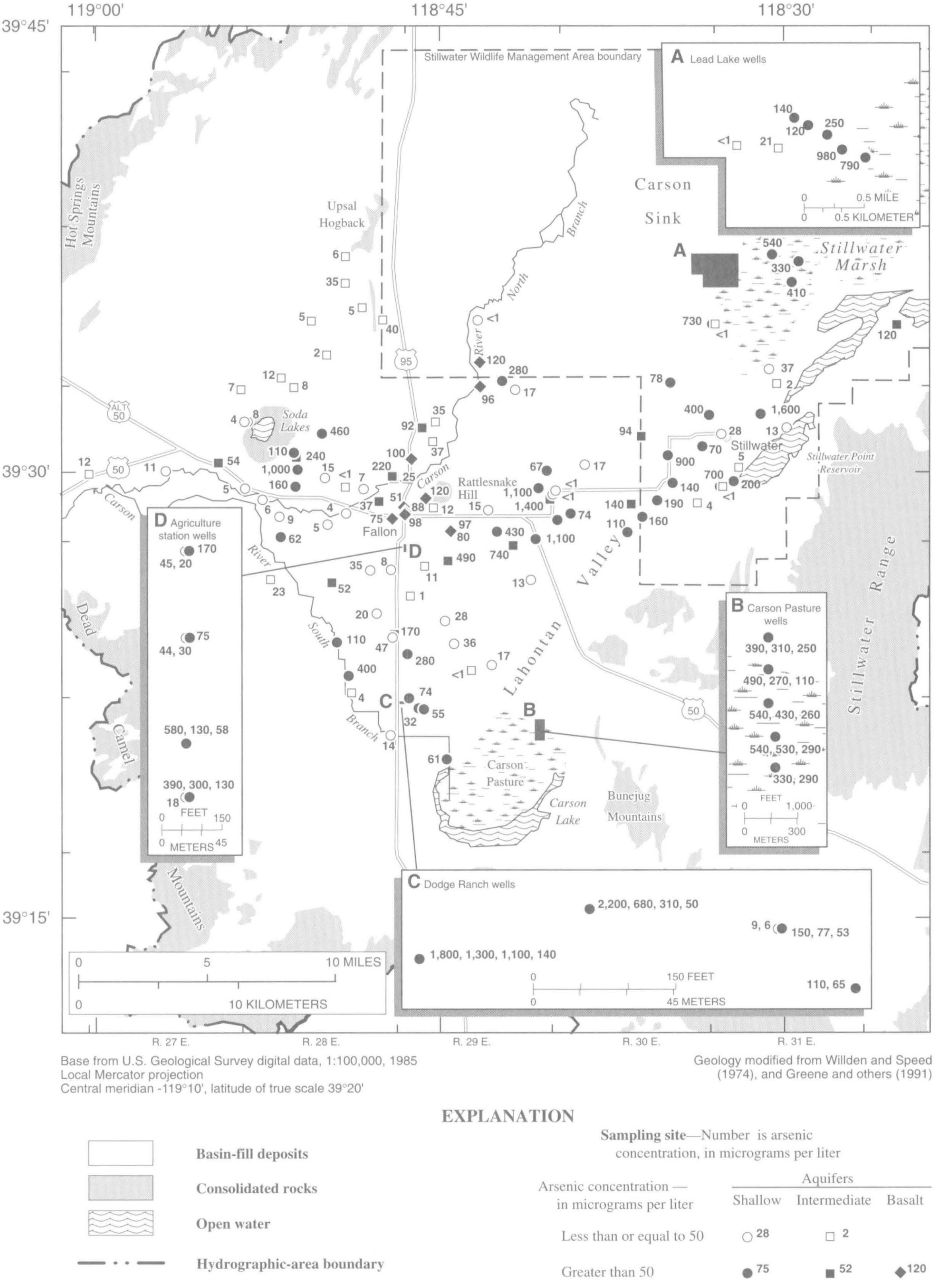


Figure 34. Ground-water sampling sites in southern Carson Desert, Nevada, where arsenic concentrations exceed Nevada State drinking-water standard (50 micrograms per liter).

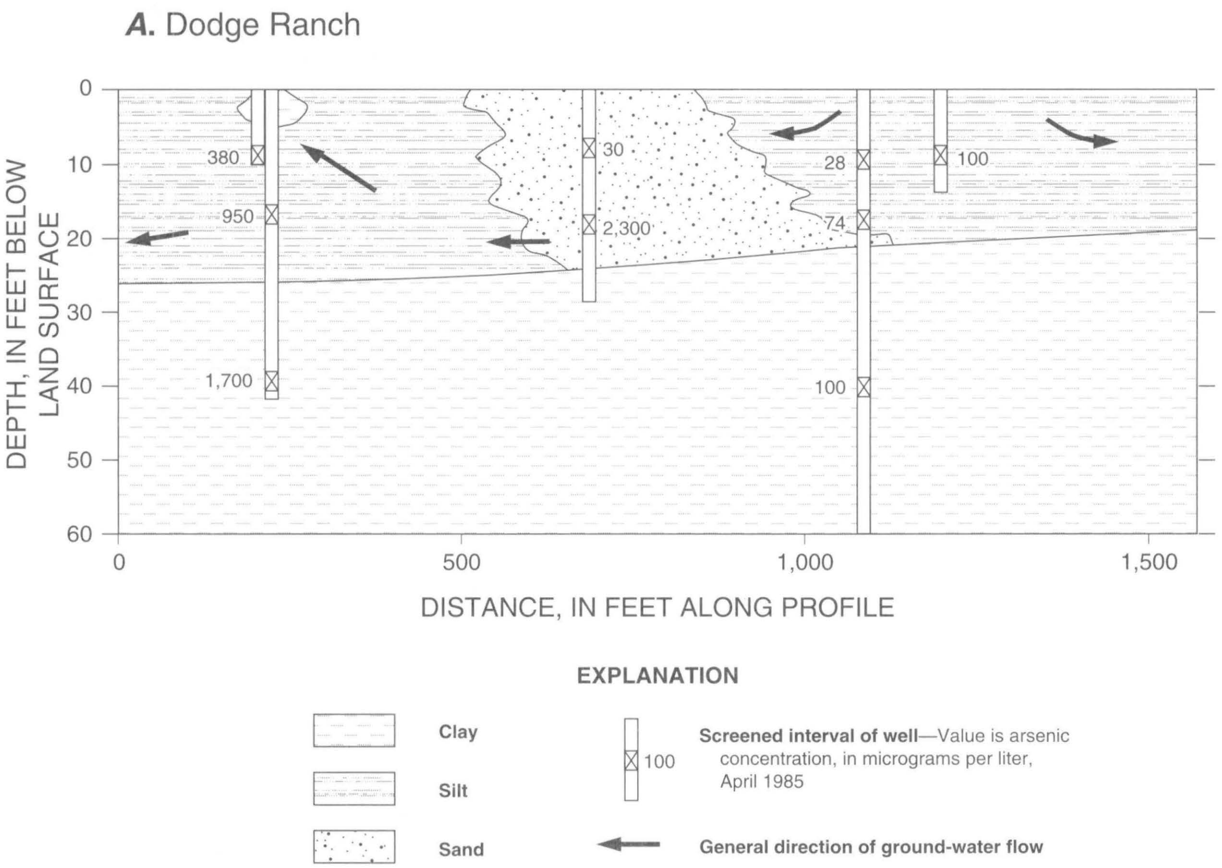


Figure 35. Arsenic concentrations in shallow ground water at two sites in southern Carson Desert, Nevada. *A*, Dodge Ranch; and *B*, Lead Lake.

oxidized to a more reduced state is (1) consumption of dissolved oxygen, (2) reduction of nitrate to nitrogen gas (denitrification), (3) dissolution of manganese oxide, (4) dissolution of iron oxide, (5) reduction of dissolved sulfate to sulfide, and (6) conversion of dissolved nitrogen gas to ammonia (Champ and others, 1979, table 2). These reactions can lead to release of other minor constituents, including arsenic, molybdenum, and uranium, if these constituents are present in sedimentary organic matter or iron and manganese oxides.

Adsorption can limit dissolved concentrations for some inorganic constituents, particularly those generally found at trace levels, such as arsenic. Because a critical discussion of models developed to quantitatively describe adsorption and the results of laboratory experiments is beyond the scope of this report, readers are referred to Davis and Hayes (1986). Briefly, adsorption is a process in which a dissolved species becomes attached to a surface of a pre-existing solid phase. An important phenomenon found in laboratory studies is the pH-dependence of adsorption. Over a narrow pH range, adsorption of ions varies from very little to nearly complete. Additionally, cations are adsorbed at higher pH values and anions are adsorbed at lower pH values. Some phases commonly found in alluvial deposits, such as iron oxides, can have a negative surface charge in solutions with pH values of about 8 or greater. Anions such as fluoride, arsenic, and molybdenum also commonly tend to be only weakly adsorbed on iron oxides in alkaline solutions. These phenomena are consistent with the electrostatic model of James and Healy (1972). Adsorption has been described as both an electrostatic interaction between an oxide surface and an adsorbing species (James and Healy, 1972) and as formation of a complex on the surface. The latter interaction is commonly called "specific" adsorption. These two ideas are combined in a single model containing terms for both interactions (Davis and others, 1978), where either can dominate.

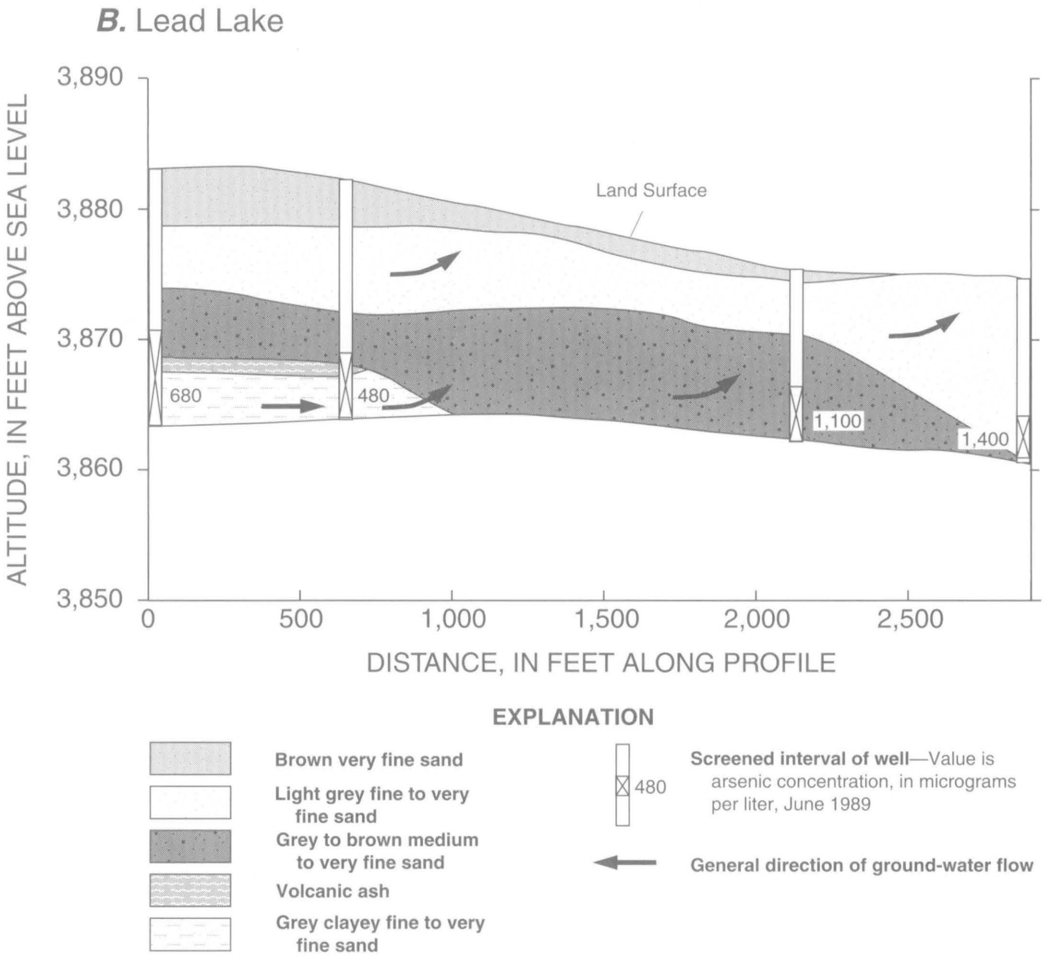
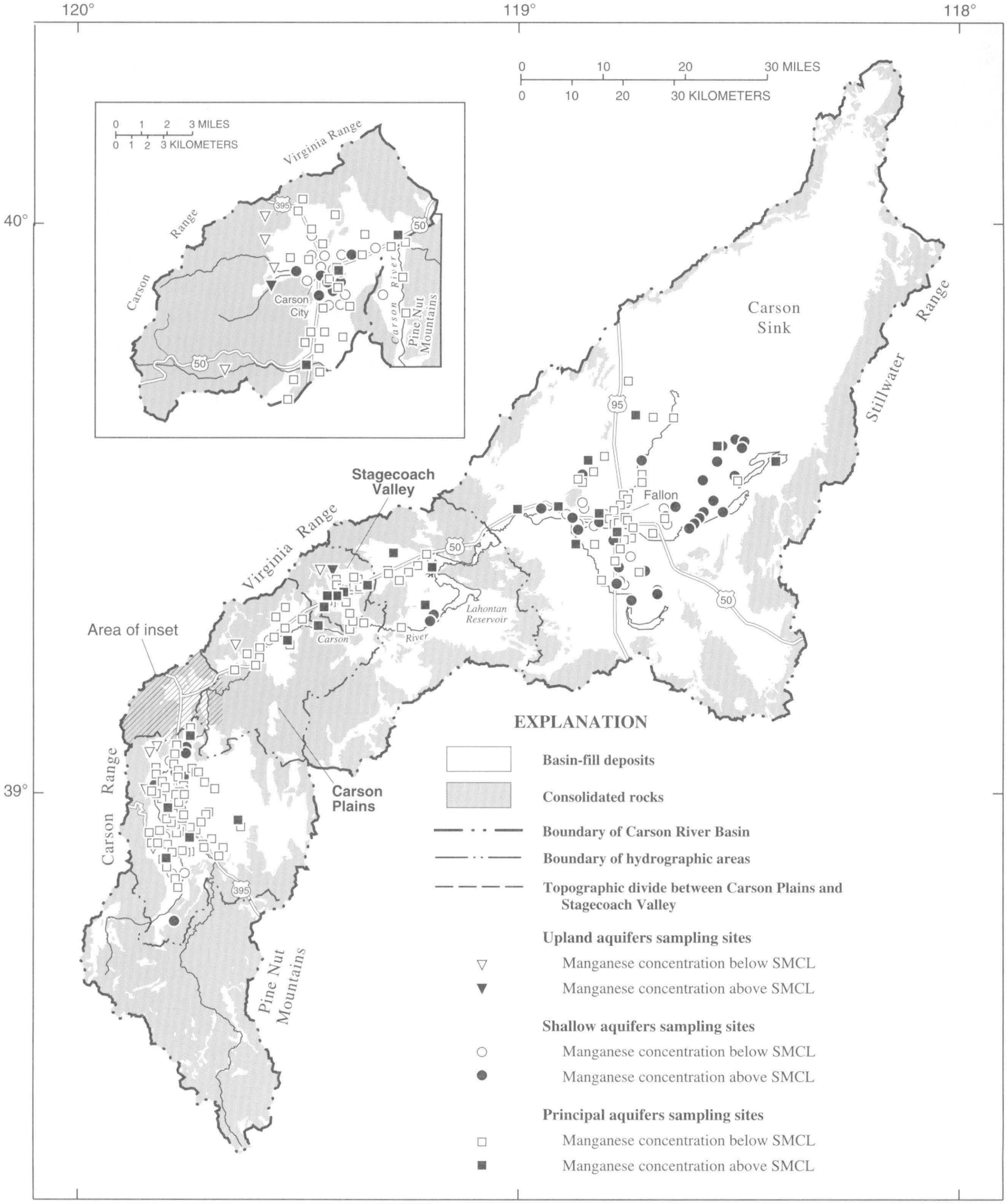


Figure 35. Continued.

Median concentrations of iron and manganese in shallow sediment sampled from the Carson River Basin are similar to estimated average concentrations in granitic rocks and somewhat lower than in basalt (table 14). These granitic and basalt rock types form much of the uplands, except for the ranges surrounding Carson Desert. Iron and manganese in unaltered granitic and basaltic rocks are mostly in mafic minerals, including amphiboles and pyroxenes. These groups of minerals generally are unstable in weathering environments. Weathering of these mafic minerals in oxygenated environments, such as streams and some ground water, results in formation of oxides on fractures and sediment surfaces. Ferric oxyhydroxides (FeOOH) and birnessite (MnO_2) are common in sediments. These oxides, which form part of total concentrations in sediments, can dissolve if they come in contact with water containing a chemically more reduced specie, such as dissolved organic carbon. For example, inundation of sediments containing organic matter can result in dissolution of the oxides.

Manganese and iron concentrations are weakly correlated (Spearman's rho is equal to 0.39), suggesting that ground water with a high concentration of manganese also may have a high concentration of iron (fig. 37*A*). Higher concentrations of both manganese and iron are found in water with low dissolved-oxygen concentrations (figs. 37*B* and *C*) and high dissolved-organic-carbon concentrations (figs. 37*D* and *E*). Manganese and iron concentrations greater than about 100 µg/L generally are in water with dissolved-oxygen concentrations less than 2 mg/L. High dissolved organic carbon and low dissolved oxygen are consistent with oxygen in recharge water reacting with organic carbon to produce a slightly reduced ground water. Pumping of wells during sampling may introduce oxygen into water prior to determination of the



Base from U.S. Geological Survey digital data, 1:100,000, 1985
Local Mercator projection
Central meridian -119°10', latitude of true scale 39°20'

Geology modified from Johnson (1977),
Stewart and others (1982),and
Greene and others (1991)

Figure 36. Ground-water sampling sites in Carson River Basin, Nevada and California, where concentrations of manganese exceed Nevada State secondary maximum contaminant level (100 micrograms per liter). SMCL, secondary maximum contaminant level.

dissolved oxygen. Consequently, water with a measured low dissolved-oxygen concentration (less than about 2 mg/L) may have even lower concentrations in an aquifer.

Dissolved organic carbon in anoxic water can react with iron and manganese oxides on aquifer material, thereby producing water with high concentrations of these two metals. Reaction of dissolved organic carbon with iron and manganese oxides is consistent with the geologic and hydrologic regime in the shallow subsurface of the Carson River Basin. This reaction probably occurs in shallow aquifers from which most of the ground-water samples with high concentrations of iron and manganese were obtained.

Sediments forming shallow aquifers consist primarily of alluvial and colluvial deposits that generally have oxide coatings (Jenne, 1968). Irrigation of agricultural and urban land has raised the water table, resulting in saturation of previously unsaturated sediments, particularly in southern Carson Desert. This change in water level apparently has resulted in release of sedimentary organic matter to the ground water. Sedimentary organic matter reacts with oxygen in recharge water and with oxide coatings on aquifer materials. High iron and manganese concentrations are common in the resulting anoxic water. Thus, water with high iron and manganese concentrations in shallow aquifers can be an indirect result of a rise in the water table by recharge from agricultural and urban activities.

Ground water in the Carson River Basin with high manganese and iron concentrations (greater than 100 µg/L) generally is at or near saturation with the carbonate minerals rhodochrosite and siderite (figs. 38*A* and *B*). Although these minerals have not been identified as discrete phases in the basin-fill sediments, they have been shown to form in nonmarine water. Siderite has been identified as a secondary mineral formed by precipitation from ground water in shallow sediments (Magaritz and Luzier, 1985) and rhodochrosite has been reported in aquifers from several localities (Jones and Bowser, 1978, p. 215-219). Iron and manganese can adsorb onto calcite surfaces or, at high metal concentrations, form iron or manganese carbonate minerals, as shown by laboratory experiments for manganese (Zachara and others, 1991). Iron and manganese carbonate, either as discrete minerals or on calcite surfaces, appear to limit metal concentrations in some ground water that has low concentrations of dissolved oxygen.

Among constituents with MCL's, arsenic is found most commonly at concentrations exceeding the standard, particularly in Carson Desert. Median arsenic concentrations in surficial sediments of the Carson

Table 14 Concentrations of selected constituents in shallow sediments of Carson River Basin, Nevada and California, and Western United States, and estimated mean concentrations in selected rock types

[Units of measure: milligrams per kilogram (equivalent to parts per million). Symbol --, values not available]

Constituent	Shallow sediments: Carson River Basin[1] Median	Carson River Basin[1] Geometric Mean	Carson River Basin[1] Maximum	Western United States[2] Geometric Mean	Western United States[2] Maximum	Estimated means: Granite[3]	Basalt[3]	Sandstone[4]	Shale[4]
Iron	30,000	29,000	68,000	26,000	100,000	27,000	86,000	18,600	38,800
Manganese	630	600	1,500	480	5,000	500	1,700	392	575
Fluoride	--	--	1,900	440	1,900	850	400	220	500
Boron	6.1	7.2	300	29	300	15	5	90	194
Lithium	37	41	130	25	130	30	12	15	46
Arsenic	10	10	73	7.0	97	1.5	2	1	7
Molybdenum	8	9	7	1.1	7	1.5	1	5	4.2
Uranium	3.3	3.7	490	2.7	7.9	4.8	6	1	4.5

[1] E.A. Frick (U.S. Geological Survey, written commun., 1992), modified from Tidball and others (1991).

[2] Shacklette and Boerngen (1984, table 2), geometric mean is estimated.

[3] Taylor (1964).

[4] Horn and Adams (1966).

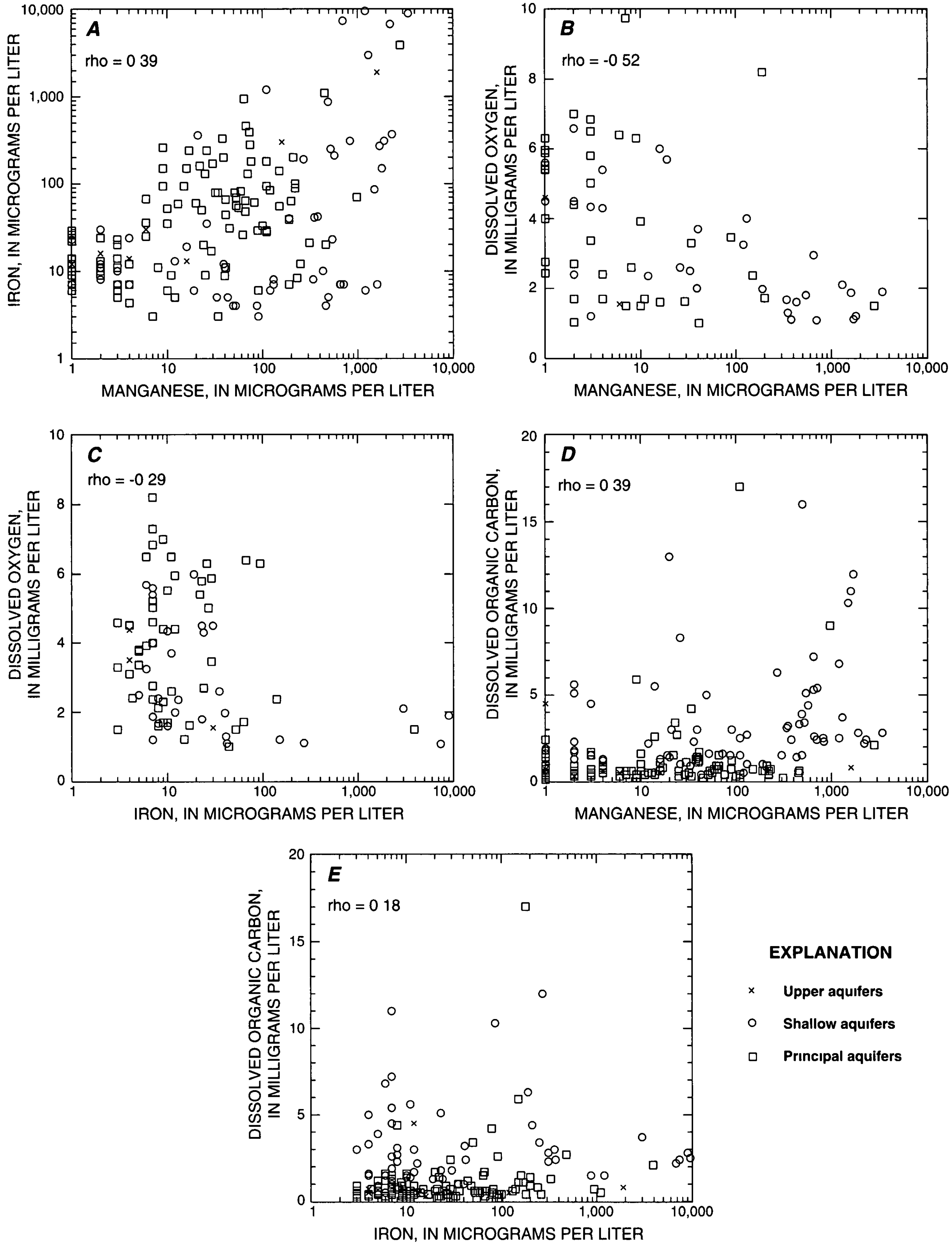


Figure 37 Relations between selected minor constituents in ground water of Carson River Basin, Nevada and California. *A*, Manganese and iron, *B*, Manganese and dissolved oxygen, *C*, Iron and dissolved oxygen, *D*, Manganese and dissolved organic carbon, and *E*, Iron and dissolved organic carbon. The rho value is Spearman's rho test statistic (Iman and Conover, 1983, p. 126-129).

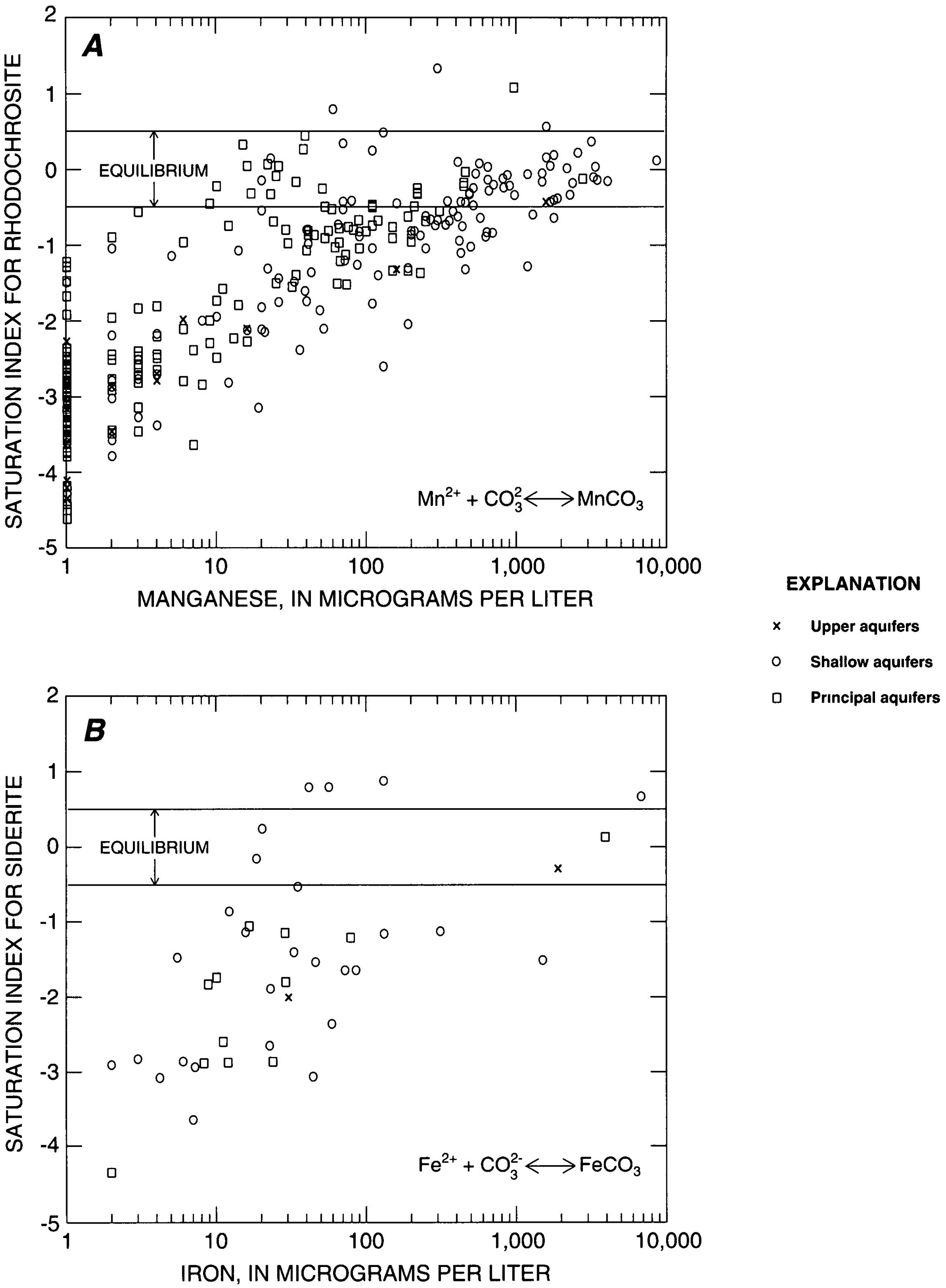


Figure 38. Relations between (*A*) manganese and the saturation index for rhodochrosite, and (*B*) iron and the saturation index for siderite in ground water of Carson River Basin, Nevada and California. The rho value is Spearman's rho test statistic (Iman and Conover, 1983, p. 126-129).

River Basin are greater than estimated average values for both granitic and basaltic rocks (table 14) Arsenic concentrations in surficial sediments also are greater in Carson Desert than in Carson and Eagle Valleys (E A Frick, U S Geological Survey, written commun , 1992) The estimated geometric mean concentration in surficial sediments in the Western United States and the estimated average concentration in shale are similar to median values for the Carson River Basin (table 14)

Arsenic concentrations in some ground water beneath Dodge Ranch (fig 35*A*) are much greater than can be attributed to evaporative concentration as shown by the relation between arsenic and chloride (fig 39) Assuming an initial arsenic and chloride concentration equal to that in the sample from Dodge Ranch with the lowest chloride concentration (24 mg/L), the effect of evaporative concentration is shown by the sloping line in figure 39 Water from two wells open to the aquifer at a depth of about 20 ft below land surface clearly have higher arsenic concentrations that can be attributed to evaporative concentration alone

Although the contribution from different solid phases to the total dissolved-arsenic concentration in water cannot be quantified, several processes that release arsenic to the aqueous system can be described Dissolution of ferric oxyhydroxide and manganese oxides, which are present as coatings on the sediments and can concentrate arsenic, is indicated by relatively high concentrations of dissolved iron and manganese in water samples This process may be the primary cause of the high concentrations in water in the shallow aquifers of the southern Carson Desert Dissolution of lithic volcanic fragments, which have arsenic concentrations greater than 30 mg/kg (Lico and others, 1986, table 6), is another potential source of dissolved arsenic in water Adsorption of arsenic on iron oxides also may limit concentrations in water in parts of the Carson River Basin

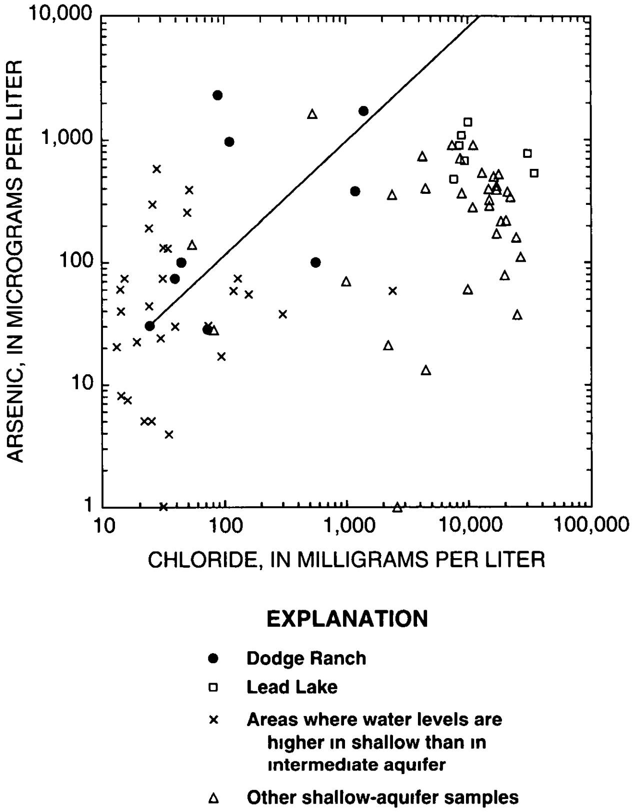


Figure 39 Relation between arsenic and chloride in shallow ground water of Carson Desert, Nevada Sloping line represents composition of water affected only by evaporative concentration, assuming initial chloride and arsenic concentrations of 24 milligrams per liter and 30 micrograms per liter, respectively

The relation between arsenic and chloride (fig 39) in water with chloride concentrations greater than about 200 mg/L can be explained by either the dissolution of chloride salts or a combination of evaporative concentration and loss of arsenic from solution Again using the data for Dodge Ranch as an example, two of the three samples with the highest chloride concentrations plot well below the sloping line that represents the effects of evaporative concentration alone This evidence, along with the stable isotope relations shown in figure 20 for shallow water in the upflow zone, suggest that evaporative concentration and loss of arsenic from solution may be occurring, at least in some shallow ground water The sample with the highest chloride at Dodge Ranch is from a well open to a depth of only 9 ft below land surface The presence of efflorescent salts at this location, which are not present at the other Dodge Ranch locations shown in figure 35*A*, suggests that evaporation affects water at this site

Fluoride concentrations generally are higher in acidic igneous rocks and in residual fluids formed during the cooling of magma than in ground water The estimated mean fluoride concentration in granitic rocks is more than twice that estimated for basalt (table 14) Amphiboles and micas, which are common in a variety of igneous rocks, typically contain some fluoride substituted for hydroxide in crystal lattices Apatite also commonly contains some fluoride Geothermal water typically contains high concentrations of dissolved fluoride commonly contains some fluoride Geothermal water typically contains high concentrations of dissolved fluoride

Geochemical controls on fluoride concentrations in nonthermal ground water commonly are mineral equilibria and adsorption (Hem, 1985, p 121) Two common minerals that contain fluoride, fluorite and fluorapatite, do not appear to limit fluoride concentrations in most ground water of the Carson River Basin (figs 40*A* and *B*) Saturation indices for fluorapatite [$Ca_5(PO_4)_3F$] suggest both oversaturation and undersaturation, which implies that this mineral is not limiting concentrations of fluoride Only a few ground-water analyses show equilibrium or oversaturation with respect to fluorite (CaF_2), suggesting an absence of solubility control

Laboratory and field data indicate that fluoride concentrations can be controlled by adsorption reactions with common minerals Laboratory data show large adsorption capacities for fluoride on minerals such as gibbsite, kaolinite, halloysite, and freshly precipitated aluminum oxide (Bower and Hatcher, 1967) Results of laboratory experiments using iron oxide (goethite) as the sorbing phase show that fluoride is specifically adsorbed Adsorption of a fluoride ion is accompanied by release of a hydroxyl ion, and is less effective with increasing pH (Hingston and others, 1967, 1972) On the basis of a statistical correlation of fluoride with pH, and leachate analyses of aquifer material, Robertson (1985) concluded that adsorption reactions are a likely control on fluoride concentrations in ground water in Arizona's alluvial basins In the Carson River Basin, fluoride concentrations are weakly correlated with pH (fig 40*C*), indicating that adsorption may be limiting concentrations in some ground water

Median concentrations of lithium in surficial sediments are similar to estimated concentrations in shales and to concentrations in sediments of the Western United States (table 14) Boron and molybdenum in sediments of the Carson River Basin have median concentrations lower than those generally found in the Western United States These relations suggest that high dissolved concentrations of these constituents in ground water may be the result of some factor other than total concentrations in the sediments Intense evapotranspiration in Carson Desert, where many of the high concentrations are found, is a likely contributing factor

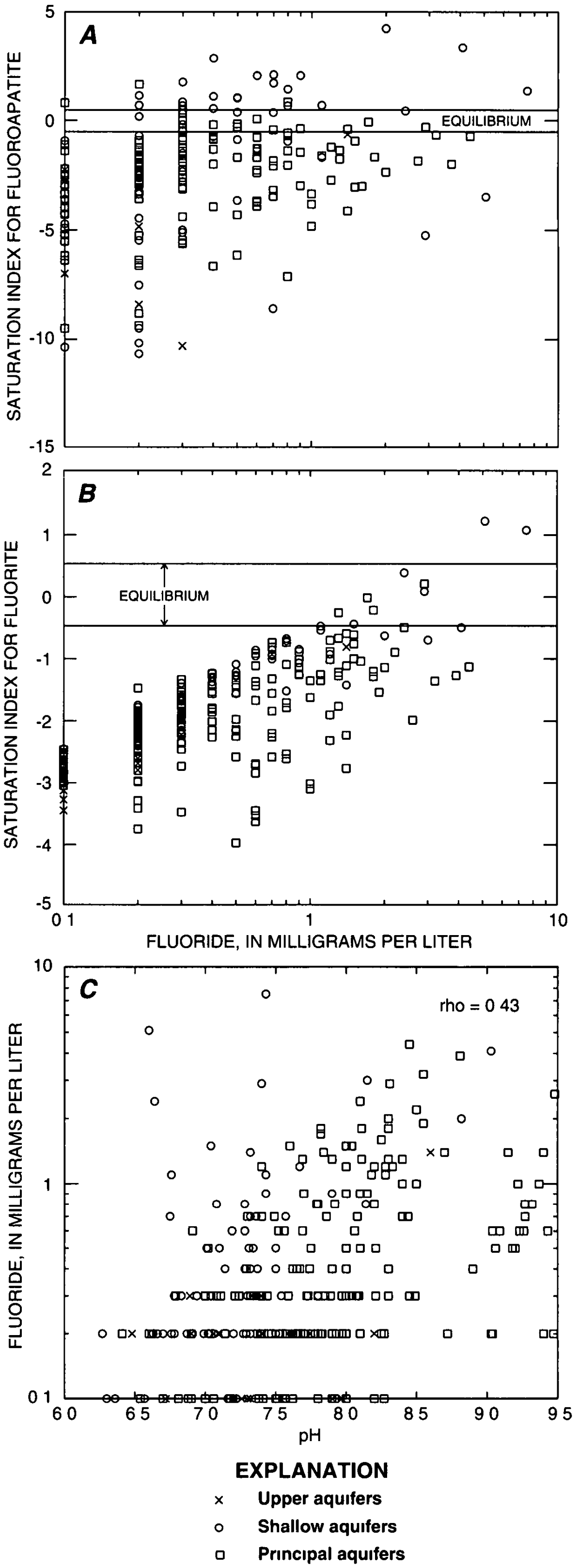


Figure 40 Relation between fluoride concentrations and (*A*) saturation index for fluorapatite, *(B)* saturation index for fluorite, and (*C*) pH in ground water of Carson River Basin, Nevada and California

Radionuclide Activities and Concentrations

By James M. Thomas

Radionuclides of greatest concern in the Carson River Basin, from a human health standpoint, are radon-222 and uranium. This concern is reflected by present and proposed drinking-water standards. Proposed standards for radium-226, radium-228, and adjusted gross alpha (table 6) generally are higher than levels in ground water in the Carson River Basin. The distribution and sources of radionuclides in ground water of the Carson River Basin are described by Thomas and others (1993).

Screening methods have been used for rapid identification of alpha and beta activity in water. These methods, called gross alpha and gross beta, are inexpensive compared to analysis for specific radionuclides and are sensitive to a variety of isotopes. Disadvantages of the methods include (1) volatile radionuclides, including tritium and radon-222, are not detected because samples are dried prior to measurement of the activity, (2) ingrowth of radioactive progeny during the time between sampling and analysis may contribute to gross-beta activity (Thomas and others, 1990, Welch and others, 1995), and (3) the analytical methods do not identify which isotopes contribute to the gross measurement. An additional measure, which has been proposed as a drinking-water standard, is called an "adjusted gross alpha" and is defined as the measured gross-alpha activity minus radium-226 and uranium. Alpha- and beta-emitting isotopes are grouped together in the discussion. Uranium is shown in figure 43 in terms of activity and concentration because the proposed drinking-water standard is expressed as a concentration and the gross-alpha activity is expressed in terms of radioactivity.

Uranium is the primary source of alpha activity in ground water of the Carson River Basin (fig. 41, Thomas and others, 1993). On the basis of a few measurements of the uranium-isotope composition, the activity ratio (AR) of uranium-234 to uranium-238 is within the range of 1 to 1.5. If the only source of alpha activity is uranium, the data will plot along the AR lines shown in figure 41. With only a few exceptions, gross-alpha activity can be accounted for by the uranium present in the water (Thomas and others, 1993). Radium-226, with a maximum measured activity of only 0.56 pCi/L, and thorium-230, with a maximum activity of 0.20 pCi/L, in four samples appear to contribute little to the total alpha activity. Polonium-210 had a maximum activity of 21 pCi/L in one sample, and this may contribute significant alpha activity to some ground water (Thomas and others, 1993).

Gross-beta activity in ground water can be accounted for by potassium-40 and uranium progeny (fig. 42). Potassium concentrations range from about 1 to 500 mg/L (for samples with gross-beta analysis), which correspond to potassium-40 activities ranging from about 0.5 to 410 pCi/L (Thomas and others, 1993). After about 100 days, ingrowth of radioactive uranium progeny produces particle emission rates approximately equal to the initial uranium decay rate, in water with a U-234/U-238 AR equal to 1.0, because one-half of the uranium decay emission would be from uranium-238 decay. Ingrowth of the progeny, combined with potassium-40 activities estimated from potassium concentrations, can produce gross-beta activities that lie along the AR line shown in figure 42. The contribution of radium-228 to gross-beta activities, in most ground-water samples, is small because of low mobility in near-neutral to alkaline water (Krishnaswami and others, 1982, Ames and others, 1983, Latham and Schwarcz, 1987). Median radium-228 activity in ground water of the Carson Desert is less than 1.0 pCi/L (fig. 43*B*).

In the upper basin, principal aquifers contain uranium and radon-222 activities with ranges and medians and ranked activities similar to those found in the

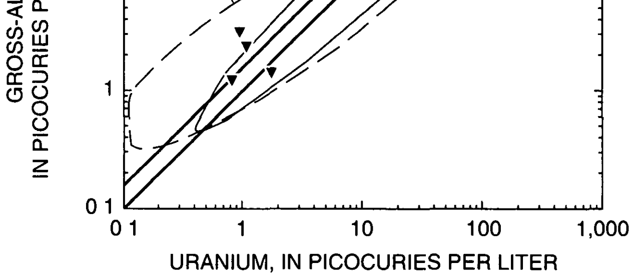


Figure 41. Relation between gross-alpha activity and uranium in ground water of Carson River Basin, Nevada and California. Envelope boundaries are derived by polar smoothing routines and encompass 75 percent of data. Activity ratio is ratio of uranium-234 to uranium-238.

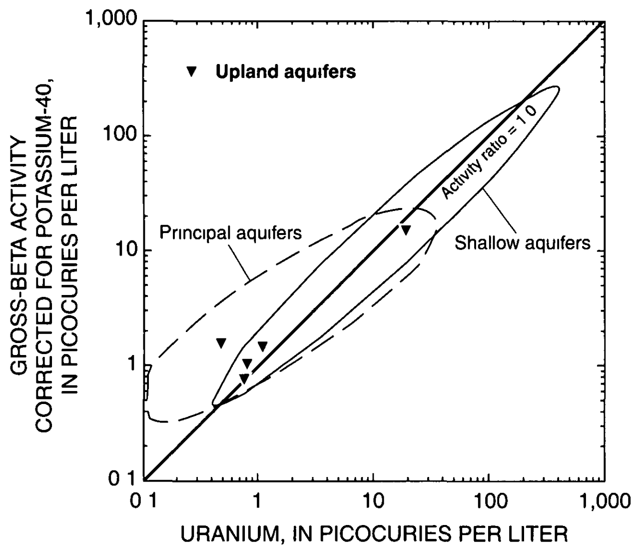


Figure 42 Relation between gross-beta activity and uranium in ground water of Carson River Basin, Nevada and California Envelope boundaries are derived by polar smoothing routines and encompass 75 percent of data

upland and shallow aquifers (fig 43*A*, table 15) The median concentration of uranium in surficial sediments is similar to estimated mean concentration in shale and the mean for sediments in the Western United States (table 14) In Carson Desert, the median uranium activities in ground water is about 30 times greater in shallow aquifers than in intermediate and basalt aquifers (fig 43*B*) The mean rank radon-222 activity of Carson Desert also is significantly higher in the shallow aquifers than in intermediate and basalt aquifers that compose the principal aquifers (table 15)

Median and ranked uranium concentrations in intermediate and basalt aquifers are the lowest in the Carson Desert (table 16) Median values decrease from 2 8 pCi/L in the upper basin to 1 3 pCi/L in Carson Desert Median radon-222 activities decrease from 1,100 to 425 pCi/L (fig 44) Similarly, ranked uranium activities in shallow aquifers are significantly higher in Carson Desert than in the upper and middle basins (fig 43, table 16) The median activity in shallow aquifers of Carson Desert (40 pCi/L) is high compared to all other aquifers in the basin (fig 43) and to the proposed standard (20 pCi/L)

Radium-226 and -228 activities in ground water are similar in upland, shallow, and principal aquifers and in valleys within the Carson River Basin (figs 43 and 44) Radium-226 activities range from a minimum reporting level of 0 02 to 0 56 pCi/L (fig 43) Radium-228 activities range from a minimum reporting level of 1 0 to 4 6 pCi/L (fig 43)

Uranium concentrations greater than the proposed standard are most commonly found in shallow aquifers of Carson Desert and upland and principal aquifers of Eagle Valley (fig 45) By far, the highest concentrations are in shallow aquifers of Carson Desert Like arsenic, uranium concentrations are highly variable over relatively short distances in shallow aquifers in Carson Desert One example at Dodge Ranch is a 10-fold increase in measured concentrations over a horizontal distance of less than 1,000 ft at depths of less than 30 ft below land surface (fig 46*A*) In general, lower concentrations are in water that has moved shorter distances through the subsurface Variations are somewhat less in ground water beneath non-irrigated land, for example near Lead Lake (fig 46*B*) In this area, measured uranium concentrations differ by a factor of about 1 3, from 180 to 240 μg/L

Eighty-seven percent of ground-water samples from principal aquifers (119 samples) have radon-222 activities greater than the proposed MCL (300 pCi/L) The proportion of samples containing radon-222 above the proposed MCL is about the same in the different aquifers The highest radon-222 activities are in upland aquifers Shallow and principal aquifers have higher radon-222 activities in the western parts of Carson and Eagle Valleys adjacent to the Sierra Nevada (fig 47) The highest radon-222 activities generally are along the western parts of Carson and Eagle Valleys adjacent to the Sierra Nevada Radon-222 in ground water on

Table 15. Statistical comparison of ranked uranium concentrations and radon-222 activities in water from principal aquifers and water from upland and shallow aquifers, Carson and Eagle Valleys and Carson Desert, Nevada and California

[Ranked uranium and radon-222 activities are higher in samples from shallow aquifers, p-values determined by Mann-Whitney method (Conover, 1980, p 216) Symbol --, no constituent]

Aquifer system	Highly significant (p less than 0 01)	Not significant (p greater than 0 05)
	Carson and Eagle Valleys	
Upland	--	Uranium, radon-222
Shallow	--	Uranium, radon-222
	Carson Desert	
Shallow	Uranium, radon-222	--

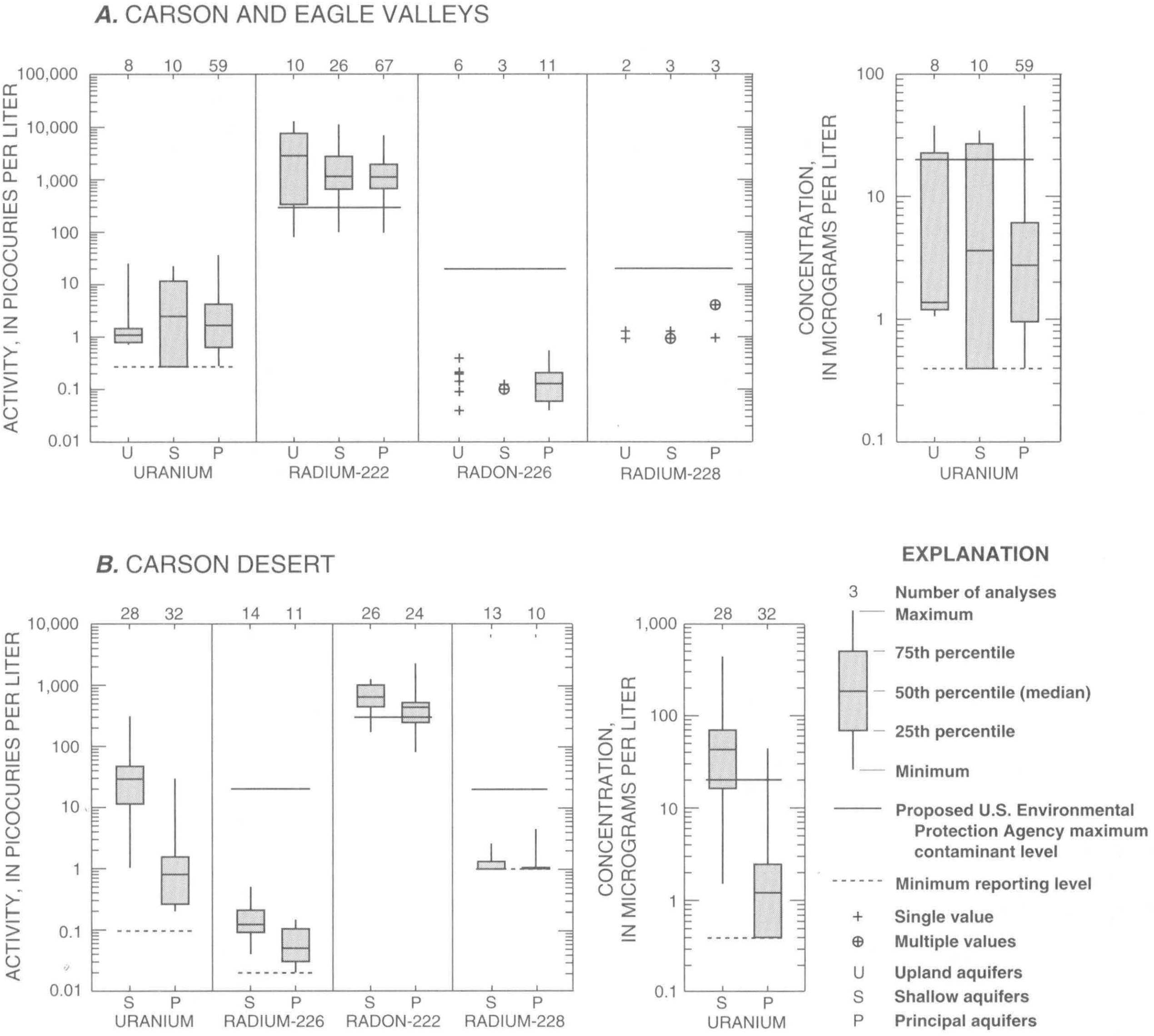


Figure 43. Summary statistics for selected radionuclides in aquifers of (*A*) Carson and Eagle Valleys, and (*B*) Carson Desert, Nevada and California.

the eastern slope of the Carson Range commonly exceeds 2,700 pCi/L and locally has been found as high as 14,000 pCi/L.

More than one-half of 41 samples from shallow aquifers and 3 of 9 samples from upland aquifers have uranium concentrations that exceed the proposed MCL. Most of the samples from the shallow aquifers that exceed the proposed standard (22 of 32) are from wells in Carson Desert. Only 7 of 112 samples from principal aquifers exceed the proposed MCL. Of those seven samples, five are from Carson and Eagle Valleys.

None of the radium-226 or radium-228 samples analyzed exceed the proposed MCL. Four percent of samples (6 of 143) analyzed for gross-alpha activity and dissolved uranium exceed the proposed MCL for adjusted gross alpha.

Processes Producing Radionuclide Activities

***By* Alan H. Welch**

In mountainous areas, uranium is dissolved by water infiltrating granitic rocks, mainly in the Sierra Nevada, and through silicic volcanic rocks in relatively

Table 16. Statistical comparison of ranked uranium concentrations and radon-222 activities in ground water from upper, middle, and lower Carson River Basin, Nevada and California

[Constituents in **bold** and nonbold have, respectively, higher and lower ranked concentrations in more downstream part of basin; p-values determined by Mann-Whitney method (Conover, 1980, p. 216). Symbol: --, no constituent)]

Area	Highly significant (p less than 0.01)	Significant (p greater than 0.01 and less than or equal to 0.05)	Not significant (p greater than 0.05)
	Principal aquifers		
Carson and Eagle Valleys compared with Dayton and Churchill Valleys	Radon-222	--	Uranium
Dayton and Churchill Valleys compared with Carson Desert	Radon-222	Uranium	--
Carson and Eagle Valleys compared with Carson Desert	Uranium, radon-222	--	--
	Shallow aquifers		
Carson and Eagle Valleys compared with Carson Desert	**Uranium**, radon-222	--	--

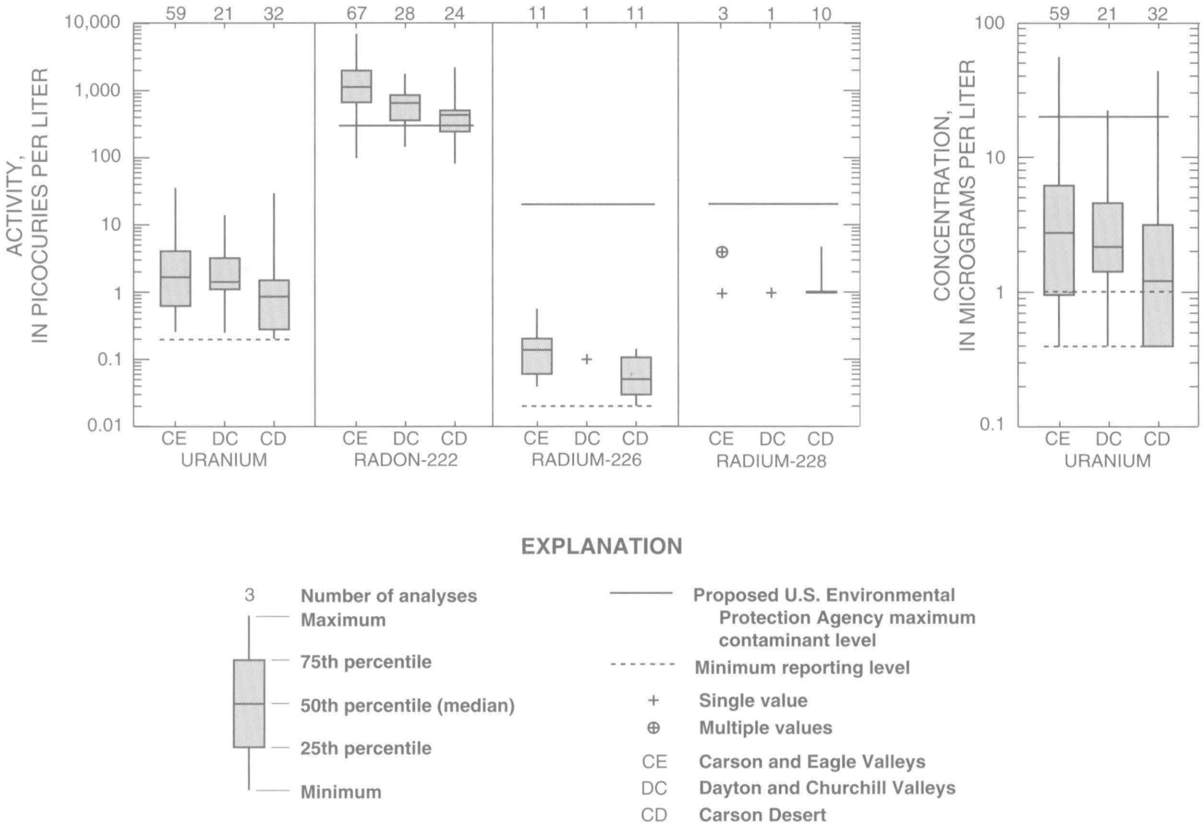
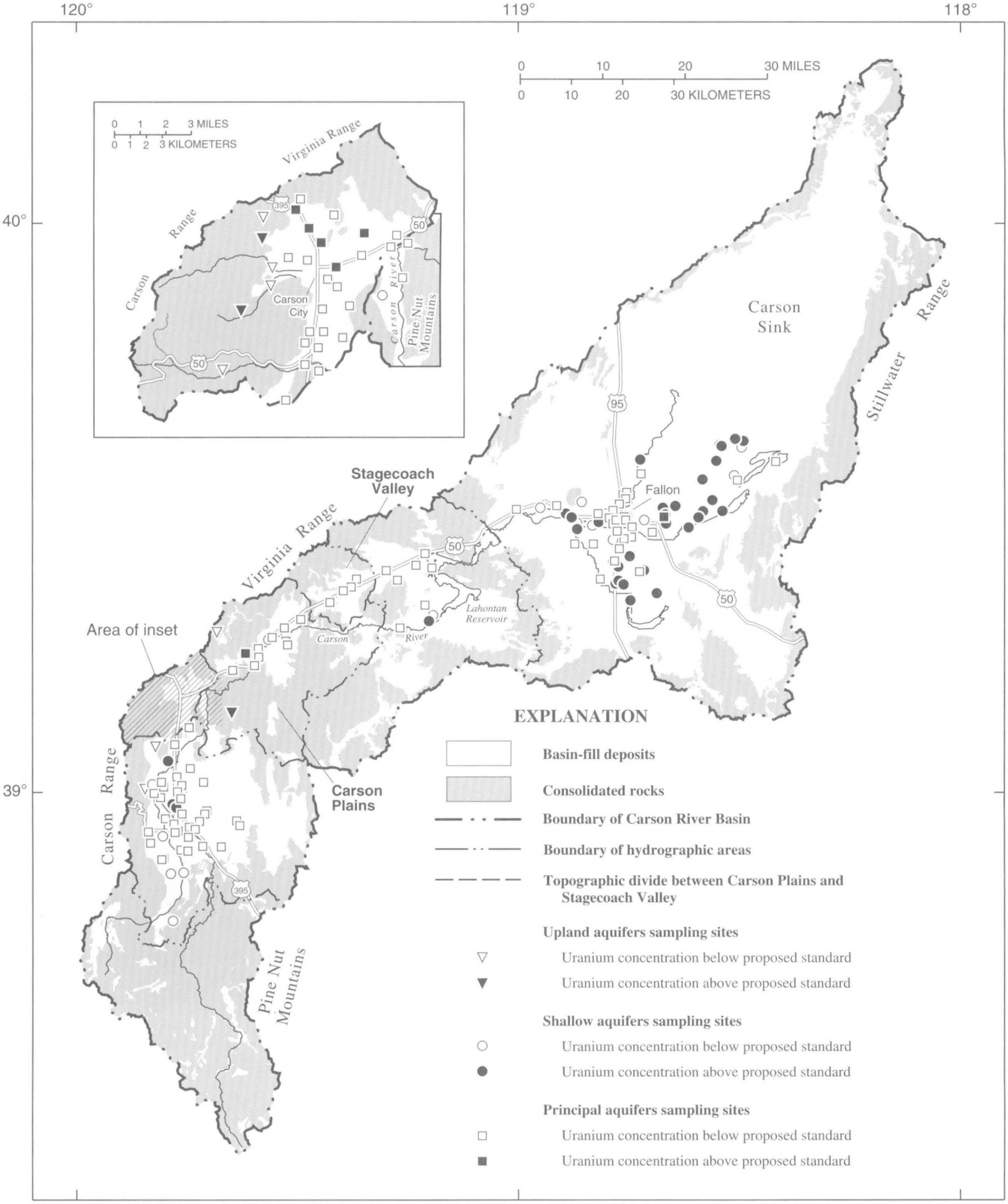


Figure 44. Summary statistics for selected radionuclides in principal aquifers in Carson River Basin, Nevada and California.



Base from U.S. Geological Survey digital data, 1:100,000, 1985
Local Mercator projection
Central meridian -119°10', latitude of true scale 39°20'

Geology modified from Johnson (1977),
Stewart and others (1982), and
Greene and others (1991)

Figure 45. Ground-water sampling sites in Carson River Basin, Nevada and California, where concentrations of uranium exceed proposed U.S. Environmental Protection Agency drinking-water standard (20 micrograms per liter).

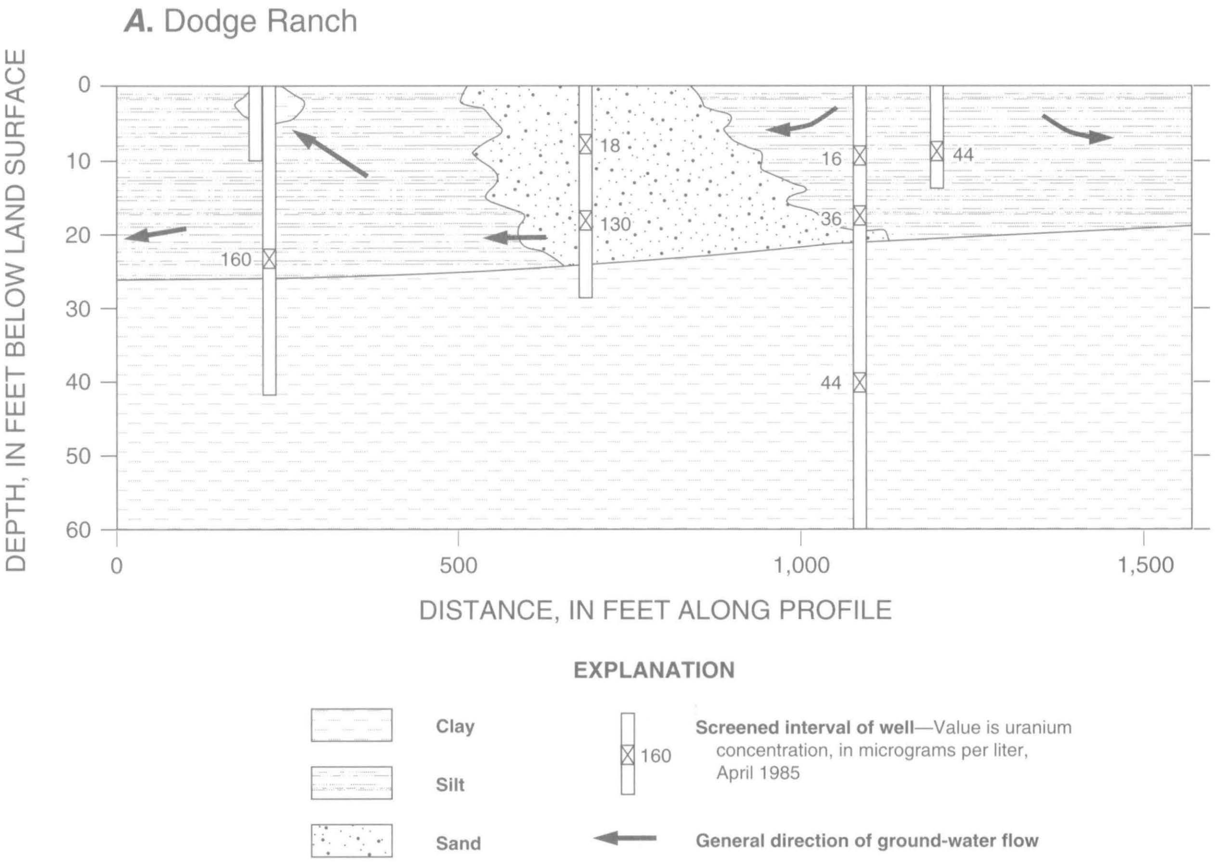


Figure 46. Uranium concentrations in shallow ground water at two sites in southern Carson Desert, Nevada. *A*, Dodge Ranch; and *B*, Lead Lake.

small areas throughout the study area. This water dissolves primary minerals containing uranium and uranium-rich metal-oxide coatings on mineral grains and in the rock matrix. Uranium concentrations in granitic rocks range from about 3 to 10 mg/kg (Otton and others, 1989, p. 25). Titanite (sphene) is the most significant contributor of uranium to the water because titanite is more abundant than zircon and is highly altered (fig. 48). Titanite is ubiquitous in granitic rock and because the titanite is highly altered, uranium is readily released to the ground water.

In ground water containing dissolved oxygen, uranium generally is present in the 6^+ oxidation state as a uranyl ion. Uranyl complexes adsorb onto surfaces of aquifer materials, such as iron oxyhydroxide (Langmuir, 1978; Hsi and Langmuir, 1985; Kamineni, 1986), organic matter (Szalay, 1964; Nakashima and others, 1984; Leventhal and others, 1986), and clay minerals (Ames and others, 1983; Kamineni, 1986), and coprecipitate with iron and manganese oxides (Kamineni, 1986; Guthrie, 1989). Consequently, dissolved uranium is removed from water and is concentrated in iron- and manganese-oxide coatings in fractures and fine-grained sediments and on organic matter (fig. 49).

Fluvial processes transport sediments containing uranium from the upper to the lower Carson River Basin. Uranium concentrations are less than 9 mg/kg in 95 percent of 351 surficial sediment samples collected throughout most of the Carson River Basin (E.A. Frick, U.S. Geological Survey, written commun., 1992; based on data from Tidball and others, 1991). Uranium concentrations are highest in sediments adjacent to the Carson Range in Carson Valley. Riparian vegetation along the Carson River has periodically been incorporated into basin-fill sediments because of flooding. In addition, vegetation in stream channels along the east slope of the Sierra Nevada has been carried down channels and buried in alluvial fans along the west side of Carson Valley. Thus, organic matter is present in basin-fill sediment in the western part of the basin, predominantly along buried river channels and alluvial fan deposits. These relatively organic-rich sediments

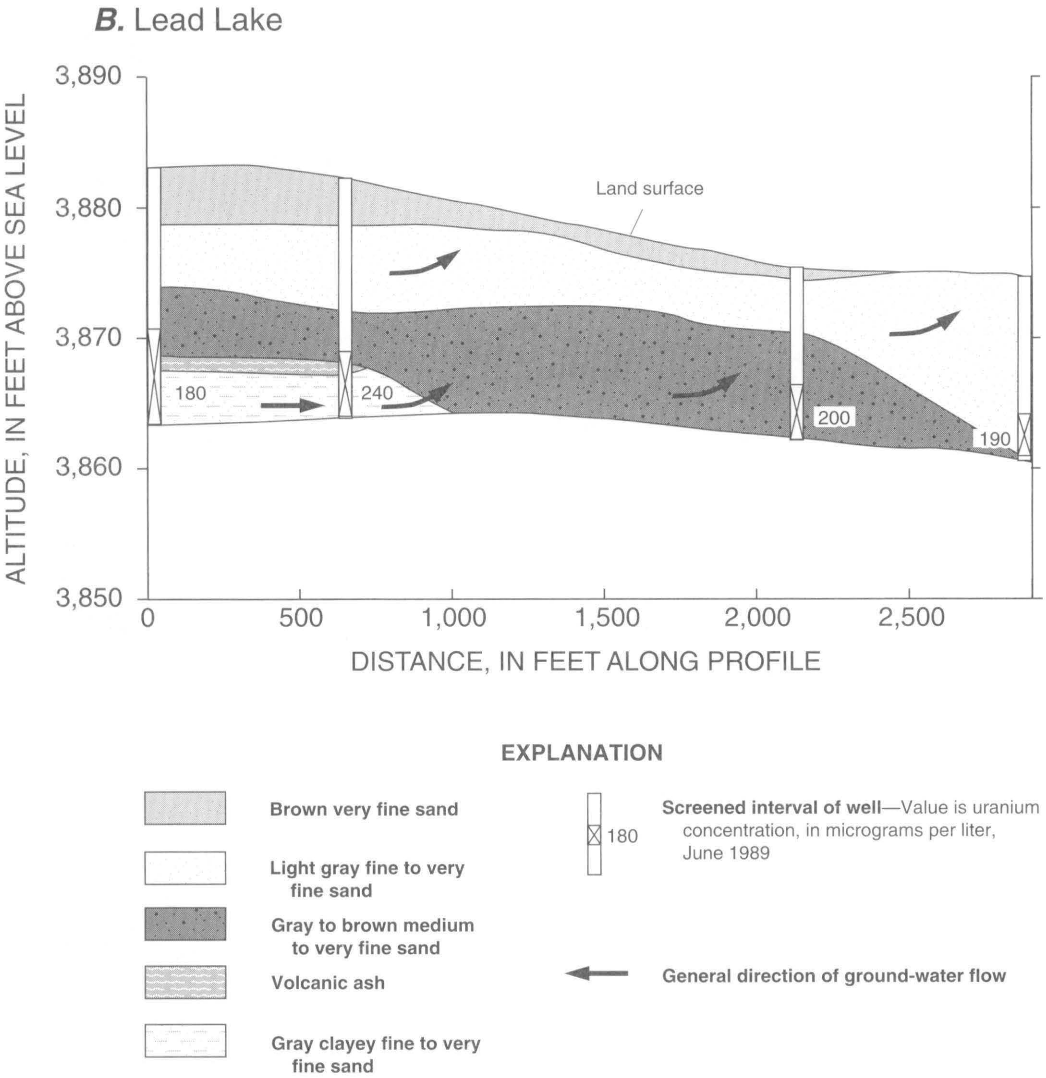
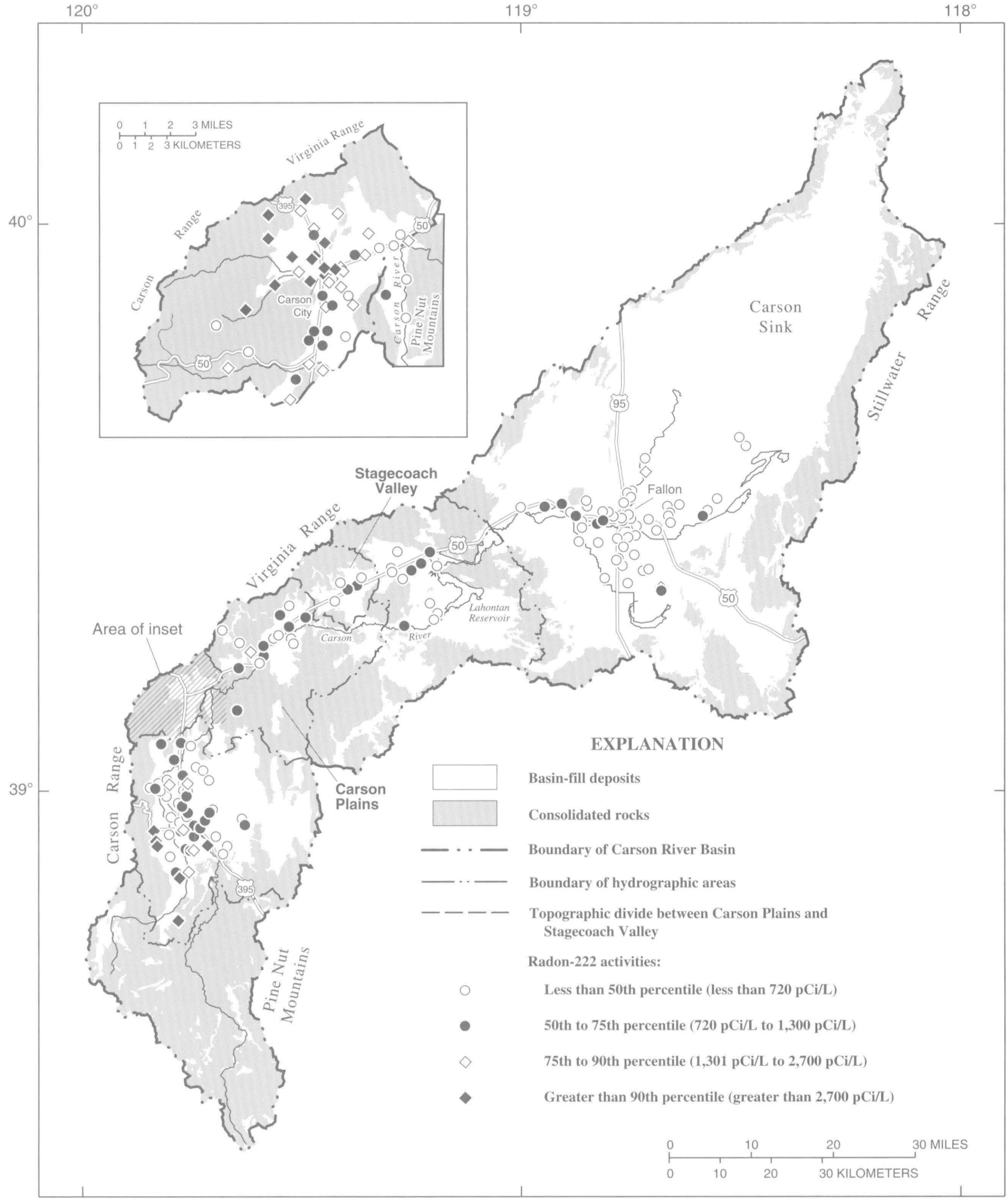


Figure 46. Continued.

contain uranium because organic matter strongly adsorbs uranium (Szalay, 1964; Nakashima and others, 1984; Leventhal and others, 1986).

Uranium can be released from organic matter and metal-oxide coatings through dissolution and desorption (Welch and Lico, 1988; Thomas and others, 1993). Uranium activities generally are less than 40 pCi/L in ground water of the Carson River Basin. Exceptions are shallow ground water in Carson Desert and a spring in the Pine Nut Mountains, where uranium activities are markedly greater. These locally high activities in the shallow ground water of Carson Desert are caused by irrigation water saturating previously dry sediments. Readily available uranium is released from hematite coatings and sedimentary organic matter by dissolution and desorption. Uranium in Carson Desert is concentrated in metal-oxide coatings on mineral grains and in sedimentary organic matter (fig. 50). Some shallow ground water has been affected by evapotranspiration, resulting in high uranium concentrations and dissolved-solids concentrations.

Radon-222 is the decay product of radium-226, but radon-222 activities measured in ground water are produced almost exclusively by radium-226 in aquifer material rather than from decay of dissolved radium-226. Highest measured radon-222 activities are in ground water from consolidated rock and unconsolidated deposits in and adjacent to the Sierra Nevada (fig. 47; Lico and Rowe, 1991). Fractures in consolidated rock along the range front allow ground water to flow



Base from U.S. Geological Survey digital data, 1:100,000, 1985
Local Mercator projection
Central meridian -119°10', latitude of true scale 39°20'

Geology modified from Johnson (1977),
Stewart and others (1982), and
Greene and others (1991)

Figure 47. Radon-222 activities in ground water of Carson River Basin, Nevada and California.

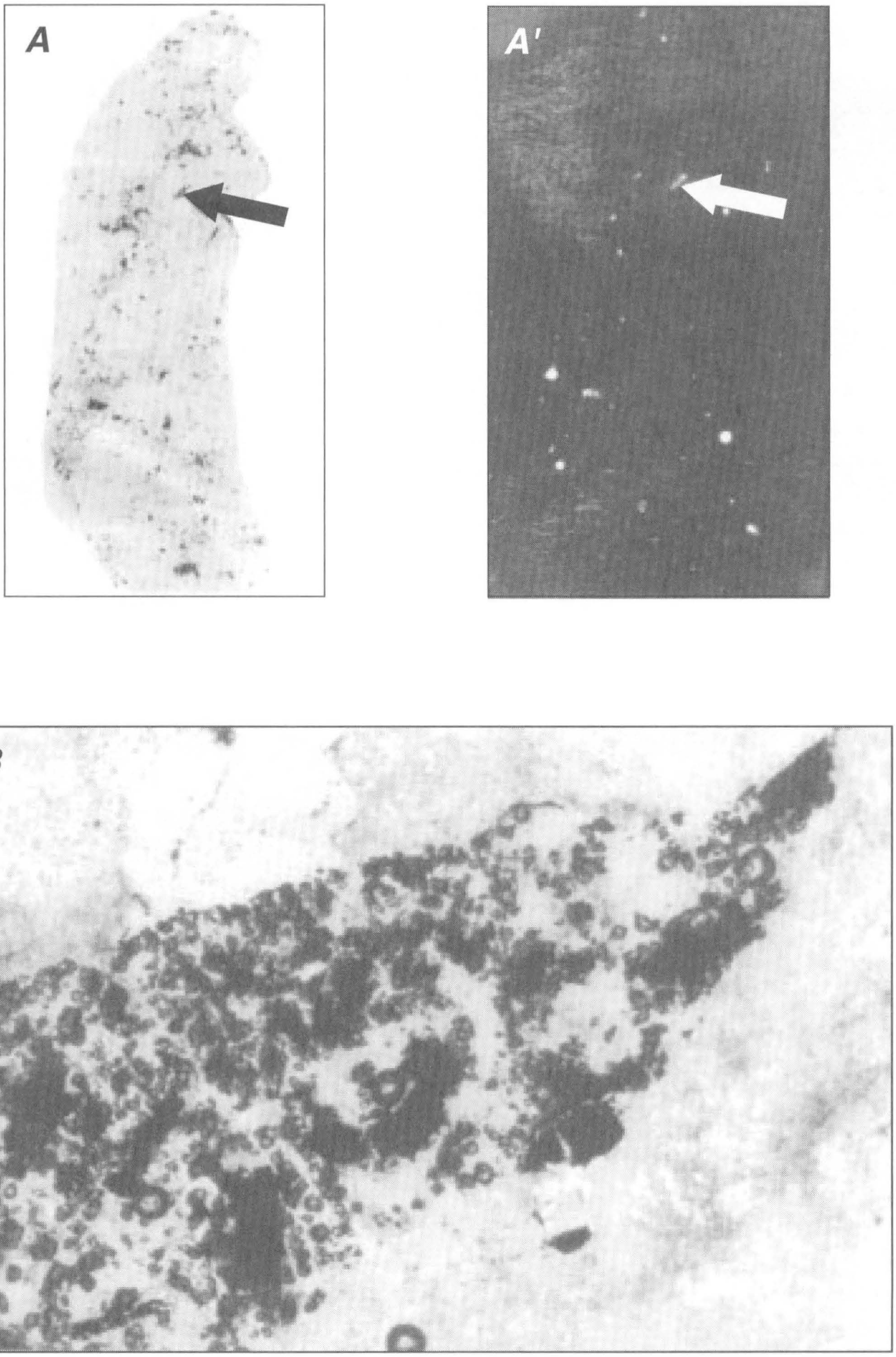
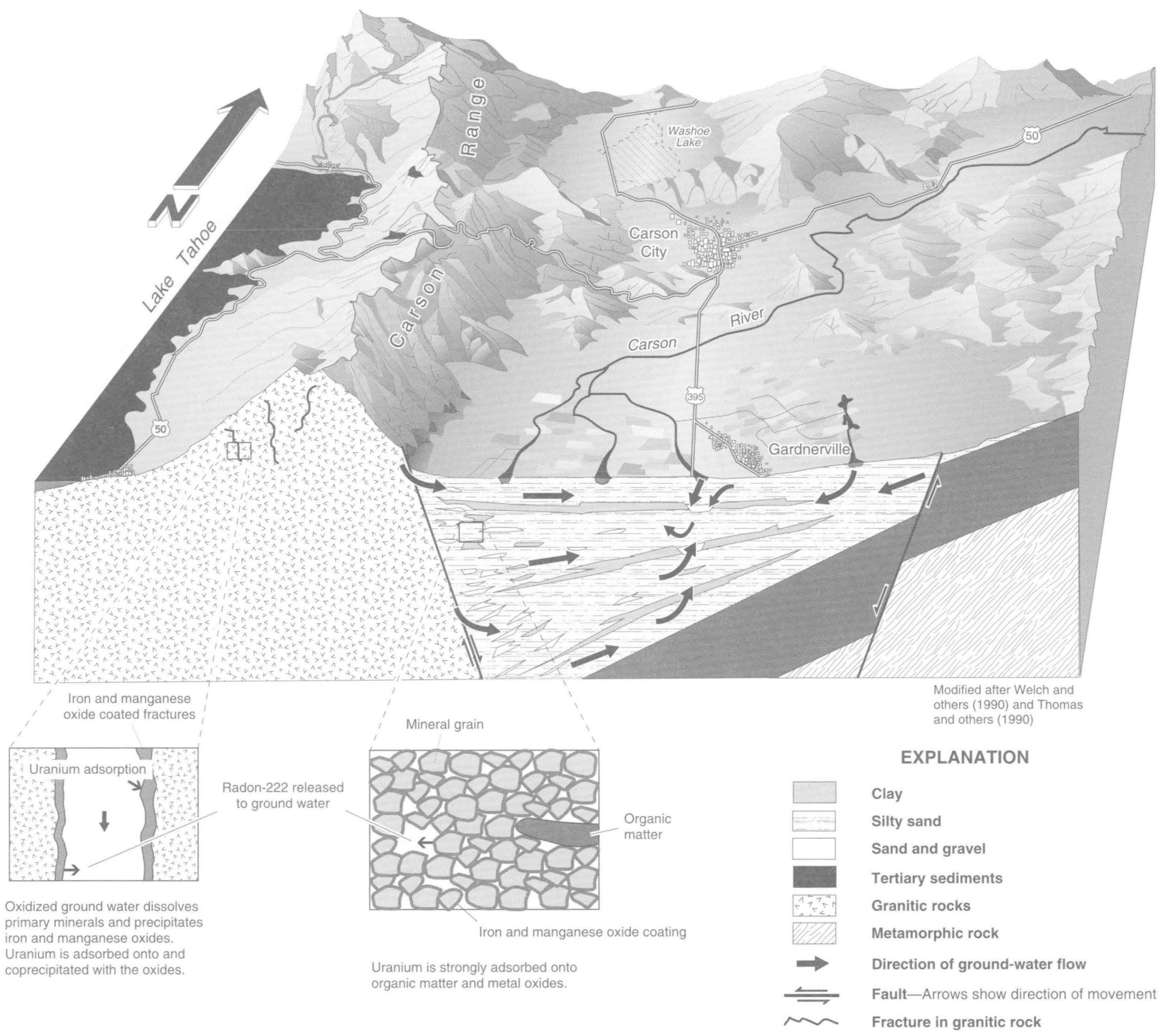


Figure 48. Radiation from shallow sediments of Carson River Basin, Nevada. *A*, Thin section (26 millimeters across) of weathered granite, and *A′*, Accompanying auto-radioluxograph exposed for 168 hours. Light areas on micrograph are produced by alpha radiation, primarily from naturally occurring uranium. Very bright circular spots on micrograph are due to emissions from zircons; more diffuse elongated light spots are from titanite. *B*, Plain light photomicrograph (2 millimeters across) showing titanite in highly altered crystal (shown by arrows in *A* and *A′*).



Oxidized ground water dissolves primary minerals and precipitates iron and manganese oxides. Uranium is adsorbed onto and coprecipitated with the oxides.

Uranium is strongly adsorbed onto organic matter and metal oxides.

Modified after Welch and others (1990) and Thomas and others (1990)

Figure 49. Schematic three-dimensional "block diagram" showing conceptual model of uranium in ground water of upper Carson River Basin, Nevada and California.

through mountain blocks and into basin-fill aquifers These fractures commonly have metal-oxide coatings that adsorb uranium and its progeny, including radium-226 Thus, ground water flowing through these fractures locally contains high radon-222 activities In addition, sediment samples collected in the western part of Carson Valley contain higher uranium concentrations than samples from other parts of the valley, so these sediments probably also contain high radium activities

Synthetic Organic Compounds

By **Stephen J Lawrence**

Ground-water samples were analyzed for as many as 154 synthetic organic compounds (Whitney, 1994) Ground-water samples from the Carson City urban area were analyzed for all 154 compounds Shallow ground-water samples from agricultural areas were analyzed for volatile compounds, insecticides, and herbicides Samples from principal aquifers were analyzed only for volatile compounds (36 compounds)

Synthetic organic compounds detected in ground-water samples from the Carson River Basin may not represent actual ground-water conditions, particularly for volatile compounds, because of sample contamination Contamination may be caused by contact with organic compounds on sampling equipment Movement of organic compounds as vapor, such as in storage areas for paint or chemicals, can contaminate samples Well construction can introduce organic compounds into ground-water samples through the use of organic-based drilling fluids, polyvinyl chloride (PVC) well casing, or cement used to connect sections of PVC casing Vinyl chloride is a major ingredient in PVC cement and can be released from well casings Phthalate esters used in the manufacture of PVC pipe used for casing can be released unless the casing is cleaned with detergent

In this study, sampling protocols included procedures designed to allow evaluation of sample contamination or loss of compounds during collection or analysis Procedures included use of "equipment blanks" to identify organic compounds introduced by sampling equipment, use of "trip blanks" to detect contamination during shipping, storage, and field transport Addition of known amounts of an organic compound to the sample allows estimation of losses by volatilization or degradation of the compounds, or matrix interference

Results of these efforts suggest that airborne compounds may be a source of several volatile compounds detected during the study At many sampling sites, wells are enclosed in buildings used for storage of products containing many of the organic compounds detected during the study Although the role these storage practices have in contaminating samples during collection is not known, the presence of organic vapor in well houses is a likely source because the sample bottle must be opened to collect the sample, thereby allowing diffusion into the bottle and the water sample In addition, airborne transport may cause persistent, but barely detectable, amounts of 1, 2 and 1,1-dichloroethane in many ground-water samples collected during this study Airborne pathways are probable because trip blanks also were contaminated and other sources of dichloroethane have not been identified Airborne transport of gasoline vapors in sampling vehicles also may affect concentrations of benzene, toluene, xylene, and ethylbenzene detected in some samples

Analysis of equipment blanks did not indicate sampling equipment as a source of organic compounds measured during the study On the basis of data from spiked samples, loss of volatile compounds in samples prior to analysis could be as high as 10 to 20 percent of initial concentration, the loss is caused by volatilization and degradation Similarly, concentrations of many herbicides and insecticides could decrease by as much as 5 percent of their initial concentration due to degradation

For the chlorophenoxy acid herbicide Dicamba, concentrations were slightly above the laboratory reporting limit in shallow samples from Churchill Valley and Carson Desert However, shallow ground-water samples from Churchill Valley and especially from Carson Desert also contain high concentrations of dissolved organic carbon Naturally occurring dissolved organic carbon may falsely indicate low concentrations of Dicamba (Whitney, 1994) Because the reported Dicamba concentrations may be caused by interference, Dicamba is not considered further in this report

Only 23 organic compounds were detected in ground-water samples Tetrachloroethylene (PCE), trichloroethylene (TCE), prometone, and chloroform were the most frequently detected organic compounds in the Carson River Basin (table 17) Two samples contained TCE concentrations greater than the MCL (5 μg/L) for that compound Because of the low proportion of samples with detectable concentrations compared to the number of samples, quantitative or

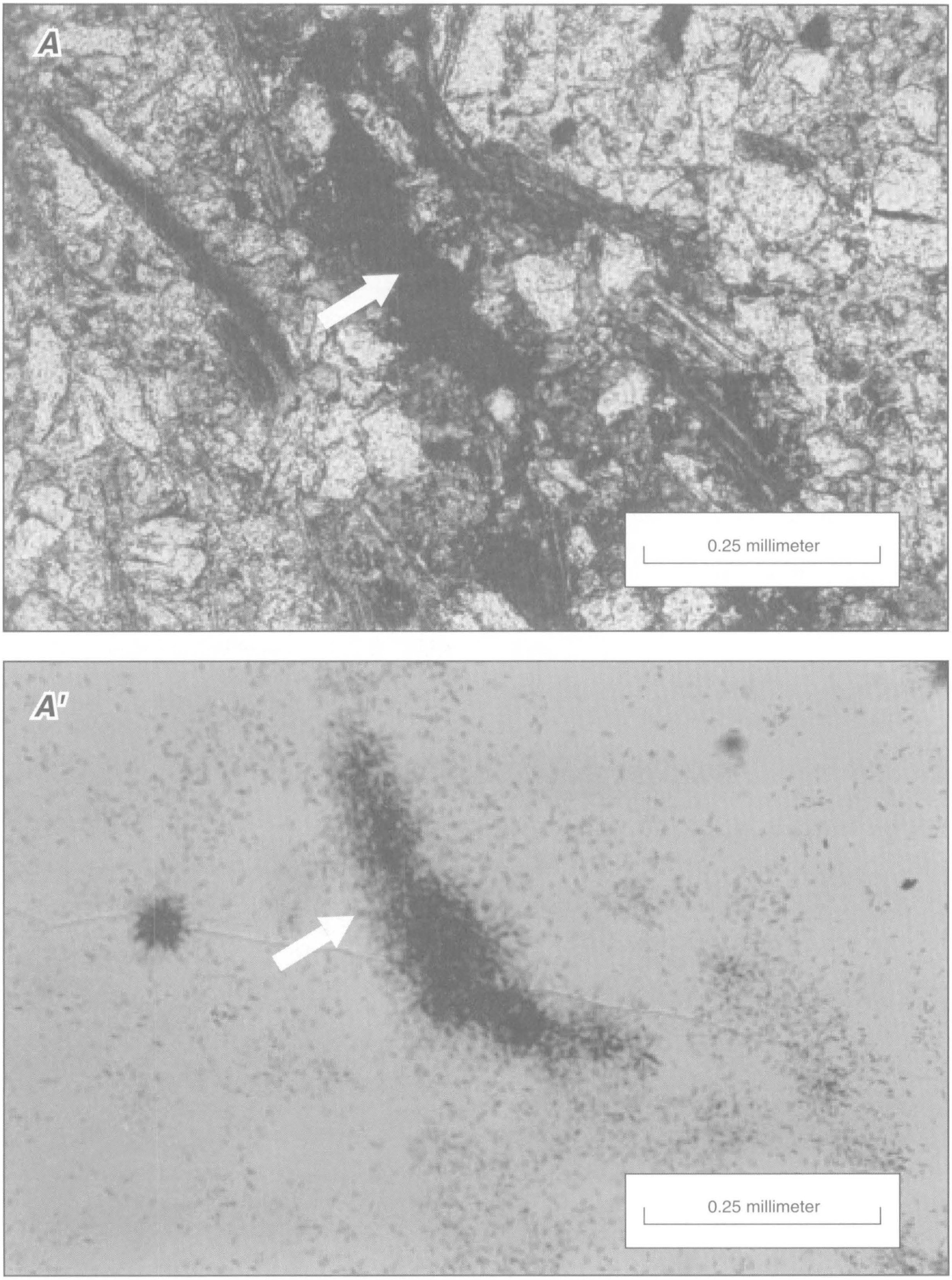


Figure 50. Fission tracks from shallow sediment of southern Carson Desert, Nevada. Tracks were produced by irradiation of sample with thermalized neutron flux. Photograph (1 millimeter across) at top of figure shows etched fission tracks that correspond to sediment sample shown below. Large area of concentrated fission tracks (shown by arrow) corresponds to metal oxides. Small areas of concentrated tracks are zircon or sphene. From Thomas and others (1993, fig. 9).

statistical comparisons between land uses and aquifers is not possible Therefore, only qualitative descriptions and comparisons are presented

Ground-water samples from Carson Valley contained PCE and TCE more commonly than any other synthetic organic compound These compounds were measured only in samples from shallow and principal aquifers (table 18) Two samples from upland aquifers contained chloroform Six samples from shallow aquifers in Carson Valley contained the herbicides 2,4-D and simazine, and the insecticides diazinon and ethion

The solvents PCE, TCE, 1,2-dichloroethylene (DCE), and 1,1,1- trichloroethane (TCA) were detected in samples of shallow ground water in Eagle Valley, primarily from the Carson City urban area (table 18) Also detected were the triazine herbicides cyanazine, prometone, and simazine The highest concentrations of PCE, TCE, DCE, chloroform, prometone, TCA, and cyanazine were found in samples from the Carson City urban area in Eagle Valley In the Dayton Valley and Churchill Valley hydrographic areas, only two synthetic organic compounds (PCE and TCA) were detected in ground-water samples These were in three samples collected from principal aquifers in Dayton Valley and one sample from a principal aquifer in Churchill Valley Shallow aquifers in Carson Desert yielded samples containing four synthetic organic compounds, three of which were herbicides or insecticides (table 18)

Samples collected from wells in shallow aquifers in urban and agricultural settings show some differences in the synthetic organic compounds most frequently detected Chloroform, prometone, PCE, TCE, and DCE were detected more frequently and at higher concentrations in samples from the urban area than in samples from agricultural areas

Table 17 Summary of synthetic organic compounds detected in ground water of Carson River Basin, Nevada and California, 1987-90

[Abbreviations µg/L, micrograms per liter, MCL, maximum contaminant level, --, MCL not established]

Constituent	Laboratory reporting limit (µg/L)	MCL (µg/L)	Number of samples	Number of samples exceeding		Maximum concentration (µg/L)
				Reporting limit	MCL	
Constituents with primary drinking-water standards						
Benzene	0 2	5	225	3	0	1 9
1,2-Dichloroethane	2	5	173	3	0	1
Vinyl chloride	2	2	229	2	1	5
1,1,1-Trichloroethane (TCA)	2	200	229	2	0	4
Trichloroethylene (TCE)	2	5	229	15	2	20
Constituents without drinking-water standards						
Bis (2-ethylhexyl) phthalate	5	--	65	1	0	13
Chloroform	2	--	229	9	0	1 7
Chloroethane	2	--	229	1	0	3 5
Chloromethane	2	--	229	1	0	2 5
Dichlorodifluoromethane	2	--	227	2	0	2
1,1-Dichloroethane	2	--	225	2	0	10
1,2-Dichloroethylene (DCE)	2	--	125	3	0	6 8
Ethylbenzene	2	--	226	2	0	5
Tetrachloroethylene (PCE)	2	--	228	16	0	44
Toluene	2	--	208	3	0	3
Xylene	2	--	221	2	0	1 5
2,4-D	01	--	85	2	0	07
Silvex	01	--	85	1	0	01
Diazinon	01	--	31	1	0	01
Ethion	01	--	31	1	0	02
Prometone	1	--	85	9	0	3 8
Simazine	1	--	85	4	0	2
Cyanazine	1	--	85	1	0	1

Table 18. Summary of synthetic organic compounds detected in ground water in the different aquifer systems of Carson River Basin, Nevada and California, by hydrographic area, 1987-90

[Abbreviation and symbol µg/L, micrograms per liter, --, concentration not determined or below laboratory reporting limit]

Constituent	Upland aquifers			Shallow aquifers			Principal aquifers		
	Number of samples	Number of samples exceeding reporting limit	Maximum concentration (µg/L)	Number of samples	Number of samples exceeding reporting limit	Maximum concentration (µg/L)	Number of samples	Number of samples exceeding reporting limit	Maximum concentration (µg/L)
Carson Valley									
Benzene	6	0	--	10	2	1.9	35	1	0.2
Chloroform	6	2	0.2	11	0	--	35	1	2
Chloroethane	6	0	--	11	1	3.5	35	0	--
Chloromethane	6	0	--	11	0	--	35	0	--
2,4-D	1	0	--	14	1	.04	0	--	--
Diazinon	0	--	--	1	1	.01	0	--	--
Dichlorodifluoromethane	6	0	--	10	0	--	35	0	--
1,1-Dichloroethane	6	0	--	11	1	10	35	1	2
Ethion	0	--	--	1	1	.02	0	--	--
Ethylbenzene	6	0	--	10	1	5	35	1	2
Simazine	1	0	--	14	2	2	0	--	--
Tetrachloroethylene (PCE)	6	0	--	11	0	--	35	4	9.8
Toluene	5	0	--	8	2	3	33	0	--
Trichloroethylene (TCE)	6	0	--	11	1	4.6	35	1	9
Vinyl chloride	6	0	--	11	2	5.0	35	0	--
Xylene	6	0	--	10	1	1.5	35	1	2
Eagle Valley									
Chloroform	4	0	--	57	4	1.5	25	0	--
Cyanazine	0	--	--	31	1	1	0	--	--
1,2-Dichloroethylene (DCE)	0	--	--	56	5	6.8	0	--	--
Prometone	0	--	--	31	9	3.8	0	--	--
Simazine	0	--	--	31	1	1	0	--	--
Tetrachloroethylene (PCE)	4	0	--	55	8	44	25	0	--
1,1,1-Trichloroethane (TCA)	4	0	--	57	1	4	25	0	--
Trichloroethylene (TCE)	4	0	--	57	15	20	25	0	--
Dayton and Churchill Valleys									
Tetrachloroethylene (PCE)	0	--	--	0	--	--	26	3	5
1,1,1-Trichloroethane (TCA)	0	--	--	0	--	--	26	1	3
Carson Desert									
2,4-D	0	--	--	30	1	.07	0	--	--
1,2-Dichloroethane	0	--	--	16	1	1.0	0	--	--
Silvex	0	--	--	31	1	.01	0	--	--
Simazine	0	--	--	29	1	1	0	--	--

Sources of synthetic organic compounds detected in ground water within the Carson River Basin are varied For example, PCE, TCE, DCE, and TCA are found in general purpose degreasing products used for a variety of tasks that range from cleaning automobile engines to treating septic systems PCE, TCE, and DCE may move into shallow ground water by leaching from septic systems (Cantor and Knox, 1986, p 82), improper disposal of used solvents, or from leaks and spills TCE and DCE also can be produced by biologically mediated degradation of PCE under anaerobic conditions (Vogel and others, 1987, p 730-734) Chloroform detected within the Carson River Basin probably is from chlorinated municipal water recharging shallow ground water Chloroethane and 1,1-dichloroethane may be degradation products of TCA

Herbicides generally are much more soluble and leachable than insecticides Accordingly, herbicides tend to be detected in ground water more commonly (Smith and others, 1988, p 43) Low affinities of herbicides for organic matter mean that they do not readily partition into soil or sediment Individual herbicides may be present in ground water in widely variable concentrations because of variable application rates, degradation rates, soil properties, and irrigation practices The herbicides prometone, simazine, cyanazine, and 2, 4-D generally do not persist in a given matrix beyond about 90 days, except in areas where the application rates of these compounds are particularly high (Helling and others, 1988, p 176, Smith and others, 1988, p 40-43) An exception is Silvex, which is less soluble, has a greater affinity for organic matter, and is more persistent in the environment than either the triazine herbicides, or 2, 4-D (Mullison, 1987, p 121-126, Verschueren, 1988, p 1143)

Insecticides such as diazinon and ethion generally persist for longer periods than herbicides and have a higher affinity for soil organic matter (Smith and others, 1988, p 37-39) Thus, detection of herbicides (except for Silvex) in ground water would be most likely within 2 or 3 months following application In contrast, diazinon and ethion could be detected throughout the year, but probably at lower concentrations than herbicides, because the insecticides are less attenuated by soil organic matter The presence of diazinon, prometone, cyanazine, simazine, 2, 4-D, Silvex, and ethion in ground water probably is caused by infiltration from irrigated landscape and (or) vegetation or weed control in ditches within urban areas, and infiltration from irrigated agricultural land

Summary of Ground-Water Quality with Respect to Federal Drinking-Water Standards

***By* Alan H. Welch**

The ground-water quality in the Carson River Basin varies considerably, both areally and among the different aquifers This variability is reflected in the frequency with which drinking-water standards established and proposed by U S Environmental Protection Agency are exceeded Inorganic constituents that most commonly exceed drinking-water standards are, in general decreasing order of frequency, manganese, arsenic, nitrate, iron, and fluoride Chloride, sulfate, and dissolved-solids concentrations also exceed the standard in some places Measured uranium and, particularly, radon-222 commonly exceed proposed Federal standards

Constituents that most typically exceed established maximum contaminant levels (MCL's) in principal and shallow aquifers are arsenic, fluoride, and nitrate (fig 51) Among these, arsenic is the most common in the Carson River Basin Nearly all arsenic concentrations that exceed the 50 μg/L MCL are in Carson Desert, the topographically lowest part of the basin In water from principal aquifers, arsenic concentrations exceed the MCL more commonly in Carson Desert than in the upper and middle Carson River Basin (table 19) In water from shallow aquifers of Carson and Eagle Valleys, arsenic concentrations more commonly exceed the MCL than in water from principal aquifers (table 19) In contrast, the frequency of exceedance for arsenic in water from shallow and principal aquifers of Carson Desert is not significantly different (table 20) Within Carson Desert, water from nearly one-half of the wells tapping principal and shallow aquifers have arsenic concentrations greater than the Federal drinking-water standard Included in the principal aquifer is the basalt aquifer, which provides the sole source of supply for Fallon and the Fallon Naval Air Station

Fluoride concentrations in some water from shallow aquifers exceed the MCL in Carson Desert and in Carson and Eagle Valleys (fig 51) In contrast, fluoride concentrations in water from principal aquifers exceed the 4 mg/L MCL only in Carson Desert

Nitrate concentrations in water from shallow and intermediate and basalt aquifers exceed the MCL (10 mg/L as nitrogen) in the Carson and Eagle Valleys and Carson Desert (fig 51) Higher nitrate values in

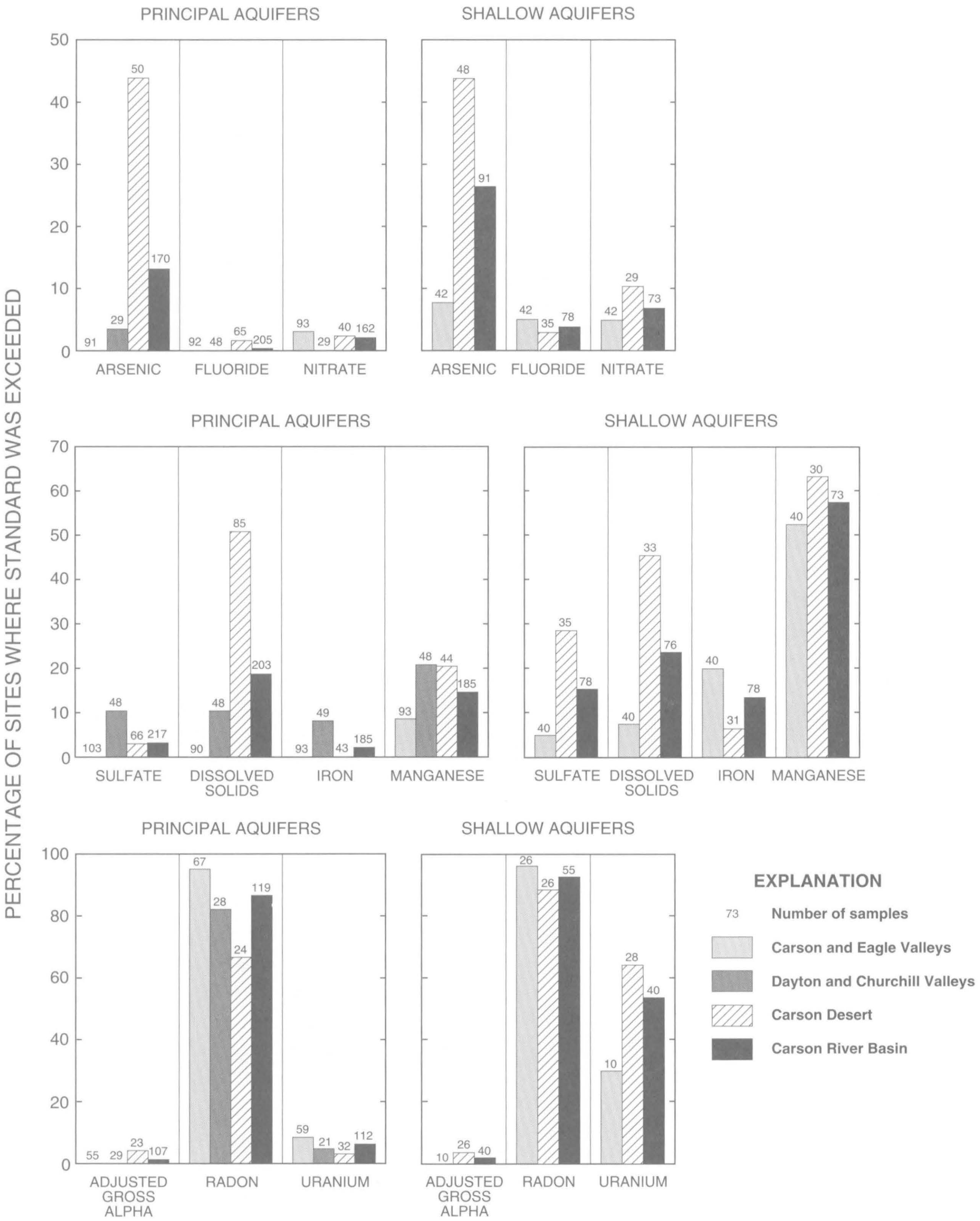


Figure 51. Percentage of ground-water sampling sites in Carson River Basin, Nevada and California, where selected inorganic constituents and radionuclides exceeded existing and proposed U.S. Environmental Protection Agency drinking-water standards.

Table 19 Statistical comparison of the frequency with which selected inorganic constituents exceed drinking-water standards in ground water from upper, middle, and lower Carson River Basin, Nevada and California

[All constituents, except for constituent in **bold**, have higher frequencies of exceedance in lower basin, p-values determined by chi-square test (Conover, 1980, p 145) Symbol --, no constituent]

Area	Highly significant (p less than 0 01)	Significant (p greater than 0 01 and less than or equal to 0 05)	Not significant (p greater than 0 05)
		Principal aquifers	
Carson and Eagle Valleys compared with Carson Desert	Sulfate, dissolved solids	Iron, manganese	Arsenic, nitrate, fluoride, radon, uranium
Dayton and Churchill Valleys compared with Carson Desert	Arsenic, dissolved solids	--	Fluoride, nitrate, sulfate, iron, manganese, uranium
Carson and Eagle Valleys compared with Carson Desert	Arsenic, fluoride, dissolved solids, **radon**	Manganese	Nitrate, sulfate, iron, uranium
		Shallow aquifers	
Carson and Eagle Valleys compared with Carson Desert	Arsenic, sulfate, dissolved solids	--	Nitrate, fluoride, iron, manganese, radon, uranium

principal aquifers of Carson and Eagle Valleys generally are in areas where septic tanks are used for domestic sewage disposal

The secondary maximum contaminant levels (SMCL's) for sulfate (500 mg/L), dissolved solids (1,000 mg/L), iron (0 6 mg/L), and manganese (0 1 mg/L) generally are exceeded more commonly in water from shallow aquifers than from principal aquifers Sulfate and dissolved-solids concentrations generally are higher in ground water in the middle and lower Carson River Basin because of evapotranspiration and dissolution of evaporite minerals, including gypsum Manganese concentrations commonly exceed the SMCL in water from shallow aquifers in both the upper and lower basin Exceedances of the manganese SMCL are less common in principal aquifers and are less common in the upper basin than elsewhere Iron exceedances are much less common than manganese throughout the basin in both shallow and principal aquifers The iron exceedances are more common in ground water from the Carson and Eagle Valleys area than from Carson Desert

The overall ground-water quality can be expressed in terms of the percentage of ground-water samples that contain one or more constituents that exceed a proposed or current drinking-water standard (fig 52) The percentages for the MCL exceedances were calculated using only samples that have been analyzed for all inorganic constituents that have an established MCL Similarly, the MCL plus SMCL percent-ages were calculated using only samples that had been analyzed for all inorganic constituents that have an established MCL or SMCL The location of these sites is shown in figures 53 and 54 The percentages labeled maximum contaminant level, adjusted gross alpha, or uranium in figure 51 are based on samples with inorganic constituents and an established MCL plus analyses of uranium and gross-alpha activity

Ground water in principal aquifers of Carson Desert most commonly contains constituents that exceed a MCL (fig 52*A*) The principal aquifers of the upper and middle basin contain ground water that generally meets the MCL's—but less commonly meets both the MCL's and SMCL's Some ground water in Carson Desert that does not meet the MCL's is from the basalt aquifer beneath Fallon (fig 53) Water with constituents exceeding either an MCL or a SMCL is present throughout much of the basin (fig 54) If the proposed standards for uranium and adjusted gross alpha are adopted, ground water in the upper and middle parts of the basin would more commonly exceed a standard (fig 52*A*) Nearly all ground water in principal aquifers of the Carson River Basin contains more radon-222 than the proposed 300 pCi/L Federal standard

Shallow aquifers sampled beneath much of the upper and lower basin commonly contain ground water that does not meet at least one established MCL or SMCL (figs 52*B* and 54) Half the samples of shallow ground water in the upper basin fail to meet at least one MCL or SMCL In Carson Desert, 80 percent of shallow ground-water samples contained at least one

Table 20 Statistical comparison of the frequency with which selected inorganic constituents exceed drinking-water standards in water from principal and shallow aquifers of Carson River Basin, Nevada and California

[All constituents have higher frequencies of exceedance in shallow aquifers, p-values determined by chi-square analysis (Conover, 1980, p 144-147) Abbreviation (s), secondary standard for fluoride Symbol --, no constituent]

Area	Highly significant (p less than 0 01)	Significant (p greater than 0 01 and less than or equal to 0 05)	Not significant (p greater than 0 05)
		Principal compared with shallow aquifers	
Carson and Eagle Valleys	Iron, manganese	Arsenic, fluoride(s), dissolved solids	Nitrate, sulfate, radon, uranium
Carson Desert	Manganese, sulfate, uranium	--	Arsenic, nitrate, fluoride(s), radon, dissolved solids, iron

constituent that exceeds a drinking-water standard If the proposed standards for uranium and adjusted gross alpha are adopted, then ground water in the upper basin would exceed a MCL in about 40 percent of the samples—compared to about 15 percent on the basis of current MCL's (fig 52*B*) In Carson Desert, the adoption of standards for these two radionuclides would increase the frequency of exceedance from about 45 to more than 70 percent Nearly all ground water in shallow aquifers in the Carson River Basin has radon-222 activities that exceed the proposed 300 pCi/L standard

SUMMARY

The Carson River Basin is an area of dramatic contrasts The Carson River drains pristine wilderness of the forested Sierra Nevada, which provides much of the basin's water The chemical composition of the Carson River changes from that of a fresh, untamed white-water river in the Headwaters Area to that of stagnant, saline sloughs and alkali lakes in Carson Desert The ground-water quality, particularly in shallow aquifers, broadly mirrors the chemical changes in the river—a major source of recharge to basin-fill aquifers Contrasts in ground-water quality within the Carson River Basin are evident across the basin, among the different aquifers, and, to a lesser extent, between shallow ground water beneath urban land and agricultural land

Although precipitation in excess of 25 in/yr can fall in the uplands, low areas that make up most of the basin typically receive 3 to 11 in/yr Precipitation decreases with increasing distance from the Sierra Nevada, which is the wettest part of the basin

Agriculture remains and important land use, but rapid increases in population have led to increased urban-land use Wildlife management areas, particularly in Carson Desert, represent another important land use Traditionally, most ground water has been used for irrigation The burgeoning population has led to increased use of ground water for domestic purposes In 1988, domestic use was nearly equal to the amount used for agricultural irrigation Total ground-water use more than tripled from 1969 to 1988

Most ground water in the Carson River Basin is withdrawn from basin-fill sediments These sediments partly fill structural basins formed by extensional faulting The faulting also raised the consolidated rocks that form the mountainous uplands The basin-fill deposits, which reach thicknesses of 10,000 feet or more, locally include volcanic rocks In the Carson Desert, volcanic rocks are an important source of supply for the City of Fallon and the Fallon Naval Air Station

Using current drinking-water standards as a measure of overall water quality, ground-water quality in principal aquifers in the upper basin generally is good Principal aquifers in the upper basin are a major source of supply for municipal systems that provide water to the communities of Minden, Gardnerville, and Carson City Precipitation falling on the Sierra Nevada infiltrates and reacts with igneous and metamorphic rocks This water, along with recharge from the Carson River in areas of heavy ground-water pumping, is the major source of recharge to principal aquifers Except for locally high concentrations of nitrate and presence of synthetic organic compounds, ground-water quality in principal aquifers generally results from chemical reactions with aquifer materials Locally, ground water with little or no dissolved oxygen contains manganese concentrations greater than the drinking-water standard Some ground water in and adjacent to the Sierra Nevada contains uranium concentrations greater than the proposed drinking-water standard Radon activities in the Sierra Nevada locally exceed 10,000 pCi/L and are highest in the Carson Basin

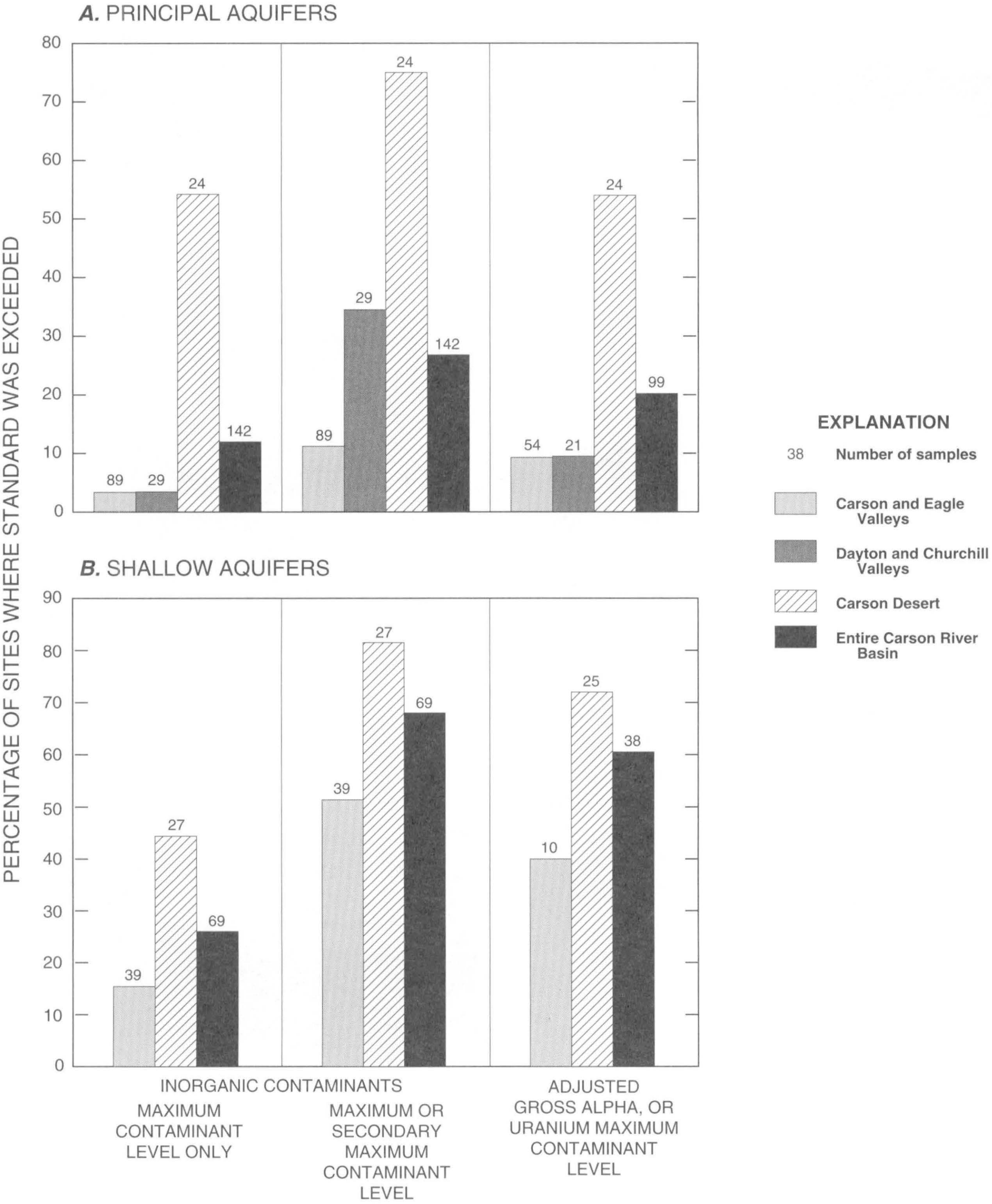
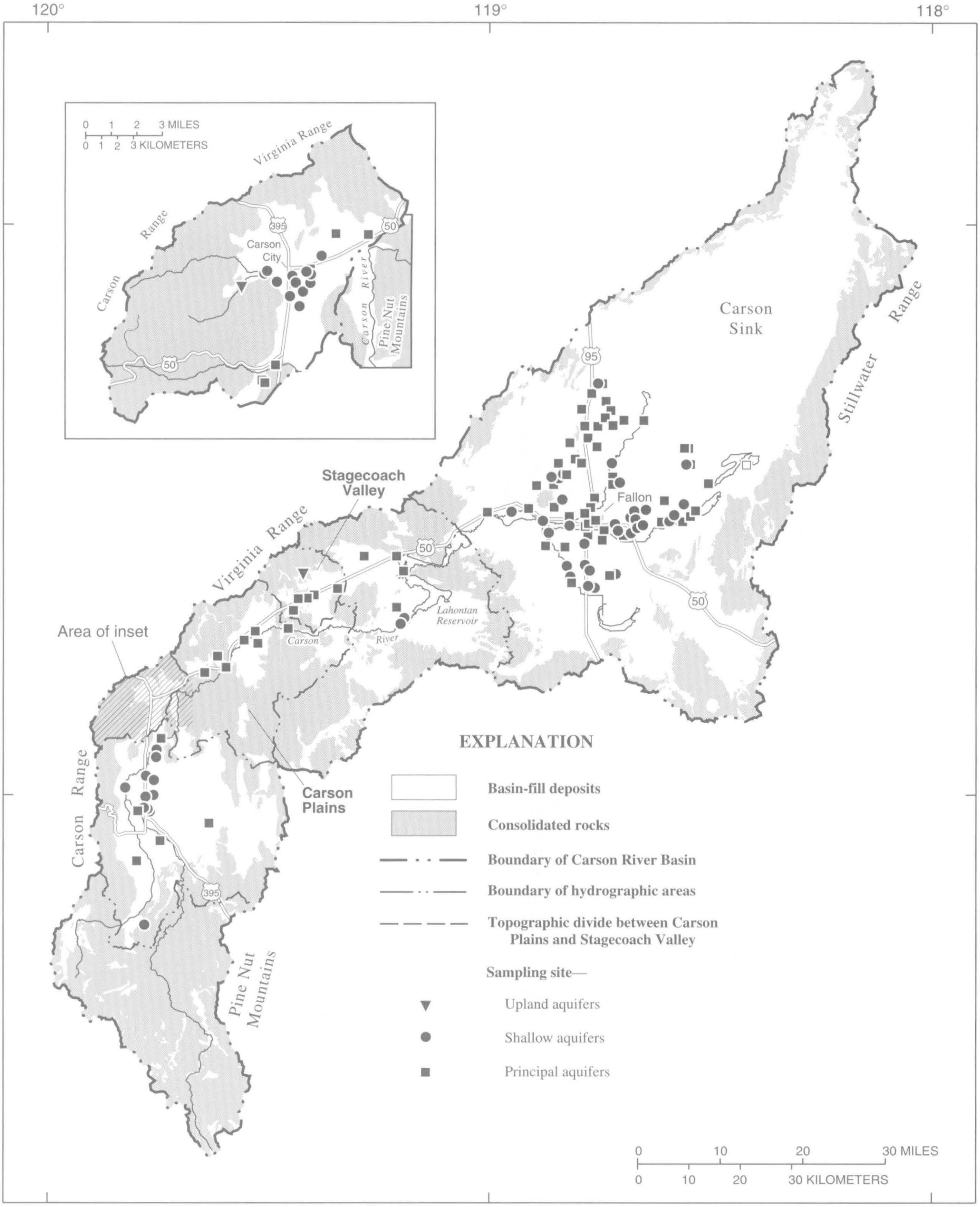


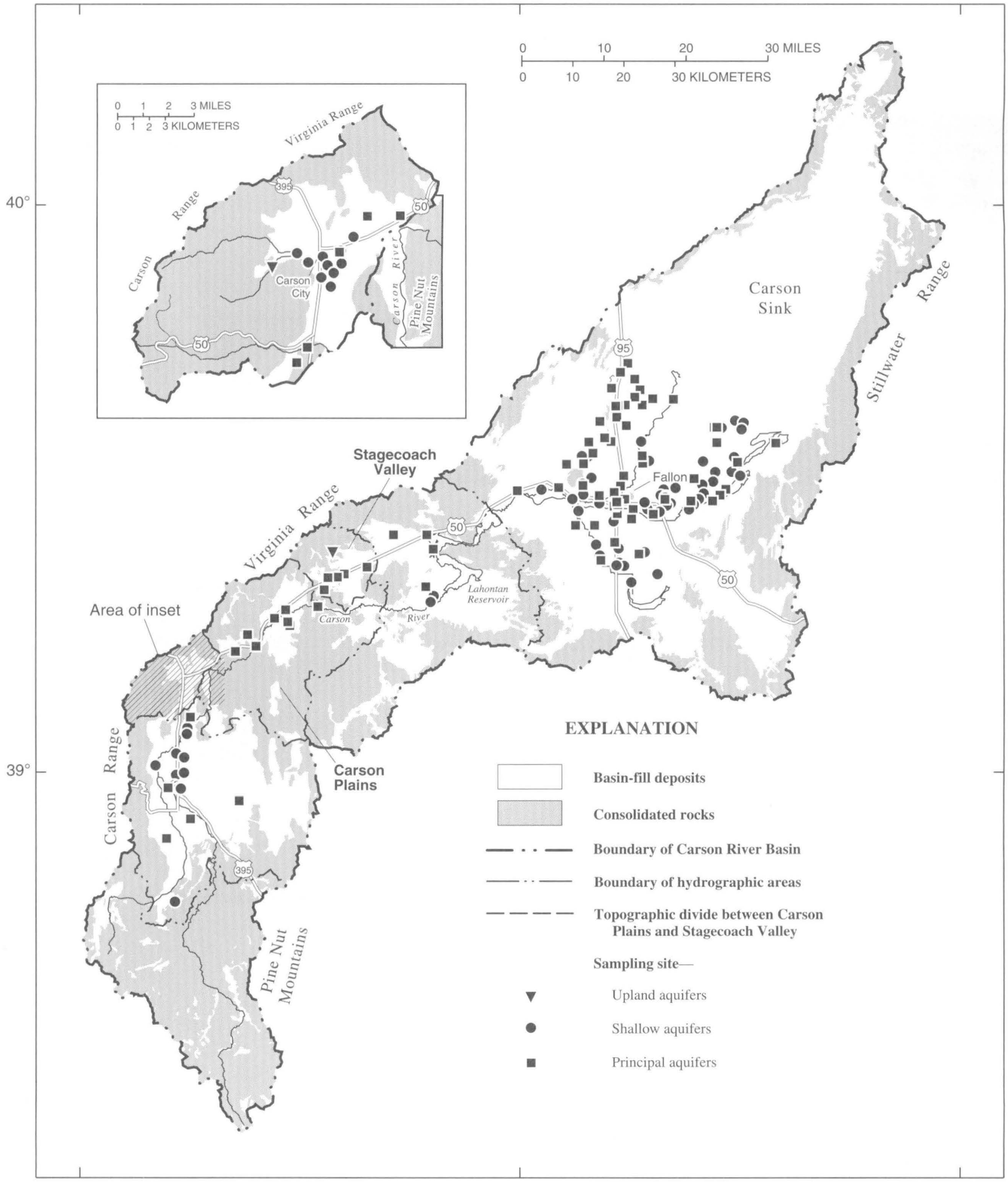
Figure 52. Summary of percentage of ground-water sampling sites in Carson River Basin, Nevada and California, where selected inorganic constituents and radionuclides exceeded existing and proposed U.S. Environmental Protection Agency drinking-water standards.



Base from U.S. Geological Survey digital data, 1:100,000, 1985
Local Mercator projection
Central meridian -119°10', latitude of true scale 39°20'

Geology modified from Johnson (1977),
Stewart and others (1982), and
Greene and others (1991)

Figure 53. Ground-water sampling sites in Carson River Basin, Nevada and California, where inorganic constituents exceed Nevada State primary maximum contaminant levels. Only sites with analyses for all inorganic constituents with primary maximum contaminant levels were considered.



Base from U.S. Geological Survey digital data, 1:100,000, 1985
Local Mercator projection
Central meridian -119°10', latitude of true scale 39°20'

Geology modified from Johnson (1977),
Stewart and others (1982), and
Greene and others (1991)

Figure 54. Ground-water sampling sites in Carson River Basin, Nevada and California, where inorganic constituents exceed Nevada State primary or secondary maximum contaminant levels. Only sites with analyses for all inorganic constituents with primary and secondary maximum contaminant levels were considered.

Shallow aquifers in Carson Valley are recharged primarily by water diverted from the Carson River, in Eagle Valley, the shallow recharge is principally from watering of lawns and other landscape vegetation Water in these aquifers contains higher concentrations of most major constituents and, compared to water in principal aquifers, more commonly contains concentrations of some minor constituents that exceed drinking-water standards Manganese exceeds the SMCL at more than 25 percent of the sampled sites Minor constituents that exceed drinking-water standards at less than 10 percent of sampled sites are arsenic, fluoride, nitrate, and iron Water from shallow aquifers more commonly contains concentrations of arsenic, fluoride, iron, and manganese in excess of the drinking-water standards than does water from the principal aquifers

Shallow aquifers beneath the upper basin locally contain herbicides, pesticides, and volatile organic compounds Beneath the urban part of Carson City, prometone, trichloroethylene, and tetrachloroethylene were found at concentrations well above the laboratory minimum reporting level Trichloroethylene was found at concentrations above the drinking-water standard With a few exceptions, ground water beneath agricultural land in Carson Valley contained, at most, low concentrations of synthetic organic compounds

Principal aquifers beneath the sparsely populated middle Carson River Basin are recharged by precipitation falling on the uplands and, locally, by the Carson River Concentrations of major constituents in water from principal aquifers in the lower basin generally are higher than in water from the principal aquifers of the upper basin Concentrations of dissolved solids, iron, manganese, and sulfate more commonly exceed drinking-water standards in principal aquifers of the middle than the upper basin

Carson Desert, at the distal end of the Carson River Basin, is a closed basin that loses water only by evapotranspiration Analyses of ground water indicate a wide range in concentrations of major and minor inorganic constituents, with dissolved solids reaching maximum concentrations greater than seawater Concentrations of sodium, chloride, bicarbonate, and dissolved solids generally are higher in shallow and principal aquifers of Carson Desert than in the upper and middle parts of the basin Minor-constituent concentrations, including those for arsenic, boron, fluoride, lithium, and molybdenum, also are higher in both shallow and principal aquifers in the Carson Desert compared with the other two parts of the basin Water in principal aquifers beneath Carson Desert generally contains lower concentrations of calcium, magnesium, bicarbonate, sulfate, lithium, manganese, molybdenum, and nitrate than water in shallow aquifers More than 10 percent of sampled ground water from both shallow and principal aquifers contains concentrations of arsenic, dissolved solids, and manganese greater than the drinking-water standards

Several minor constituents reach unusually high concentrations in shallow aquifers of Carson Desert Notable are arsenic, iron, manganese, and uranium Among these four elements, all except uranium reach concentrations greater than 1 mg/L Processes leading to the high concentrations include evapotranspiration and reactions of sedimentary organic matter with metal oxides Locally, these reactions appear to be an indirect result of a rise in the water table in response to application of irrigation water for agricultural activities

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