

Ground-Water Quality and Geochemistry in Carson and Eagle Valleys, Western Nevada and Eastern California

By Alan H. Welch

U.S. GEOLOGICAL SURVEY

Open-File Report 93-33

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



Carson City, Nevada
1994

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

U.S. GEOLOGICAL SURVEY
GORDON P. EATON, Director



Any use of trade names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

**For additional information
write to:**

**District Chief
U.S. Geological Survey
333 West Nye Lane, Room 203
Carson City, NV 89706-0866**

**Copies of this report can be
purchased from:**

**U.S. Geological Survey
Earth Science Information Center
Open-File Reports Section
Box 25286, MS 517
Denver Federal Center
Denver, CO 80225-0046**

CONTENTS

	Page
Abstract	1
Introduction.....	3
Background	3
Purpose and Scope	3
Location System for Wells	3
Acknowledgments.....	6
Description of Study Area	6
Location and Physiography	6
Climate	6
Land and Water Use	6
Hydrology	8
Surface-Water Hydrology	8
Ground-Water Hydrology	8
Basin Structure	8
Hydrogeologic Units	10
Mineralogy of the Basin-Fill Sediments	11
Movement of Ground Water and Isotope Hydrology	12
Carson Valley	12
General Ground-Water Hydrology	12
Isotope Hydrology	13
Eagle Valley	17
General Ground-Water Hydrology	17
Isotope Hydrology	17
Water Quality and Aqueous Geochemistry	21
Surface Water	25
Ground Water	26
Major Inorganic Constituents	27
Water Quality and its Relation to Nevada State Drinking-Water Standards.....	27
Processes Affecting Major Constituent Concentrations	42
Minor Inorganic Constituents	58
Water Quality and its Relation to Nevada State Drinking-Water Standards.....	58
Processes Affecting Minor Constituent Concentrations	60
Radionuclides	71
Water Quality and its Relation to Drinking-Water Standards	71
Processes Affecting Radionuclide Concentrations	72
Synthetic Organic Compounds	78
Summary and Conclusions	87
References Cited.....	89
Appendix—Summary Statistics for Ground-Water Quality of Carson and Eagle Valleys.....	93

FIGURES

	Page
1-4. Maps showing:	
1. Location of Carson and Eagle Valleys within Carson River Basin	4
2. Geology of Headwaters Area of Carson River Basin	5
3. Hydrogeologic features of Carson Valley and location of ground-water sampling sites.....	7
4. Hydrogeologic features of Eagle Valley and location of ground-water sampling sites.....	9
5. Map showing stable-isotope composition of hydrogen in ground water at selected sites in Carson Valley	14
6. Diagram showing relation between stable-isotope composition of hydrogen and oxygen in surface and ground water of Carson Valley	15
7. Map showing tritium activity in ground water at selected sites in Carson Valley	18
8. Diagram showing relation between stable-isotope composition of hydrogen and oxygen in Ash Canyon Creek and ground water of Eagle Valley	19
9. Map showing stable-isotope composition of hydrogen in ground water at selected sites in Eagle Valley	20
10. Map showing tritium activity in ground water at selected sites in Eagle Valley.....	22
11-23. Diagrams showing:	
11. General chemical composition of Carson River	25
12. General chemical composition of ground water in Carson and Eagle Valleys	39
13. Concentrations of major constituents and dissolved solids in ground water of Carson and Eagle Valleys	40
14. Concentrations of major constituents and dissolved solids in ground water from principal aquifers in east and west sides of Carson and Eagle Valleys.....	42
15. Relation between concentration of sulfate and isotopic composition of dissolved sulfate	45
16. Relation between concentration of sulfate and ratio of sulfate to chloride.....	46
17. Relation between concentration of dissolved inorganic carbon and stable-isotope composition of carbon in principal aquifers on west side of Carson and Eagle Valleys	47
18. Relation between concentration of dissolved oxygen and dissolved inorganic carbon in principal aquifers on west side of Carson and Eagle Valleys	48
19. Relation between concentration of sodium and calcium in principal aquifers on west side of Carson and Eagle Valleys	51
20. Median values of mass transfer for closed- and open-system geochemical models, excluding aluminum..	52
21. Relation between chemical activities of calcium and sodium, calcium and magnesium, calcium and potassium, sodium and silica, calcium and silica, magnesium and silica, and potassium and silica in ground water of Carson and Eagle Valleys	56
22. Saturation indices for calcite and amorphous silica in ground water of Carson and Eagle Valleys.....	59
23. Concentrations of fluoride, nitrate, arsenic, manganese, and iron in upland, shallow, principal, and thermal aquifers in Carson and Eagle Valleys	68
24. Maps showing location of wells with concentrations of dissolved constituents that exceed Nevada State drinking-water standards in aquifers of Carson and Eagle Valleys	69
25-29. Diagrams showing:	
25. Relation between concentrations of dissolved iron and manganese, manganese and oxygen, iron and oxygen, manganese and dissolved organic carbon, and iron and dissolved organic carbon in ground water	73
26. Relation between dissolved manganese and saturation index for rhodochrosite and dissolved iron and saturation index for siderite.....	74
27. Radioactivity from gross alpha, uranium, radium-226, and radon-222; concentrations of uranium; and gross-beta activity and radium-228 activity in ground water of Carson and Eagle Valleys	75
28. Relation between gross-alpha and uranium activity in ground water of Carson and Eagle Valleys	78
29. Relation between gross-beta activity minus gross-beta contribution from potassium-40 and uranium activities in ground water from principal aquifers in Carson and Eagle Valleys	79
30. Map showing uranium concentrations in ground water at selected sites in Carson and Eagle Valleys	80
31. Map showing radon-222 activities in ground water at selected sites in Carson and Eagle Valleys	82
32. Schematic diagram showing major processes affecting distribution of uranium and radon-222 in ground water within Carson and Eagle Valleys	85

TABLES

	Page
1. Principal minerals identified in shallow sediments of Carson and Eagle Valleys	11
2. Nevada State drinking-water standards for public water-supply systems	23
3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys	28
4. Phases included in geochemical mass-transfer reactions and limitations of selected models	44
5. Thermodynamic data for minerals and equations adapted for calculation of saturation and disequilibrium indices at 15 degrees Celsius	55
6. Equations for calculation of phase boundaries at 15 degrees Celsius.....	58
7. Estimated age of ground water in principal aquifers at selected sites in Carson and Eagle Valleys	60
8. Summary of inorganic constituents that exceed and do not exceed Nevada State drinking-water maximum contaminant levels and secondary maximum contaminant levels in ground water of Carson and Eagle Valleys	61
9. Concentrations of minor constituents in ground water at selected sites in Carson and Eagle Valleys	62
10. Number of sites in Carson and Eagle Valleys where ground water has one or more inorganic constituents exceeding Nevada State maximum contaminant levels and secondary maximum contaminant levels	72
11. Concentrations of radionuclides in ground water at selected sites in Carson and Eagle Valleys	76
12. Uranium-isotope data for ground water in Carson and Eagle Valleys	79
13. Summary of number of radionuclide sites with analyses that exceed and do not exceed Nevada State maximum contaminant levels and maximum contaminant levels proposed by U.S. Environmental Protection Agency in ground water of Carson and Eagle Valleys.....	84
14. Summary of selected organic constituents that exceed and do not exceed Nevada State drinking-water maximum contaminant levels in ground water of Carson and Eagle Valleys.....	86

CONVERSION FACTORS, VERTICAL DATUM, AND ADDITIONAL ABBREVIATIONS

Multiply	By	To obtain
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
foot (ft)	0.3048	meter
foot per year (ft/yr)	0.3048	meter per year
inch (in.)	25.40	millimeter
inch per year (in/yr)	25.40	millimeter per year
mile (mi)	1.609	kilometer

Temperature: Degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by using the formula $^{\circ}\text{C} = (^{\circ}\text{F} - 32)/1.8$.

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.

Additional abbreviations:

µg/L (microgram per liter)

µS/cm (microsiemens per centimeter at 25°C)

mg/L (milligram per liter)

mmol/L (millimole per liter)

mmol/kg (millimole per kilogram)

pCi/L (picocurie per liter)

Ground-Water Quality and Geochemistry in Carson and Eagle Valleys, Western Nevada and Eastern California

By Alan H. Welch

ABSTRACT

Aquifers in Carson and Eagle Valleys are an important source of water for human consumption and agriculture. Sedimentary deposits that partly fill Carson and Eagle Valleys form the principal aquifers that supply most ground water used for municipal and agricultural purposes. The principal aquifers are overlain by shallow aquifers that are generally not used for supply. Thermal water and some ground water in the higher altitudes flow through fractured consolidated rocks that underlie and contain the basin-fill sediments. Water from upland aquifers is used for both municipal and domestic supply. Thermal water is used for aquaculture and recreational bathing.

Concentrations of major constituents in water from the principal aquifers on the west side of Carson and Eagle Valleys appear to be a result of natural geochemical reactions with minerals derived primarily from igneous rocks. Evaluation of the results from mass-balance models, combined with mineralogic and thermodynamic data, indicates that observed concentrations of major constituents in water result from overall reactions involving plagioclase feldspar, carbon dioxide, and calcite along with (1) potassium feldspar, silica, pyrite, and sodium chloride, and (2) some combination of the silicate minerals chlorite, biotite, hornblende, and augite. Clay minerals produced by the reactions appear to be beidellite or kaolinite.

In general, water from the principal aquifers is acceptable for drinking when compared with present (1990) Nevada State drinking-water maximum contaminant level standards. Water was collected and analyzed for all inorganic constituents that have primary or secondary drinking-water standards. About 3 percent of these sites had constituents that exceeded one or more primary standards, and water at about 10 percent of the sites had at least one constituent that exceeded a secondary standard. Arsenic exceeded the standard in water at less than 1 percent of principal aquifer sites; nitrate exceeded its standard in water at 3 percent of 93 sites. Water with high concentrations of nitrate from wells in the principal aquifer was in areas where septic systems are used and indicates that contamination may be entering the wells. The only constituent concentrations that were higher than a secondary standard in water from the principal aquifers were manganese, at 8 percent of the sites, and fluoride at 1 percent of the sites.

Water in the upland aquifers generally contains concentrations of constituents that do not exceed State primary drinking-water standards. Iron and manganese were the only constituents that were greater than their standards in water from the upland aquifers. Water at only one site had concentrations greater than the secondary standards.

The shallow aquifers were found to have ground water with several constituents having concentrations greater than the primary standards.

These constituents were arsenic, cadmium, fluoride, lead, and nitrate. The concentrations of fluoride, iron, manganese, sulfate, and dissolved solids locally exceeded secondary standards. Of the sites that had water analyzed for all inorganic constituents with a standard, 15 percent exceeded one or more primary standards and 59 percent were found to exceed at least one secondary standard. The standard for arsenic was exceeded at 8 percent of the sites; fluoride and nitrate each exceeded their standards at 5 percent of the sites. Manganese in ground water most commonly exceeded the secondary standard at about half of the 40 sites and iron exceeded its standard in water at 20 percent of the sites.

All water from thermal aquifers was found to have at least one constituent at a concentration that exceeded a standard. These aquifers yielded water that had fluoride concentrations that were greater than the standard at five of six sites. Other constituents that exceeded a drinking-water standard were arsenic, iron, manganese, sulfate, and dissolved solids.

Iron and manganese concentrations greater than the drinking-water standards were in ground water with little or no dissolved oxygen. Chemically reduced forms of these elements are more soluble than the oxidized forms present in water containing oxygen. Water with higher manganese and iron concentrations appears to be in equilibrium with the carbonate minerals siderite and rhodochrosite, indicating that concentrations of these elements are limited by the solubility of these minerals.

Concentrations of naturally occurring radionuclides in water from the principal aquifers exceed the proposed Federal standards for some constituents, but were not found to be above present (1990) State standards. Measured gross-alpha activities in water do not exceed the 15 picocuries per liter primary standard, which excludes uranium and radon-222 at sites where both gross alpha and uranium were determined. The uranium concentrations exceeded the proposed Federal standard of 20 micrograms per liter at 10 percent

of the sites. Of the ground-water sites analyzed for uranium and all the inorganic constituents with primary standards, 15 percent exceed one or more established standard. If the proposed 20 micrograms per liter standard for uranium is applied to the sites, then 23 percent would exceed at least one standard. This represents a 50-percent increase in the frequency of exceedance. On the basis of only a few analyses for radium-226 and -228, the ground water does not appear to exceed either the present combined standard or the proposed 20 picocuries per liter for each of these radionuclides.

Almost all ground water sampled from the principal aquifers exceeds the proposed standard for radon of 300 picocuries per liter. Ground-water sampling sites with the highest radon activities in water are most common in the upland aquifers in the Sierra Nevada and in the principal aquifers beneath the west sides of Carson and Eagle Valleys. The high radon-222 activities appear to be a result of uranium being concentrated on iron and manganese oxides that coat detrital grains and fractures in granitic bedrock and in sedimentary organic matter within the basin-fill sediments.

Ground water from the shallow aquifers beneath the urban part of Carson City and near the Douglas County airport contains measurable concentrations of some synthetic organic compounds. Concentrations in water samples from the shallow aquifer system beneath Carson City generally do not exceed standards. Water from only one site contained concentrations of trichloroethylene greater than the drinking-water standard of 5 micrograms per liter. Samples of ground water from the principal aquifers did not contain organic compounds for which drinking-water standards have been established at concentrations greater than the reporting levels.

INTRODUCTION

Background

Beginning in 1986, the U.S. Congress has annually appropriated funds for the U.S. Geological Survey to test and refine concepts for a National Water-Quality Assessment (NAWQA) Program. The long-term goals of this full-scale program are to (1) provide a nationally consistent description of current water-quality conditions for a large part of the Nation's surface- and ground-water resources, (2) define long-term trends (or absence of trends) in water quality, and (3) identify, describe, and explain, as possible, the major factors that affect the observed water-quality conditions and trends.

Information obtained will be available to water managers, policy makers, and the general public to provide an improved scientific basis for evaluating the effectiveness of water-quality management programs and to provide a data base for assessing the likely effects of contemplated changes in land- and water-management practices. Concepts for a full-scale NAWQA Program are described by Hirsch and others (1988).

The NAWQA Program is organized into study units on the basis of specific hydrologic systems. The study units include large parts of aquifers or aquifer systems and major river basins. The study units are large areas ranging from a few thousand to several tens of thousands of square miles.

This report includes the results of a study done under a pilot phase of NAWQA conducted in seven project areas throughout the country. These project areas were selected to represent diverse hydrologic environments and water-quality conditions. The seven pilot projects include four that are concerned primarily with surface-water areas and three that are concerned primarily with ground-water systems. The surface-water project areas are the Yakima River Basin in Washington; lower Kansas River Basin in Kansas and Nebraska; upper Illinois River Basin in Illinois, Indiana, and Wisconsin; and Kentucky River Basin in Kentucky. The ground-water project areas are Carson River Basin in Nevada and California (figs. 1 and 2); Central Oklahoma aquifer in Oklahoma; and Delmarva Peninsula in Delaware, Maryland, and Virginia. Geochemical and hydrologic data available through 1987 were summarized by Welch and others (1990)

as part of the Carson River Basin Pilot Project—most of the background hydrogeology in this report is derived from that study.

Purpose and Scope

The primary purpose of this report is to describe the geochemistry of ground water of Carson and Eagle Valleys, with an emphasis on water in aquifers used for domestic or public water supply. Description of the geochemistry includes a discussion of general water quality and the physical and chemical processes that produce the observed quality. Data collected from 1987 to 1990 as part of the Carson River Basin NAWQA project are the primary source of information used for this report, particularly for areas where little new sampling occurred, although other data are included. Sources of data are given in the sections where they are discussed. This report expands an earlier study by Welch and others (1990), which provided a description of ground-water quality on the basis of historical data, but included little information on concentrations of radionuclides and synthetic organic compounds. This report emphasizes processes that produced the observed water quality, and summarizes the analyses of radionuclides and synthetic organic compounds in ground water.

Location System for Wells

Ground-water site locations used in this report are identified by site numbers defined in later sections. The locations are further identified as a "local site identification" (table 3).

Local site identifications are based on the rectangular subdivision of public lands, referenced to the Mount Diablo base line and meridian. A complete designation of a site consists of (1) township number north of the base line; (2) range east of the meridian; (3) 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 sequence number that distinguishes between wells that lie in the same tract within the section. For example, well N14 E19 14 BBD1 is the first recorded in the SE 1/4 NW 1/4 NW 1/4 of section 14, township 14 north, range 19 east. Township and range numbers are shown along the margins of maps within this report except in figure 1.

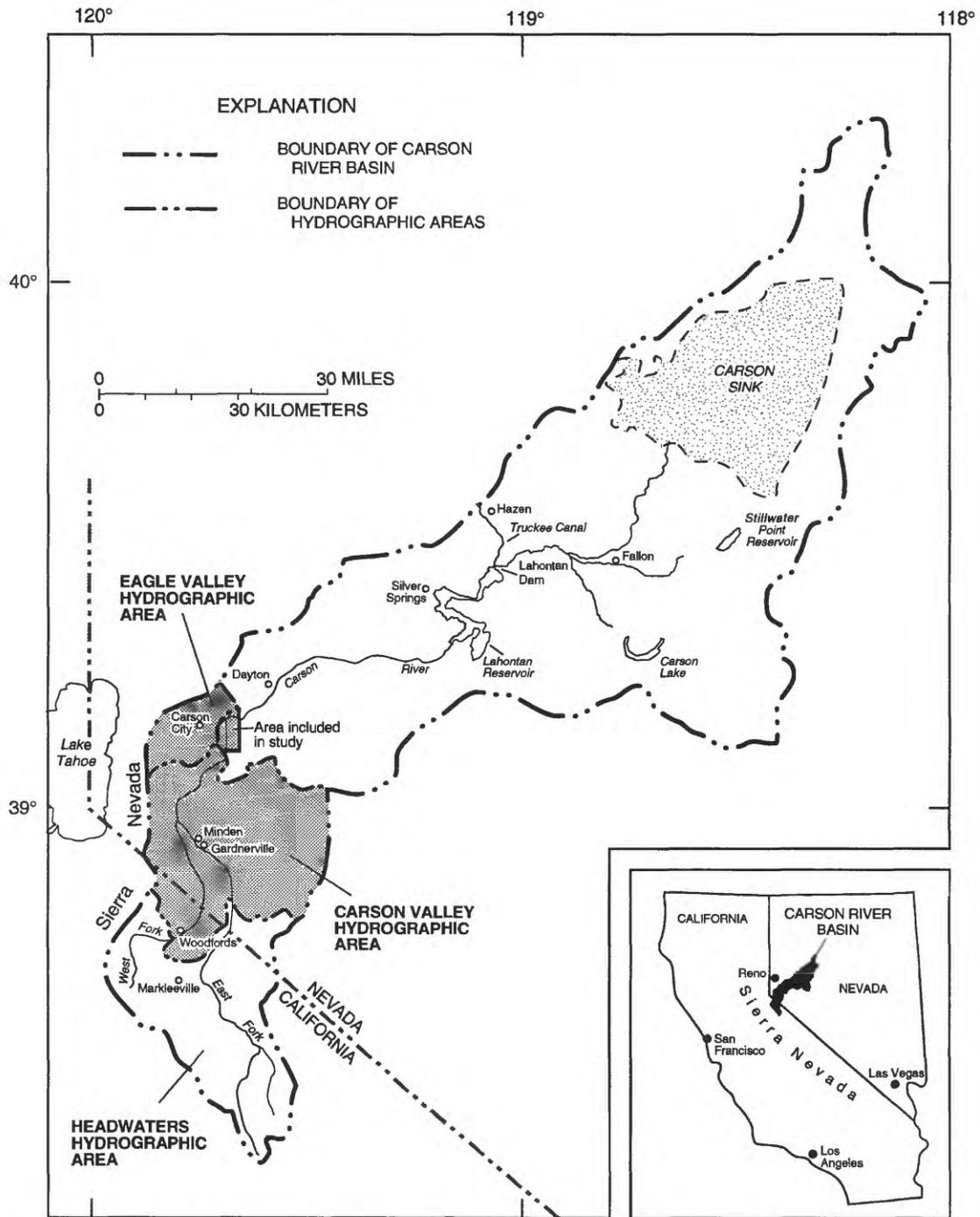


Figure 1. Location of Carson and Eagle Valleys within Carson River Basin.

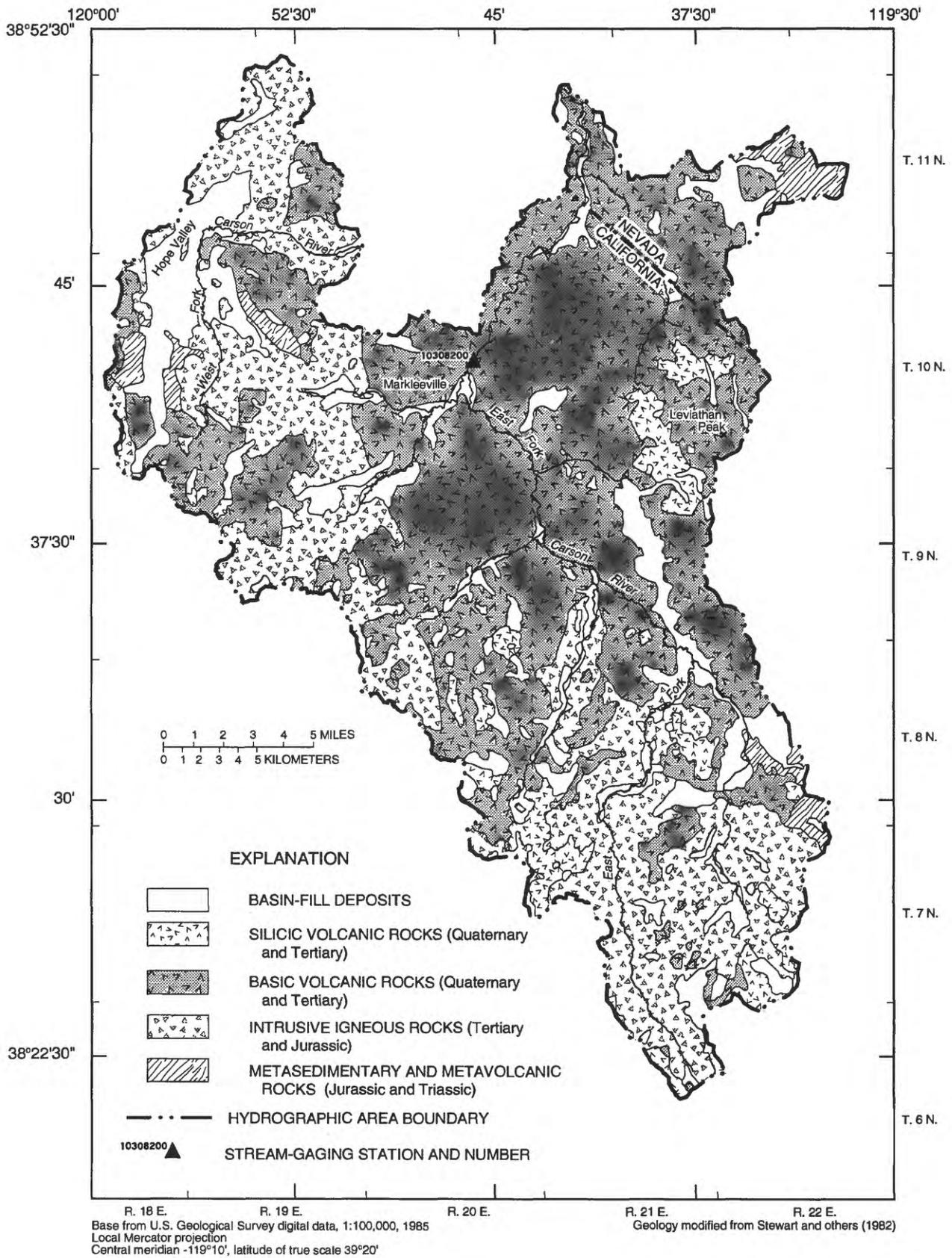


Figure 2. Geology of Headwaters Area of Carson River Basin.

Acknowledgments

Appreciation is extended to residents and water purveyors in Carson and Eagle Valleys for permitting access to wells for sampling. Larry Benson of the U.S. Geological Survey provided stable-isotope data for the Carson River.

DESCRIPTION OF STUDY AREA

Location and Physiography

The Carson and Eagle Valley area is mostly in western Nevada and partly in eastern California (fig. 1). The study area includes the Carson Valley and Eagle Valley hydrographic areas as defined by the Nevada Division of Water Resources (Rush, 1968). This report includes, as part of the Eagle Valley hydrographic area, an area in Dayton Valley that is to the west of the Carson River and is primarily a flood plain of the Carson River and receives ground-water flow from Eagle Valley.

The study area is surrounded by mountains with alluvial fans and pediments that extend to the valley lowlands and flood plains of the Carson River. Major mountain ranges that bound the area include the Carson Range (a part of the Sierra Nevada) to the west and Pine Nut Mountains to the east (fig. 3). Lowland parts of the two valleys consist of alluvial-filled valleys that contain the major producing aquifers in the area. A subtle alluvial divide separates the two valleys.

A major feature of Carson and Eagle Valleys is the generally north-flowing Carson River. Most of the flow in the Carson River is contributed by two principal tributaries, the East and West Forks that flow out of the Sierra Nevada. The two forks converge in Carson Valley where the Carson River flows northward and then to the east of Eagle Valley. During the growing season, much of the river flow is diverted into an extensive network of irrigation ditches and drains in Carson Valley for surface-water management in agricultural areas where there are sloughs and old river channels. With the exception of the East and West Forks, streams in the area are generally ephemeral for most of their reach, although some tributaries contribute flow to the Carson River, particularly during periods of spring runoff.

Climate

The climate of Carson and Eagle Valleys is greatly affected by the Sierra Nevada, which receives as much as 20-40 in/yr of precipitation at higher altitudes of the western-bounding Carson Range and in much of the Headwaters Area of Carson River to the south. The valley floors and the Pine Nut Mountains to the east are in the rain shadow of the Sierra Nevada and are notably drier, receiving only 5 to 11 in/yr in the lowlands. Precipitation falls as winter snow at high altitudes, as winter snow and rain at lower altitudes, and as summer thundershowers throughout the area. The proportion of precipitation that falls in the valleys during the summer ranges from 10 to 12 percent of that which falls in the Sierra Nevada.

Much of the ground-water discharge from Carson and Eagle Valleys, particularly in the lowlands, is a result of evapotranspiration. Rates of evapotranspiration for the most common types of vegetation have been estimated by Maurer (1986) for Carson Valley on the basis of a review of earlier work. At lower altitudes in the basin, estimated evaporation and evapotranspiration rates are 3.5 ft/yr for irrigated land, 2.5 ft/yr for open water, 1.2 ft/yr for phreatophytes (primarily rabbitbrush), and 0.75 ft/yr for xerophytes (primarily sagebrush and greasewood; Maurer, 1986, table 7). All these rates, except those for xerophytes, are greater than the mean precipitation rate for the valley floors.

Land and Water Use

Carson Valley has been a major agricultural area in Nevada since the 1850's. About 47,000 acres were under irrigation, which represents about 15 percent of total land use in the valley (Welch and others, 1990, table 3), during the period from 1973 to 1980. Range and forest land constitute the predominant land use, representing about 80 percent of the total area. Urban use has increased since 1980, primarily on land formerly used for agricultural purposes, but agricultural acreage is currently (1990) much greater than the urban acreage. The land use in Eagle Valley, like Carson Valley, is dominantly range and forest land, which constitute about 85 percent of the 47,000 acres in the basin (estimates are for 1973; Welch and others, 1990, table 3). Unlike Carson Valley, very little of the land in Eagle Valley is used for agricultural purposes (less than 1,100 acres). About 4,800 acres or about 10 percent of the land in 1973 (Welch and others, 1990a, table 3) are

in urban use. This estimate of urban land use is actually much lower than the present (1990) use, as indicated by an approximate doubling of population in Eagle Valley from about 20,000 in 1973 to about 41,000 in 1990 (Maud Naroll, Nevada State Demographer, oral commun., 1990). The increase in urban acreage has been primarily on land formerly used for agriculture or rangeland.

Carson Valley river flow, and thus the quantity of water used for irrigation, fluctuates annually as a function of snowpack storage of winter precipitation. All available surface water is generally used, and in dry years additional ground water is pumped to supplement small supplies, resulting in a wide range in annual ground-water withdrawals. Estimates of ground-water use ranged from 7,400 acre-ft in 1982 to 22,000 in 1968 (Welch and others, 1990a, p. 22). Ground-water pumpage for 1987 was 6,500, 3,600, 1,800, and 1,500 acre-ft for agricultural, municipal, aquaculture, and domestic use, respectively (Berger, 1990). Because Eagle Valley (where Carson City is located) is primarily urban, the largest water use is for municipal supply, although some domestic wells also are used in Carson City. Total ground-water withdrawal was estimated to be about 8,000 acre-ft in 1987 (Welch and others, 1990a, fig. 7).

HYDROLOGY

Surface-Water Hydrology

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 about 3 mi northwest of Minden (fig. 1). Just north of the confluence of the two forks, the river exits Carson Valley and then flows northward about 1 to 2 mi to the east of Eagle Valley. The Carson River does not enter Eagle Valley. The surface-water flow in Carson Valley is characterized by uncontrolled springtime high flows of the Carson River. During the summer irrigation season, flows are greatly diminished by diversions. Flows are affected by about 130 agricultural diversions with return flow being a result of ground-water seepage and surface drains (Brown and others, 1986). In Carson Valley, river diversions, and to a lesser extent ground-water pumpage and runoff from irrigated agricultural land, provide recharge for the shallow ground-water system.

Allerman Canal (fig. 3) marks the eastern extent of irrigation supplied by diversion from the Carson River, except in the northernmost part of Carson Valley.

Streams draining the Sierra Nevada on the west sides of the valleys are important sources of ground-water recharge, particularly in Eagle Valley, where Clear Creek and streams in Vicee, Ash, and Kings Canyons are major sources of ground-water recharge (fig. 4). Except during periods of high runoff in the springtime, these streams in Eagle Valley do not flow out of the basin because of high infiltration rates on the alluvial fans on the west side of the valley (Maurer and Fischer, 1988). A small quantity of surface water is diverted from Kings Canyon Creek for agricultural irrigation in Eagle Valley and from the Carson River for use along the flood plain between the river and the eastern boundary of the Eagle Valley hydrographic area.

Ground-Water Hydrology

Basin Structure

Carson and Eagle Valleys are partly filled structural basins formed as a result of Tertiary and Quaternary extensional faulting. Basin-fill deposits are as much as 5,000 ft thick in Carson Valley; the greater thicknesses are along the west margin of the valley floor (Maurer, 1985, p. 5 and pl. 2). The greater depth to the underlying basement rocks on the west side of the basin indicates greater vertical movement along the western basin-bounding fault than along faults to the east. About halfway in its course through the valley (T. 13 N.), the Carson River is displaced to the west of the valley center. The displacement may be, in part, a result of greater movement along the faults in the west side of the valley compared with faults in the eastern parts of the basin. The general absence of large alluvial fans at the east mouths of streams draining the high-relief Sierra Nevada to the west may be also a consequence of continuing subsidence along the base of the Sierra Nevada displacing the Carson River to the west. This continuing subsidence results in reworking of sediments derived from the Sierra Nevada by the Carson River, thereby inhibiting the formation of large alluvial fans. Relatively small fans in northwestern Carson Valley contrast with the much larger fans present in the western part of Eagle Valley, such as at the mouths of Kings and Ash Canyons, that were not affected by a through-flowing river.

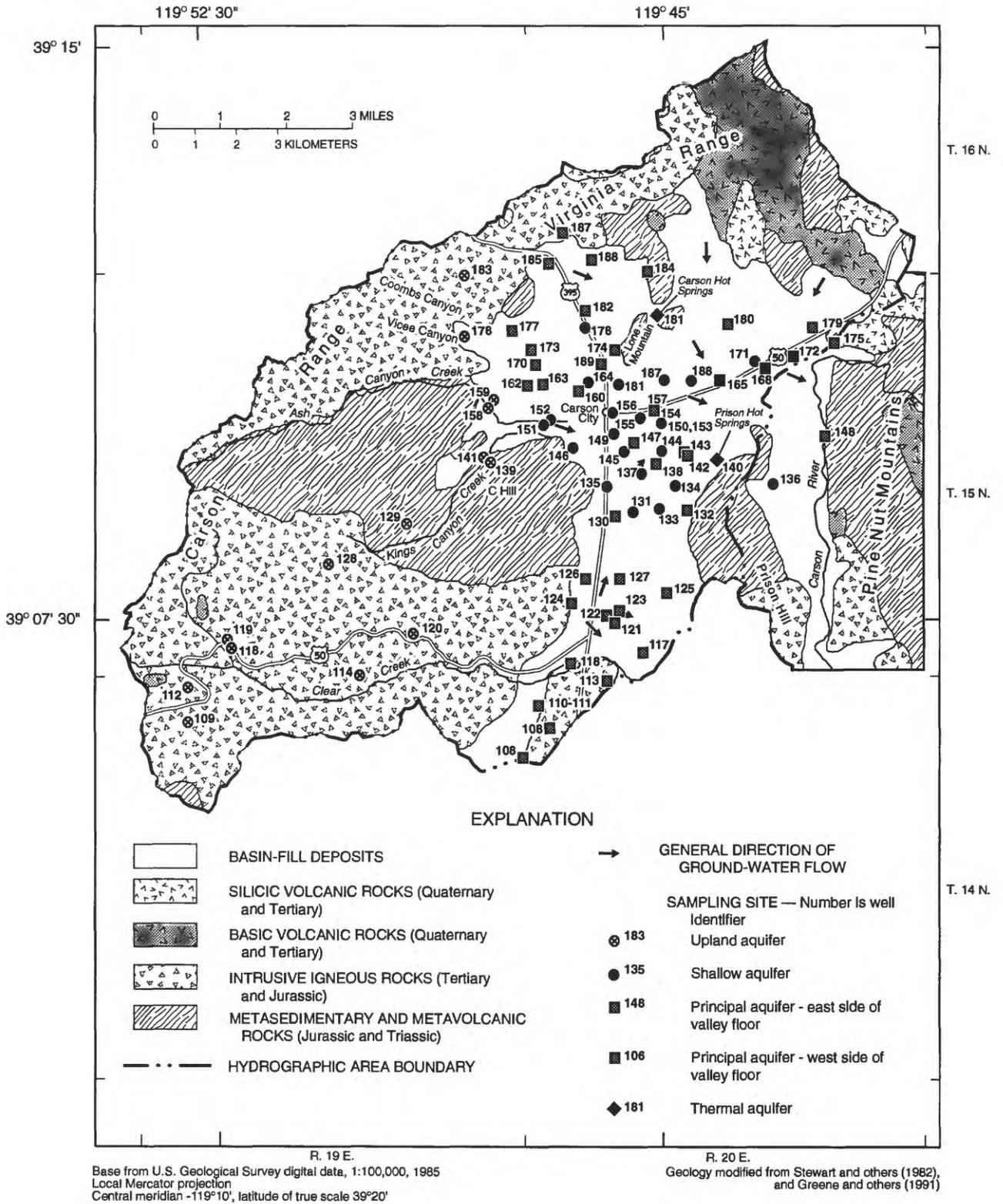


Figure 4. Hydrogeologic features of Eagle Valley and location of ground-water sampling sites.

The basin beneath Eagle Valley consists of several north-northeast-trending fault blocks (Arteaga, 1982, p. 26). The structural basin is divided into two smaller subbasins by shallow bedrock that extends from C Hill northeast to Lone Mountain (fig. 4) and the main part of the Virginia Range (Arteaga, 1982, p. 26). A western structural basin, which has a maximum depth of about 1,200 ft (Arteaga, 1982, p. 26), is bounded on the east by the shallow bedrock and on the west by the Carson Range. A larger subbasin, which has a maximum depth of about 2,000 ft (Arteaga, 1982, p. 26), underlies the east part of the valley and is bounded on the west by shallow bedrock, C Hill, and Lone Mountain, and on the east by Prison Hill and its north-trending subsurface extension.

Hydrogeologic Units

The Carson River drainage above Carson Valley (Headwaters Area) is a major source for the basin-fill sediments in Carson Valley and has the same general rock types as those found in basin fill beneath Carson and Eagle Valleys (figs. 2, 3, and 4). About 87 percent of surficial geology in the Headwaters Area consists of bedrock rather than basin-fill deposits. The bedrock area has been mapped primarily as basic volcanic rocks (about 58 percent of the area) and intrusive igneous rocks (about 34 percent). The Headwaters Area drained by the West Fork of the Carson River is underlain by the intrusive igneous rocks, whereas the East Fork area is predominantly underlain by basic volcanic rocks (fig. 2). Less than 6 percent of the bedrock area is mapped as either the metamorphosed sedimentary and volcanic rock group or the silicic volcanic rock group (as defined for Carson and Eagle Valleys).

On the basis of differences in lithology and rock chemistry, consolidated rocks are grouped into four hydrogeologic units (figs. 3 and 4). One unit, consisting of metamorphosed Triassic and Jurassic sedimentary and volcanic rocks, is exposed in the Carson Range, in northern and eastern Eagle Valley, and in the southern part of the Pine Nut Mountains. These rocks compose about 30 percent of total bedrock outcrop area. The Carson Range and parts of the Pine Nut Mountains are composed of Jurassic to Tertiary granodiorite and quartz monzonite, which account for almost one-half (about 48 percent) of the areal extent of the bedrock. A very small amount (less than 1 percent) of exposed bedrock is composed of silicic volcanic rocks and is combined with the granodiorite and quartz

monzonite. A third unit, consisting of Tertiary and Quaternary basalt, andesite, and trachyte is found in southern Carson Valley and in the Virginia Range in northeastern Eagle Valley. These basic volcanic rocks constitute a little less than one-quarter (about 23 percent) of exposed bedrock.

Undifferentiated basin-fill deposits are exposed primarily in the basin floor and underlie the valley lowlands. Basin-fill deposits are composed primarily of sediment derived from the surrounding bedrock and make up the matrix of the principal aquifers of Carson and Eagle Valleys. With the exception of one well in eastern Eagle Valley, which draws water from volcanic rocks, all pumped wells in the area tap sedimentary aquifers.

Basin-fill deposits in Carson Valley include Tertiary lacustrine and fluvial sandstone, mudstone, shale, marl, and limestone that are exposed extensively along the east side of the valley and in parts of the Pine Nut Mountains. The deposits are as thick as 1,000 ft or more on the east side of the valley (Moore, 1969, p. 12; Maurer, 1986, p. 12), and because they dip westward beneath younger fill, they may underlie the valley at depth along the western margin. These deposits are overlain along the east side of the valley by Quaternary and Tertiary deposits that consist mostly of fluvial gravels as much as 50 ft thick (Moore, 1969, p. 14, 15). The youngest deposits in the valley are Quaternary alluvial fans that consist of boulder and cobble gravels adjacent to mountains and extensive areas of fluvial clay, silt, sand, and gravel deposited on the Carson River flood plain (Moore, 1969, pl. 1).

Quaternary basin-fill sediments in Eagle Valley are exposed and Tertiary deposits are found at greater depths (Welch and others, 1990a, p. 13). Deeply incised Kings, Ash, Vicee, and Coombs Canyons have large fans at their mouths. The fans merge into one broad fan slope of sand and gravel along the west side of the valley extending as much as 1 mi east from the mountain front. These deposits persist to depths of at least 500 ft in this part of the valley and probably extend to bedrock (Welch and others, 1990a, p. 13). Similar fans border the valley to the north along the Virginia Range and to the east along Prison Hill (Bingler, 1977; Trexler and others, 1980). Deposits on valley lowlands consist of fine sands, silty and muddy sands, and gravels (Bingler, 1977; Trexler and others, 1980) and have a greater proportion of clay and silt than the fans on the west side of the valley (Welch and others, 1990a, p. 13).

Mineralogy of the Basin-Fill Sediments

Mineralogy of basin-fill sediments is determined by the types of rocks that supply the sediments and by chemical and mechanical weathering processes that have affected the material. Identified minerals were used as the basis for evaluating the geochemical processes that produced the observed ground-water quality in the area. Mineralogy of the basin-fill sediments reflects the variety of source rocks supplying sediment to the basin. Source material includes plutonic, mafic and intermediate volcanic, meta-volcanic, and metasedimentary rocks. Petrographic examination, x-ray diffractometry, and scanning-electron microscopy of 27 samples collected as cores and cuttings during the hollow-stem auger drilling of shallow wells (less than 40 ft deep) in Carson Valley were methods used to determine the mineralogy of the

sediments (Patrick Goldstrand, U.S. Geological Survey, written commun., 1990) summarized in table 1. Samples were collected at sites in agricultural land throughout much of Carson Valley. Bulk chemistry of the samples is discussed by Tidball and others (1991). Sediments at these shallow aquifer sites are believed to have been derived from the same sources as the deeper sediments that comprise the principal aquifers. Therefore, the minerals identified in the shallow sediments are probably also present in the principal aquifers.

About 34 percent of the sediments are composed of a variety of volcanic lithic fragments rather than grains that are generally composed of only one mineral. About 90 percent of the volcanic lithic fragments were derived from basalt and about 10 percent from metamorphosed andesite. The basaltic lithic fragments consist of about 60 percent groundmass, 35 percent

Table 1. Principal minerals identified in shallow sediments of Carson and Eagle Valleys

[Minerals were identified using x-ray diffraction, scanning-electron microscopy, and optical mineralogy (Patrick Goldstrand, U.S. Geological Survey, written commun., 1990)]

Primary Minerals	
Plagioclase feldspar	Plagioclase composition ranges from albite to labradorite. Most common composition is andesine, comprising about 37 percent of total. About 87 percent of plagioclase ranges in composition from oligoclase to labradorite. Slight alteration to chlorite, kaolinite, and illite.
Potassium feldspar	Slight alteration to chlorite and kaolinite.
Quartz	Unaltered.
Hornblende	Strong alteration to chlorite.
Biotite	Slight alteration to chlorite.
Pyroxenes (mostly augite)	Little or no alteration.
Prehnite	Less than 0.2 percent of the sediment.
Ilmenite or magnetite	Iron-rich minerals.
Secondary Minerals	
Beidellite	Common weathering product of plagioclase.
Chlorite	Weathering product of hornblende among other minerals.
Kaolinite	Weathering product of feldspar.
Illite	Weathering product of feldspar.

plagioclase feldspar, 3 percent augite, and 2 percent magnetite or ilmenite. The 10 percent of the volcanic lithic fragments derived from metamorphosed andesite is composed of about 50 percent groundmass, 25 percent plagioclase feldspar, 15 percent quartz, and 5 percent hornblende and prehnite.

Individual grains of plagioclase feldspar, quartz, and potassium feldspar make up about 26, 20, and 9 percent, respectively, of the sediments. Biotite, pyroxene (primarily augite), and ilmenite plus magnetite, each contribute about 1 percent of the sediments. The composition of plagioclase feldspars differs both among and within mineral grains (see Deer and others, 1967, p. 318, for classification of plagioclase feldspar). Most of the plagioclase feldspar varies in composition from oligoclase to labradorite, with andesine being the most common feldspar. Individual hornblende grains constitute less than 1 percent of the sediments. Lithic fragments of sedimentary rocks compose the remaining 8 percent of the sediments. These sedimentary lithic fragments are composed of, in general order of abundance, a fine-grained matrix, quartz, plagioclase feldspar, biotite, pyroxene, and hornblende.

Although calcite has not been identified in the granitic bedrock of the Sierra Nevada, indirect evidence suggests that this mineral is being dissolved to produce the observed water chemistry of alpine lakes and perennial springs. Geochemical reaction modeling (Garrels and Mackenzie, 1967; Bowser and Jones, 1990) indicates that calcite dissolves to produce the water chemistry of perennial springs described by Feth and others (1964) that issue from granitic rocks in the northeastern Sierra Nevada. An examination of the water chemistry of alpine lakes underlain by granitic bedrock in the Sierra Nevada by Stauffer (1990) indicates that at least some lake water contains dissolved calcite. Geochemical reaction modeling of water in a watershed in the Rocky Mountain National Park in Colorado, which is underlain by granite and gneiss (mineralogically similar to granite) and careful examination of the mineralogy indicate that calcite is present in both hydrothermally altered rock and along microfractures in otherwise unaltered granite (Mast and Drever, 1990). Taken together, these studies indicate that calcite is a plausible phase for inclusion in the list of reactive minerals that may be present in the granitic bedrock.

Most minerals in the sediments have been altered, although not all grains have been affected to the same degree. Chemical weathering of alumino-

silicate minerals has produced the clay minerals (in general order of abundance) beidellite, kaolinite, and chlorite. In addition, iron-oxide coatings are present on some grains, particularly on the iron minerals magnetite and ilmenite, and the silicate minerals pyroxene and hornblende.

Movement of Ground Water and Isotope Hydrology

For purposes of discussion, ground-water systems in Carson and Eagle Valleys are separated into groups and have informal names. Ground-water systems in higher altitudes, primarily in the Sierra Nevada, are referred to as "upland aquifers." The term "shallow aquifers" is defined here as the upper 30 ft of saturated thickness of the basin-fill sediments. The term "principal aquifers" refers to the deeper part (generally from 30 to 200 ft) of the ground-water system, currently the primary source of ground water used for irrigation, municipal, and domestic supply. Principal aquifers have been further subdivided on the basis of being located in either the east or west sides of the valleys. The "thermal aquifers" are defined here on the basis of measured ground-water temperatures greater than 30°C. These aquifers contain water that almost certainly circulates in the fractured bedrock and basin-fill sediments, and discharges as thermal springs.

Carson Valley

General Ground-Water Hydrology

Ground-water systems in Carson and Eagle Valleys have been studied in detail and are fairly well understood. The ground-water basin in Carson Valley contains two discontinuous confined alluvial aquifers, that together make up the principal aquifers, and a shallow aquifer. Confined aquifers are along the west margin of the valley within deposits of alluvial fans and beneath the central part of the valley. Contours of the altitude of the water table show that ground water moves toward the Carson River from both sides of the valley, and generally northward along the river (Maurer, 1986, fig. 3B). Shallow aquifers are hydraulically connected to the river which, depending on time of year and reach of the river, may either be gaining or losing. Where available, the water-level contours for deeper, confined aquifers in Carson Valley indicate ground-water-flow directions similar to those of the shallow aquifers, which generally are water-table aquifers (Maurer, 1986, fig. 3B).

A water budget for the basin-fill aquifers indicates that inflow and outflow for Carson Valley is about 170,000 acre-ft/yr (Maurer, 1986, p. 60). The ground-water system is dominated by the river, which accounts for much of the inflow of ground water to the basin. Sources of discharge are subsurface underflow to Carson Valley to the south and to the east towards the Carson River.

Isotope Hydrology

A water molecule has variable concentrations of the stable isotopes of hydrogen and oxygen. Hydrogen has stable isotopes with masses of 1 and 2 and oxygen has two stable isotopes with masses of 16 and 18 that are commonly used in studies of ground-water systems. The stable-isotope composition of water can be used as an indicator of the source of recharge to ground-water systems because, in general, the stable-isotope composition of nonthermal water is not affected by processes other than evaporation in the subsurface. Stable hydrogen-isotope and oxygen compositions are expressed as relative to a standard (Vienna Standard Mean Ocean Water) in units of "permil" or "parts per thousand" (Fritz and Fontes, 1980). Because precipitation that provides recharge to ground-water systems in Carson and Eagle Valleys is lighter than the standard mean ocean water, the values expressed in the permil units are all negative. When waters of differing compositions are compared, the lighter water (water containing less of the heavier isotope) has a more negative permil value than the heavier water.

The primary factor that controls the stable-isotope composition of the ground water in the basin-fill sediments of Carson and Eagle Valleys is the composition of the recharge water. In Carson Valley, the primary sources of ground-water recharge to the principal aquifers are the Carson River and streams draining the uplands, and upland aquifers in the Carson Range to the west and the Pine Nut Mountains to the east. Other local sources of recharge to the principal aquifers include the shallow and thermal aquifers. On the basis of discharge at three hot springs in Carson Valley, the quantity of flow from thermal aquifers appears to be relatively small compared with recharge from the other sources listed above. Shallow aquifers do not appear to be a major source of recharge to the principal aquifers.

Among the three primary sources of recharge to Carson Valley, water in principal aquifers on the east side of the valley generally has the lightest isotopic

composition (most negative permil values; figs. 5 and 6, and table 3) as represented by the composition of samples from sites 20, 39, 46, 84, 90, and 93 (fig. 3). These sites are northeast of areas affected by irrigation water diverted from the Carson River and probably are largely recharged by precipitation falling on the Pine Nut Mountains to the east. The location of Allerman Canal marks the eastern limit of irrigation from the Carson River. At site 20 (fig. 3), located at a sanitary landfill, one well sample had a stable-isotope composition that plots on figure 6 to the right of most of the other water in this area, indicating that the sample may have been affected by evaporation prior to recharge. Except for the sample from a domestic well located in an area irrigated by ground water (site 39, fig. 3), the other four samples have a hydrogen-isotope composition ranging from -128 to -122 permil, which is lighter than the range found for other major sources of recharge discussed below.

The hydrogen-isotope composition of recharge to Carson Valley from upland aquifers and streams flowing from the Sierra Nevada appears to be in the range from about -118 to -110 permil (figs. 5 and 6). Water draining the Sierra Nevada to the west of Carson Valley, which is a source of recharge to the ground-water system, had a hydrogen-isotope composition ranging from about -118 to -110 permil on the basis of 11 samples collected at eight sites from June to August 1981 by the U.S. Geological Survey (fig. 6). Excluding one relatively heavy isotope sample from site 78, upland aquifers yielded water with a hydrogen-isotope composition ranging from -117 to -109 permil with a median of -113.5 permil.

The Carson River, which drains the headwaters of the Carson River Basin to the south and west, has the heaviest (least negative) stable-isotope composition of the three major sources of recharge to the principal aquifers of Carson Valley (fig. 6). The stable-isotope compositions were determined for 16 and 27 monthly samples collected from May 1985 through September 1987 at the Woodfords and Gardnerville gages, respectively (U.S. Geological Survey, unpublished data). The data for the two sites have minimum, median, and maximum hydrogen-isotope values within 1 permil, which indicates that the Carson River has a fairly constant composition between the two gage sites. Taken together, data for the two sites yielded minimum, median, and maximum values of -110, -104, and -98 permil, respectively.

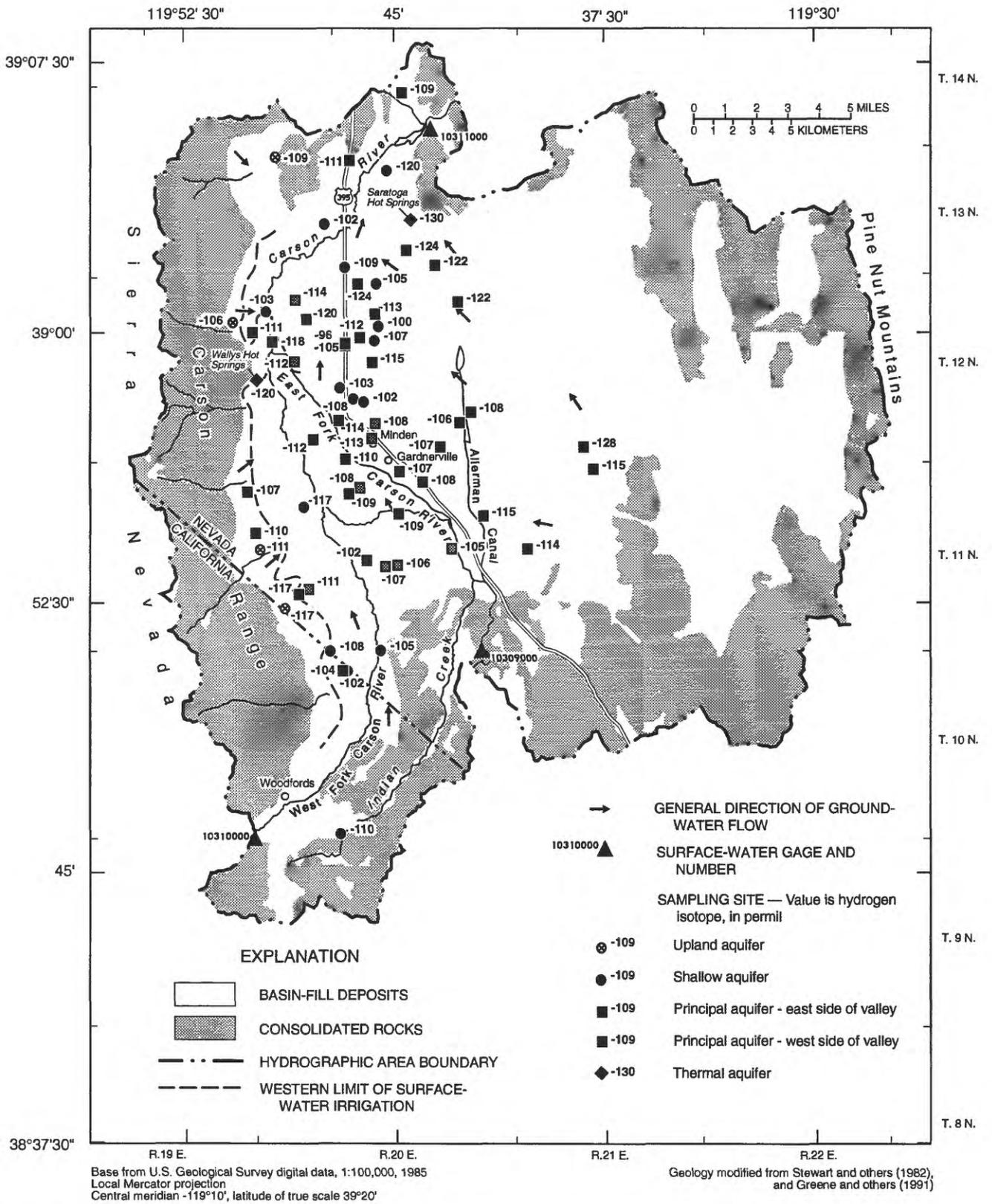
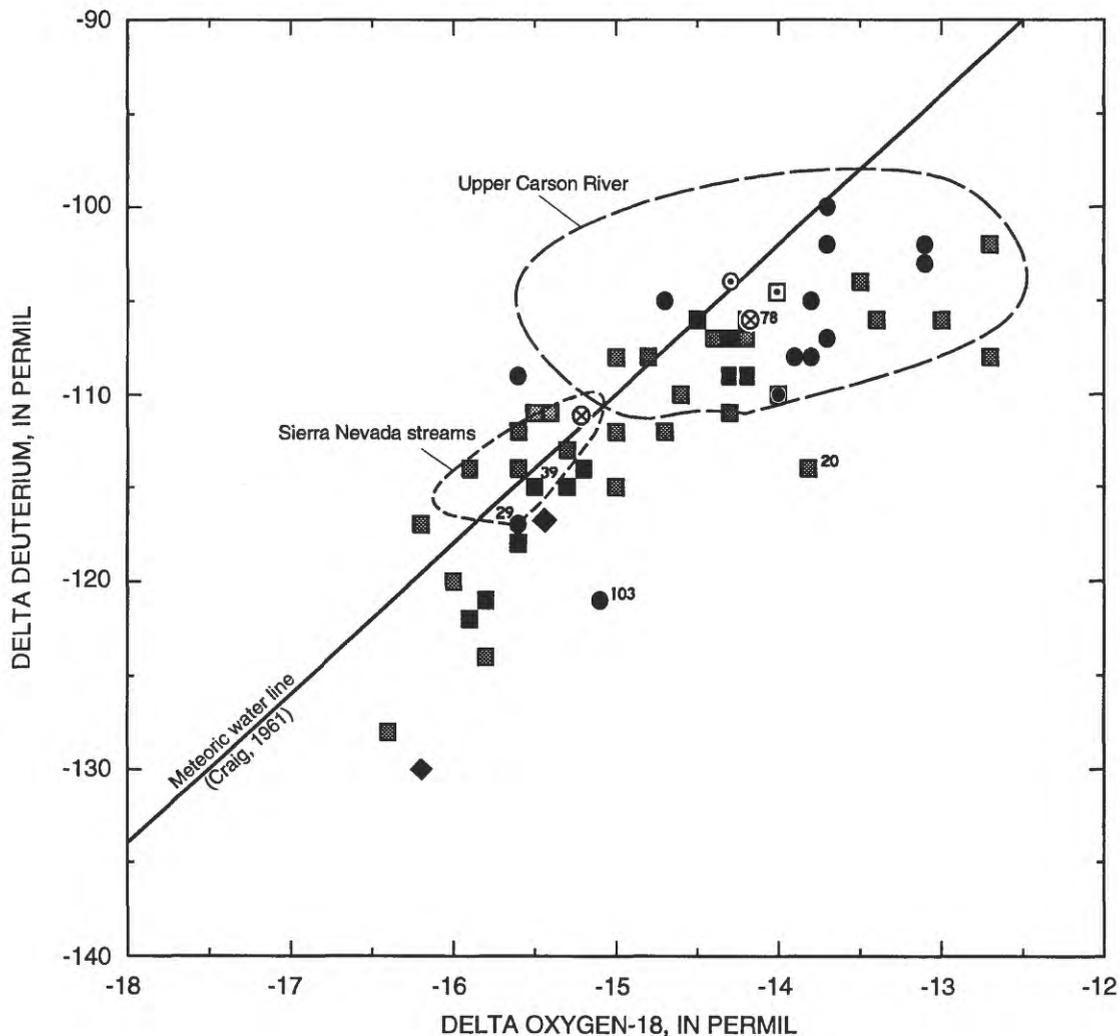


Figure 5. Stable-isotope composition of hydrogen in ground water at selected sites in Carson Valley.

The source of recharge to the shallow and principal aquifers in Carson Valley may be inferred from the hydrogen-isotope composition of the ground water and recharge. Water from the shallow aquifers in agricultural areas generally has an isotopic composition within the range found for the Carson River, which is the primary source of water used for irrigation. This

similarity in the hydrogen-isotope composition indicates that the Carson River is the primary source of recharge to the shallow aquifers. Two shallow wells (sites 29 and 103, fig. 3) yielded water with a hydrogen-isotope composition lighter than that of the Carson River. Both wells are near the Carson River and away from major pumping wells in areas that appear to have



- EXPLANATION
- | | |
|---|---------------------|
| ⊗ ⁷⁸ Upland aquifer | ⊙ Woodfords |
| ● ⁴⁶ Shallow aquifer | □ Near Gardnerville |
| ■ ²⁰ Principal aquifer - east side of valley | |
| ▣ Principal aquifer - west side of valley | |
| ◆ Thermal aquifer | |

Figure 6. Relation between stable-isotope composition of hydrogen (delta deuterium) and oxygen in surface water and ground water of Carson Valley. Number is site (see fig. 3).

a potential for upward flow from the principal to the shallow aquifers. Thus, water at these sites may originate as upward flow from the principal aquifers. Alternatively, water at the sites may be from local recharge from sources other than the Carson River. This possibility seems unlikely for site 29 because of the presence of sloughs between the Carson Range (the most likely source of local recharge with a light hydrogen-isotope composition) and the well site. Runoff from the Carson Range almost certainly would be diverted by the sloughs before reaching the well at site 29. Additionally, water at this site contained a tritium activity of only 1.8 picocuries per liter (pCi/L), which indicates (as discussed below) that ground water at this site was probably recharged more than 38 years before the present (1990). The other site is downgradient from two sources of local recharge—Saratoga Hot Springs (a hydrogen-isotope composition of -130 permil) and treated sewage from the Lake Tahoe Basin applied to the land. Treated sewage has a much heavier hydrogen-isotope composition than water at site 103 (-120 permil; fig. 5) indicating that the sewage is an unlikely source for most of the water at this site. Treated sewage from Incline Village probably is at least as isotopically heavy as water from Lake Tahoe—the source of water for the municipality (Carl Thodal, U.S. Geological Survey, oral commun., 1991). Lake Tahoe water has a much heavier hydrogen-isotope composition of about -58 permil (from four samples; Loeb, 1987, table 21).

Water from principal aquifers on the western edge of Carson Valley (R. 19 E.), with one exception (site 31, fig. 3), had a hydrogen-isotope composition less than or equal to -110 permil. These values correspond to the upper range found for recharge from the Sierra Nevada, as indicated by the measured composition of stream water flowing from the Sierra Nevada to Carson Valley.

Except for one site on the east side of the valley (site 27, fig. 3), the principal aquifers beneath south-central Carson Valley (T. 12 N., R. 20 E.) had a stable-isotope composition ranging from -109 to -102 permil. This range is within that found for the Carson River (-110 to -98 permil), indicating that the river is a major source of recharge in that area.

In most of the northern part of the valley, the hydrogen-isotope composition in the principal aquifers generally is lighter than the composition of the Carson River, which indicates that the principal aquifer is recharged principally from precipitation (in the

form of either precipitation runoff or flow through the upland aquifers) in the Carson Range and the Pine Nut Mountains.

Tritium is a radioactive isotope of hydrogen (^3H) that is part of the water molecule. Tritium has a half life of 12.33 years (Friedlander and others, 1981), so it can be used as an indicator of recent ground-water age (age here is the time the water has been isolated from the atmosphere). This information can be helpful in understanding the hydrology of an aquifer system by identifying areas where ground water has recently been exposed to the atmosphere. Tritium content in the atmosphere prior to above-ground detonation of nuclear weapons, which began in 1952, was produced by the impact of cosmic neutrons on nitrogen nuclei in the upper atmosphere, resulting in a steady-state activity (Fontes, 1980, p. 79). Assuming that present (1990) tritium levels are approaching the activity in precipitation present prior to above-ground nuclear testing, the activity is estimated to be about 25 pCi/L. Radioactive decay of the 25 pCi/L during a period of 57 years results in a tritium level less than 1 pCi/L. Thus, ground water containing less than 1 pCi/L of tritium today (1990) is probably older than 57 years. Major releases to the atmosphere from nuclear testing resulted in tritium activities greater than 10 pCi/L since 1954, with high activities in precipitation producing present-day activities greater than 100 pCi/L in 1958-59 and from 1962 to 1969. Mixing of water with different tritium activities can produce intermediate values. On the basis of this broad outline, the tritium data for Carson and Eagle Valleys is interpreted using the following general guidelines: (1) ground water having tritium activities less than 1 pCi/L is greater than 57 years, (2) values from 1 to 10 pCi/L are either a mixture of pre- and post-nuclear-testing water or is water ranging in age from about 38 to 57 years, (3) activities greater than 10 pCi/L are less than 38 years old or are a mixture of pre- and post-nuclear-detonation water, and (4) activities greater than 100 pCi/L are a result of major releases during the periods listed above.

Much of the ground water sampled in Carson Valley contains tritium activities greater than 10 pCi/L, indicating that at least a component of the water was recharged since about 1952. In much of south-central Carson Valley, tritium activities greater than 10 pCi/L indicate that the ground water was recharged within the last 38 years (fig. 7). These tritium activities are taken as corroborative evidence that the ground water is from

the Carson River, as indicated by the stable-isotope composition. Tritium activities less than 0.4 pCi/L in water for most wells in the northern and eastern parts of the valley indicate that this water is older than water in the south-central area. Lower tritium activities in the north-central part of the valley are compatible with the northward ground-water flow direction indicated by water-level altitudes (fig. 7). The low values in the northernmost and easternmost parts of the valley indicate that ground water in these areas is relatively old. This may be a result of slow rates of ground-water flow owing to low permeabilities, upward hydraulic head beneath the lower altitude of the valley floor (fig. 3; Maurer, 1986), and modest recharge rates in the relatively low mountains to the east.

The isotopic composition of water in Carson Valley, both the stable-isotope composition and tritium activities is largely consistent with the hydrologic relations described by Maurer (1986). The isotopic composition of ground water in the south-central part of Carson Valley indicates that recharge of water from the Carson River is reaching the principal aquifers. This could not be determined by data available as of 1986 (Maurer, 1986). The isotopic composition of the water appears to be a more sensitive indicator than surface-water budgets developed by Maurer (1986) of recharge from the Carson River to the principal aquifers. This difference notwithstanding, the stable-isotope composition of water indicates hydraulic relations that are largely compatible with the previous work of Maurer (1986). The primary use of stable-isotope data is to provide an opportunity to evaluate and refine existing concepts of the hydrology of Carson Valley.

Eagle Valley

General Ground-Water Hydrology

The Eagle Valley ground-water basin consists of a shallow water-table aquifer and one or more deeper semi- to fully confined alluvial aquifers (Arteaga, 1982). The confining beds are composed of discontinuous clay lenses at different depths. Confined conditions are most pronounced in the area northwest of Prison Hill where ground-water flows in northerly, northwesterly, and southwesterly directions converge. Although flow is somewhat complex because of several areas of consolidated rocks with low permeabilities, the movement is generally toward the Carson River to the east.

Steady-state recharge in Eagle Valley as of 1964 was an estimated 4,900 acre-ft/yr (Arteaga, 1982, p. 18), mainly as runoff and underflow along the west side of the valley and infiltration of streamflow and irrigation water (both agricultural and landscape) in other parts of the valley.

Isotope Hydrology

The stable-isotope composition of ground water in much of the principal aquifers beneath the western part of Eagle Valley generally is similar to the composition of water in the Carson Range as represented by Ash Canyon Creek and the upland aquifers (figs. 8 and 9). Measured hydrogen-isotope composition of the upland aquifers and precipitation runoff ranged from about -112 to -100 permil. Available data indicate that principal aquifers beneath the western part of Eagle Valley have a hydrogen-isotope composition ranging from -115 to -103 permil. Wells tapping principal aquifers along surface-water drainages yield water with the heaviest hydrogen-isotope compositions, ranging from -105 to -103 permil (fig. 9). The heavier composition may be a result of a minor amount of evaporation affecting the water prior to recharge. Sites 162 and 163 (fig. 4) are below a sand pit that ponds water accumulated during periods of spring runoff prior to recharging the ground-water system (Maurer and Fischer, 1988). Evaporation from the surface of the pond could result in recharge having a heavier hydrogen-isotope composition than runoff from other drainages on the west side of Eagle Valley.

Wells at sites 153-155 (fig. 4) are relatively shallow (total depths of 19, 29, and 58 ft below land surface) and are in a municipal park near a deeper well that pumps relatively large quantities of water (site 157, fig. 4) along the lower reach of Clear Creek. Because the wells are in an irrigated park, the two shallowest wells are probably recharged by water that has been affected by evaporation. The tritium content of the water from the shallow well at site 153 was 57 pCi/L, which is consistent with relatively young water being recharged from the creek. Water from the deeper, unpumped well has a stable hydrogen-isotope composition similar to that of local shallow ground water, with a tritium activity less than 5.7 pCi/L. The difference may be partly a result of downward flow caused by pumping of the deeper well at site 157. The water from the pumped well in this area had a stable hydrogen-isotope composition of -112 permil,

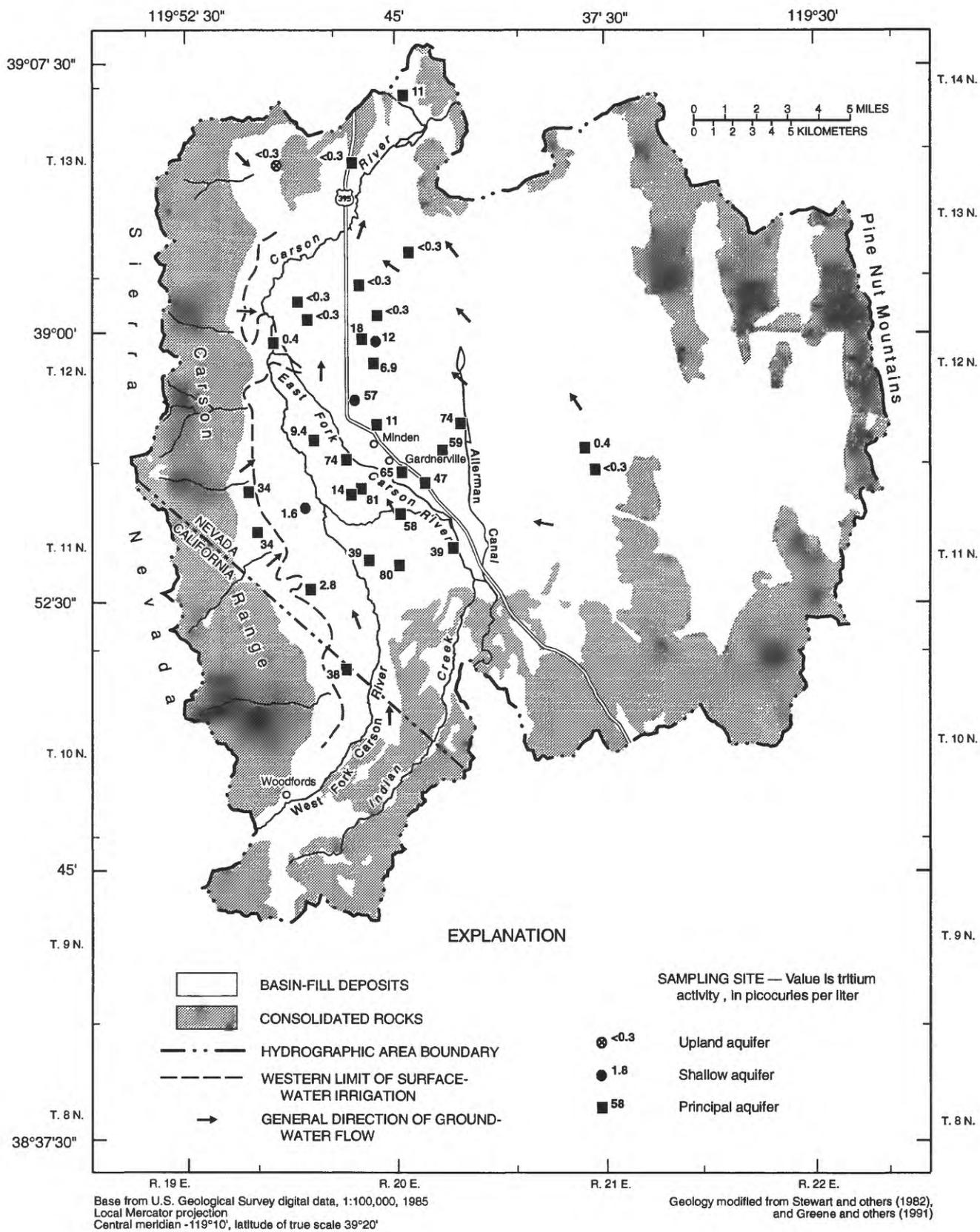


Figure 7. Tritium activity in ground water at selected sites in Carson Valley.

which does not indicate that the local shallow ground water is the primary source of recharge to this well, although continued pumping may eventually induce recharge into the principal aquifers. The tritium content of deeper water, <0.3 pCi/L, also is consistent with the conclusion that local shallow ground water and surface water do not provide recharge to the principal aquifers.

With the exception of one sample, ground water in the principal aquifers in northeastern Eagle Valley is lighter (having a hydrogen-isotope composition of -122 to -115 permil) than the water in other parts of the basin (fig. 9). The lighter composition is probably because precipitation is lighter in the recharge area to the northeast than in recharge in the Carson Range. The one heavier isotope sample at site 180 in the north-east (-107 permil) may be a result of recharge of water

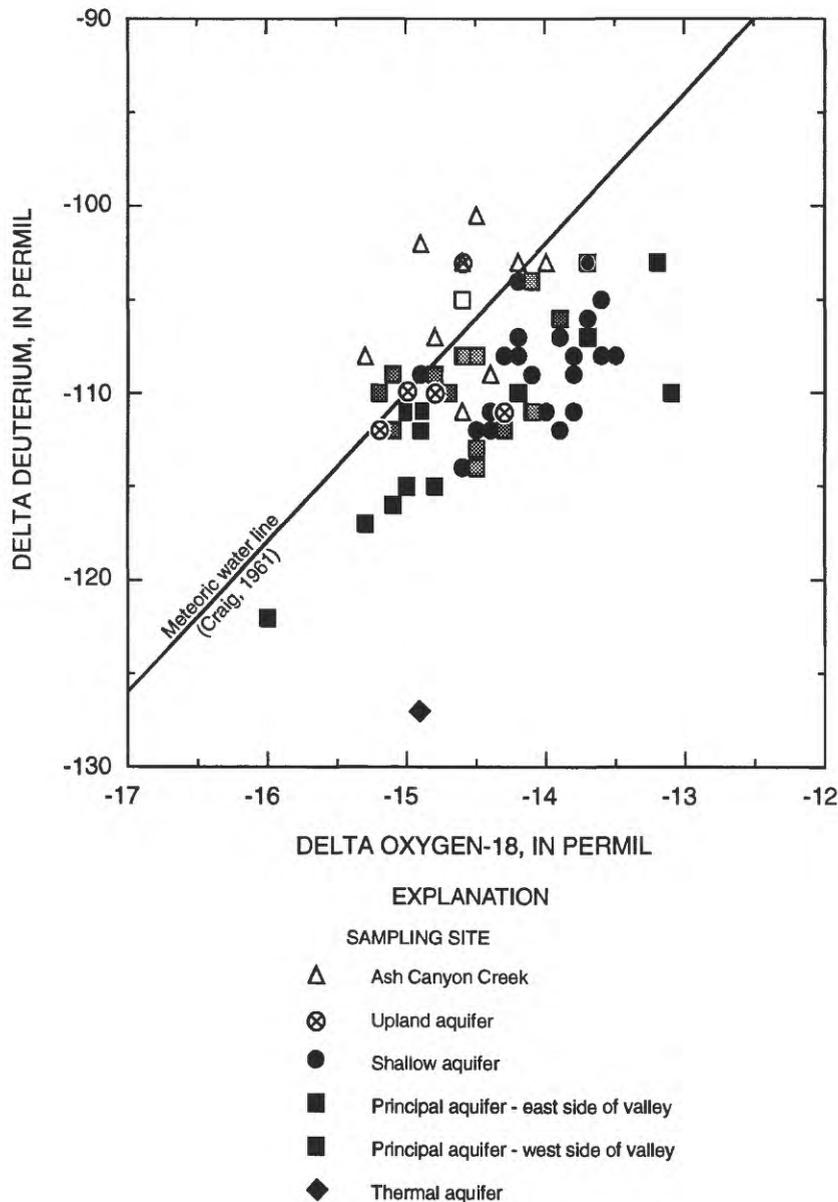


Figure 8. Relation between stable-isotopic composition of hydrogen (delta deuterium) and oxygen in Ash Canyon Creek and ground water of Eagle Valley.

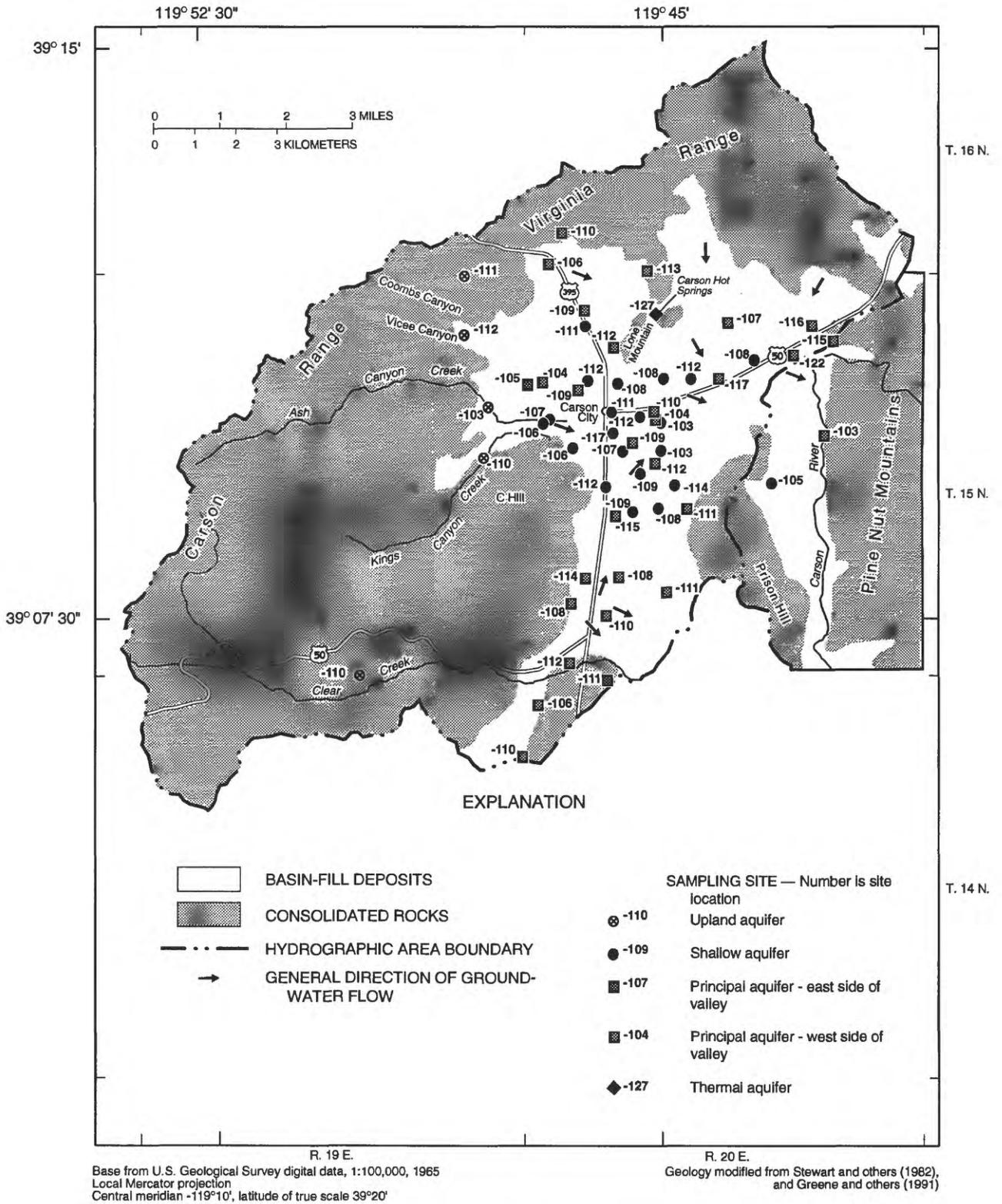


Figure 9. Stable-isotope composition of hydrogen in ground water at selected sites in Eagle Valley.

from the municipal water supply, either from lawn watering or from septic-tank discharge. A tritium activity of 32 pCi/L was found in water from this 68-ft-deep well. This activity indicates that the age of the water is relatively young. The shallow depth of the well, the somewhat heavy stable-isotope composition (-107 permil), and the tritium activity are consistent with recharge of young water that has been affected by evaporation.

Tritium activities in water from principal aquifers of Eagle Valley are generally less than 1 pCi/L except along the margins of the basin-fill deposits (fig. 10). The low tritium activities (<1 pCi/L) in most of the ground water indicate that the age of the water is at least 57 years. The presence of measurable tritium in ground water in principal aquifers of the northern half of Eagle Valley is consistent with the location of these areas close to recharge areas. The principal aquifer along the Carson River (site 148; fig. 4) contains relatively young ground water, as indicated by a tritium content of 29 pCi/L. The hydrogen-isotope composition at this site (-103 permil; figs. 4 and 9) is similar to local shallow ground water (-105 permil) at site 136, which is recharged by irrigation water diverted from the Carson River and is in the range found for the Carson River. Together, the tritium and stable-isotope composition indicate that ground water at this site is derived from the Carson River, either directly from induced infiltration through the river bottom or from locally applied irrigation water.

WATER QUALITY AND AQUEOUS GEOCHEMISTRY

This section describes the quality of the water in the principal aquifers and the processes that lead to the observed water quality. The water quality of the other aquifers and the Carson River is discussed primarily for the purpose of presenting a clearer understanding of the water quality in the principal aquifers. For instance, because upland aquifers and the Carson River both recharge the principal aquifers, a description of the water quality in these units provides a basis for understanding the water quality in the principal aquifers.

Because ground water is an important source for both domestic and public water, the Nevada State drinking-water standards for public water supplies provide an appropriate reference for evaluating the quality of ground water. The standards (table 2) consist

of primary maximum contaminant levels (MCL's), secondary maximum contaminant levels (SMCL's), and secondary preferred standards (SPS's). The MCL's, which are health related and enforceable Federally and by the State, specify maximum permissible concentrations of constituents in water delivered to the user of a public water-supply system. The SMCL's relate to the aesthetic quality of water and are State, but not Federally, enforceable. The SPS's may be applied if the concentrations are locally attainable—if not, the SMCL's apply (Nevada Bureau of Consumer Health Protection Services, 1980, p. 8; Jeffery A. Fontaine, Nevada Bureau of Consumer Health Protection Services, oral commun., 1989). The MCL's, SMCL's, and SPS's were adopted by the State of Nevada in 1988. The MCL's adopted by the State for inorganic constituents are equal to the values established by the U.S. Environmental Protection Agency (USEPA; 1986a). In general, the concentrations adopted by the State as SPS's follow the guidelines established by the USEPA (1986b). SMCL's adopted by the State, except for fluoride, have SPS's for the same set of constituents, with the SMCL being greater than the SPS for a particular constituent. Although a MCL has not been established for radon, the USEPA (1991) has proposed a value of 300 pCi/L. The proposed MCL for uranium is 20 µg/L, with radium-226 and -228 each having a proposed MCL of 20 pCi/L (USEPA; 1991). A 15-pCi/L MCL for "adjusted gross alpha" also has been proposed, which is equal to the measured gross alpha minus radon-222, radium-226, and uranium.

Diagrams of the type represented by figures 11 and 12 display the general chemical ionic composition of individual pH and dissolved-solids concentrations of water in samples. The diagram consists of two triangular and three rectangular fields (Zaporozec, 1972, p. 38). Each chemical analysis is plotted as five points on the diagram. In combination, the five points plotted for each sample provide an indication of the overall chemical composition of the water. The relative proportions of major cations (calcium, magnesium, and sodium plus potassium) and major anions (sulfate, chloride, and carbonate plus bicarbonate) are shown on the left and upper triangles, respectively. The pH (or discharge) and dissolved-solids concentrations for the water samples are plotted in the bottom and right rectangles, respectively. The primary advantage of the type of diagram represented by figure 11 is that it provides a visual representation, on a single illustration, of eight major chemical constituents, pH or dis-

Table 2. Nevada State drinking-water standards for public water-supply systems

[Units of measure and symbol: milligrams per liter, except as noted; --, standard does not exist for the indicated constituent or property]

Constituent or property	Maximum contaminant level (MCL) ^a	Secondary maximum contaminant level (SMCL) ^b	Secondary preferred standard (SPS) ^c
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 nitrogen	10	--	--
Selenium	.01	--	--
Silver	.05	--	--
Sulfate	--	500	250
Total dissolved solids	--	1,000	500
Zinc	--	--	5.0
pH	--	--	>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 ^d (excluding radium-226, radon, and uranium), in picocuries per liter	15	--	--
Gross beta, in millirems per year	4	--	--
Radium-226 and -228 (combined), in picocuries per liter	5	--	--

Table 2. Nevada State drinking-water standards for public water-supply systems—Continued

Constituent or property	Maximum contaminant level (MCL) ^a	Secondary maximum contaminant level (SMCL) ^b	Secondary preferred standard (SPS) ^c
Radionuclides—Continued			
Radium-226 ^d , in picocuries per liter	20	--	--
Radium-228 ^d , in picocuries per liter	20	--	--
Radon-222 ^d , in picocuries per liter	300	--	--
Uranium ^d	.02	--	--

^aMaximum contaminant levels (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 (Jeffrey A. Fontaine, Nevada Bureau of Consumer Health Protection Services, oral commun., 1989). MCL's are adopted by The Nevada Bureau of Consumer Health Protection Services (1980) from National Drinking Water Regulations (U.S. Environmental Protection Agency, 1986a, 1986b).

^bSecondary maximum contaminant levels (SMCL's) are based on aesthetic qualities and are enforceable by State of Nevada (NBCHS, 1980). Best available technology is determined by State of Nevada (Jeffrey A. Fontaine, Nevada Bureau of Consumer Health Protection Services, oral commun., 1989). SMCL's, except for magnesium, are adopted from National Drinking Water Regulations (U.S. Environmental Protection Agency, 1986b, p. 587-590). SMCL's have not been established by State of Nevada for copper, pH, and zinc.

^cSecondary preferred standards (SPS's) must be met unless water of that quality is not available, in which case SMCL's must be met if they exist (Nevada Bureau of Consumer Health Protection Services, 1980, p. 8-9).

^dProposed standard (U.S. Environmental Protection Agency, 1991).

charge, and dissolved-solids concentration of the ground water in a particular location. The principal application of this type of diagram is to examine where the data points tend to group in each of the five individual triangular and rectangular fields. The outlying rectangles may be used to display values for measures other than pH and dissolved solids. For example, discharge is shown on figure 11 in the field commonly used for pH. The arrows in figure 11 show how the cation and anion points for a single analysis are projected from the cation and anion triangles to the central rectangle and then to the pH and dissolved-solids rectangles. The central rectangle thus functions primarily as a transitional area to connect the four outside triangular and rectangular plots.

Boxplots (Tukey, 1977) are used to display statistics regarding the distribution of reported concentrations for selected constituents. The statistical components are represented visually by features known as "boxes" and "whiskers." A box defines the spread of the middle 50 percent of the data (the concentrations that lie between the 25th and 75th percentiles). The median value of the data (that is, the 50th percentile) is indicated by the horizontal line within the box. The vertical lines beyond each end of the box are called

whiskers. They show the range of concentrations and extend beyond the ends of the box to the maximum and minimum data values.

Nonparametric rather than parametric statistics are used in this report because water quality and other environmental data do not, or cannot be demonstrated to, fit some known distribution. Nonparametric approaches use data ranks rather than actual values. Additionally, nonparametric tests are nearly as powerful as parametric approaches. For a comparison of mean ranks, the results of a Wilcoxon-Mann-Whitney test (Iman and Conover, 1983, p. 280-287) are given in this report. Correlations between concentrations are generally evaluated using Spearman's rho, which is a measure of the increasing or decreasing relation between two variables (Iman and Conover, 1983, p. 126-129). Values for Spearman's rho are reported only when they are valid at the 95th confidence level or greater.

The following part of this report discusses ground-water quality and has four subsections that consider the major inorganic constituents, minor inorganic constituents, radionuclides, and synthetic organic compounds in ground water. The subsections each describe the general water quality and the processes that affect the concentrations of the various

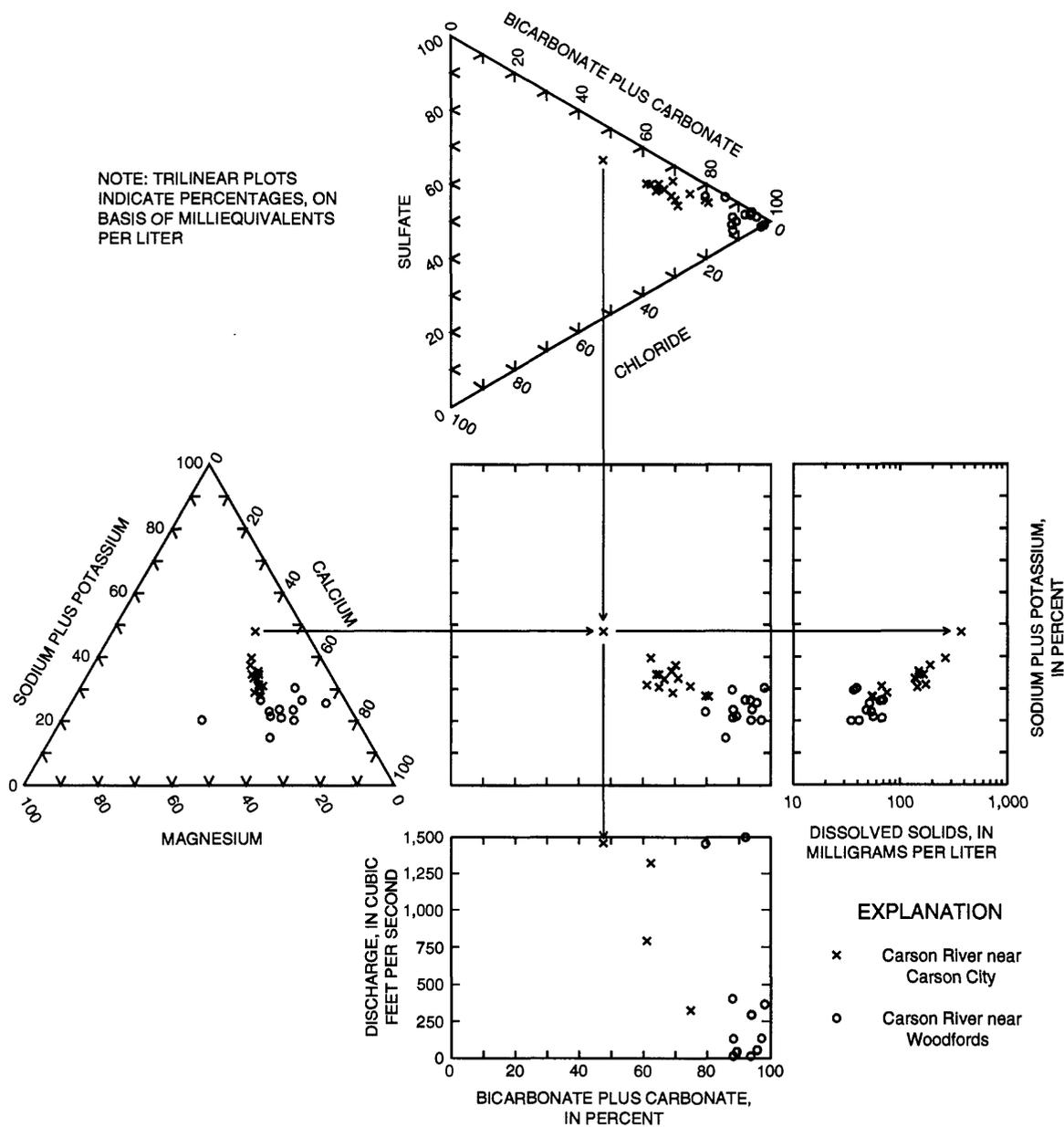


Figure 11. General chemical composition of Carson River.

constituents. Because most constituents present at concentrations exceeding the Nevada State drinking-water standards are minor inorganic constituents, the relation between inorganic water quality and standards is discussed in the minor constituent subsection. Within Carson and Eagle Valleys, the major inorganic constituents constitute 98 percent or more of the total solute load; minor inorganic constituents are generally at concentrations less than 1 mg/L.

Surface Water

The Carson River is the major surface-water feature in the Carson-Eagle Valley area. Chemical analyses of the river water for major constituents are available for samples collected by the U.S. Geological Survey at streamflow gages upstream from Carson Valley near the town of Woodfords (gage number 10310000) and near Carson City (gage number 10311000, fig. 3). Additional gages with more than

30 years of flow data above and within the study area are located near Markleeville, Calif. (gage number 10308200, fig. 2), and near Gardnerville, Nev. (gage number 10309000, fig. 3). Water-quality data used herein are stored in the U.S. Geological Survey's National Water Information System (see Maddy and others, 1990, for a description of the system). Analyses of major constituents have been determined for only a limited number of samples from these gage sites. At the gage near Woodfords, 13 samples collected from 1961 to 1988, and the Carson City gage, 14 samples collected from 1977 to 1984, had major constituent analyses. Land between the upstream gage 10310000 and Carson Valley is largely undeveloped. Therefore, water quality measured at the upstream gage is considered a good representation of the largest volume of surface water entering the study area. The downstream gage 10311000, near Carson City, is below the reach of the river that receives return flow from agricultural land and discharge of treated sewage in Carson Valley.

Water from the Carson River is primarily a calcium-sodium-bicarbonate type with a dissolved-solids concentration ranging from about 30 to about 400 mg/L (fig. 11) at the two gage sites. A limited number of samples for which all the major constituents have been analyzed indicate that river water at the downstream gage can be generally characterized as having a greater dissolved-solids content and a greater percentage of sodium plus potassium and sulfate than the water above Carson Valley near Woodfords. These differences in water quality, particularly for periods of low flow during late summer and autumn, have been attributed to the effects of drainage from agricultural land and the discharge of treated sewage, as suggested by Spane (1977). Possible effects on surface-water quality caused by recent changes in land and water use have not been evaluated.

Ground Water

As mentioned earlier, most of the data used to characterize the ground-water quality were collected as part of the NAWQA program. Other sources of data include inorganic chemical analyses of springs in the Carson Range (Feth and others, 1964), and inorganic chemical and tritium analyses for ground water in Eagle Valley (Szecsody and others, 1983). Data collected prior to the NAWQA program for ground-

water-quality monitoring in Carson Valley (see Garcia, 1989, table 7) are used also as a basis for describing the ground-water quality.

The selection of locations sampled as part of the Carson River Basin NAWQA project was based on an overall design for a study of the entire Carson River Basin (Welch and Plume, 1987) using a nationally consistent quality-assurance plan (Matraw and others, 1989). The NAWQA sampling included about 30 existing wells tapping the upland and principal aquifers in each of the two valleys studied, for a total of about 60 wells. Shallow wells were drilled for the purpose of sampling the upper part of the shallow aquifers using protocols described by Hardy and others (1989). In general, the shallow wells were drilled to depths less than 30 ft and were completed 20 ft below the shallow water table, or less. Ten wells were drilled and sampled on agricultural land at sites selected using a program written by Scott (1990) designed to ensure random locations. Nine of the sites are in Carson Valley and one is along the flood plain of the Carson River to the east of Eagle Valley (site 136, fig. 4).

Shallow wells also were drilled at 20 sites in the urban part of Eagle Valley. The site-selection process for wells drilled in the Carson City urban area, which is described in detail by (S.J. Lawrence, U.S. Geological Survey, written commun., 1992), led to drilling at 20 locations on approximately a 1/2 mi grid. Although more than one well was drilled at two sites in the urban setting, only one well was used in this areal characterization of ground-water quality.

Ground water was sampled using protocols described by Hardy and others (1989), which include purging of wells using positive displacement pumps and monitoring of selected constituents until stable readings are obtained. In general, samples collected as part of this study were analyzed by the U.S. Geological Survey National Water-Quality Laboratory in Arvada, Colo., using the methods described by Fishman and Friedman (1985) and Wershaw and others (1987). Radionuclides (other than radon) were analyzed by a contractor to the USGS laboratory. Stable isotopes of water were analyzed by the U.S. Geological Survey laboratory in Menlo Park, Calif.

On-site measurements included pH, water temperature, specific conductance, dissolved oxygen, alkalinity, electrochemical potential (Eh), and, in some cases, sulfide. These measurements, except for alkalinity and sulfide, were made using a flow-through cell. The pH meter and electrode system were calibrated at

each site using two buffer solutions (pH 7 and either 4 or 10) that bracketed the expected pH of the sample. Water temperature was measured with a calibrated mercury thermometer. The specific conductance meter and electrodes were calibrated at each site with a standard potassium chloride solution that had about the same conductance as the sample. Dissolved oxygen was measured with a calibrated polarographic oxygen-sensing electrode. Alkalinity was determined immediately after sample collection by incremental titration with standardized sulfuric acid (either 0.16 or 1.6 normal), from which carbonate and bicarbonate were calculated (Barnes, 1964). Eh was determined using the method of Thorstenson and Fisher (1979), which employs a platinum-calomel combination electrode. Concentration of sulfide was determined by specific-ion electrodes using the method of Lico and others (1982).

Any characterization of the general ground-water quality in Carson and Eagle Valleys is no better than the data upon which it is based. Basic characterization of wells used for ground-water sampling for this study are included in table 3. More detailed information on the wells is included in Whitney, 1994. General characterization of regional ground-water quality is usually constrained by the areal and vertical characterization of the sample sites. Although this study included designs of specific well networks, the resulting data base still has limitations that constrain the interpretation of the data. First, only six sites were available for the thermal aquifers. In contrast, analyses of water from the shallow and principal aquifers are available for about 40 and 100 sites, respectively.

A second constraint is introduced by uses of water from the sampled wells. Wells tapping principal aquifers are generally used for drinking water or irrigation and thus may represent a biased sample because wells drilled for public-water supply that produce poor-quality water are generally abandoned. Consequently, using pumped wells to sample principal aquifers may indicate a greater percentage of water that meets the drinking-water standards than is truly representative of the entire aquifer system. Wells tapping the principal aquifers also have different open intervals or have annuluses filled with gravel. The differing well construction among the principal aquifers means that some wells pump water from an interval of 100 ft or greater, whereas other wells produce water from an interval of 30 ft or less. Because all wells tapping the principal aquifers are water-supply wells, used primarily for

domestic, municipal, and irrigation purposes, the open intervals generally are opposite the more productive parts of the aquifer. Thus, water quality of the finer grained, less productive parts of the principal aquifers are probably not well represented by the available data. Available wells also tap only the upper part of the principal aquifer system. The wells sampled are generally less than 400 ft deep, whereas the basin fill locally has thicknesses of 5,000 ft or greater (Maurer, 1985). Because of these limitations, data from this study are probably more representative of ground water used for public supplies from the principal aquifers rather than of all ground water in Carson and Eagle Valleys.

Major Inorganic Constituents

Water Quality and Its Relation to Nevada State Drinking-Water Standards

In general, ground water in the principal aquifers of Carson and Eagle Valleys is dilute, with dissolved-solids concentrations less than 1,000 mg/L and pH values ranging from near neutral to alkaline (fig. 12). Sodium and calcium are the dominant cations in most of the ground water. Relatively high sodium percentages are generally associated with pH values greater than about 8.0. Bicarbonate is the dominant anion in most of the ground water.

In general, the Carson River, both upstream and downstream of Carson Valley, is more dilute than water in either the principal or shallow aquifers. Ranked concentrations of calcium, magnesium, sodium, and chloride were significantly less in the river than in the two aquifer systems, on the basis of the Mann-Whitney test at the 95-percent confidence level (see Iman and Conover, 1983, p. 280-287, for an explanation of this nonparametric procedure). Water in the shallow and upland aquifers contained proportions of major cations similar to those found in the principal aquifer. Thermal water contained greater proportions of sulfate and chloride than most of the nonthermal ground water.

Although the proportions of major ions in most nonthermal ground water are similar, the ranked concentrations are significantly different. In general, the principal aquifers had concentrations of major ions greater than those found in the upland aquifers, but less than those in the shallow aquifers (figs. 12 and 13). More specifically, the ranked calcium, sodium, magnesium, chloride, sulfate, and bicarbonate concentrations

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys

Symbol: U, upland aquifers; S, shallow aquifers; P, principal aquifers.

Latitude and longitude: In degrees, minutes, and seconds.

Local site identification: Township, range, section number, location within the section, and sequence number. See page 3 for description of complete site-numbering system.

Total depth of well: Sources of information are drillers' logs (on file at Nevada Division of Water Resources, Carson City) or files of the U.S. Geological Survey.

Primary water use: H, domestic; I, irrigation; N, industrial; P, public supply; Q, aquaculture; R, recreation; S, stock; U, unused.

[Specific conductance, pH, bicarbonate, and carbonate were measured in field; those marked 'L' were measured in laboratory. Units of measure and symbols: mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mV, millivolts; $^{\circ}\text{C}$, degrees Celsius; --, not determined; <, less than; pCi/L, picocuries per liter; PMC, percent modern carbon. Isotope standards: deuterium and oxygen are relative to Vienna Standard Mean Ocean Water; carbon-13 relative to Pee-Dee Belemnite; sulfur relative to Canyon Diablo meteorite]

Site (figs. 3 and 4)	Symbol	Latitude	Longitude	Local site identification	Altitude of land surface (feet)	Total depth of well (feet)	Primary water use	Date	Time	Specific conductance ($\mu\text{S}/\text{cm}$)	pH (standard units)	Eh (mV)	Water temperature ($^{\circ}\text{C}$)	Oxygen, dissolved (mg/L)	
78	U	390021	1195043	N13 E19 09ADCA1	4,810	180	H	08-27-87	1100	283	7.1	--	12.0	--	
104	U	390457	1194913	N14 E19 14BBD1	5,040	100	H	06-09-88	1500	117	8.6	310	17.5	4.6	
CARSON VALLEY															
Upland aquifers															
1	S	384616	1194655	N11 E20 31CABD2	5,500	11	U	07-19-88	1200	92	6.3	300	16.5	4.0	
29	S	385522	1194813	N12 E19 13BABB1	4,700	17	U	08-23-88	1400	152	7.8	410	15.3	<1.0	
53	S	385820	1194608	N13 E20 20CBBC1	4,710	8	U	08-03-87	1000	665	7.4	0	14.5	<1.0	
56	S	385822	1194625	N13 E20 19DABC1	4,700	8	U	08-09-88	1100	695	7.3	290	14.0	<1.0	
58	S	385834	1194641	N13 E20 19ACCC1	4,694	11	U	09-05-86	1445	645	7.4	--	13.5	--	
59	S	385842	1194656	N13 E20 19BACC1	4,680	17	U	07-06-88	1100	667	7.3	160	14.0	<1.0	
64	S	385948	1194644	N13 E20 18BAAA1	4,682	20	U	09-04-86	1340	875	7.4	--	13.0	--	
67	S	390000	1194541	N13 E20 08CDAB1	4,700	16	U	08-09-88	1500	417	7.0	280	15.5	<1.0	
83	S	390048	1194934	N13 E20 03DDDB1	4,660	23	U	07-14-88	1400	948	7.0	140	14.5	<1.0	
86	S	390137	1194536	N14 E20 32DCCC1	4,679	21	U	06-30-87	1415	397	7.9	--	13.5	--	
89	S	390205	1194643	N14 E20 30DCCB1	4,654	20	U	09-02-86	1545	425	7.6	--	15.0	--	
96	S	390317	1194730	N14 E19 25BDDDB2	4,660	18	U	07-20-88	1300	615	7.0	120	16.0	<1.0	
100	S	390407	1194519	N14 E20 20AAB1	--	25	U	08-29-83	1045	779 L	7.4	--	14.0	--	
103	S	390446	1194514	N14 E20 17ADCA1	4,640	27	U	01-14-88	1500	4,190	6.6	--	13.5	--	

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Sym- bol	Lat- itude	Longi- tude	Local site identification	Altitude of land surface (feet)	Total depth of well (feet)	Primary water use	Date	Time	Specific conductance (µS/cm)	pH (standard units)	Eh (mV)	Water temperature (°C)	Oxygen, dissolved (mg/L)
Principal aquifers—east side of valley														
14	P	385321	1194050	N12 E20 24ADCC2	4,980	145	H	08-24-87	1600	507	7.9	--	14.0	--
20	P	385412	1194014	N12 E21 18CAB1	--	--	H	08-24-87	1800	455	7.5	--	21.0	--
27	P	385509	1194148	N12 E20 11ADD1	4,900	125	H	08-20-87	1700	272	8.0	--	13.0	--
39	P	385626	1193752	N13 E21 33CDDD1	5,206	132	I	06-16-88	1100	437	7.4	290	15.5	5.5
46	P	385703	1193813	N13 E21 33BCAB1	5,200	163	H	05-09-88	1300	377	8.0	120	14.5	<1.0
84	P	390106	1194243	N13 E20 02CBB1	4,860	176	H	06-25-87	1845	335	8.0	--	20.5	--
87	P	390139	1194619	N14 E20 31DDC1	4,680	257	H	08-04-88	1200	212	8.2	100	21.0	<1.0
90	P	390208	1194332	N14 E20 34BDBD1	4,760	100	H	08-25-87	1615	328	7.6	--	16.0	--
91	P	390208	1194355	N14 E20 34BCC1	--	--	H	05-08-83	1200	584 L	7.9 L	--	--	--
92	P	390222	1194624	N14 E20 31AAC1	--	--	I	08-30-83	0910	257	8.2	--	16.0	--
93	P	390232	1194432	N14 E20 28CDC1	4,700	88	H	05-05-88	1430	481	7.8	340	13.7	2.4
107	P	390558	1194443	N14 E20 09BAB1	--	--	P	08-29-83	1410	223	7.1	--	--	--
Principal aquifers—west side of valley														
3	P	385049	1194645	N11 E20 06BDA1	4,840	70	H	07-28-88	1400	265	6.4	310	18.0	2.1
12	P	385303	1194802	N12 E19 24CCAA1	4,740	82	H	06-16-88	1600	123	7.8	290	15.5	2.4
16	P	385343	1194714	N12 E20 19BBB1	--	--	H	08-22-83	1315	210	7.2	--	12.5	--
17	P	385345	1194451	N12 E20 16CCD1	4,820	176	N	08-10-88	1100	352	7.8	310	17.5	3.9
18	P	385352	1194554	N12 E20 17CCD1	4,760	91	H	05-05-88	1100	222	6.8	420	13.0	6.8
21	P	385414	1194254	N12 E20 15ADD1	4,840	375	P	07-21-88	1600	214	7.0	330	21.0	2.4
28	P	385512	1194448	N12 E20 09BCAD1	4,760	450	I	07-14-88	1100	208	7.2	--	13.0	8.2
30	P	385546	1194637	N12 E20 06DB1	4,720	120	H	05-04-88	1500	276	7.5	370	11.5	2.8
31	P	385548	1195013	N12 E19 03CABD1	4,780	107	I	06-15-88	1330	146	6.5	320	11.5	4.8
32	P	385554	1194614	N12 E20 06ADDD1	4,720	460	I	07-25-88	1100	232	7.6	--	15.5	--
34	P	385604	1194356	N12 E20 4ADA1	4,760	300	P	08-23-88	1100	406	7.1	--	13.0	3.8
37	P	385613	1194557	N12 E20 05BBD1	--	--	H	08-30-83	1235	232	7.4	--	12.0	--
38	P	385621	1194445	N12 E20 04BAB1	4,750	300	P	07-21-88	1200	372	6.9	310	20.5	<1.0
43	P	385642	1194645	N13 E20 31BAAA1	4,700	413	I	07-27-88	1100	221	7.7	280	14.5	5.4
47	P	385716	1194754	N13 E19 25CDD1	4,700	260	I	07-25-88	1400	207	8.0	--	15.5	--
55	P	385821	1194750	N13 E19 24CADD1	4,680	401	S	08-18-83	1525	165	8.3	--	15.0	--
81	P	390037	1194807	N13 E19 12BBAD1	4,667	400	S	06-09-88	1130	112	8.4	-20	18.5	1.0
101	P	390407	1194649	N14 E20 19BAD1	--	160	H	08-24-83	1455	220	8.3	--	16.0	--
105	P	390503	1194635	N14 E20 18ABAB1	4,760	425	H	07-28-88	1000	240	9.1	260	22.0	2.3

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Sym- bol	Lat- itude	Longi- tude	Local site identification	Altitude of land surface (feet)	Total depth of well (feet)	Primary water use	Date	Time	Specific conductance ($\mu\text{S}/\text{cm}$)	pH (standard units)	Eh (mV)	Water temperature ($^{\circ}\text{C}$)	Oxygen, dissolved (mg/L)
Thermal aquifers														
97	T	390318	1194830	N14 E19 23DD1	--	--	Q	1979 ^a	--	--	7.9	--	46.0	--
98	T	390324	1194424	N14 E20 21DC1	--	--	R	1979 ^a	--	--	8.5	--	50.0	--
99	T	390343	1194505	N14 E20 20DAA1	--	26	U	08-26-83	1130	1,220	7.3	--	40.0	--
EAGLE VALLEY Upland aquifers														
129	U	390846	1194917	N15 E19 23CCBB1	5,840	--	S	06-02-89	1200	149 L	8.9 L	--	--	--
141	U	390938	1194800	N15 E19 13CDBB1	5,200	250	H	09-08-88	1100	276	6.9	230	16.5	<1.0
159	U	391023	1194749	N15 E19 12CDBC1	--	--	H	01-31-81	--	138 L	7.0	--	21.0	--
176	U	391113	1194819	N15 E19 02DDDC1	5,240	250	P	09-07-88	1330	111	8.0	--	26.0	1.5
Shallow aquifers														
131	S	390855	1194529	N15 E20 20DBBD1	4,660	14	U	05-31-89	1345	762	7.3	--	15.7	4.5
133	S	390857	1194502	N15 E20 21CBBC1	4,660	20	U	01-18-89	1005	540	7.0	--	12.5	4.5
134	S	390915	1194446	N15 E20 21BACC1	4,640	18	U	03-07-89	1115	370	7.1	--	12.1	3.4
135	S	390915	1194555	N15 E20 20BBD1	4,660	16	U	06-01-89	1345	2,046	6.8	--	13.9	2.1
136	S	390917	1194307	N15 E20 22ABCA1	4,600	14	U	08-30-88	1400	470	7.3	380	18.0	<1.0
137	S	390925	1194520	N15 E20 20ABAA1	4,650	15	U	06-05-89	1145	1,020	7.0	--	14.7	1.7
144	S	390943	1194500	N15 E20 16BCBC3	4,640	20	U	06-09-89	1300	696	7.2	--	14.3	<1.0
145	S	390943	1194538	N15 E20 17CAD1	4,670	21	U	06-01-89	1130	1,013	6.8	--	18.7	1.9
146	S	390945	1194628	N15 E20 18DCA1	4,720	20	U	06-02-89	1445	500	6.6	--	15.7	4.5
149	S	390957	1194548	N15 E20 17CABA3	4,670	25	U	06-07-89	1145	1,144	6.7	--	18.1	1.1
150	S	391005	1194500	N15 E20 16BBBB1	4,650	21	U	06-01-89	0945	388	7.3	--	16.6	1.6
151	S	391005	1194657	N15 E20 18ACAA1	4,730	21	U	06-08-89	0910	729 L	7.3 L	--	--	--
152	S	391007	1194653	N15 E20 08BAC1	4,720	30	U	06-08-89	1500	237	6.3	--	12.1	2.0
153	S	391008	1194506	N15 E20 17AADC4	4,648	29	U	09-03-87	1400	364 L	7.0	--	14.5	<1.0
155	S	391010	1194521	N15 E20 17ABD1	4,660	19	U	05-31-89	0930	670	6.6	--	15.0	4.3
156	S	391013	1194550	N15 E20 17BACC1	4,680	19	U	01-12-89	1500	1,090	6.9	--	10.0	--
166	S	391039	1194430	N15 E20 09DBD1	4,640	11	U	06-06-89	1130	1,730	7.4	--	15.7	1.8
171	S	391053	1194325	N15 E20 10BDDA1	4,640	18	U	03-07-89	1400	1,300	7.2	--	12.6	1.7

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Sym- bol	Lat- tude	Longi- tude	Local site identification	Altitude of land surface (feet)	Total depth of well (feet)	Primary water use	Date	Time	Specific conduct- ance (μ S/cm)	pH (standard units)	Eh (mV)	Water temper- ature (°C)	Oxygen, dissolved (mg/L)
Principal aquifers—east side of valley														
148	P	390955	1194215	N15 E20 14CAAA1	4,600	500	P	06-08-88	1300	590	7.9	150	17.0	<1.0
165	P	391039	1194402	N15 E20 09DACC1	4,680	96	H	09-20-88	1100	350	8.5	470	13.0	1.6
172	P	391058	1194246	N15 E20 10ADDA2	4,610	1,250	P	08-24-88	1300	658	8.1	290	22.5	<1.0
179	P	391121	1194228	N15 E20 02CDCC1	4,620	125	N	08-19-88	1430	210	8.1	--	18.0	<1.0
180	P	391123	1194353	N15 E20 03CCCB1	4,700	68	H	08-30-88	1100	1,010	7.1	390	14.5	5.9
Principal aquifers—west side of valley														
106	P	390542	1194720	N14 E19 12ADAB1	4,900	155	H	05-03-88	1200	245	8.0	370	13.5	1.7
108	P	390604	1194653	N14 E20 06CCAC1	--	--	H	03-14-81	--	266 L	6.6	--	2.0	--
110	P	390622	1194703	N14 E20 06CBA1	4,840	94	H	08-11-86	1010	750	7.3	--	12.5	--
111	P	390623	1194705	N14 E20 06CBAB2	4,840	--	H	08-27-87	1735	528	7.4	--	14.0	--
113	P	390642	1194554	N14 E20 05BBAB1	4,800	290	P	08-17-88	1300	144	6.9	340	19.0	6.0
116	P	390655	1194631	N15 E20 31DCC1	4,770	60	P	08-15-88	1500	170	7.0	200	15.0	<1.0
122	P	390733	1194555	N15 E20 32BBDA1	4,740	590	P	05-24-88	1500	205	7.2	--	14.0	1.6
126	P	390802	1194617	N15 E20 29BBDB1	4,720	120	H	08-16-88	1500	178	7.4	--	15.5	4.3
127	P	390803	1194542	N15 E20 29BCAC1	4,720	560	P	05-24-88	1030	218	7.5	350	17.0	1.5
130	P	390852	1194546	N15 E20 20CAC1	4,680	99	H	08-18-88	1400	226	7.5	370	16.0	<1.0
138	P	390933	1194506	N15 E20 17DDDA1	4,643	604	P	09-08-88	1500	181	8.1	370	27.0	3.5
154	P	391008	1194506	N15 E20 17AADC5	4,648	58	U	09-02-87	1400	34 L	7.2	--	14.5	<1.0
157	P	391014	1194507	N15 E20 17AADC1	4,650	700	P	08-25-88	1000	186	8.2	330	17.0	<1.0
160	P	391031	1194623	N15 E20 07DDBB1	4,730	470	P	08-26-87	1100	214 L	7.2	--	16.0	7.4
162	P	391035	1194715	N15 E19 12DADD2	4,805	470	P	05-11-88	1400	190	7.0	290	13.0	5.8
163	P	391036	1194700	N15 E20 07CACB1	4,787	92	H	09-04-87	0830	--	6.6	--	11.0	5.2
174	P	391104	1194548	N15 E20 08BDBB1	4,720	227	P	09-02-88	0930	178	8.3	410	20.0	4.5
182	P	391133	1194617	N15 E20 06DAAC2	4,732	455	P	05-25-88	1030	191	8.2	--	28.0	1.7
184	P	391204	1194514	N15 E20 05ABDA1	4,720	120	P	08-17-88	0930	237	7.4	320	22.0	2.4
185	P	391210	1194653	N16 E19 36DAAC1	4,860	91	P	08-12-88	1000	259	6.9	300	20.0	2.6
Thermal aquifers														
140	T	390936	1194405	N15 E20 161	--	--	U	1979 ^a	--	--	8.8	--	24.0	--
181	T	391130	1194505	N15 E20 16AD1	--	--	R	1979 ^a	--	--	8.8	--	50.0	--

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Hard- ness (mg/L as CaCO ₃)	Calcium dis- solved (mg/L as Ca)	Magne- sium dis- solved (mg/L as Mg)	Sodium dis- solved (mg/L as Na)	Potas- sium dis- solved (mg/L as K)	Alka- linity (mg/L as CaCO ₃)	Bicar- bonate (mg/L as HCO ₃)	Car- bonate (mg/L as CO ₃)	Sulfate dis- solved (mg/L as SO ₄)	Chlo- ride dis- solved (mg/L as Cl)	Fluo- ride dis- solved (mg/L as F)	Silica dis- solved (mg/L as SiO ₂)	Solids, dis- solved, sum of consti- tuents (mg/L)	Solids, dis- solved, residue at 180°C (mg/L)	Solids, dis- solved, sum of consti- tuents (mg/L)
CARSON VALLEY																
Upland aquifers																
78	08-27-87	130	41	5.7	15	2.8	150	180	<1	11	1.0	0.2	23	172	188	
104	06-09-88	33	13	.05	14	1.0	57	66	1	1.3	1.0	1.4	17	--	82	
Shallow aquifers																
1	07-19-88	34	9.9	2.3	5.5	1.4	40	49	<1	2.0	3.2	0.2	21	--	70	
29	08-23-88	50	13	4.1	15	2.0	72	88	<1	7.5	80	.3	34	--	120	
53	08-03-87	250	59	25	52	2.5	310	380	<1	54	5.6	.3	63	--	446	
56	08-09-88	290	81	22	61	2.3	340	410	<1	71	8.5	.2	58	--	508	
58	09-05-86	240	66	19	65	3.3	340	410	<1	46	8.3	.2	55	476	465	
59	07-06-88	200	54	15	86	3.5	310	380	<1	56	9.2	.3	46	--	455	
64	09-04-86	340	100	23	61	4.7	260	320	<1	150	63	.2	54	532	613	
67	08-09-88	170	50	11	38	3.5	190	240	<1	47	6.6	.2	52	--	324	
83	07-14-88	250	68	20	94	7.8	390	480	<1	50	9.4	.2	36	--	521	
86	06-30-87	83	20	8.1	58	1.9	150	180	<1	54	8.5	.9	54	282	295	
89	09-02-86	130	41	7.4	35	5.5	140	180	<1	62	11	.4	48	288	297	
96	07-20-88	120	36	7.6	90	4.0	220	270	<1	50	34	1.5	26	--	382	
100	08-29-83	140	53	.73	110	2.7	41	50	<1	300	23	2.9	39	548	556	
103	01-14-88	970	370	10	620	8.2	110	140	<1	1,800	220	5.0	55	3,250	3,160	
Principal aquifers—east side of valley																
14	08-24-87	240	75	14	26	2.5	190	230	<1	70	19	0.1	32	348	351	
20	08-24-87	99	32	4.7	48	2.5	140	180	<1	34	16	.1	31	266	255	
27	08-20-87	110	33	6.2	16	2.4	110	130	<1	22	9.0	.1	32	185	185	
39	06-16-88	180	52	12	27	1.8	190	230	<1	32	5.8	.3	28	--	272	
46	05-09-88	130	35	11	25	3.8	110	140	<1	63	6.4	.3	35	--	246	
84	06-25-87	37	9.7	3.1	58	4.3	120	1400	<1	38	8.3	1.5	78	280	271	
87	08-04-88	22	7.6	.73	38	3.6	58	71	<1	37	5.7	1.1	63	--	192	
90	08-25-87	58	15	5.0	55	3.5	110	130	<1	49	15	1.5	65	260	274	
91	05-08-83	110	27	9.5	87	--	--	--	--	56	27	1.7	61	--	--	
92	08-30-83	17	4.7	1.3	42	4.3	44	54	<1	47	6.1	.8	59	140	192	
93	05-05-88	110	38	4.2	63	4.8	150	180	<1	76	15	1.8	60	--	351	
107	08-29-83	83	24	5.7	20	1.3	120	140	<1	5.1	5.2	.2	35	151	166	

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Hard- ness (mg/L as CaCO ₃)	Calcium dis- solved (mg/L as Ca)	Magne- sium dis- solved (mg/L as Mg)	Sodium dis- solved (mg/L as Na)	Potas- sium dis- solved (mg/L as K)	Alka- linity (mg/L as CaCO ₃)	Bicar- bonate (mg/L as HCO ₃)	Car- bonate (mg/L as CO ₃)	Sulfate dis- solved (mg/L as SO ₄)	Chlo- ride dis- solved (mg/L as Cl)	Fluo- ride dis- solved (mg/L as F)	Silica dis- solved (mg/L as SiO ₂)	Solids, dis- solved, residue at 180°C (mg/L)	Solids, dis- solved, sum of consti- tuents (mg/L)
Principal aquifers—west side of valley															
3	07-28-88	110	30	9.6	11	3.7	55	67	<1	24	41	0.2	34	--	186
12	06-16-88	34	9.5	2.4	15	1.4	56	68	<1	9.4	.40	.3	25	--	97
16	08-22-83	90	24	7.2	12	2.7	95	120	<1	14	2.8	<.1	35	154	155
17	08-10-88	110	27	9.6	45	2.0	160	200	<1	24	7.7	.8	35	--	247
18	05-05-88	94	22	9.5	11	3.3	91	110	<1	13	6.4	.1	46	--	166
21	07-21-88	85	23	6.6	14	1.7	80	97	<1	28	5.7	0.1	30	--	157
28	07-14-88	83	22	6.8	14	2.1	81	99	<1	25	4.4	.1	32	--	155
30	05-04-88	110	28	9.3	14	3.8	100	130	<1	26	6.1	.1	34	--	184
31	06-15-88	55	17	2.9	7.3	2.4	52	63	<1	1.9	5.3	.1	22	--	90
32	07-25-88	94	25	7.6	14	2.4	91	110	<1	22	5.8	.1	32	--	163
34	08-23-88	190	52	15	23	2.8	190	230	<1	42	8.9	0.1	31	--	288
37	08-30-83	88	23	7.5	14	2.9	95	120	<1	16	4.0	.2	34	149	159
38	07-21-88	160	44	13	19	2.9	170	200	<1	25	6.3	.1	28	--	239
43	07-27-88	88	24	6.6	15	2.4	93	110	<1	20	4.6	.2	32	--	160
47	07-25-88	69	19	5.2	20	2.8	84	100	<1	22	4.8	.2	37	--	161
55	08-18-83	26	7.6	1.8	24	3.4	66	81	<1	18	2.6	.4	48	137	146
81	06-09-88	8.0	2.4	.53	23	2.7	49	56	2	11	1.3	.7	57	--	128
101	08-24-83	13	3.5	.96	44	1.0	54	66	<1	42	10	2.0	38	166	174
105	07-28-88	17	6.3	.19	51	2.5	87	91	7	16	11	.5	18	--	157
Thermal aquifers															
97	1979 ^a	11	4.3	<0.05	142	1.6	60	73	<1	133	91	7.8	38	--	454
98	1979 ^a	420	166	.10	161	5.0	22	5.0	11	617	39	3.3	33	--	1,040
99	08-26-83	170	66	.74	170	3.9	32	39	<1	470	38	5.1	35	798	808

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Hard- ness (mg/L as CaCO ₃)	Calcium dis- solved (mg/L as Ca)	Magne- sium dis- solved (mg/L as Mg)	Sodium dis- solved (mg/L as Na)	Potas- sium dis- solved (mg/L as K)	Alka- linity (mg/L as CaCO ₃)	Bicar- bonate (mg/L as HCO ₃)	Car- bonate (mg/L as CO ₃)	Sulfate dis- solved (mg/L as SO ₄)	Chlo- ride dis- solved (mg/L as Cl)	Fluo- ride dis- solved (mg/L as F)	Silica dis- solved (mg/L as SiO ₂)	Solids, dis- solved, residue at 180°C (mg/L)	Solids, dis- solved, sum of consti- tuents (mg/L)
EAGLE VALLEY															
Upland aquifers															
129	06-02-89	60	16	4.9	7.1	3.2	72	88	<1	5.0	0.5	--	23	--	103
141	09-08-88	110	29	8.8	22	2.6	160	190	<1	5.1	1.6	0.3	35	--	198
159	01-31-81	53	16	3.2	6.7	1.8	--	--	--	1.3	.6	--	25	--	--
176	09-07-88	26	8.0	1.4	17	2.2	63	77	<1	1.5	.9	.1	19	--	88
Shallow aquifers															
131	05-31-89	280	79	20	57	0.7	300	370	<1	74	36	0.4	56	--	503
133	01-18-89	240	67	17	38	.9	210	250	<1	39	12	.2	50	--	348
134	03-07-89	140	37	11	26	1.3	150	180	<1	25	8.9	.2	41	--	239
135	06-01-89	570	170	35	310	3.3	420	510	<1	760	63	.7	36	--	1,630
136	08-30-88	180	57	10	31	2.0	180	210	<1	49	13	.5	55	--	323
137	06-05-89	450	130	30	61	2.7	460	560	<1	96	67	.3	31	--	695
144	06-09-89	300	76	26	39	2.4	330	400	<1	25	35	.1	31	--	433
145	06-01-89	430	120	31	68	3.3	440	530	<1	100	65	.2	32	--	682
146	06-02-89	220	58	18	21	1.1	190	230	<1	32	24	.2	43	--	310
149	06-07-89	380	110	26	88	5.5	320	380	<1	110	120	.2	29	--	678
150	06-01-89	180	53	11	21	1.0	260	310	<1	9	9	.2	33	--	291
151	06-08-89	350	94	27	25	4.2	380	470	<1	8	5	.3	40	--	434
152	06-08-89	97	29	5.9	14	2.5	130	160	<1	5	5	.1	30	--	171
153	09-03-87	150	44	9.5	16	--	--	--	--	--	--	--	34	--	--
155	05-31-89	280	81	18	30	6.5	180	220	<1	18	97	.1	26	--	384
156	01-12-89	380	110	26	66	5.0	220	260	<1	140	88	.2	24	--	590
166	06-06-89	240	74	14	330	1.6	700	860	<1	240	83	7.5	52	--	1,220
171	03-07-89	530	120	55	94	5.4	410	500	<1	220	43	.5	58	--	844
Principal aquifers—east side of valley															
148	06-08-88	200	74	2.5	51	2.4	120	150	<1	160	14	0.8	30	--	410
165	09-20-88	85	30	2.2	42	2.6	100	120	5	46	16	.3	48	--	250
172	08-24-88	140	51	4.0	79	5.0	49	60	<1	240	14	.9	21	--	440
179	08-19-88	68	22	3.0	81	5.0	81	100	<1	27	6.8	.5	58	--	190
180	08-30-88	350	88	31	82	5.0	250	300	<1	110	63	.2	46	--	570

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Hard- ness (mg/L as CaCO ₃)	Calcium dis- solved (mg/L as Ca)	Magne- sium dis- solved (mg/L as Mg)	Sodium dis- solved (mg/L as Na)	Potas- sium dis- solved (mg/L as K)	Alka- linity (mg/L as CaCO ₃)	Bicar- bonate (mg/L as HCO ₃)	Car- bonate (mg/L as CO ₃)	Sulfate dis- solved (mg/L as SO ₄)	Chlo- ride dis- solved (mg/L as Cl)	Fluo- ride dis- solved (mg/L as F)	Silica dis- solved (mg/L as SiO ₂)	Solids, dis- solved, residue at 180°C (mg/L)	Solids, dis- solved, sum of consti- tuents (mg/L)
Principal aquifers—west side of valley															
106	05-03-88	54	18	2.0	34	1.8	80	100	<1	21	13	1.5	33	--	170
108	03-14-81	74	23	4.0	26	1.2	--	--	--	25	12	--	46	--	--
110	08-11-86	240	77	12	56	2.2	170	200	<1	44	69	.7	55	519	420
111	08-27-87	180	62	7.3	40	2.5	180	220	<1	25	16	.7	46	354	300
113	08-17-88	72	20	5.3	20	1.0	86	100	<1	8.9	5.6	.6	49	--	160
116	08-15-88	50	15	2.9	20	1.2	78	100	<1	7.9	6.0	.3	32	--	130
122	05-24-88	70	20	4.9	18	1.2	93	110	<1	4.7	2.9	.3	34	--	140
126	08-16-88	61	15	5.6	15	1.1	67	80	<1	7.1	4.0	.1	38	--	130
127	05-24-88	69	19	5.1	16	1.1	89	110	<1	3.1	2.1	.2	36	--	140
130	08-18-88	67	18	5.2	26	1.3	85	100	<1	19	5.4	.7	42	--	170
138	09-08-88	42	15	1.1	28	.9	76	90	<1	16	4.7	.6	27	--	140
154	09-02-87	140	41	9.0	24	--	--	--	--	--	--	--	32	--	--
157	08-25-88	58	19	2.5	20	.8	97	120	<1	3.2	1.1	.1	24	--	130
160	08-26-87	82	23	5.9	12	2.1	100	130	<1	1.2	3.2	.1	28	--	140
162	05-11-88	80	23	5.4	9.2	2.1	90	110	<1	5.2	1.0	.3	27	--	130
174	09-02-88	57	20	1.7	21	1.0	100	120	<1	2.9	1.1	.1	27	--	130
182	05-25-88	46	17	.90	25	1.4	88	110	<1	8.6	3.0	.3	33	--	140
184	08-17-88	71	22	3.9	26	.7	100	120	<1	10	3.9	.1	35	--	160
185	08-12-88	130	35	10	26	3.4	111	130	<1	5.2	4.7	.1	35	--	230
Thermal aquifers															
140	1979 ^a	36	14	.33	82	2.0	39	50	<1	148	21	5.8	33	--	330
181	1979 ^a	6.0	2.2	<.05	99	1.6	68	60	13	89	27	7.5	60	--	330

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Delta deuterium (permil)	Delta oxygen-18 (permil)	Delta carbon-13 (permil)	Carbon-14 (PMC)	Tritium (pCi/L)	Delta sulfur-34 (permil)
CARSON VALLEY							
Upland Aquifers							
78	08-27-78	-106	-14.2	--	--	--	--
104	06-09-88	-109	-14.7	--	--	<0.3	--
104	07-14-89	--	--	-16.0	--	--	--
Shallow Aquifers							
1	07-19-88	-110	-14.0	--	--	--	--
29	08-23-88	-117	-15.6	--	--	1.8	--
53	08-03-87	-102	-13.5	--	--	--	--
56	08-09-88	-108	-13.8	--	--	67	--
59	07-06-88	-103	-13.6	--	--	--	--
67	08-09-88	-107	-13.7	--	--	42	--
83	07-14-88	-103	-13.1	--	--	--	--
86	06-30-87	-105	-14.7	--	--	--	--
96	07-20-88	-102	-13.1	--	--	--	--
Principal aquifers—east side of valley							
39	06-16-88	-115	-15.5	-11.2	--	<0.3	-2.6
46	08-11-88	--	--	-12.3	89	--	--
84	05-09-88	-128	-16.4	--	--	.4	--
84	06-25-87	-122	-15.9	--	--	--	--
87	08-04-88	-121	-15.8	-10.0	46	<0.3	4.7
93	05-05-88	-124	-15.8	--	--	<.3	--
Principal aquifers—west side of valley							
3	07-28-88	-104	-13.5	-17.4	119	36	4.9
12	06-16-88	-111	-15.4	-15.4	--	2.8	-4.5
17	08-10-88	-106	-13.0	--	119	80	5.7
18	05-05-88	-102	-12.7	--	--	39	--
21	07-21-88	-106	-14.5	-12.4	105	39	-1.9
28	07-14-88	-106	-14.2	-14.8	122	58	-1.5
30	05-04-88	-109	-14.3	--	--	140	--
31	06-15-88	-107	-14.2	-14.4	--	34	--

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Delta deuterium (permil)	Delta oxygen-18 (permil)	Delta carbon-13 (permil)	Carbon-14 (PMC)	Tritium (pCi/L)	Delta sulfur-34 (permil)
Principal aquifers—west side of valley—Continued							
32	07-25-88	-108	-15.0	--	115	81	-2
34	08-12-88	--	--	-16.4	--	--	--
38	08-23-88	-108	-12.7	-14.6	105	47	.1
43	07-21-88	-107	-14.4	-14.0	110	65	.6
	07-27-88	-110	-14.6	-13.1	99	74	.9
47	07-25-88	-112	-15.0	-13.1	88	9.4	3.6
81	06-09-88	-120	-16.0	-16.5	--	<.3	20.7
105	07-28-88	-111	-14.3	-13.1	55	<.3	--
98	1979 ^a	-130	-16.2	--	--	--	--
Thermal aquifers							
EAGLE VALLEY							
Upland aquifers							
141	09-08-88	-110	-15.0	--	--	6.4	--
159	01-31-81	--	--	--	--	31	--
176	09-07-88	-112	-15.2	--	--	3.7	--
Shallow aquifers							
131	05-31-89	-109	-13.8	--	--	--	--
135	06-01-89	-112	-14.4	--	--	--	--
136	08-30-88	-105	-13.6	--	--	35	--
137	06-05-89	-109	-14.1	--	--	--	--
144	06-09-89	-103	-13.7	--	--	--	--
145	06-01-89	-107	-13.9	--	--	--	--
146	06-02-89	-108	-13.8	--	--	--	--
149	06-07-89	-111	-14.4	--	--	--	--
151	06-08-89	-106	-13.7	--	--	--	--
152	06-08-89	-107	-14.2	--	--	--	--
153	09-03-87	-104	-14.2	--	--	57	--
155	05-31-89	-110	-14.2	--	--	--	--
156	01-12-89	-108	-14.1	--	--	--	--
166	06-06-89	-112	-13.9	--	--	--	--
171	03-07-89	-110	-13.7	--	--	--	--

Table 3. Concentrations of major constituents, physical properties, stable-isotope composition, and well information for ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Delta deuterium (permil)	Delta oxygen-18 (permil)	Delta carbon-13 (permil)	Carbon-14 (PMC)	Tritium (pCi/L)	Delta sulfur-34 (permil)
Principal aquifers—east side of valley							
148	06-08-88	-103	-13.2	-13.0	106	29	16
165	09-20-88	-117	-15.3	-13.8	39	1.1	5.7
172	08-24-88	-122	-16.0	-14.0	39	.4	18.1
179	08-19-88	-116	-15.1	-10.5	--	.7	6.3
180	08-30-88	-107	-13.7	-14.4	104	32	6.2
Principal aquifers—west side of valley							
106	05-03-88	-110	-14.2	--	--	<0.3	--
108	03-14-81	-	--	--	--	<6.0	--
113	08-17-88	-111	-14.1	-12.0	95	<.3	4.8
116	08-15-88	-112	-14.3	--	--	.6	--
122	05-24-88	-110	-14.7	-14.9	90	1.2	5.0
126	08-16-88	-114	-14.5	-12.9	81	1.2	8.9
127	05-24-88	-107	-14.8	-14.8	81	.4	4.4
130	08-18-88	-115	-14.8	-13.6	72	<.3	.9
138	09-08-88	-112	-14.9	-16.1	52	<0.3	8.6
154	09-02-87	-103	-13.7	--	--	<5.7	--
157	08-25-88	-112	-15.1	-15.3	60	<.3	--
160	08-26-87	--	--	-14.7	88	<1.0	--
162	05-11-88	-105	-14.6	--	--	--	--
163	09-04-87	-104	-14.1	--	--	58	--
174	09-02-88	-112	-14.9	-15.8	74	<.3	--
182	05-25-88	-109	-14.8	-14.9	69	<.3	6.1
184	08-17-88	-113	-14.5	-14.2	79	4.2	5.4
185	08-12-88	-106	-13.9	--	--	13	--
Thermal aquifers							
181	1979 ^a	-127	-14.9	--	--	--	--

^a Trexler and others, 1980.

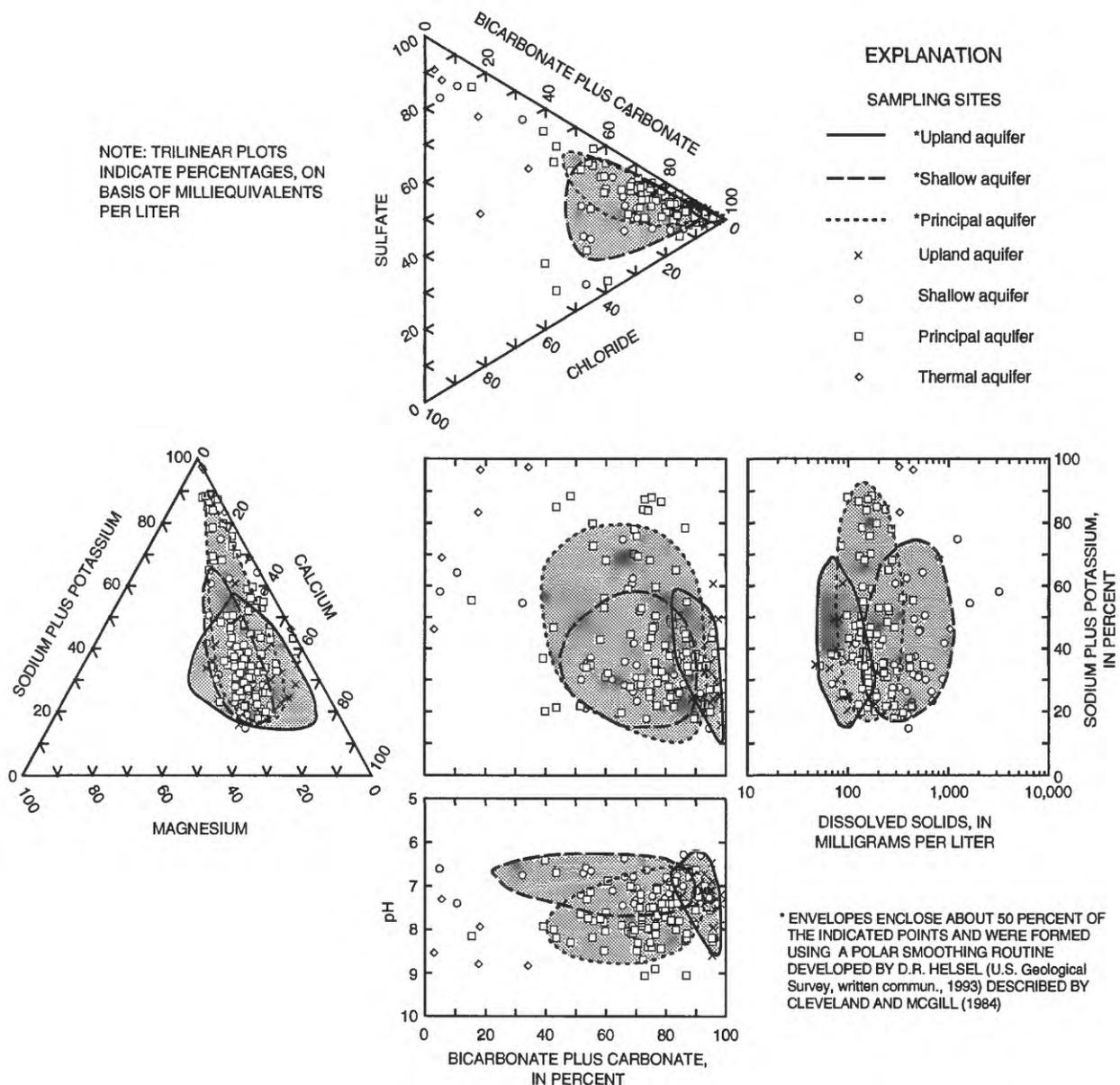


Figure 12. General chemical composition of ground water in Carson and Eagle Valleys.

were statistically greater in the principal aquifers than in the upland aquifers (at a 95-percent confidence level using the nonparametric Mann-Whitney test). This difference in the concentrations is consistent with the upland aquifers as sources of recharge for the principal aquifers.

In contrast to the upland aquifers, all the ions listed above were found at statistically significant greater ranked concentrations in the shallow aquifers than in the principal aquifers at the same confidence level. Chloride, which was found with higher concentrations in the shallow aquifers in particular, is not

removed from water by natural processes. Greater concentrations of major constituents indicate that the shallow aquifers are not the main source of recharge to the principal aquifers. Geochemical reactions in groundwater systems such as those found in Carson and Eagle Valleys generally do not decrease the overall concentration of major ions.

Nonthermal water in principal aquifers of northeastern Carson Valley (sites 84, 87, and 90-93, fig. 3 and table 3) has somewhat higher concentrations of sulfate and fluoride and a higher proportion of sodium than other nonthermal ground water in Carson Valley.

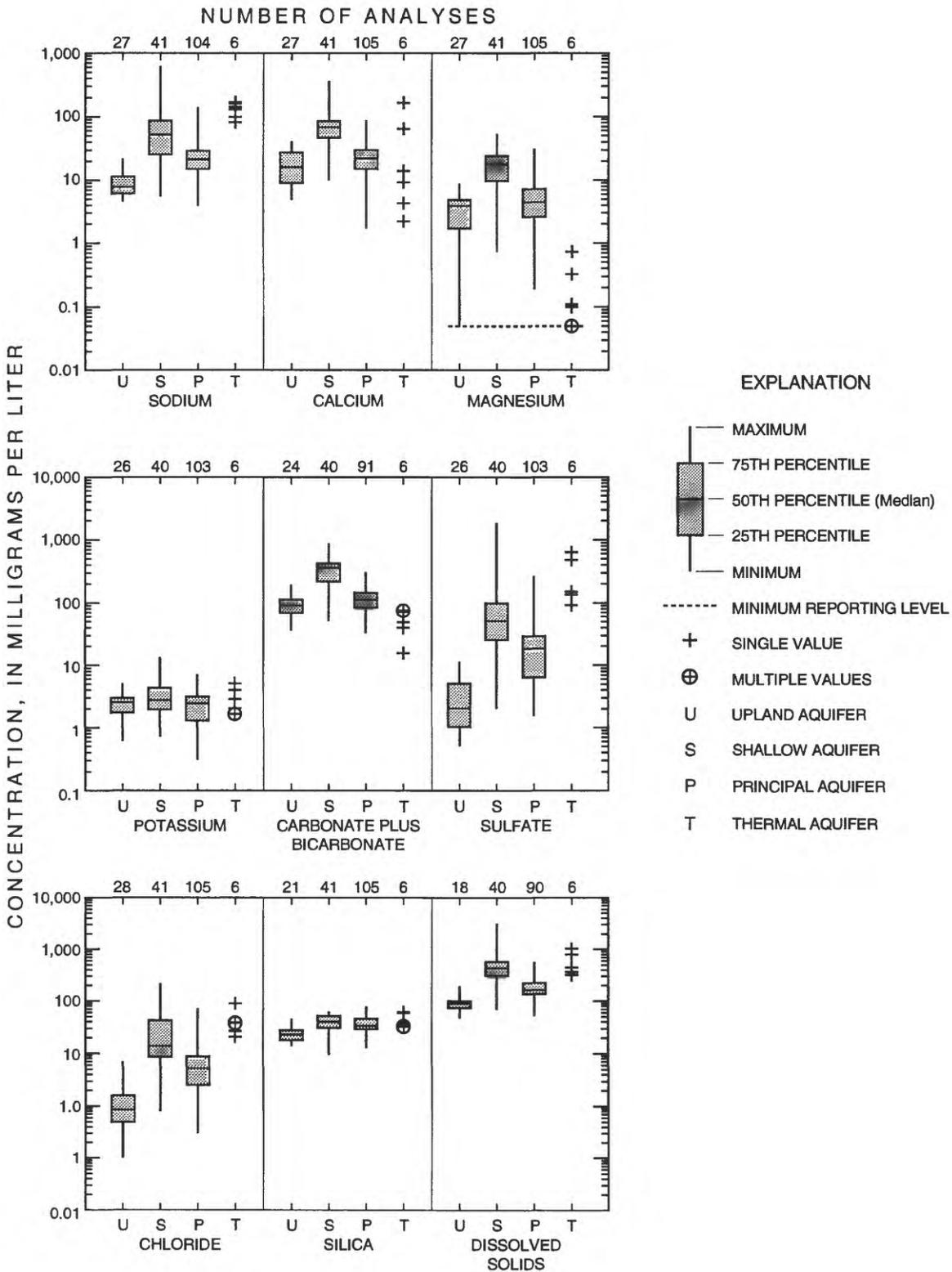


Figure 13. Concentrations of major constituents and dissolved solids in ground water of Carson and Eagle Valleys.

These characteristics can be explained as either the result of upflow from a thermal system or reaction with aquifer materials that are mineralogically different from the sediments elsewhere in the basin. Water in this northeastern area has some of the characteristics of thermal waters, which are described as generally having "high contents of alkali chlorides, SiO₂, B, and As" (White and others, 1971, p. 77), but is not very similar to Saratoga Hot Springs in northeastern Carson Valley (site 98, table 3). The nonthermal ground water in northeastern Carson Valley generally had a higher proportion of sodium, greater than 68 percent of the total cations, and silica concentrations (median concentrations at the sites ranged from 59 to 78 mg/L) than other water in the principal aquifers. Although arsenic concentrations are generally, but not invariably, high in thermal water in the western United States (Welch and others, 1988, fig. 3), Saratoga Hot Springs contained only 5 µg/L of arsenic. Therefore, the somewhat high arsenic (ranging from 17 to 54 µg/L for sites 87, 90, 92, and 93, fig. 3) near the hot spring is not necessarily a good indicator of the presence of thermal water within the Carson and Eagle Valleys area. Although silica concentrations were moderately high in the nonthermal ground water in northeastern Carson Valley (greater than 59 mg/L), water discharging at Saratoga Hot Spring contained only 33 mg/L of silica. These relations and the relatively low median temperatures measured at the wells (from 15 to 21°C) do not indicate that ground water in northeastern Carson Valley is primarily upflow from a thermal system. A more likely explanation for the higher concentrations of sulfate, fluoride, and the sodium dominance is that they result from low-temperature reactions with aquifer sediments. The reason for a chemical difference between the sediments in northeastern Carson Valley and the valley in general is not obvious. The local bedrock is composed of metamorphic rocks that may include marine evaporites containing gypsum. Also, Tertiary sediments that may have formed in a closed basin and therefore are partly composed of nonmarine evaporite minerals containing sulfate are present to the east.

Within the western parts of Carson and Eagle Valleys, ground water in the principal aquifers had areal differences in the concentrations of major constituents. Among the major constituents, the chloride and sulfate anions are considered to be the least affected by geochemical reactions, such as mineral precipitation, adsorption, or exchange. This property, of largely remaining in solution after entering the water,

is referred to as being "conservative." Because these two anions are relatively conservative, their concentrations can be used as indicators of the chemical composition of the aquifers with which the water has reacted.

Concentrations of some major constituents in parts of the principal aquifers derived primarily from plutonic rocks on the west sides of the valleys were, as a group, less than the concentrations in aquifers derived from plutonic and other rock types to the east. Specifically, the ranked calcium, sodium, potassium, chloride, and sulfate concentrations were significantly lower in the western parts of both valleys (fig. 14) than in those parts derived from a wider variety of rock types at the 95-percent confidence level (using the Mann-Whitney test). Although a higher evaporation-to-precipitation ratio in the east side may be part of the reason for the observed differences, the difference in rock type appears to be a contributing factor for higher concentrations, particularly for sulfate.

Chloride concentrations in ground water associated with granitic bedrock areas to the east of the main body of the Carson Range were relatively high compared with those in ground water in principal aquifers of the western area. Just south of Clear Creek, median chloride concentrations ranged from 11 to 64 mg/L at sites 105 (fig. 3), 106, 108, 110, and 111 (fig. 4), in contrast to median and 75th percentile concentrations for the principal aquifers in the western parts of the valleys of about 4 and 6 mg/L (fig. 14 and appendix), respectively. Sulfate concentrations at these sites tended to be high relative to other areas in the western parts of the valleys, with all but one of the sites having median concentrations ranging from 16 to 38 mg/L, which is equal to or greater than the 75th percentile for sulfate in other areas of the western parts of the valleys (about 20 mg/L; fig. 14 and appendix). These higher concentrations may be related to the deeply weathered condition of the bedrock in this area. A more rapid release of these anions owing to the greater surface-area-to-water ratio in comparison to areas underlain by fractured bedrock might be expected. Weathered bedrock may not have had these anions "flushed-out" to the same extent as in the basin-fill sediments, which have been transported by water. A contributing factor for the presence of chloride and sulfate in some ground water in this area may be the use of on-lot septic systems.

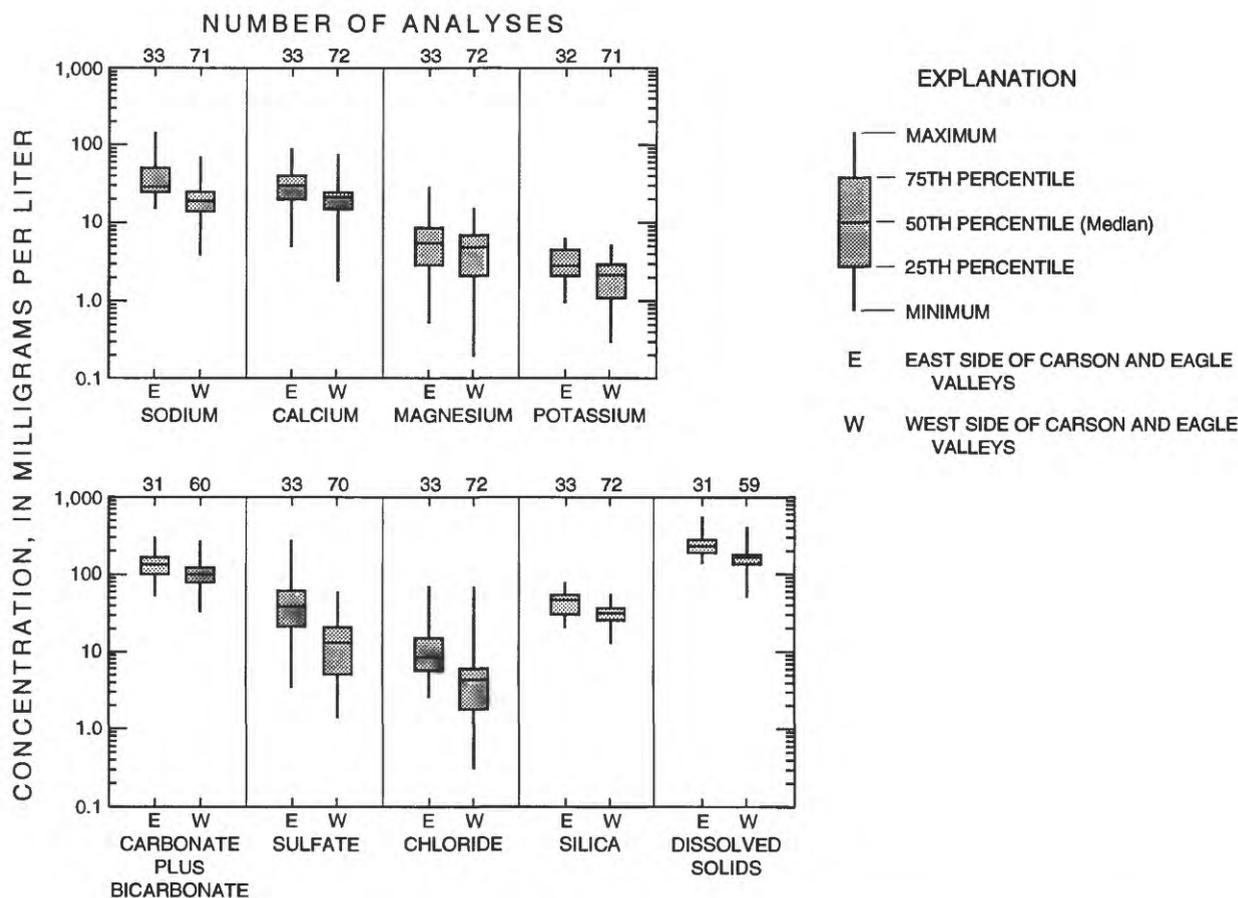


Figure 14. Concentrations of major constituents and dissolved solids in ground water from principal aquifers in east and west sides of Carson and Eagle Valleys.

Processes Affecting Major Constituent Concentrations

Ground water in principal aquifers of Carson and Eagle Valleys is in contact with sediment derived from intrusive and extrusive igneous and metamorphic rocks in the adjacent Carson Range and the headwaters of the Carson River. Concentrations of the major constituents are primarily a result of reactions with the minerals derived from the bedrock and their weathered products. Because the flow of ground water within the sediments is not known in detail, and many of the wells sampled tap ground water from different depths, the development of geochemical reaction models along flow paths is not possible. The approach used for evaluation of possible geochemical models within this report is the design of a general model consisting of a set of reactions that results in a simulated water that has general characteristics of the water in the principal aquifers. The geochemical models are evaluated for consistency with (1) mineralogic data for a limited set of samples

collected in the shallow subsurface in Carson Valley, (2) the bulk geochemistry of sediments in Carson and Eagle Valleys, (3) the chemical and isotopic composition of the ground water, and (4) thermodynamic calculations of mineral equilibrium. Although a unique general geochemical model cannot be determined, other geochemical models may be consistent with available data. The general geochemical model is believed to provide a suitable description of the geochemical processes that resulted in the observed major-constituent water quality.

Processes that produce the observed water quality can be presented as geochemical reactions or a geochemical model. A geochemical model for a ground-water system can be evaluated by using a mass-balance approach that generally incorporates chemical and isotopic data for ground water and aquifer matrix, thermodynamic data for phases of interest (minerals, gases, and amorphous phases), and hydrologic knowledge (Plummer and others, 1983). Commonly, models

are developed for segments of the system between sampling locations along a flow path. This approach was not used for ground water in Carson and Eagle Valleys because sampling locations generally were not along flow paths and most wells do not draw water from discrete depths because of the long open intervals common in pumped wells. In contrast, the approach used here consisted of assuming that the water quality in the basin-fill deposits, derived primarily from the Sierra Nevada, is a result of a common set of reactions. This approach has led to models that are consistent with available data.

The mass-balance approach yields unique numerical solutions (if any exist) for a particular set of phases and water-quality data. Formulation of a unique solution requires that the number of phases be equal to the total number of elements and isotopes used in the geochemical model. Minerals that were identified (table 4), along with calcite, constitute the principal aquifer materials beneath the west part of the valley floor. These phases represent a set of probable phases that react with, or precipitate from, the through-flowing ground water. Illite was excluded from the geochemical models because it is not believed to be formed or altered under geochemical and temperature conditions in the nonthermal aquifers of Carson and Eagle Valleys. Illite in the basin-fill sediments was probably formed during the late stages of formation of the igneous rocks that constitute the bedrock of the Sierra Nevada. Illite is relatively stable in near-surface conditions, as indicated by its common presence in soils (Graf von Reichenbach and Rich, 1975) and is therefore not considered to be a reacting phase. Minerals that are abundant in the basin-fill deposits (table 1) were included in the list of possible phases with the addition of cation-exchange reactions, carbon dioxide, pyrite, and sodium chloride. Pyrite is an accessory mineral in plutonic and metamorphic rocks and is a plausible source for sulfate in the ground water. Gypsum is not considered a plausible phase for the west side of the valley because it has only been identified in northeastern Eagle Valley and the metamorphic rocks in the Carson Range are not believed to contain marine evaporites. Chloride, with an equivalent amount of sodium, is assumed to enter ground water from fluid inclusions in mineral grains or from road salt.

The mass-balance approach requires that exact mineral compositions be used. However, an exact chemical composition for some of the identified minerals has not been determined. In general, the chemical

formulas used in geochemical models for dissolving minerals correspond to compositions for minerals commonly found in the Sierra Nevada—the primary source of sediment to the valleys. The composition used for plagioclase feldspar, which is the mineral generally found in the granitic rocks of the Sierra Nevada, is in the range corresponding to andesine with a molar ratio of sodium to calcium of 2:1. A chemical formula for hornblende was used to represent the amphibole mineral group that is common in granitic rocks. Similarly, biotite is a common accessory mineral in granites. The pyroxene composition corresponds to the mineral augite, which is a common mineral in volcanic rocks of the type found in the headwaters of the Carson River Basin. The sodium end-member (beidellite) was used for the clay, with the inclusion of an exchange "phase" that allows sodium to be released to ground water in exchange for either calcium or magnesium. These divalent cations have the highest concentrations in the ground water.

In general, ground water in principal aquifers beneath the western parts of Carson and Eagle Valleys contains measurable dissolved oxygen concentrations (6 of 37 sites have dissolved oxygen concentrations of less than 1 mg/L). The presence of measurable oxygen indicates that chemical reduction of dissolved nitrate and sulfate is not likely in the ground water. The general absence of measurable nitrite and absence of sulfide odor indicate that reduction of nitrogen and sulfur is not an important process in the aerobic ground water. Assuming oxygen had not entered the ground water in the principal aquifers since the water reached equilibrium with the atmosphere, less than about 10 mg/L of oxygen could have reacted with reductants such as sedimentary organic matter and sulfide minerals in the aquifer. Therefore, geochemical models for the western parts of the principal aquifers do not include redox reactions.

Ground water in the principal aquifers beneath eastern Carson and Eagle Valleys had dissolved oxygen concentrations less than 1 mg/L in 9 of 18 sites. The low dissolved oxygen may be a result of reaction with sulfide minerals or sedimentary organic matter. The generally low nitrite concentrations and absence of sulfide odor indicate that most of the ground water is not strongly reducing.

The stable-isotope composition of dissolved inorganic sulfur and carbon can be used to evaluate geochemical models. The differences in the stable-isotope composition of dissolved inorganic carbon and

Table 4. Phases included in geochemical mass-transfer reactions and limitations of the selected models

[Limitations: --, phase is included, but not "forced" to be in model; D, mineral may dissolve, but not precipitate; F, only models that include this phase are included—mineral is "forced" into the set of models considered; M, only monovalent cation (sodium or potassium) can be exchanged into water; P, mineral may precipitate, but not dissolve. $\delta^{13}\text{C}$ is isotope composition of carbon in dissolving phase]

Phase	Limitations		
	Silicate model	Closed-system model	Open-system model
Plagioclase (andesine) ($\text{Ca}_{0.37}\text{Na}_{0.63}\text{AlSi}_3\text{O}_8$)	D	F, D	F, D
Potassium feldspar KAlSi_3O_8	--	--	--
Silica SiO_2	--	--	--
Biotite $\text{KMg}_3\text{AlSi}_3\text{O}_{10}(\text{OH})_2$	D	D	D
Pyroxene (Augite) ($\text{Ca}_{0.34}\text{Mg}_{0.39}\text{Fe}_{0.27}\text{Si}_2\text{O}_6$)	D	D	D
Amphibole (Hornblende) $\text{Na}_{0.5}\text{Ca}_2\text{Mg}_{3.5}\text{Fe}_{0.5}\text{Al}_{1.8}\text{Si}_7\text{O}_{22}(\text{OH})_2$	D	D	D
Na-beidellite $\text{Na}_{0.33}\text{Al}_{2.33}\text{Si}_{3.67}\text{O}_{10}(\text{OH})_2$	P	P	P
Kaolinite $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$	P	P	P
Calcite CaCO_3	P	F, D, $\delta^{13}\text{C} = 0$	--
Chlorite $\text{Mg}_5\text{Al}_2\text{Si}_3\text{O}_{10}(\text{OH})_8$	--	--	--
Sodium chloride NaCl	F, D	F, D	F, D
Pyrite FeS_2	F, D	F, D	F, D
Gypsum $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	--	--	--
Carbon dioxide CO_2	--	F, D, $\delta^{13}\text{C} = 19$	--
Na-Ca exchange	M	M	M
Na-Mg exchange	M	M	M

sulfur in Carson and Eagle Valleys can be a result of several factors, including (1) a variation in the amount or isotopic composition of minerals containing sulfur and carbon that are dissolved by the ground water, (2) mineral precipitation, and (3) differences in the isotopic composition of recharge.

The sulfur-isotope composition of water on the west side of the valleys with sulfate concentrations less than about 50 mg/L is generally lighter (more negative) in Carson Valley than in Eagle Valley (fig. 15).

The difference may be due to a greater proportion of metamorphic rocks in the Carson Range west of Eagle Valley than in the area that has supplied sediment to Carson Valley (see figs. 2-4). The sulfur-isotope composition of water with sulfate concentrations less than 50 mg/L is within the range reported for granitic rocks in the circum-Pacific belt by Ishihara and Sasaki (1989). The isotopic composition of dissolved sulfur in the principal aquifers probably is not affected by mineral precipitation, but is a result of the composition in

the rocks. Mineral precipitation of sulfur is not considered important because concentrations of sulfate and sulfide generally are well below concentrations that could form common sulfur-bearing minerals, such as gypsum and pyrite.

The heaviest sulfur-isotope composition found in Carson Valley was east of Jurassic and Triassic metavolcanic and sedimentary rocks in the Carson Range (20.7 permil; site 81, table 3). Therefore, basin-fill deposits east of the Carson Range may have a greater proportion of sediment derived from these rocks than deposits in other parts of Carson Valley.

Sulfate concentrations were greater than 50 mg/L in the northeastern part of Eagle Valley and vicinity (figs. 4 and 15). Ground water with the heaviest sulfur-isotope composition was in the range generally found for sulfate in Jurassic marine evaporites (about 16 to 20 permil; Claypool and others, 1980, fig. 9), which are present as gypsum in the uplands to the northeast (Bingler, 1977). Dissolution of gypsum with a typical marine evaporite sulfur-isotope composition by water

with a sulfur-isotope composition in the range found in other parts of Eagle Valley (about 5 to 12 permil) would result in sulfur-isotope compositions along the "gypsum solution" line shown in figure 15. The "gypsum solution" trend is based on an initial composition equal to that found in water at site 182 in north-central Eagle Valley—a sulfate concentration of 8.6 mg/L and a sulfur-isotope composition equal to 6.1 permil (fig. 4, table 3) and a sulfur-isotope composition in gypsum of 18 permil. Data for ground water at three sites (148, 172, and 175; fig. 4) lie along the line that indicates that gypsum is dissolving. The data also lie along a gypsum solution line on figure 16, which is based on the assumption that chloride remained at a constant concentration as gypsum dissolved. Chloride concentrations have a relatively narrow range (8.4 to 14 mg/L) at the three sites. Sulfate concentrations at these sites, therefore, are probably a result of the dissolution of marine gypsum either in the bedrock or as detrital material in the basin fill. Some of the sulfate in this northeastern area probably is derived also from volca-

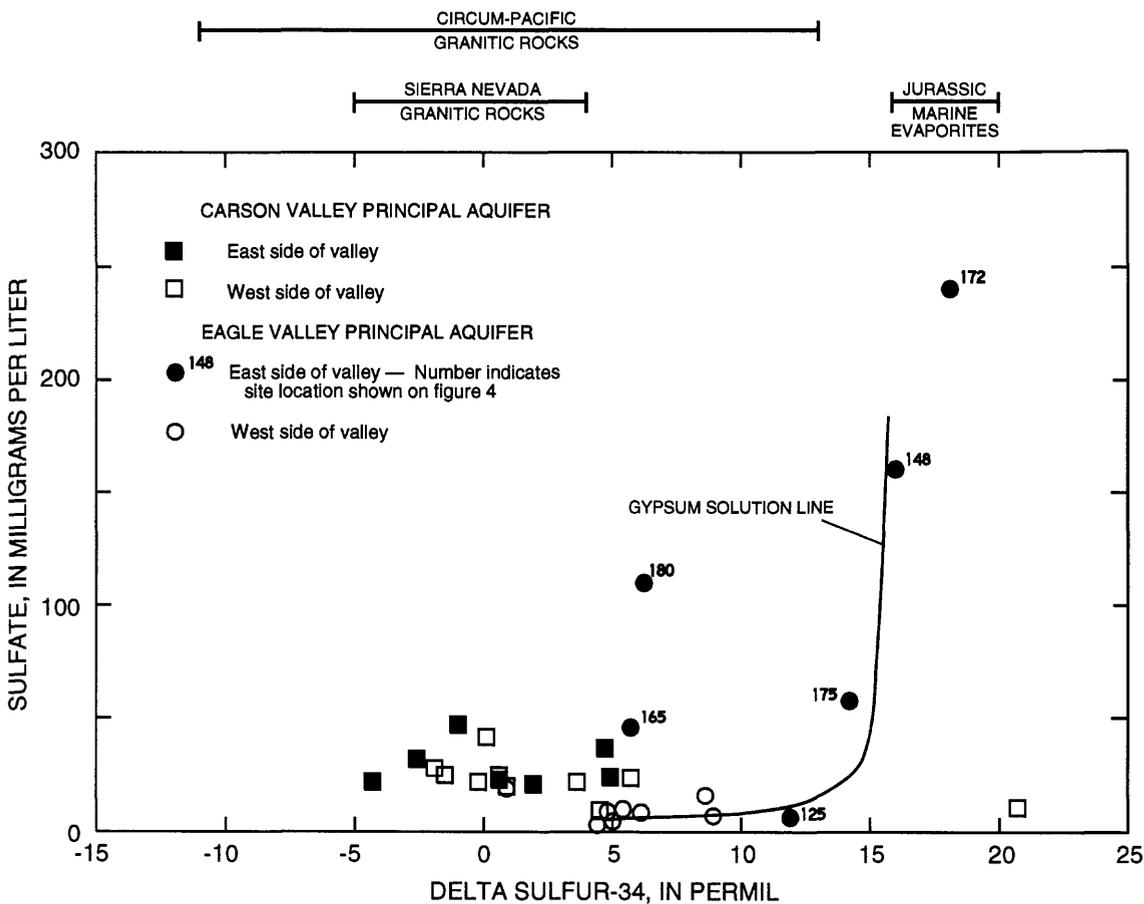


Figure 15. Relation between concentration of sulfate and isotopic composition of dissolved sulfate.

nic rocks in the uplands, as indicated by the data for sites 165 and 180 (fig. 4), which have concentrations of 46 and 110 mg/L, respectively. Ground-water flow originates in uplands that are composed primarily of volcanic rocks (the sulfur-isotope composition of sulfides in volcanic rocks generally ranges from about -10 to 5 permil; Krouse, 1980, fig. 11-1). This composition is consistent with the ground water having a lighter sulfur-isotope composition than ground water farther to the east.

The stable-isotope composition of carbon in ground water is affected by the composition of the various sources of carbon. Much of the carbon enters ground water as dissolved carbon dioxide when the water percolates down through the root zone. The carbon stable-isotope composition in the root zone has not been determined in the study area, but can

be estimated by the composition in ground water and studies of carbon in the unsaturated zone elsewhere in the Great Basin.

The carbon-isotope composition of ground water in the unsaturated zone can be controlled by equilibrium with carbon dioxide. The composition is a mixture of atmospheric and plant-respired carbon dioxide. The carbon dioxide in the unsaturated zone is primarily dependent upon metabolic pathways of plant biomass on the land surface. Two pathways, known as C₃ and C₄, involved in photosynthetic fixation of carbon are highly correlated with the resulting carbon-isotope composition of the plant material (Deines, 1980, p. 329).

In the Headwaters Area of the Carson River Basin, most natural vegetation, including pines and firs, use the C₃ pathway (Quade and others, 1989, table 2).

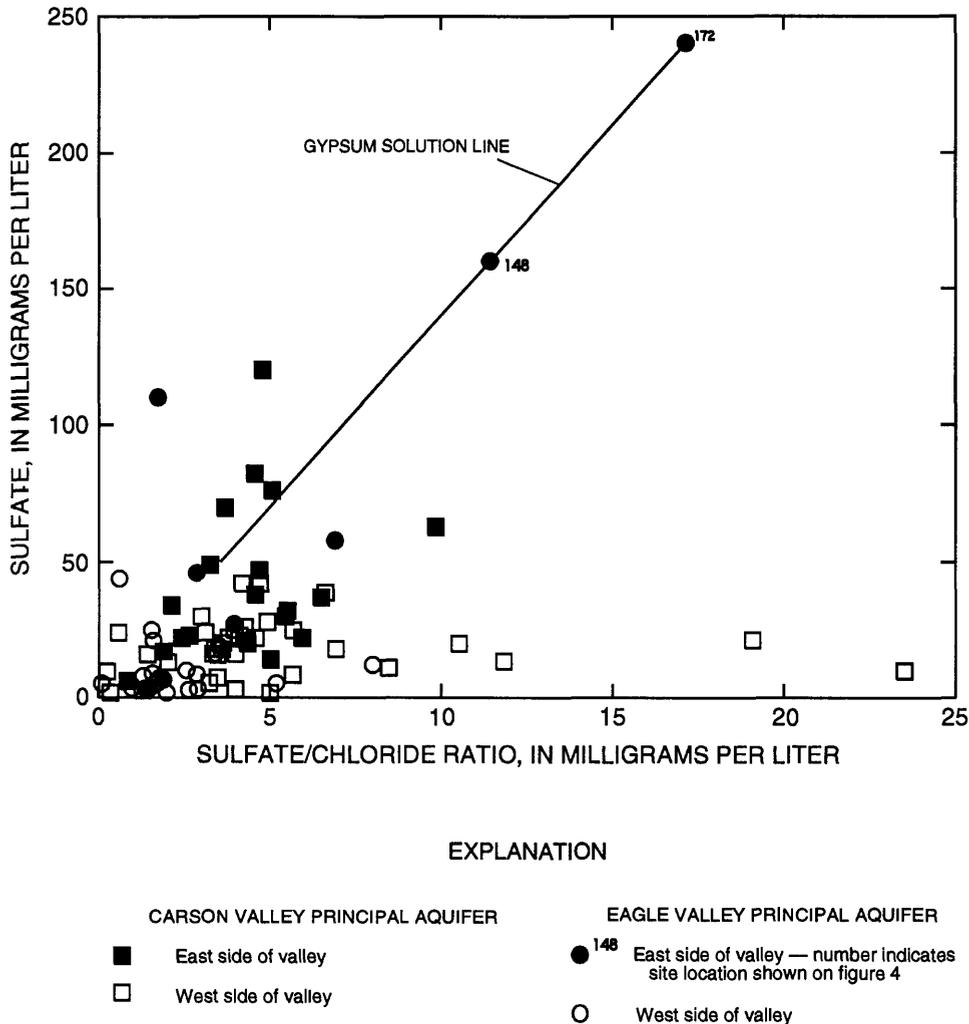


Figure 16. Relation between concentration of sulfate and ratio of sulfate to chloride.

The carbon-isotope composition of carbon dioxide from C₃-pathway plants averages about -27 permil (Deines, 1980; Cerling, 1984). Plants using the C₄ pathway, such as *Atriplex*, are present in the lower altitudes of Carson and Eagle Valleys and produce a carbon-isotope composition of about -13 permil (Deines, 1980; Cerling, 1984). As a result of areal differences in the types of vegetation, the carbon dioxide in soil has a variable composition, which ranges from about -12 to -20 permil for an area with both C₃ and C₄ vegetation in southern Nevada (Quade and others 1989; Amundson and others, 1988).

The carbon-isotope composition of dissolved inorganic carbon, along with values for temperature and the distribution of the carbonate species, may be used to estimate the stable-isotope composition of carbon dioxide gas in equilibrium with water. Algorithms by Plummer and others (1991) for estimating fractionation factors of Thode and others (1965), Mook and others (1974), and Mook (1980) permit the estimation of the carbon-isotope composition of carbon dioxide in equilibrium with water in the principal aquifers. Most of the estimated values for the equilibrium carbon dioxide (fig. 17) are in the range found in soil gas by Quade

and others (1989). These estimates used a temperature of 12°C and the distribution of the carbonate species indicated by WATEQ4 (Ball and others, 1987), a program that calculates chemical equilibria of natural waters. Estimated values indicate that the carbon-isotope composition in the principal aquifer could be a result of isotopic equilibrium with soil carbon dioxide. This conclusion was made on the assumption that the pH values and dissolved inorganic carbon concentrations are little changed from the time of equilibration to the time the water reaches the sampled wells.

Dissolution of carbonate minerals is a second possible source of carbon. Carbonate minerals are in metamorphosed marine sedimentary rocks in the Sierra Nevada. The stable-isotope composition of the marine carbonate has not been determined; however, marine limestone generally has a composition of about zero permil. Other possible sources of carbon include carbonate formed during the late stages of the emplacement of the granitic rocks in the Sierra Nevada, eolian carbonate, and sedimentary organic matter in the basin-fill deposits. Although carbonate minerals may be present in granitic rocks of the Sierra Nevada in recharge areas, the presence of carbonate minerals

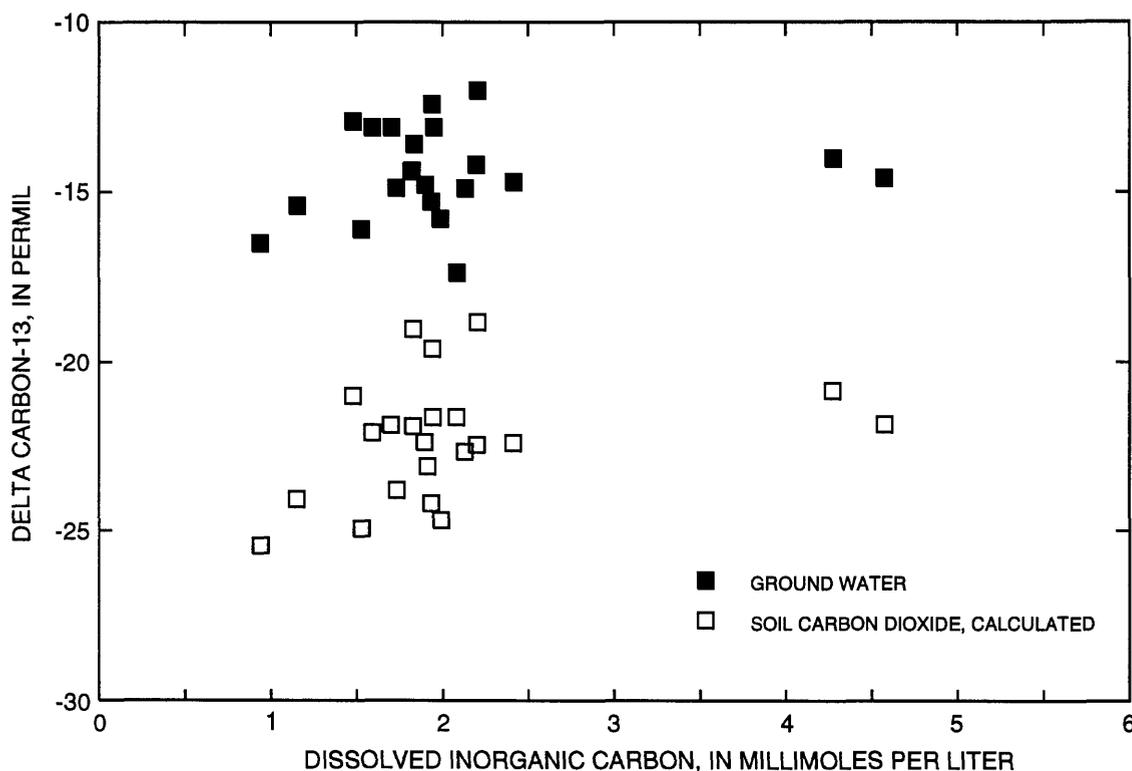


Figure 17. Relation between concentration of dissolved inorganic carbon and stable-isotope composition of carbon in principal aquifers on west side of Carson and Eagle Valleys.

has not been documented in either the Carson River Basin or elsewhere. Sedimentary organic matter may supply a small amount of carbon to the total dissolved inorganic carbon, but measurable concentrations of dissolved oxygen in ground water indicates that only a small amount of organic matter could be oxidized. The recharge water is not likely to contain more than about 10 mg/L of dissolved oxygen, which is the constituent that could oxidize the organic matter (fig. 18). Therefore, only a few milligrams per liter of the dissolved inorganic carbon could be from the oxidation of sedimentary organic matter.

The inclusion of the exchange of sodium for calcium and magnesium in the geochemical models is consistent with the use of sodium beidellite in the models. Although the cation composition of beidellite is not known, calcium and sodium are both likely to be present in the beidellite clay mineral. The inclusion in the geochemical models of a phase simulating exchange represents, at least in part, a correction for the uncertainty in the cation composition of beidellite. Additionally, the exchange is consistent with the release of sodium for calcium and magnesium from phases that exchange cations, such as most clay

minerals, and phases such as sedimentary organic matter and oxide coatings that are commonly found in sediments (Jenne, 1968). A divalent cation, such as calcium, can exchange with a monovalent cation, such as sodium, when a phase is formed in a dilute water and then subsequently comes in contact with more concentrated water with the same major cation ratios (see, for example, Drever, 1982, p. 82-85). Exchange will proceed even if the ratio of the cations in the dilute and more concentrated water is the same (assuming the equilibrium constant for exchange on the solid phase remains constant). Therefore, a clay mineral formed in equilibrium with water in the upland part of the basin (in equilibrium with dilute ground or surface water) that becomes part of the basin-fill aquifer will release sodium if the ground water has greater concentrations of sodium and calcium, even if the ratio of these two cations in water is the same in the two parts of the hydrologic system. Because of lower concentrations of potassium and magnesium, the effect on the geochemical models due to excluding the other exchange reactions is probably minor compared to other uncertainties in the overall model.

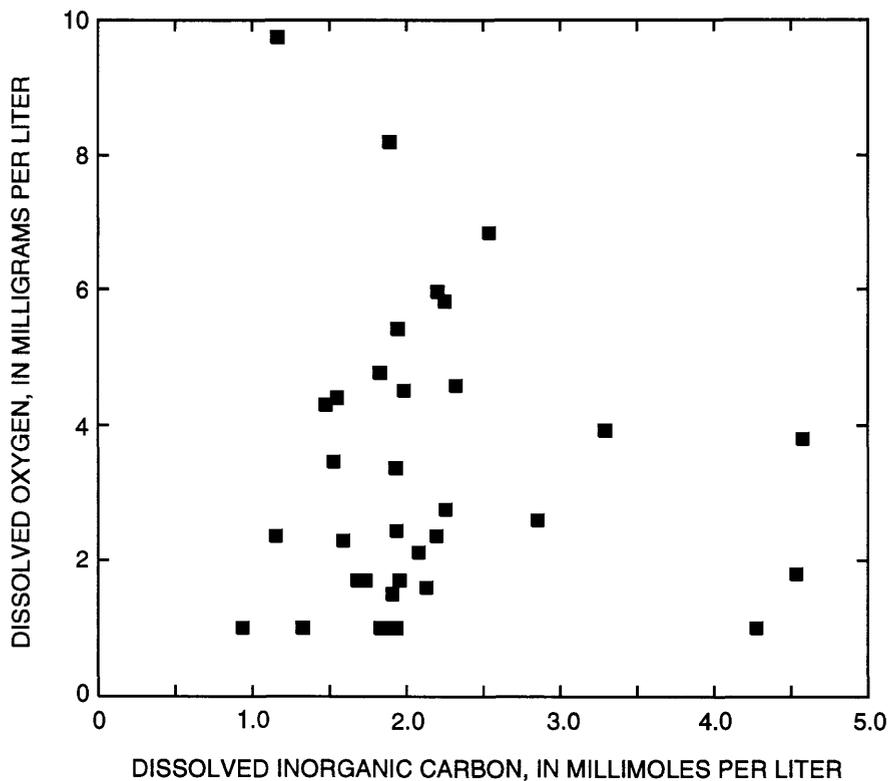


Figure 18. Relation between concentration of dissolved oxygen and dissolved inorganic carbon in principal aquifers on west side of Carson and Eagle Valleys.

Geochemical modeling using the program named "BALANCE" (Parkhurst and others, 1982) results in a set of phases that are mathematically consistent with the change in water quality from recharge to the sampled water at selected sites in the principal aquifer. For a given set of possible phases and initial recharge quality, the program BALANCE determines which combinations of the possible phases are consistent with the observed water quality.

Geochemical modeling of ground water in Carson and Eagle Valleys results in a "general" model for a set of minerals and physical conditions. A general model consists of a reaction consistent with observed water quality. The general model is based on a set of "specific" models. A specific model is one of a set of reactions that is consistent with the observed water quality and other specified conditions.

A simple example of the development of a general model from specific models can be seen for an increase in concentrations of calcium, magnesium, and dissolved inorganic carbon. Phases that produce the increases include the minerals calcite (CaCO_3) and magnesite (MgCO_3) that occur with exchange of calcium for magnesium and with dissolution of carbon dioxide in the soil zone. A set of specific models could consist of (1) dissolution of calcite, magnesite, and exchange of calcium for magnesium; (2) dissolution of calcite, carbon dioxide, and the exchange of calcium for magnesium; and (3) dissolution of magnesite, carbon dioxide, and the exchange of magnesium of calcium. A general model for this set of specific models is the dissolution of calcite, magnesite, and carbon dioxide with exchange.

Three general mass-balance models for ground water in those parts of the principal aquifers derived primarily from plutonic rocks include the phases listed in table 4. Each model starts with the chemical composition of atmospheric precipitation and a set of phases with the concentrations of the major dissolved constituents plus aluminum in ground water and, for some of the models, the stable-isotope composition of carbon. As many as 10 phases may be included in each, individual model because up to 10 constituents (sodium, calcium, magnesium, potassium, dissolved inorganic carbon, chloride, sulfate, silica, aluminum, and the stable-isotope composition of carbon) are included in the models. Differences between the general models are a result of changing the constituent concentrations and restrictions on the individual

phases. The general models are (1) a "silicate" model that does not include calcite as a possible source for calcium and dissolved inorganic carbon (calcite is not allowed to dissolve, but may precipitate); (2) a "closed-system" model that includes calcite as possible input and includes carbon-isotope data; and (3) an "open-system" model that includes a reaction step consisting of isotopic equilibration of carbon with carbon dioxide in the unsaturated zone.

All possible combinations of the phases indicated in table 4 were evaluated using a version of the program BALANCE (Parkhurst and others, 1982) for 23 samples of ground water from the principal aquifers composed primarily of material derived from intrusive igneous rocks. For each of the general models, the average amounts of mass input and output for each unique combination of phases was calculated. Specific models were retained for further consideration only if two certain criteria were met. First, only those specific models that numerically met the constraints for at least 80 percent (18 of 23) of the chemical analyses tested were retained. Second, a specific model was rejected if the calculated mass transfer entering the water was greater than five times the average increase in dissolved-solids content in ground water. Aluminum is not included in the calculated input mass because aluminum probably remains in a solid phase during weathering to clay minerals. Only models that were valid for 80 percent of the sites were retained in order to present specific models that were valid for most of the modeled ground water. The limitation on the total mass transfer was imposed to demonstrate that models with relatively modest amounts of dissolution and precipitation can explain the observed water quality. Linear combinations of the specific models represent additional numerically valid models. For instance, the sum of one-half the mass transfer of each of the phases from two other specific models represents a valid model that meets the second criterion. A model that consists mostly of an "accepted" specific model, combined with a small amount of a "rejected" specific model, is therefore a satisfactory solution to a general model.

Criteria were selected to retain specific models that were numerically possible and compatible with both the observed mineralogy and the general ground-water quality. An evaluation of the resulting set of specific models indicates whether a general model describing the major reactions is a satisfactory repre-

sentation of the processes that lead to the observed ground-water quality. This overall modeling approach usually cannot be used to accept or reject minerals in a proposed general model, but may give information about the relative amounts of input from the various phases and provide a basis for accepting or rejecting a general model.

The program BALANCE uses concentrations of dissolved constituents to calculate the amount of dissolution and precipitation of phases. Concentrations used with BALANCE are the difference between an initial and a final composition. Final compositions in all three general models were the measured concentrations in the ground water. Initial compositions for the silicate and closed-system models consisted of the average concentrations in Sierra Nevada precipitation (Feth and others, 1964, table 3), except aluminum. Aluminum concentrations are generally low (10 µg/L or less) in ground water with pH values in the range found for Carson and Eagle Valleys. Accordingly, the aluminum concentrations were set to zero, which is consistent with concentrations being the same in the initial and final water. The carbon-isotope composition in precipitation was assumed to be -19 permil, a value consistent with equilibrium between the water and plants in the upland area.

The open-system model includes two steps. The first step started with the average precipitation composition and simulated the dissolution of calcite and carbon dioxide. Concentrations at the end of this simulation were used for the initial conditions for the mass-balance model. The initial concentrations, in milligrams per liter, were:

Constituent	Precipitation (Feth, 1964)	Open-system model
Calcium	0.46	0.46
Magnesium	.17	.17
Sodium	.40	25.3
Potassium	.32	.32
Total dissolved inorganic carbon (as bicarbonate)	27.9	119.4
Sulfate	.95	.95
Chloride	.5	.5
Silica	.16	.16
Aluminum	0	0
Carbon-13, in permil	-19.0	not included

Previous workers have developed geochemical models based on the mass-balance approach that indicate the calcium to sodium ratios in perennial springs issuing from granitic rocks in the Sierra Nevada are too high to be explained by dissolution of plagioclase feldspar with an average composition in the range found in most of the igneous plutons in the Sierra Nevada (Garrels and Mackenzie, 1967; Bowser and Jones, 1990) and other areas underlain by felsic bedrock (Mast and Drever, 1990). Possible reasons for the higher ratio in water are: (1) another calcium-bearing mineral, such as hornblende or augite, is being weathered; (2) plagioclase feldspar has zones with calcium to sodium ratios that are higher than the average composition, and these zones are differentially being weathered (see Mast and Drever, 1990); and (3) calcite is being dissolved.

The calcium to sodium ratio of most water in the models discussed also are greater than the ratio in the average plagioclase feldspar (fig. 19 and table 4). The silicate model did not produce any specific models that met criteria summarized above. All the specific models have amounts of mass transfer that exceed at least one of the criteria. In contrast to the models for the Sierra Nevada by the other workers, the calcium-bearing minerals augite and hornblende were included in the models for ground water in Carson and Eagle Valleys. Optical examination of the plagioclase feldspar in shallow sediments from Carson and Eagle Valleys shows compositional zoning, although zones with higher calcium concentrations do not appear to be preferentially weathered (Patrick Goldstrand, U.S. Geological Survey, written commun., 1990). The present information indicates that calcium is derived from a mineral not included in the silicate general model.

Calcite is a possible source of calcium and is included in closed- and open-system general models. Although calcite has not generally been reported in granitic rocks of the Sierra Nevada, hydrothermal alteration is locally present, which could form calcite. Additionally, calcite may be in the metamorphic rocks that form part of the Sierra Nevada. Other possible sources of calcite include eolian transport and pedogenic formation in soils.

The closed-system general model is similar to the silicate model with addition of calcite. The model is referred to as a "closed-system" because it does not include isotopic exchange between dissolved inorganic carbon and carbon dioxide in the atmosphere or the

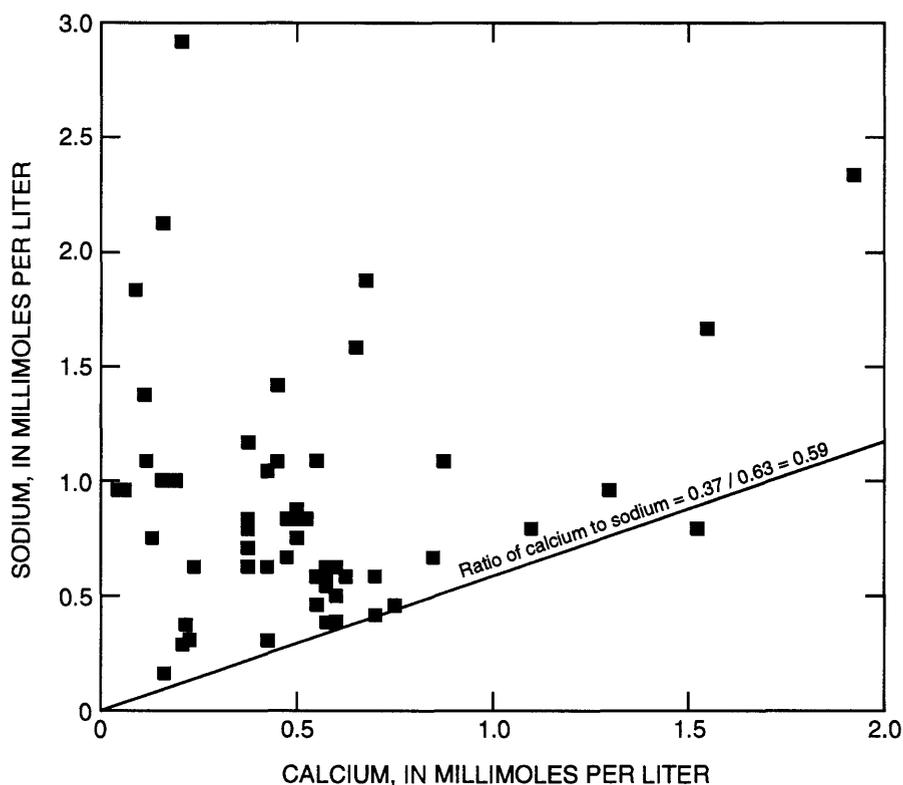


Figure 19. Relation between concentration of sodium and calcium in principal aquifers on west side of Carson and Eagle Valleys.

unsaturated zone. Restated, the modeled carbon-isotope composition in water is calculated from the isotopic composition of incoming carbon dioxide gas and calcite. This model uses estimated values for the carbon-isotope composition of the calcite and carbon dioxide in the unsaturated zone.

Median values for mass transfer of minerals for a closed-system model are indicated in figures 20A and B. The amounts of mass transfer indicate the molar (or atomic) mass contributed by the phases, not the mole fraction for each phase, to allow comparison with the molar concentrations in ground water. Positive values indicate dissolution and negative values indicate precipitation. These models have some broad similarities as a group. Plagioclase feldspar represents a major source of dissolved solids, with median values for the models generally ranging from 0.5 to 2.25 millimoles per liter (mmol/L). Calcite and carbon dioxide together supply about 2 mmol/L. Pyrite plus sodium chloride has median values that are small relative to the total amount of mass transfer, with values generally less than 0.35 mmol/L. The amount of dissolving silica is variable, with input values ranging from 0 to about

2.2 mmol/L. All the specific models include some cation exchange of less than 0.5 mmol/L (fig. 20B). Precipitation of either sodium beidellite or kaolinite is present in all the specific models. Because any linear combination of the models also represent valid models of a closed system, the data displayed in figures 20A and B indicate that an overall model that includes all the indicated phases is consistent with the observed major constituent concentrations.

The third general model considered is an open-system model. The model includes two reaction steps. The first reaction step simulates a system that is open with respect to carbon dioxide in the presence of calcite. Starting with the average composition of precipitation (Feth, 1964), carbon dioxide and calcite were added until a composition with a log partial pressure of carbon dioxide equal to -2.5 atmospheres and a saturation index of -0.5 for calcite (which is in the range found in the upland aquifers) was reached. This reaction step results in the dissolution of about 0.9 and 1.05 mmol/L of calcite and carbon dioxide, respectively. The program PHREEQE (Parkhurst and others, 1980), which allows geochemical reaction

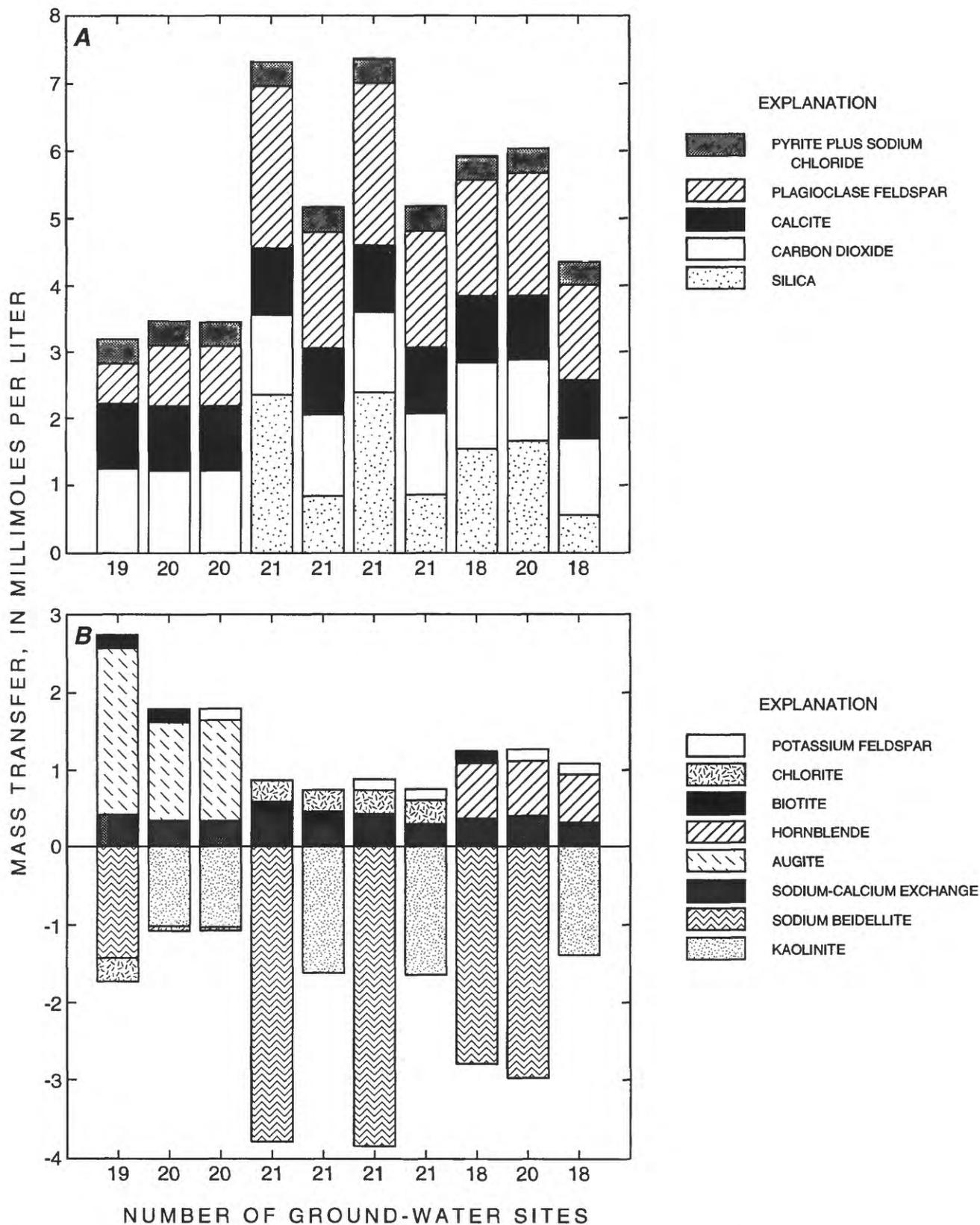


Figure 20. Median values of mass transfer for closed-system (A and B) and open-system (C and D) geochemical models, excluding aluminum.

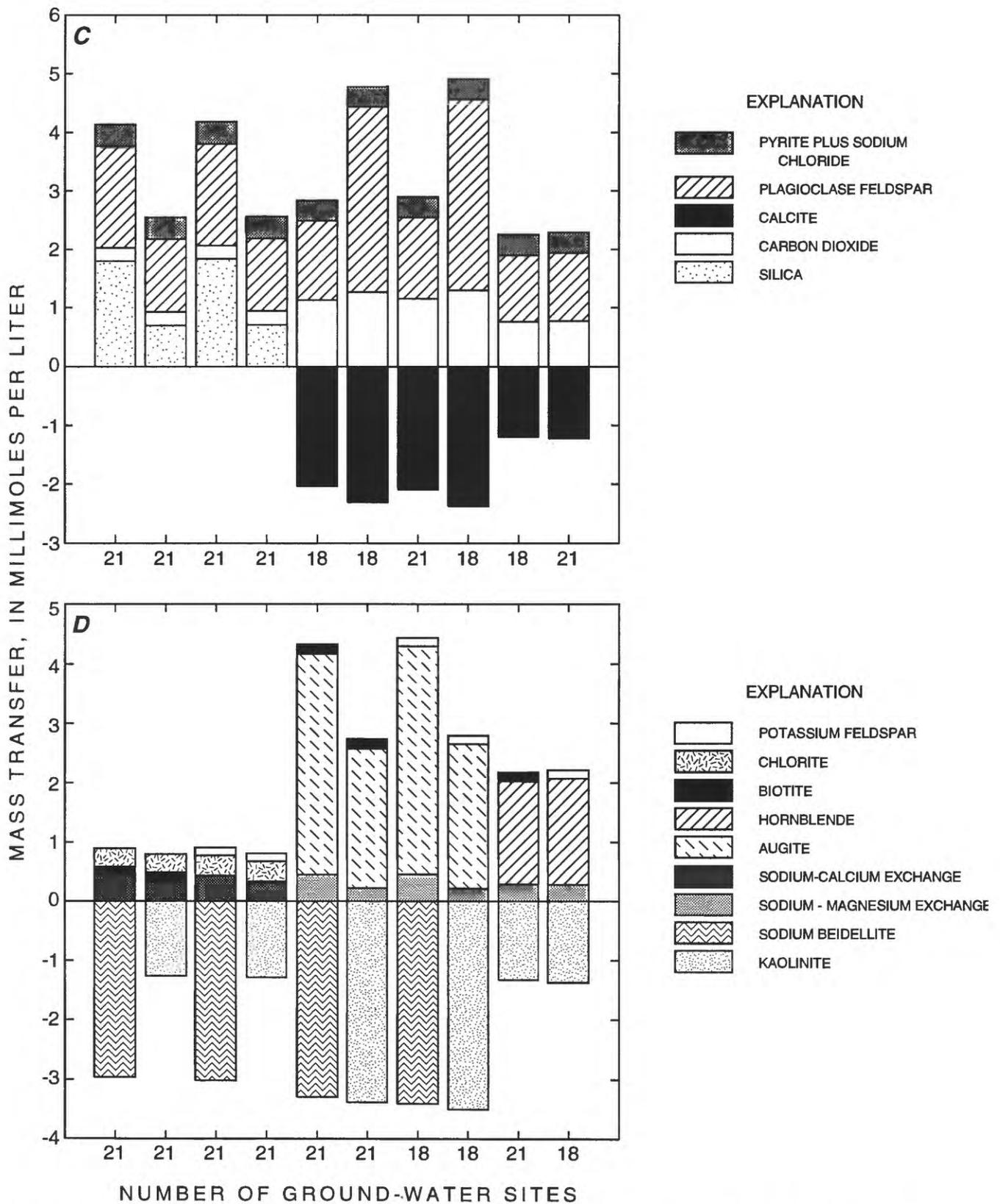


Figure 20. Median values of mass transfer for closed-system (A and B) and open-system (C and D) geochemical models, excluding aluminum—Continued.

modeling, was used to simulate this first reaction step. This reaction simulates a system where atmospheric precipitation reacts with calcite and carbon dioxide in the unsaturated zone, resulting in isotopic equilibrium with the carbon dioxide. The approach is based on the assumption that this step is fast compared with silicate hydrolysis that probably also is proceeding during recharge. The second reaction step in the general open-system model consists of reaction with the minerals present in the basin-fill sediments. This step is similar to the closed-system model except that the initial water quality has already reacted with calcite and carbon dioxide. The mass transfers for the reactions are indicated in figures 20C and D. The amounts of precipitation and dissolution indicated by the specific models are broadly similar to the amounts estimated by the closed-system model, with the exception that most of the carbon dioxide and calcite dissolved in the first reaction step. Some of the models indicate that calcite precipitates. A major source of dissolved solids in the second step is plagioclase feldspar (fig. 20A). All the phases considered are represented in one or more of the open-system specific models.

The general models indicated by the data shown on figures 20A through D are consistent with the thermodynamic state of the ground water. Thermodynamic data used for the phases in the general models and corresponding saturation indices and phase boundaries are shown in tables 5 and 6, respectively. Chemical activity diagrams, shown in figure 21, indicate: (1) the chemical activity ratios for Carson and Eagle Valleys ground water generally plot along slopes consistent with cation exchange reactions (figs. 21A-C). Specifically, a ratio of 2 will result where the aqueous geochemistry is controlled by the exchange of a divalent cation for a monovalent cation (Drever, 1982), which corresponds to a slope of 2 on figures 21A and C. Similarly, plots of two cations with the same valence will result in a slope of 1 on a diagram like figure 21B if exchange controls the cation ratio. Most data for the principal aquifers lie along trends consistent with cation exchange as the geochemical control on the ratios of the major cations. (2) The clay minerals kaolinite and beidellite are stable weathering products in the principal aquifers. Activity diagrams (figs. 21D-G) show the activities for different types of ground water on stability fields for minerals that are stable and commonly form in ground-water systems. The chemical activities of most ground

water in Carson and Eagle Valleys appear to be stable with respect to kaolinite or beidellite, or both. This conclusion is supported by the fact that most of the data plot within the stability fields for these minerals. Thermodynamic data for beidellite may not be valid in a strict thermodynamic sense (May and others, 1986). In contrast, studies of systems where beidellite is forming have shown that water appears to have stable ionic compositions that correspond to that indicated by solubility constants determined for beidellite (see Drever, 1982, p. 177-190), which may be a result of a steady-state condition rather than true equilibrium. Although commonly adopted thermodynamic data for beidellite may not represent true equilibrium, the data are useful for comparison with other systems where beidellite has been observed to be forming.

Saturation indices, which are a measure of the thermodynamic state of a solution, have been calculated for calcite and amorphous silica. For the purposes of discussion, saturation indices of less than -0.5 are considered undersaturated, values from -0.5 to 0.5 are considered saturated, and values greater than 0.5 are oversaturated. Ground water in the principal aquifers was generally below or at saturation with respect to calcite (fig. 22A), which is consistent with dissolution in the geochemical models. The ground water was generally saturated with respect to amorphous silica (fig. 22B), which also is consistent with specific models that indicate precipitation or dissolution of amorphous silica.

In summary, the results of mass-balance modeling was consistent with (1) phases identified in the basin-fill deposits of Carson and Eagle Valleys, (2) chemical activity of major cations and silica, (3) saturation indices for calcite and amorphous silica, (4) phase relations for silicate minerals indicated by activity diagrams, and (5) mineralogic relations in shallow sediments, based on examination of thin sections. The mass-balance approach does not yield unique solutions in systems like those found in Carson and Eagle Valleys because the number of possible reacting phases is greater than the number of "elements." This approach yields a set of models that, taken together, provides a general geochemical model for the major inorganic constituents.

The age of ground water can be estimated by using the amounts and source of carbon indicated by the general models. Because the open-system general model assumes isotopic equilibrium after approaching

Table 5. Thermodynamic data for minerals and equations adapted for calculation of saturation and disequilibrium indices at 15 degrees Celsius

[Log₁₀ K is logarithm, to base 10, of equilibrium constant for reaction]

Mineral	Log ₁₀ K	Reaction
Albite	-18.661 ^a	NaAlSi ₃ O ₈ +8H ₂ O ↔ Na ⁺ +Al(OH) ₄ ⁰ + 3H ₄ SiO ₄ ⁰
Microcline	1.193 ^a	KA1Si ₃ O ₈ +4H ⁺ +4H ₂ O ↔ K ⁺ +Al ³⁺ +3H ₄ SiO ₄ ⁰
Kaolinite	8.333 ^b	A1 ₂ Si ₂ O ₅ (OH) ₄ +6H ⁺ ↔ 2Al ³⁺ +2H ₄ SiO ₄ ⁰ + H ₂ O
Amorphous silica	-2.7 ^b	SiO ₂ +2H ₂ O ↔ H ₄ SiO ₄ ⁰
Gibbsite	8.690 ^c	A1(OH) ₃ +3H ⁺ ↔ Al ³⁺ +3H ₂ O
Ca-beidellite	-48.18 ^d	Ca _{0.17} A1 _{2.33} Si _{3.67} O ₁₀ (OH) ₂ +12H ₂ O ↔ 0.17Ca ²⁺ +2.33Al(OH) ₄ ⁰ +3.67H ₄ SiO ₄ ⁰ +2H ⁺
Mg-beidellite	-48.25 ^d	Mg _{0.17} A1 _{2.33} Si _{3.67} O ₁₀ (OH) ₂ +12H ₂ O ↔ 0.17Mg ²⁺ +2.33Al(OH) ₄ ⁰ + 3.67H ₄ SiO ₄ ⁰ + 2H ⁺
Na-beidellite	-48.04 ^d	Na _{0.33} A1 _{2.33} Si _{3.67} O ₁₀ (OH) ₂ +12H ₂ O ↔ 0.33Na ⁺ +2.33Al(OH) ₄ ⁰ + 3.67H ₄ SiO ₄ ⁰ +2H ⁺
K-beidellite	-48.32 ^d	K _{0.33} A1 _{2.33} Si _{3.67} O ₁₀ (OH) ₂ +12H ₂ O ↔ 0.33K ⁺ +2.33Al(OH) ₄ ⁰ + 3.67H ₄ SiO ₄ ⁰ +2H ⁺
Chlorite (14Å)	72.235 ^e	Mg ₅ A1 ₂ Si ₃ O ₁₀ (OH) ₈ +16H ⁺ ↔ 5Mg ²⁺ +2Al ³⁺ +3H ₄ SiO ₄ ⁰ + 6H ₂ O
Gypsum	-4.58 ^b	CaSO ₄ •2H ₂ O ↔ Ca ²⁺ +SO ₄ ²⁻ + 2H ₂ O
Calcite	-8.43 ^f	CaCO ₃ ↔ Ca ²⁺ + CO ₃ ²⁻
Siderite	-10.45 ^b	FeCO ₃ ↔ Fe ²⁺ + CO ₃ ²⁻
Rhodochrosite	-10.39 ^g	MnCO ₃ ↔ Mn ²⁺ + CO ₃ ²⁻
Al(OH) ₄ ⁰	-23.779 ^b	Al ³⁺ +4H ₂ O ↔ Al(OH) ₄ ⁰ + 4H ⁺

^aRobie and Waldbaum, 1968.

^bBall and others, 1987.

^cMay and others, 1979.

^dHelgeson, 1969.

^eHelgeson and others, 1978.

^fPlummer and Busenberg, 1982.

^gMorgan, 1982.

equilibrium with calcite, the age can be computed directly from measured carbon-14 activities. The closed-system general model requires that carbon-14 be corrected for dissolution of nonradiogenic carbon from calcite. The contribution of calcite to dissolved inorganic carbon is estimated on the basis of measured carbon-13 values and an estimate of the carbon-13 value of the calcite. Two values for the carbon-13 of the calcite are used for the estimated ages presented in table 7. The carbon-13 value of zero permil corresponds to an average marine limestone, with -5 an arbitrarily chosen value. Although one general model cannot be clearly shown to be more accurate than the others, the carbon-isotope composition is consistent with an open-system model. The primary uncertainty

associated with estimating an age on the basis of the closed-system model is the absence of data on the carbon-isotope composition of calcite being dissolved.

Estimated ages of ground water in the eastern parts of Carson and Eagle Valleys are based on the same geochemical model for carbon as that used for the areas to the west. Dissolution of gypsum can result in the precipitation of calcite. Because gypsum dissolution is indicated by relatively high sulfate concentrations, ages of ground water were not estimated for sites in the northeastern part of Eagle Valley.

The results shown in table 7, which are restricted to sites where tritium activities are less than 1 pCi/L, indicate a considerable range in possible ages. Because dissolution of calcite dilutes the carbon-14 content, the

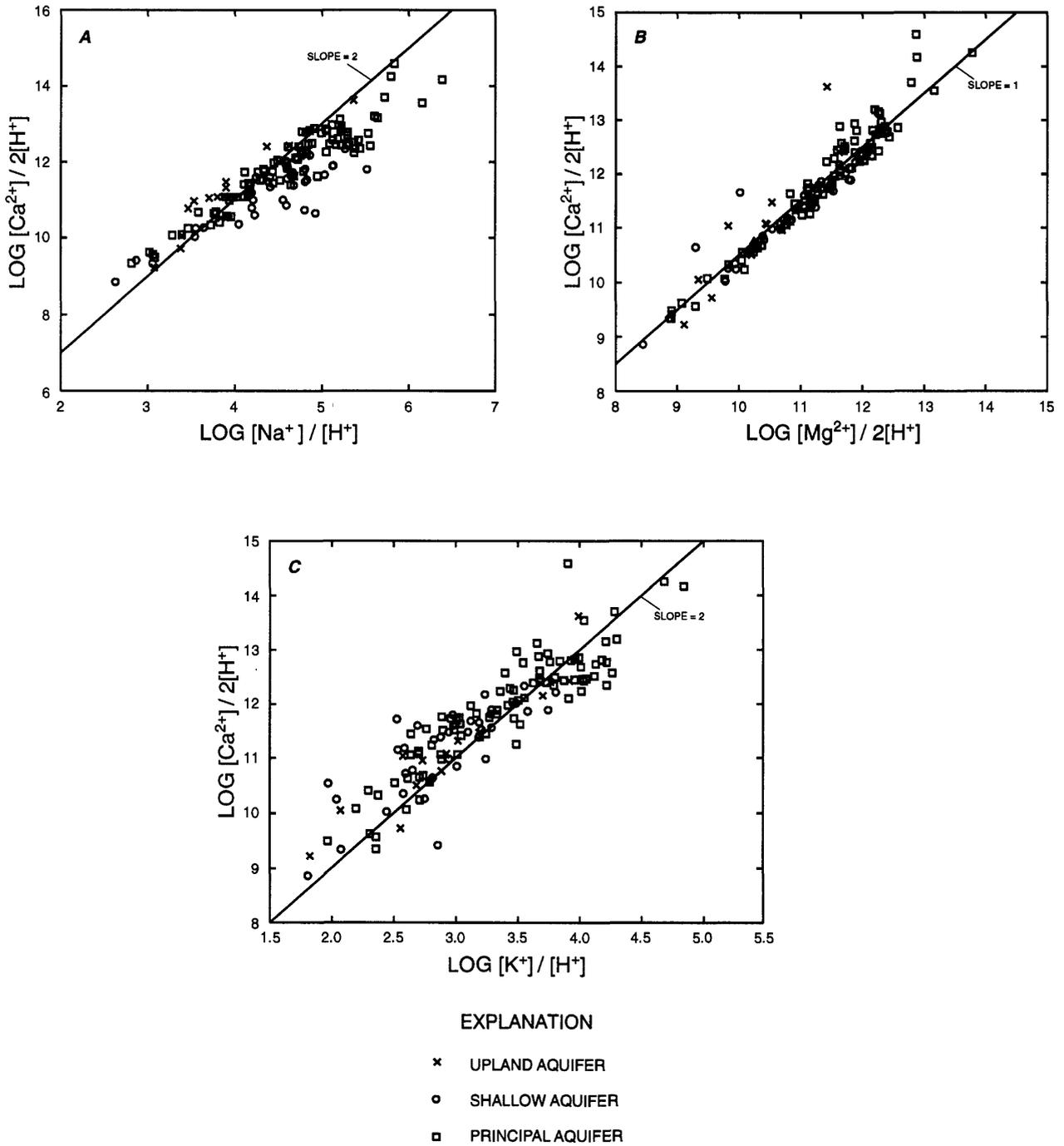


Figure 21. Relation between the chemical activities of **A**, calcium and sodium; **B**, calcium and magnesium; **C**, calcium and potassium; **D**, sodium and silica; **E**, calcium and silica; **F**, magnesium and silica; and **G**, potassium and silica in ground water of Carson and Eagle Valleys.

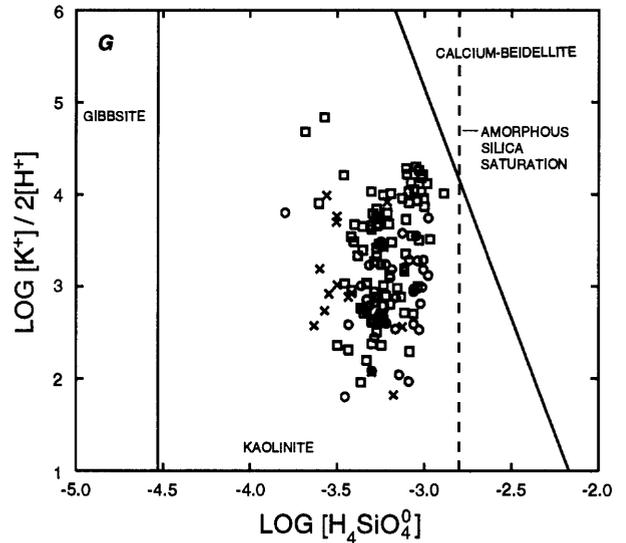
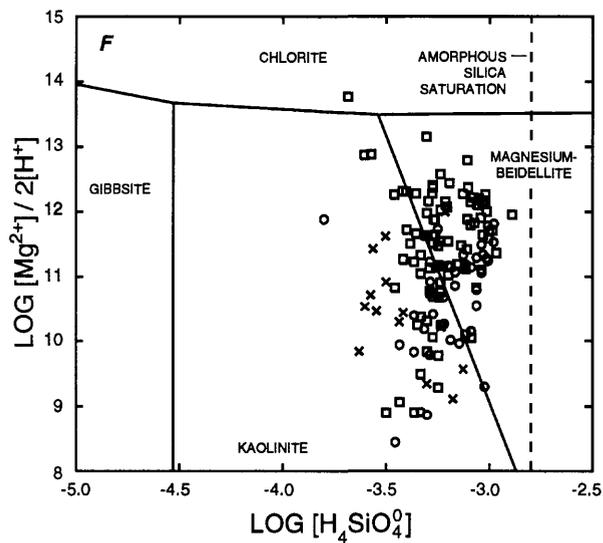
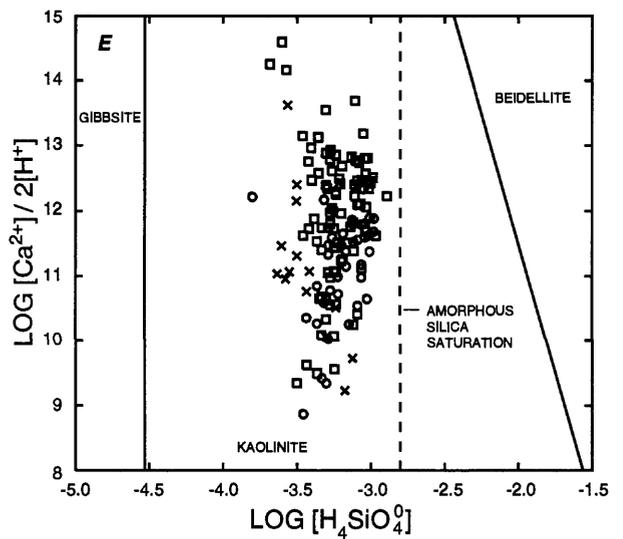
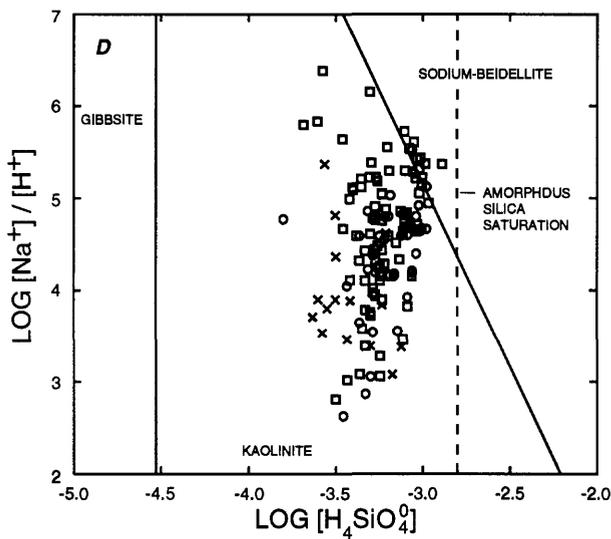


Figure 21. Relation between the chemical activities of *A*, calcium and sodium; *B*, calcium and magnesium; *C*, calcium and potassium; *D*, sodium and silica; *E*, calcium and silica; *F*, magnesium and silica; and *G*, potassium and silica in ground water of Carson and Eagle Valleys—Continued.

Table 6. Equations for calculation of phase boundaries at 15 degrees Celsius

[Logarithm values are to base 10]

Phase boundary	Equation
Albite-sodium-beidellite	$\log [\text{Na}^+/\text{H}^+] = 5.36 - 1.67 \log [\text{H}_4\text{SiO}_4^0]$
Kaolinite-sodium-beidellite	$\log [\text{Na}^+/\text{H}^+] = -6.83 - 4 \log [\text{H}_4\text{SiO}_4^0]$
Kaolinite-calcium-beidellite	$\log [\text{Ca}^{2+}/2\text{H}^+] = -14.51 - 8 \log [\text{H}_4\text{SiO}_4^0]$
Kaolinite-magnesium-beidellite	$\log [\text{Mg}^{2+}/2\text{H}^+] = -14.93 - 8 \log [\text{H}_4\text{SiO}_4^0]$
Microcline-kaolinite	$\log [\text{K}^+/\text{H}^+] = 2.93 - 2 \log [\text{H}_4\text{SiO}_4^0]$
Kaolinite-potassium-beidellite	$\log [\text{K}^+/\text{H}^+] = -7.67 - 4 \log [\text{H}_4\text{SiO}_4^0]$
Microcline-potassium-beidellite	$\log [\text{K}^+/\text{H}^+] = -2.19 - 1.67 \log [\text{H}_4\text{SiO}_4^0]$
Kaolinite-gibbsite	$\log [\text{H}_4\text{SiO}_4^0] = -4.53$
Amorphous silica	$\log [\text{H}_4\text{SiO}_4^0] = -2.7$
Chlorite-kaolinite	$\log [\text{Mg}^{2+}/2\text{H}^+] = 12.780 - 0.2 \log [\text{H}_4\text{SiO}_4^0]$
Chlorite-gibbsite	$\log [\text{Mg}^{2+}/2\text{H}^+] = 10.96 - 0.6 \log [\text{H}_4\text{SiO}_4^0]$
Chlorite-magnesium-beidellite	$\log [\text{Mg}^{2+}/2\text{H}^+] = 13.595 - 0.029 \log [\text{H}_4\text{SiO}_4^0]$

closed-system models yield younger ages than the open-system models. In general, estimated ages for closed-system models range from recent to about 4,000 years, with water in the central part of Eagle Valley having the greatest ages. If the calculated ages using either model are satisfactorily accurate, then much of the ground water in principal aquifers beneath central Eagle Valley is unlikely to become contaminated by surface sources under hydrologic conditions that existed prior to development of the ground-water system. In contrast, measurable tritium or high carbon-14 content in ground water in the west part of Carson Valley (table 3 and fig. 7) suggests water being withdrawn from the principal aquifers is relatively young and has the potential to be contaminated by surface sources.

Minor Inorganic Constituents

Water Quality and Its Relation to Nevada State Drinking-Water Standards

Minor constituents that are most commonly found at concentrations greater than the MCL in Carson and Eagle Valleys are arsenic, fluoride, and nitrate (table 8 and figs. 23 and 24). Median arsenic

concentrations in the nonthermal aquifers are all less than 10 µg/L and range from less than 1 to 110 µg/L. Arsenic concentrations in the principal aquifers exceed the MCL of 0.05 mg/L (50 µg/L) at only 1 of 91 ground-water sites (in north-central Carson Valley). None of the arsenic concentrations in the upland aquifers exceed the MCL. Of 39 samples from the shallow aquifers, three have arsenic concentrations greater than 50 µg/L. Of 5 samples from the thermal aquifers, only water discharging from Carson Hot Springs exceeds the arsenic MCL.

Fluoride concentrations in the nonthermal aquifers are generally less than 1 mg/L (appendix). None of the samples from either the upland or principal aquifers exceeds the 4 mg/L MCL and only two samples from shallow aquifer sites exceed the MCL. In contrast, 5 of 6 samples from the thermal aquifer exceed the MCL for fluoride (table 8).

Nitrate concentrations exceed the 10 mg/L MCL in samples from 3 of 93 sites where wells tap the principal aquifers. High nitrate concentrations are in samples from wells in suburban areas that use septic systems (sites 110, 111, and 180, fig. 24; and table 9), which indicates that sewage may be entering the wells. Nitrate concentrations at two sites where wells tap the shallow aquifers in central Eagle Valley also

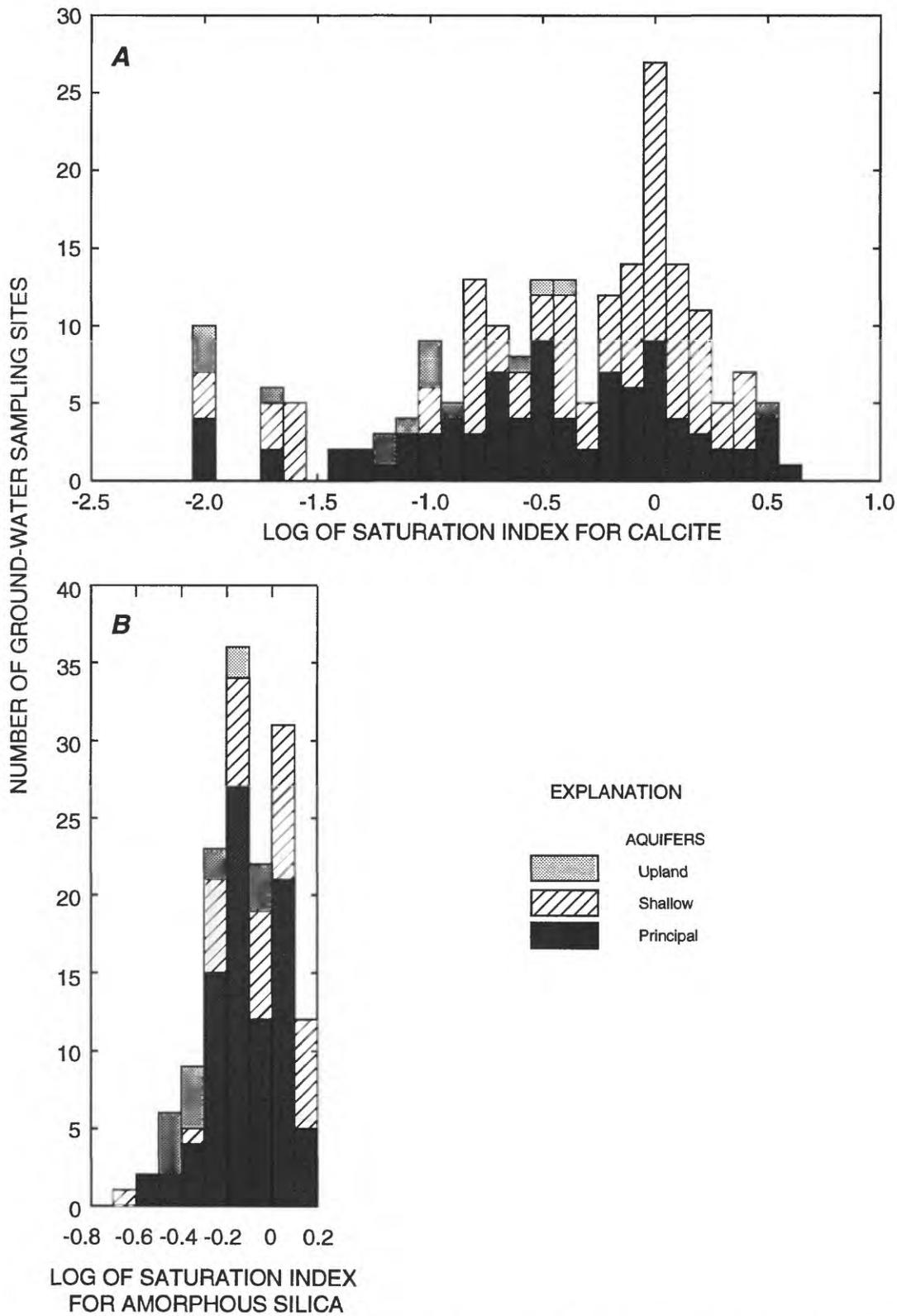


Figure 22. Saturation indices for *A*, calcite and *B*, amorphous silica in ground water of Carson and Eagle Valleys.

Table 7. Estimated age of ground water in principal aquifers at selected sites in Carson and Eagle Valleys

[Abbreviations and symbols: pCi/L, picocuries per liter; PMC, percent modern carbon; <, less than; --, negative calculated age; $\delta^{13}\text{C}$, delta carbon-13, relative to Pee Dee Belemnite standard]

Site	Tritium (pCi/L)	Carbon-14 (PMC)	Estimated age (years)		
			Closed system, $\delta^{13}\text{C}$ (permil)		Open system
			0	-5	
Carson Valley					
105	<0.3	55	1,900		5,000
Eagle Valley					
113	<0.3	95	--	--	400
127	.4	80	--	--	1,800
130	<.3	72	--	--	2,700
138	<.3	52	4,100	2,200	5,500
157	<.03	60	2,500	600	4,300
160	<1.0	88	--	--	1,100
174	<.3	74	1,000	--	2,500
182	<.3	69	1,000	--	3,000

exceed the MCL. Although few nitrate concentrations presently exceed the MCL, use of septic systems and land application of treated sewage may lead to more areas having high nitrate concentrations in the future. Four sewage-treatment facilities that serve areas within the Lake Tahoe Basin export all their treated effluent to the Carson River Basin. Treated sewage effluent originating from within the Carson River Basin and imported from the Tahoe Basin is used to irrigate agricultural land, reconstructed wetlands, and golf courses in Carson and Eagle Valleys. Recharge of treated effluent could result in local increases in nitrate concentrations in ground water.

Constituents that most commonly exceed a SMCL are iron and manganese (table 8). Iron and manganese concentrations in the shallow aquifers have a greater median value than in the upland and principal aquifers (fig. 23). In the principal aquifers, manganese exceeds the 0.1 mg/L SMCL at 9 of 93 sites scattered throughout much of Carson and Eagle Valleys. Measured iron concentrations at 93 principal aquifer sites are below the SMCL. Water from only one upland aquifer well, in the western part of Eagle Valley (fig. 24), had concentrations of iron and manganese

that exceeded SMCL's. Of samples from 40 sites with iron and manganese analyses for the shallow aquifers, 8 and 21 sites, respectively, exceed the SMCL's. Other SMCL's, including dissolved solids and sulfate, are exceeded in samples from a few sites where wells tap the shallow and thermal aquifers, but less commonly than for iron and manganese.

Ground water from 89 sites where wells tap the principal aquifer were analyzed for all the inorganic constituents with MCL's or SMCL's. At these sites, water from 3 sites exceeds one or more of the MCL's and water from 10 sites has at least one constituent that exceeds a MCL or a SMCL (table 10). Ground water from shallow aquifers has inorganic constituents at concentrations greater than MCL's and SMCL's much more commonly than the principal aquifers, with samples from 23 of 39 sites having at least one constituent exceeding an inorganic MCL or SMCL (table 10). Part of this difference between the shallow and principal aquifers may be due to the abandonment of wells tapping the principal aquifers that produce poor water quality. Among the different aquifer systems defined for this study, the thermal aquifers discharge water that most commonly exceeds an MCL or SMCL (table 10). In contrast, water from only one upland aquifer site has concentrations of constituents that exceed the SMCL's for iron and manganese.

Processes Affecting Minor Constituent Concentrations

Iron and manganese concentrations are moderately well correlated (Spearman's rho = 0.67; Iman and Conover, 1983). Thus, ground water with a high concentration of manganese tends to have a high concentration of iron (fig. 25A). The higher concentrations of both iron and manganese are in water with relatively low measured dissolved oxygen concentrations (figs. 25B and C) and relatively high dissolved organic-carbon concentrations (figs. 25D and E). Manganese and iron concentrations greater than about 100 $\mu\text{g/L}$ generally have dissolved oxygen concentrations less than 2 mg/L. Relatively high dissolved organic carbon and low dissolved oxygen (figs. 25B-E) are consistent with the reaction of oxygen with organic carbon in recharge water to produce a slightly reduced ground water. Pumping of wells during sampling may have introduced a small amount of oxygen into the water prior to determination of oxygen—thus water with low measured oxygen (less than about 1-2 mg/L) actually may have lower concentrations in the aquifer.

Table 8. Summary of inorganic constituents that exceed and do not exceed Nevada State drinking-water maximum contaminant levels (MCL's) and secondary maximum contaminant levels (SMCL's) in ground water of Carson and Eagle Valleys

[See table 2 and text for explanation of MCL's and SMCL's]

Constituent with an established MCL	Upland aquifers			Shallow aquifers			Principal aquifers			Thermal aquifers			All aquifers		
	Total number of sites	Number of sites exceeding MCL	Number of sites	Total number of sites	Number of sites exceeding MCL	Number of sites	Total number of sites	Number of sites exceeding MCL	Number of sites	Total number of sites	Number of sites exceeding MCL	Number of sites	Total number of sites	Number of sites exceeding MCL	Number of sites
Arsenic	17	0	39	3	91	1	4	1	151	4	1	151	4	4	
Barium	9	0	40	0	92	0	4	0	145	0	0	145	0	0	
Cadmium	9	0	40	1	92	0	1	0	142	1	0	142	1	1	
Chromium	9	0	40	0	92	0	1	0	142	0	0	142	0	0	
Fluoride	23	0	40	2	92	0	6	5	161	7	5	161	7	7	
Lead	9	0	40	1	92	0	1	0	142	1	0	142	1	1	
Mercury	8	0	39	0	91	0	2	0	140	0	0	140	0	0	
Nitrate	9	0	41	2	93	3	4	0	147	5	0	147	5	5	
Selenium	8	0	40	0	92	0	1	0	141	0	0	141	0	0	
Silver	9	0	40	0	92	0	1	0	142	0	0	142	0	0	

Constituent with an established SMCL	Upland aquifers			Shallow aquifers			Principal aquifers			Thermal aquifers			All aquifers		
	Number of sites	Number of sites exceeding SMCL	Number of sites	Total number of sites	Number of sites exceeding SMCL	Number of sites	Total number of sites	Number of sites exceeding SMCL	Number of sites	Total number of sites	Number of sites exceeding SMCL	Number of sites	Total number of sites	Number of sites exceeding SMCL	Number of sites
Chloride	28	0	41	0	105	0	6	0	180	0	0	180	0	0	
Fluoride	23	0	40	3	92	1	6	6	161	9	6	161	9	9	
Dissolved solids	18	0	40	3	90	0	6	1	154	4	1	154	4	4	
Iron	18	1	40	8	93	0	3	1	154	10	1	154	10	10	
Magnesium	27	0	41	0	105	0	6	0	179	0	0	179	0	0	
Manganese	9	1	40	21	93	8	2	1	144	31	1	144	31	31	
Sulfate	26	0	40	2	103	0	6	1	175	3	1	175	3	3	
Total number of sites sampled	32		42		107		6		187			187			

Table 9. Concentrations of minor constituents in ground water at selected sites in Carson and Eagle Valleys

[Units of measure and symbols: mg/L, milligrams per liter; µg/L, micrograms per liter; --, not determined; <, less than]

Site (figs. 3 and 4)	Date	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)
CARSON VALLEY									
Upland aquifers									
78	08-27-87	--	--	--	--	--	--	--	--
104	06-09-88	<1	13	<10	<1	<5	<3	<10	<4
Shallow aquifers									
1	07-19-88	<1	45	<10	<1	<5	7	<10	<4
29	08-23-88	14	34	20	<1	<5	5	<10	5
53	08-03-87	22	41	480	<1	<1	5	<10	18
56	08-09-88	14	69	390	<1	<5	4	<10	27
58	09-05-86	19	100	410	1	<10	250	<10	--
59	07-06-88	13	76	420	<1	<5	<3	<10	21
64	09-04-86	21	97	290	1	<10	190	<10	--
67	08-09-88	55	54	190	<1	<5	360	<10	27
83	07-14-88	<1	230	310	<1	<5	6,800	<10	30
86	06-30-87	--	--	--	--	--	--	--	--
89	09-02-86	43	140	190	1	<10	870	<10	--
96	07-02-88	<1	81	570	<1	<5	<3	<10	37
100	08-29-83	11	20	640	1	<10	1,200	<10	--
103	01-14-88	--	--	--	--	--	--	--	--
Principal aquifers—east side of valley									
14	08-24-87	--	--	--	--	--	--	--	--
20	08-24-87	--	--	--	--	--	--	--	--
27	08-20-87	--	--	--	--	--	--	--	--
39	06-16-88	4	100	20	<1	<5	<3	<10	7
46	05-09-88	4	120	30	<1	<5	100	<10	14
84	06-25-87	--	--	--	--	--	--	--	--
87	08-04-88	23	29	180	<1	<5	9	<10	22
90	08-25-87	--	--	--	--	--	--	--	--
92	08-30-83	46	43	190	<1	<10	33	<10	--
93	05-05-88	19	57	230	<1	16	4	<10	23
107	08-29-83	4	72	50	<1	<10	74	<10	--
Principal aquifers—west side of valley									
3	07-28-88	<1	67	30	<1	<5	8	<10	6
12	06-16-88	1	30	30	<1	<5	140	<10	<4
16	08-22-83	<1	41	30	<1	<10	<3	10	--
17	08-10-88	15	74	180	<1	<5	6	<10	30
18	05-05-88	3	87	70	<1	<5	7	<10	15
21	07-21-88	2	62	160	<1	<5	<3	<10	24
28	07-14-88	1	63	150	<1	<5	7	<10	20
30	05-04-88	4	91	160	<1	<5	7	<10	25
31	06-15-88	<1	26	20	<1	<5	2	<10	6
32	07-25-88	2	84	140	<1	<5	5	<10	22

Table 9. Concentrations of minor constituents in ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)
Principal aquifers—west side of valley—Continued									
34	08-23-88	2	140	220	<1	<5	5	<10	29
37	08-30-83	4	91	170	<1	<10	14	<10	--
38	07-21-88	3	130	170	<1	<5	5	<10	25
43	07-27-88	4	82	160	<1	<5	<3	<10	19
47	07-25-88	9	72	150	<1	<5	8	<10	21
55	08-18-83	18	53	70	<1	<10	29	10	--
81	06-09-88	34	20	70	<1	<5	44	<10	6
101	08-24-83	6	22	240	<1	10	69	<10	--
105	07-28-88	14	17	120	<1	<5	9	<10	7
Thermal aquifers									
97	1979 ^a	20	<.10	2,100	--	--	--	--	350
98	1979 ^a	<5	.10	1,400	--	--	--	--	95
99	08-26-83	9	23	1,000	1	<10	5,600	<10	--
EAGLE VALLEY									
Upland aquifers									
141	09-08-88	6	90	<10	<1	<5	1,900	<10	12
176	09-07-88	3	8	10	<1	<5	30	<10	16
Shallow aquifers									
131	05-31-89	9	150	160	<1	<5	23	<10	16
133	01-18-89	<1	140	60	<1	<5	8	<10	19
134	03-07-89	1	110	30	<1	<5	7	<10	17
135	06-01-89	15	58	190	<3	<15	3,000	<30	42
136	08-30-88	10	80	220	<1	<5	4	10	35
137	06-05-89	1	100	20	<1	<5	8	<10	29
144	06-09-89	14	150	40	2	<5	310	10	15
145	06-01-89	20	260	40	<1	<5	9,000	30	10
146	06-02-89	<1	57	20	<1	<5	30	<10	26
149	06-07-89	5	270	80	<1	<5	7,400	<10	12
150	06-01-89	2	62	10	<1	<5	10	<10	10
151	06-08-89	1	110	30	1	<5	1,800	<10	29
152	06-08-89	<1	24	10	<1	<5	40	<10	6
153	09-03-87	--	55	20	<1	<5	45	<10	15
155	05-31-89	<1	100	<10	<1	<5	24	10	38
156	01-12-89	1	160	120	<1	<5	28	<10	33
166	06-06-89	110	120	2,700	<1	<5	23	<10	92
171	03-07-89	9	320	260	<1	<5	6	<10	18

Table 9. Concentrations of minor constituents in ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Arsenic, dissolved ($\mu\text{g/L}$ as As)	Barium, dissolved ($\mu\text{g/L}$ as Ba)	Boron, dissolved ($\mu\text{g/L}$ as B)	Cadmium, dissolved ($\mu\text{g/L}$ as Cd)	Chromium, dissolved ($\mu\text{g/L}$ as Cr)	Iron, dissolved ($\mu\text{g/L}$ as Fe)	Lead, dissolved ($\mu\text{g/L}$ as Pb)	Lithium, dissolved ($\mu\text{g/L}$ as Li)
Principal aquifers—east side of valley									
148	06-08-88	5	36	290	<1	<5	64	<10	47
165	09-20-88	49	170	100	<1	<5	17	<10	<4
172	08-24-88	2	14	340	<1	<5	9	<10	6
179	08-19-88	20	74	50	<1	<5	<.3	<10	<4
180	08-30-88	2	180	80	<1	<5	29	<10	7
Principal aquifers—west side of valley									
106	05-03-88	4	22	210	<1	<5	10	<10	140
110	08-11-86	--	--	--	--	--	--	--	--
111	08-27-87	--	--	--	--	--	--	--	--
113	08-17-88	6	41	60	<1	<5	12	<10	65
116	08-15-88	2	24	30	<1	<5	8	<10	58
122	05-24-88	2	53	20	<1	<5	<3	<10	32
126	08-16-88	2	42	20	<1	<5	<3	<10	8
127	05-24-88	2	37	10	<1	<5	3	<10	<4
130	08-18-88	17	51	70	<1	<5	12	10	7
138	09-08-88	31	27	60	<1	<5	29	<10	<4
154	09-02-87	--	53	30	<1	<5	3	<10	10
157	08-25-88	8	28	10	<1	<5	<3	<10	5
160	08-26-87	1	15	10	<1	<5	<3	<10	8
162	05-11-88	1	23	10	<1	<5	<3	<10	8
163	09-04-87	--	--	--	--	--	--	--	--
174	09-02-88	9	17	10	<1	<5	4	<10	9
182	05-25-88	23	31	40	<1	<5	<3	<10	11
184	08-17-88	28	43	30	<1	<5	7	<10	11
185	08-12-88	2	50	10	<1	<5	11	<10	30
Thermal aquifers									
181	1979 ^a	75	<.10	1,500	--	--	30	--	216

Table 9. Concentrations of minor constituents in ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Man- ganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Carbon, organic, dissolved (mg/L as C)
CARSON VALLEY									
Upland aquifers									
78	08-27-87	--	--	--	--	0.16	<0.01	<0.01	0.5
104	06-09-88	1	<0.1	<1	<1	1.0	<.01	<.01	.7
Shallow aquifers									
1	07-19-88	130	<.1	<1	<1	0.58	<0.01	<0.01	1.0
29	08-23-88	43	<.1	<1	<1	<.10	<.01	<.01	.4
53	08-03-87	490	<.1	<1	1	<.10	<.01	.08	3.9
56	08-09-88	460	<.1	<1	<1	.92	.03	.03	3.3
58	09-05-86	520	<.1	<1	<1	.93	.06	.02	3.4
59	07-06-88	110	<.1	1	1	.68	<.01	<.01	2.5
64	09-04-86	270	<.1	<1	<1	.62	.05	1.2	6.3
67	08-09-88	21	<.1	<1	<1	1.5	<.01	.04	3.0
83	07-14-88	2,200	<.1	<1	<1	.13	.01	.90	2.2
86	06-30-87	--	--	--	--	<.10	<.01	.18	2.8
89	09-02-86	490	<.1	<1	<1	<.10	<.01	.22	1.5
96	07-20-88	20	<.1	<1	2	.87	<.01	.03	--
100	08-29-83	110	<.1	<1	<1	<.10	<.00	.22	1.5
103	01-14-88	--	--	--	--	<.01	.01	.12	--
Principal aquifers—east side of valley									
14	08-24-87	--	--	--	--	2.8	<0.01	<0.01	1.1
20	08-24-87	--	--	--	--	4.3	<.01	<.01	.6
27	08-20-87	--	--	--	--	1.0	<.01	.03	.7
39	06-16-88	<1	<0.1	<1	<1	.46	<.01	<.01	.7
46	05-09-88	220	<.1	<1	<1	<.10	<.01	.07	.4
84	06-25-87	--	--	--	--	1.5	<.01	.01	.5
87	08-04-88	40	<.1	<1	<1	<.10	<.01	.04	1.1
90	08-25-87	--	--	--	--	1.0	<.01	<.01	.6
92	08-30-83	100	<.1	<1	<1	<.10	<.00	.16	.3
93	05-05-88	4	<.1	1	<1	.86	<.01	<.01	.7
107	08-29-83	310	<.1	<1	<1	<.10	<.00	.03	.5
Principal aquifers—west side of valley									
3	07-28-88	<1	.2	<1	<1	0.93	0.01	0.07	0.7
12	06-16-88	150	<.1	<1	1	<.10	<.01	<.01	.7
16	08-22-83	<1	.1	<1	2	1.8	<.00	<.00	.4
17	08-10-88	10	<.1	<1	<1	2.0	<.01	<.01	1.6
18	05-05-88	3	<.1	3	<1	1.3	<.01	<.01	.7
21	07-21-88	1	<.1	<1	<1	.54	<.01	<.01	.7
28	07-14-88	190	<.1	<1	<1	1.2	<.01	<.01	.6
30	05-04-88	1	<.1	<1	<1	2.2	<.01	.03	.5
31	06-15-88	<1	<.1	<1	1	2.4	<.01	<.01	.6
32	07-25-88	<1	<.1	<1	<1	1.6	<.01	<.01	.6

Table 9. Concentrations of minor constituents in ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Man- ganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Carbon, organic, dissolved (mg/L as C)
Principal aquifers—west side of valley—Continued									
34	08-23-88	<1	<.1	<1	<1	1.8	<.01	<.01	.6
37	08-30-83	1	<.1	<1	<1	.90	<.00	<.00	.5
38	07-21-88	<1	<.1	<1	1	1.3	<.01	<.01	.8
43	07-27-88	1	<.1	<1	<1	.86	<.01	<.01	.7
47	07-25-88	<1	<.1	<1	<1	.80	<.01	<.01	.8
55	08-18-83	110	<.1	<1	<1	<.10	<.00	.07	.2
81	06-09-88	41	<.1	<1	<1	<.10	<.01	.21	1.2
101	08-24-83	53	.1	<1	<1	<.10	<.00	<.00	.6
105	07-28-88	<1	<.1	<1	<1	1.0	<.01	<.01	.5
Thermal aquifers									
97	1979 ^a	--	--	--	--	<.01	--	--	--
98	1979 ^a	--	--	--	--	<.01	--	--	--
99	08-26-83	330	<.1	<1	<1	<.10	<.00	0.38	--
EAGLE VALLEY									
Upland aquifers									
141	09-08-88	1,600	<.1	<1	<1	<.10	<.01	0.03	0.8
176	09-07-88	6	<.1	<1	<1	<.10	<.01	<.01	.5
Shallow aquifers									
131	05-31-89	1	<.1	<1	<1	17	<.01	0.01	1.8
133	01-18-89	2	<.1	<1	<1	15	<.01	.01	2.6
134	03-07-89	200	<.1	<1	<1	3.2	<.01	<.01	1.4
135	06-01-89	1,300	<.1	<1	<3	<.10	<.01	.09	3.7
136	08-30-88	87	<.1	<1	<1	<.10	<.01	.02	1.5
137	06-05-89	340	<.1	<1	4	4.7	.01	.04	3.1
144	06-09-89	830	<.1	<1	2	<.10	<.01	.02	2.3
145	06-01-89	3,400	<.1	<1	3	<.10	<.01	.18	2.8
146	06-02-89	2	<.1	<1	<1	11	<.01	.01	1.8
149	06-07-89	700	<.1	<1	<1	.23	<.01	.17	2.4
150	06-01-89	430	<.1	<1	<1	<.10	<.01	.05	1.4
151	06-08-89	1,600	<.1	<1	<1	<.10	<.01	.09	3.7
152	06-08-89	190	<.1	<1	<1	<.10	<.01	.02	1.0
153	09-03-87	460	--	<1	<1	<.10	<.01	.03	2.5
155	05-31-89	4	<.1	<1	2	2.4	<.01	<.01	1.3
156	01-12-89	28	<.1	2	1	17	<.01	.04	3.9
166	06-06-89	540	<.1	<1	2	<.10	<.01	.02	5.1
171	03-07-89	46	<.1	1	<1	11	<.01	.02	2.9
Principal aquifers—east side of valley									
148	06-08-88	66	<.1	<1	<1	<.10	<.01	0.06	1.5
165	09-20-88	29	<.1	<1	1	<.10	.01	.01	.4
172	08-24-88	25	<.1	<1	<1	<.10	<.01	.04	.3
179	08-19-88	220	<.1	<1	<1	<.10	<.01	.01	.6
180	08-30-88	1	<.1	2	<1	20	<.01	.02	2.4

Table 9. Concentrations of minor constituents in ground water at selected sites in Carson and Eagle Valleys—Continued

Site (figs. 3 and 4)	Date	Manganese, dissolved ($\mu\text{g/L}$ as Mn)	Mercury, dissolved ($\mu\text{g/L}$ as Hg)	Selenium, dissolved ($\mu\text{g/L}$ as Se)	Silver, dissolved ($\mu\text{g/L}$ as Ag)	Nitrogen, nitrate, dissolved (mg/L as N)	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Carbon, organic, dissolved (mg/L as C)
Principal aquifers—west side of valley									
106	05-03-88	2	<.1	<.1	<.1	0.39	<.01	<.01	0.4
110	08-11-86	--	--	--	--	19	<.01	<.03	2.4
111	08-27-87	--	--	--	--	12	<.01	<.01	1.1
113	08-17-88	1	<.1	<.1	<.1	2.4	<.01	<.01	.5
116	08-15-88	230	<.1	<.1	<.1	.43	<.01	<.01	.7
122	05-24-88	16	<.1	<.1	1	.85	<.01	.01	.6
126	08-16-88	<.1	<.1	<.1	<.1	3.7	<.01	<.01	.4
127	05-24-88	7	<.1	<.1	<.1	1.1	<.01	<.01	.6
130	08-18-88	4	<.1	<.1	<.1	.48	<.01	<.01	.5
138	09-08-88	89	<.1	<.1	<.1	<.10	<.01	.06	.7
154	09-02-87	460	--	<.1	<.1	<.10	<.01	.04	1.4
157	08-25-88	1	<.1	<.1	<.1	.15	<.01	<.01	.5
160	08-26-87	<.1	--	<.1	1	.49	<.01	.01	.5
162	05-11-88	<.1	<.1	<.1	2	.52	<.01	.02	.4
163	09-04-87	--	--	--	--	.88	<.01	.01	1.2
174	09-02-88	<.1	<.1	<.1	<.1	.31	<.01	<.01	.4
182	05-25-88	4	<.1	<.1	<.1	.34	<.01	<.01	.5
184	08-17-88	<.1	<.1	<.1	<.1	1.7	<.01	<.01	.4
185	08-12-88	8	<.1	<.1	<.1	1.7	.03	.01	.6
Thermal aquifers									
181	1979 ^a	--	--	--	--	<.01	--	--	--

The dissolved organic carbon in anoxic water can further react with iron and manganese oxides, if they are present on the aquifer material, producing water with relatively high concentrations of these two metals.

Reaction of dissolved inorganic carbon with iron and manganese oxides is consistent with the geohydrologic regime in the shallow subsurface of Carson and Eagle Valleys. Most of the sampled ground water with high concentrations of iron and manganese came from the shallow aquifers. The shallow aquifer sediments primarily consist of alluvial and colluvial deposits which, in general, have oxide coatings (Jenne, 1968). Prior to irrigation of agricultural and urban land, the water table was probably below present altitudes throughout much of area, particularly in areas away from surface-water drainages. Application of water for urban and agricultural use has led to wetting of previously unsaturated sediments. The rise in water level apparently has resulted in the dissolution of sedimentary organic matter, which then reacted with the oxygen in the recharge water and subsequently with the oxide

coatings on the aquifer materials. Thus, water with high iron and manganese concentrations in the shallow aquifers may be an indirect result of raising the water table by recharge from agricultural and urban activities.

Ground water in Carson and Eagle Valleys with relatively high iron and manganese concentrations is generally at or near saturation with respect to the carbonate minerals siderite and rhodochrosite (figs. 26A and B). Although these minerals have not been identified as discrete phases in the basin-fill sediments, they have been shown to form in anaerobic nonmarine water. Siderite has been identified as a secondary mineral precipitating from oxygen-depleted ground water in shallow sediments (Magaritz and Luzier, 1985) and rhodochrosite has been reported from several localities (Jones and Bowser, 1978, p. 215-219). Iron and manganese may sorb onto calcite surfaces, and at high metal concentrations, form discrete solid phases of the sorbates, as indicated by laboratory experiments for manganese (Zachara and others, 1991). Formation of iron and manganese carbonate phases, either as discrete

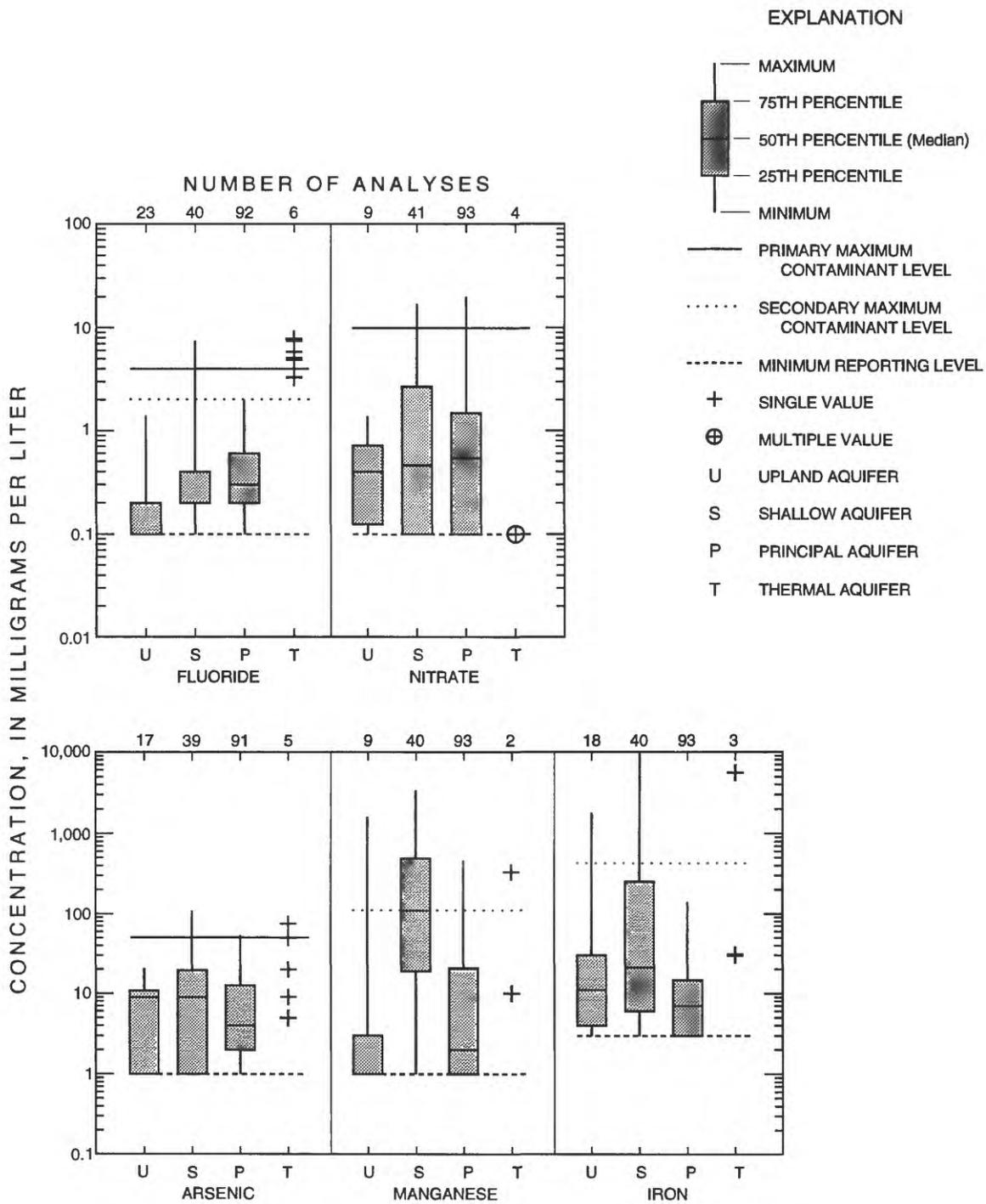


Figure 23. Concentrations of fluoride, nitrate, arsenic, manganese, and iron in upland, shallow, principal, and thermal aquifers in Carson and Eagle Valleys.

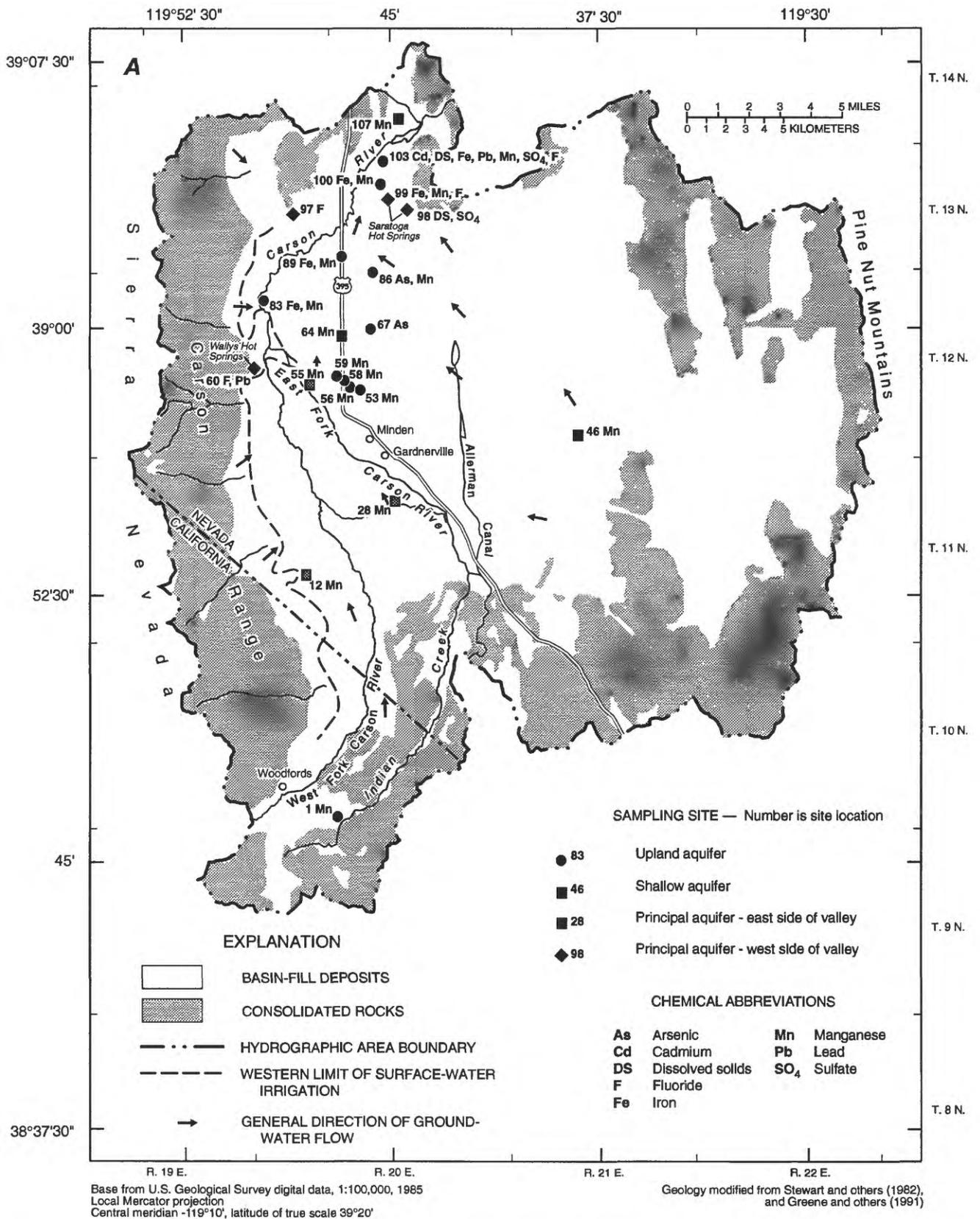


Figure 24. Location of wells with concentrations of dissolved constituents that exceed Nevada State drinking-water standards in aquifers of **A**, Carson and **B**, Eagle Valleys. Fluoride is shown for exceedances of maximum contaminant level, but not secondary maximum contaminant level.

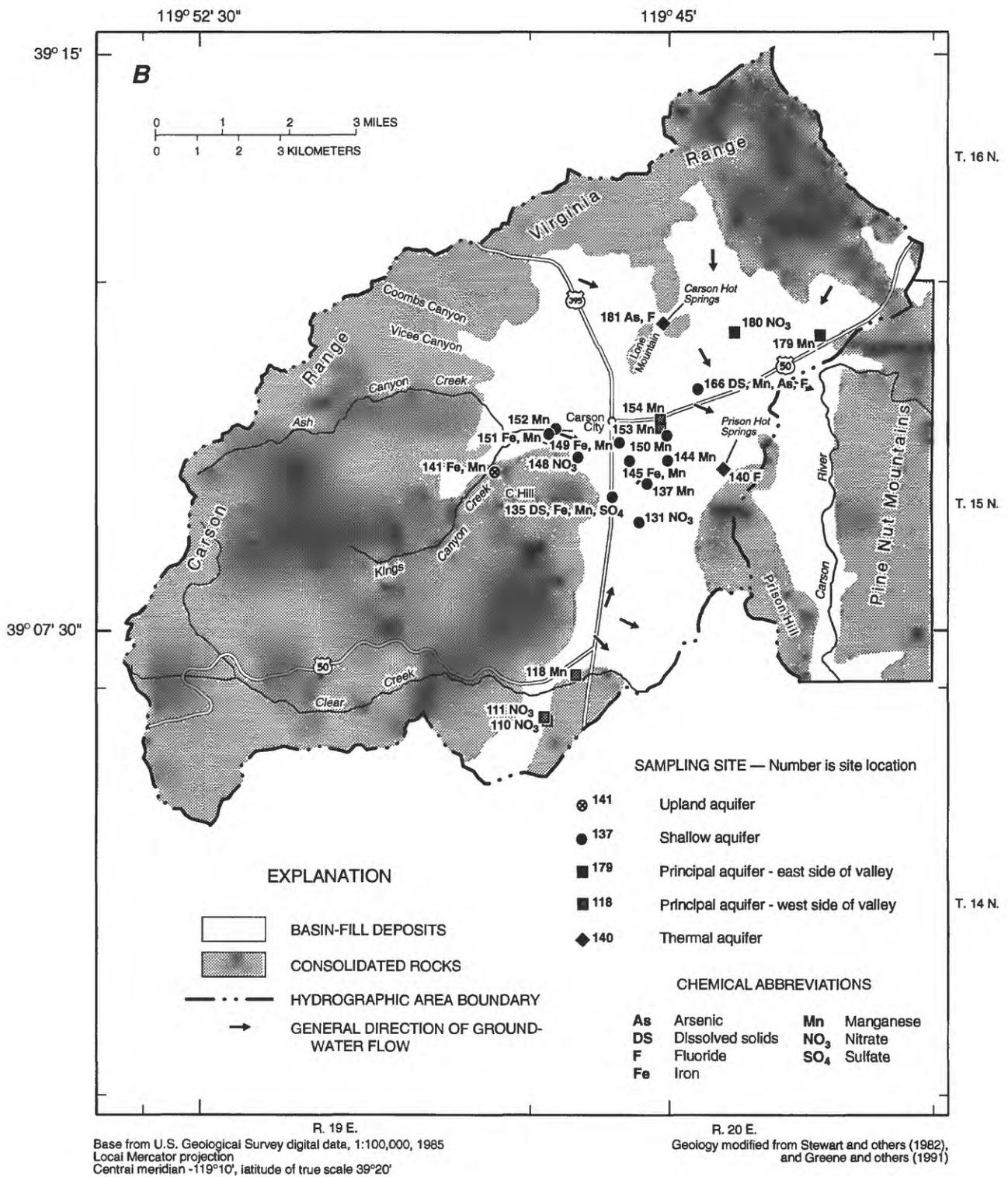


Figure 24. Location of wells with concentrations of dissolved constituents that exceed Nevada State drinking-water standards in aquifers of *A*, Carson and *B*, Eagle Valleys. Fluoride is shown for exceedances of maximum contaminant level, but not secondary maximum contaminant level—Continued.

minerals or on calcite surfaces, appears to limit concentrations of the two metals in some ground water with low dissolved oxygen concentrations.

Radionuclides

Water Quality and Its Relation to Drinking-Water Standards

Radionuclides in ground water of the Carson River Basin that are of concern include uranium and its radioactive progeny, particularly radon. Measurements of gross-alpha and beta activities are commonly used as indicators of the presence of radionuclides and are used as screening methods for public-water supplies (USEPA, 1991). These two gross-activity measurements provide an estimate of the total contribution from dissolved alpha and beta emitters, except for gases and water. Because the analyses are made on dried residue (Thacher and others, 1977), the measured radioactivity does not reflect the activities of tritium or of gases such as radon.

The uranium activities and gross-alpha activities range from less than 1 to about 40 pCi/L. Although the number of analyses available for the upland and shallow aquifers is limited, these two aquifer systems appear to have uranium activities and gross-alpha activities in the same general range as found in the principal aquifers (fig. 27A; table 11). Uranium generally does not exceed the proposed standard, which is based on concentration rather than activity. Gross-beta activities generally ranged from about 2 to 30 pCi/L (fig. 27C). Limited analyses for gross-beta activities indicated little difference in the ranges for these two gross measurements among the aquifers sampled. Activity caused by dissolved radium-226 (an alpha-emitting isotope) was generally low relative to the gross-alpha activity (fig. 27). On the basis of only a few analyses for radium-226 and -228 (18 and 8 analyses, respectively) the ground water does not appear to exceed either the present (1990) combined MCL (5 pCi/L, table 2) or the proposed 20 pCi/L (USEPA, 1991) for each of these radionuclides. Radon-222 activities range from about 100 to more than 10,000 pCi/L with the few analyses of the upland aquifers having some of the highest concentrations.

In general, uranium is the primary source of gross-alpha activity in ground water of Carson and Eagle Valleys (fig. 28), assuming the uranium activity ratio (the ratio of the activity of uranium-234 to

uranium-238 expressed in pCi/L) is in the range found for ground water in the Carson River Basin. The radioactivity of a given mass of uranium is produced by the contribution from three isotopes. Because these isotopes have different half-lives, the mass of each isotope must be accounted for when estimating the alpha activity from a measurement of a mass of uranium. Two uranium isotopes, uranium-234 and uranium-238, are the primary sources of gross-alpha activity in ground water of the entire Carson River Basin; a third uranium isotope, uranium-235, provides less than 5 percent of the total alpha activity from the dissolved uranium (Faure, 1986, p. 288). The uranium activity ratio has a narrow range, from 1.0 to 1.33, for dissolved uranium concentrations up to about 60 pCi/L. Although the uranium-isotope composition was determined for samples from only seven ground-water sites in Carson and Eagle Valleys (table 12), the uranium activity ratios were within the range found elsewhere in the Carson River Basin (Thomas and others, 1993). Almost all sampled ground water had uranium concentrations within 5 pCi/L of the gross-alpha activity (fig. 28).

The gross-beta activities in ground water of Carson and Eagle Valleys are all less than 30 pCi/L (appendix and fig. 27). Naturally occurring sources of beta activity in ground water probably include potassium-40 and radium-228. Additional potential sources of beta activity are progeny of uranium-238 produced between the time of sample collection and counting (Thomas and others, 1993). The ingrowth of beta-emitting progeny of uranium-238 plus the contribution of potassium-40 can account for the measured gross-beta activities (fig. 29).

The uranium concentrations in the different aquifers exceeded the proposed 20 µg/L limit (USEPA, 1991) at 10 of 77 sites (table 13). The sites with uranium concentrations greater than 20 µg/L tap shallow aquifers in the northern half of Carson Valley and upland and principal aquifers in Eagle Valley (fig. 30). Except for sites in the east, water from all principal aquifer sites of northern Eagle Valley exceeds 10 µg/L, including 5 sites with uranium concentrations greater than proposed MCL. Of 39 ground-water sites where water has been analyzed for uranium and all the inorganic constituents with MCL's, 6 samples exceed one or more MCL. If the proposed 20 µg/L MCL for uranium is applied to the 39 samples, then water from 9 of

Table 10. Number of sites in Carson and Eagle Valleys where ground water has one or more inorganic constituents exceeding Nevada State maximum contaminant levels and secondary maximum contaminant levels

[Analyses that include all inorganic constituents with established maximum contaminant levels and secondary maximum contaminant levels are considered "comprehensive" for purpose of this summary.]

	Number of sites with analyses that exceed the primary maximum contaminant level	Number of sites with analyses that exceed the primary or secondary maximum contaminant level	Total number of sites
Upland aquifers			
All sites	0	1	32
Sites with comprehensive analyses	0	1	8
Shallow aquifers			
All sites	6	24	42
Sites with comprehensive analyses	6	23	39
Principal aquifers			
All sites	3	11	107
Sites with comprehensive analyses	3	10	89
Thermal aquifers			
All sites	5	6	6
Sites with comprehensive analyses	1	1	1
All aquifers			
All sites	14	42	187
Sites with comprehensive analyses	10	35	137

the sites would exceed at least one MCL, which represents a 50 percent increase in the frequency of exceedance.

Almost all ground-water samples from the principal aquifers (97 of 103 sites) exceed the proposed 300 pCi/L MCL for radon (USEPA, 1991). The highest radon activities (greater than 5,000 pCi/L) are most common in the upland aquifers in the Sierra Nevada and in the principal aquifers on the west sides of Carson and Eagle Valleys (fig. 31).

In summary, measured radioactivities do not exceed the established MCL for gross-alpha activity or radium-226 plus radium-228 (table 13). However, almost all the measured radon-222 activities exceed the proposed MCL of 300 pCi/L. The uranium concentrations in the various aquifers exceed the proposed

20 µg/L limit at 10 of 77 sites. None of the limited number of analyses for radium-226 and radium-228 exceed 5 pCi/L, the proposed MCL (USEPA, 1991).

Processes Affecting Radionuclide Concentrations

A conceptual model explaining the uranium and radon-222 concentrations in ground water of the Carson River Basin has been proposed (Thomas and others, 1993). The model is consistent with the areal distribution of the radon-222 concentrations (fig. 31) and uranium concentrations in the surficial sediments in Carson Valley (Thomas and others, 1993). Briefly, the conceptual model consists of:

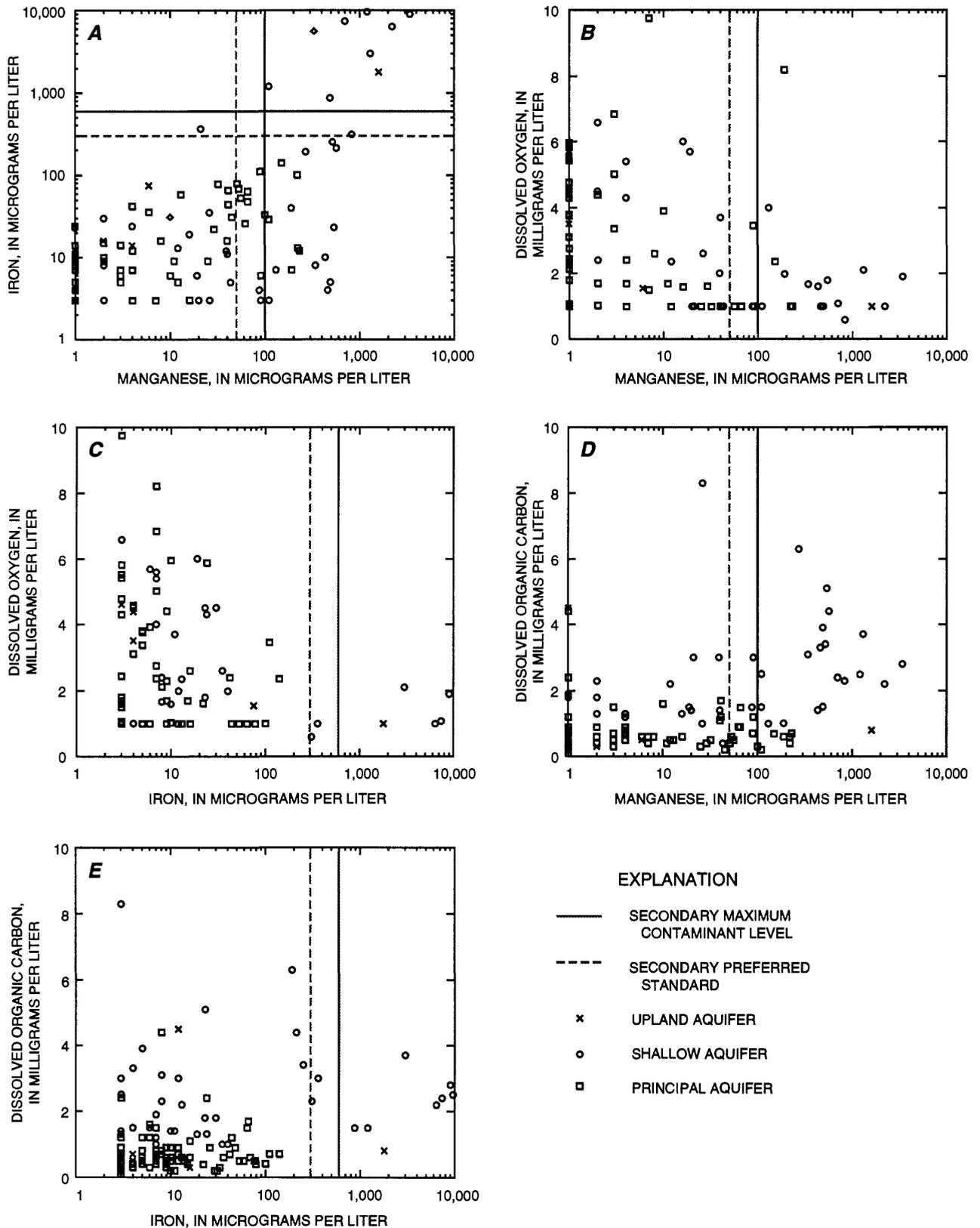


Figure 25. Relation between concentrations of dissolved **A**, iron and manganese; **B**, manganese and oxygen; **C**, iron and oxygen; **D**, manganese and dissolved organic carbon; and **E**, iron and dissolved organic carbon in ground water. Data displayed on the graphs include values below the laboratory minimum detection level.

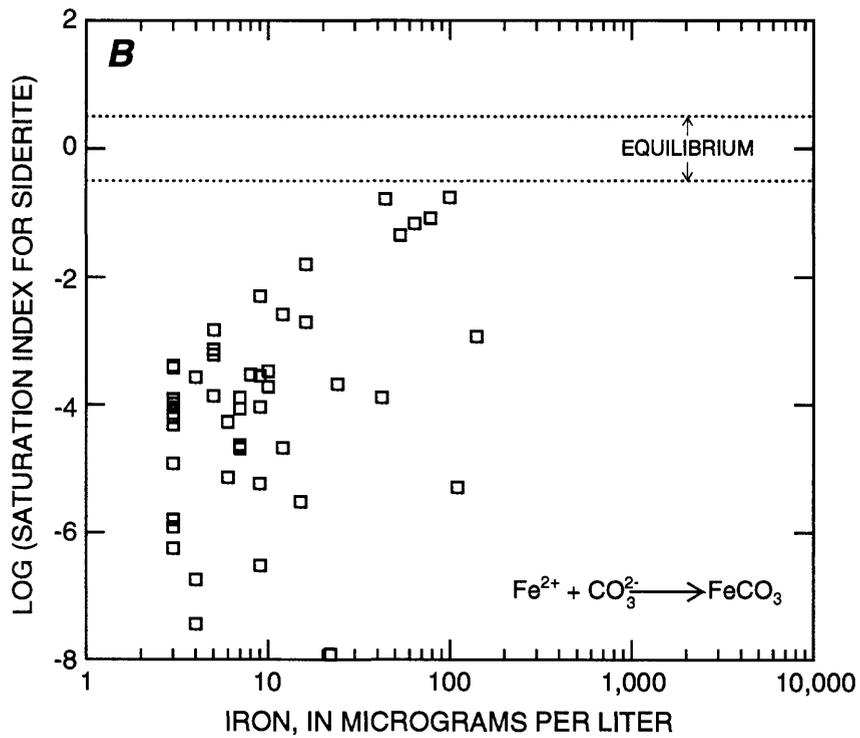
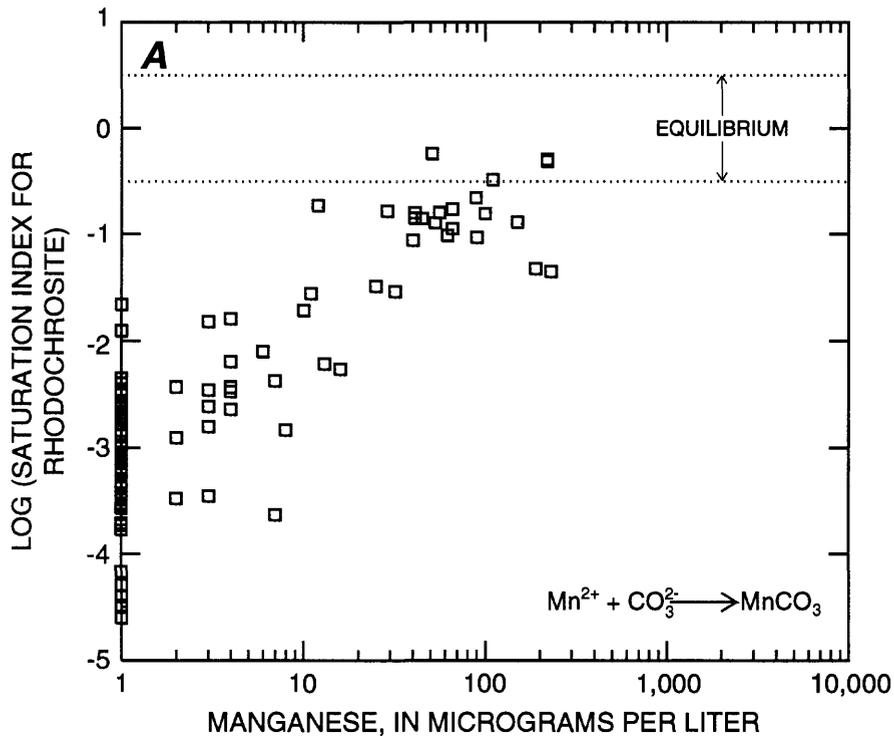


Figure 26. Relation between **A**, dissolved manganese and saturation index for rhodochrosite and **B**, dissolved iron and saturation index for siderite. Data displayed on the graphs include values below the laboratory minimum detection levels.

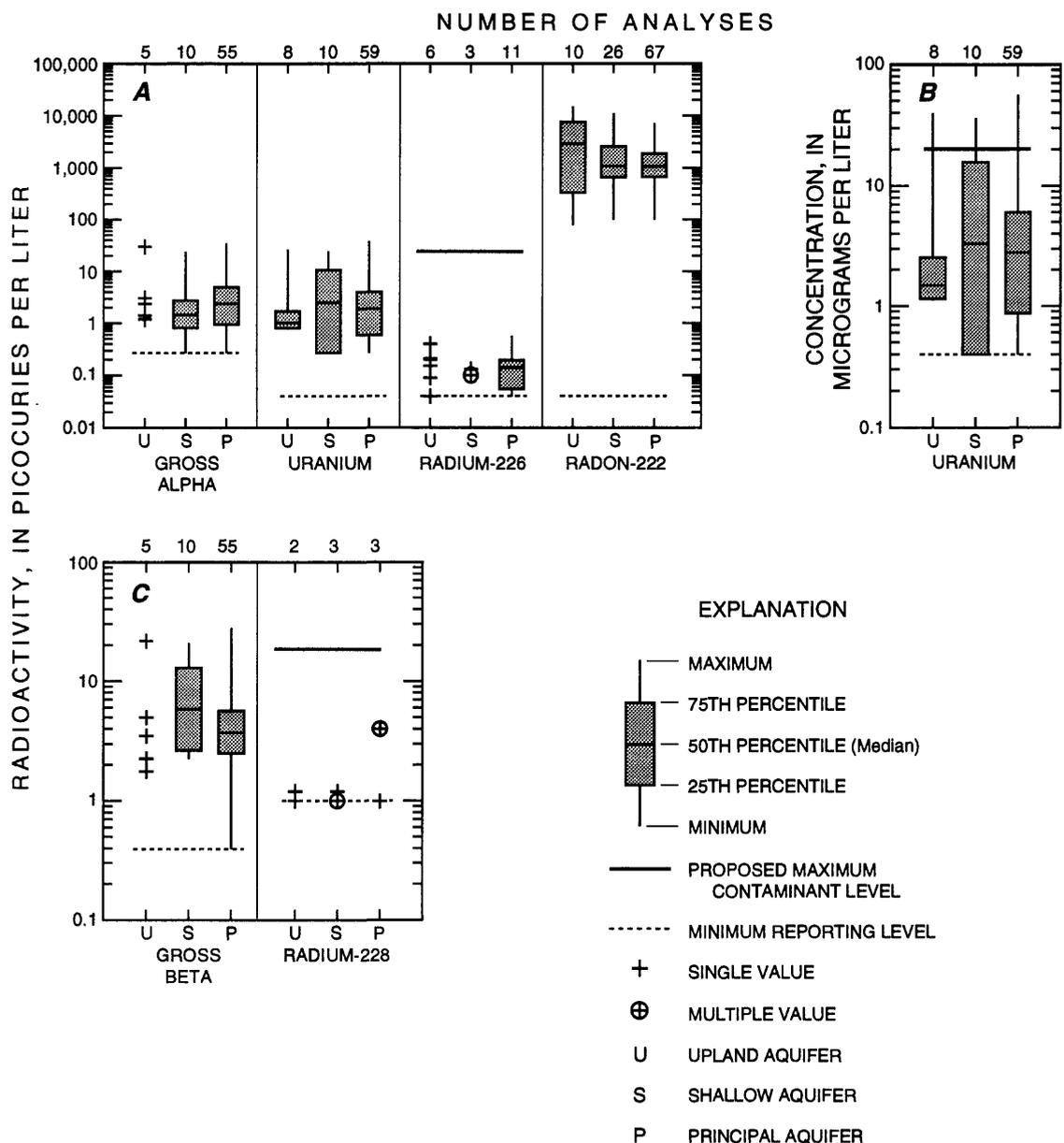


Figure 27. Summary statistics for **A**, gross alpha, uranium, radium-226, and radon-222 activity; **B**, concentrations of uranium; and, **C**, gross-beta activity and radium-228 activity in ground water of Carson and Eagle Valleys.

(1) Weathering of primary minerals in the Sierra Nevada resulting in the release of uranium to ground water in the upland aquifers.

(2) Adsorption and coprecipitation of the uranium onto iron and manganese oxides. Radioactive progeny of uranium in the decay series between uranium-238 and radon-222 also are strongly adsorbed to aquifer materials.

(3) Additional adsorption of uranium and radium onto sedimentary organic matter in the basin-fill sediments, such as along the base of the Sierra

Nevada. Radioactive progeny of uranium in the decay series between uranium-238 and radon-222 are again strongly adsorbed to aquifer materials.

This model, shown schematically on figure 32, has been outlined by Thomas and others (1993). The model explains the relatively high concentrations of radon-222, which is produced by the decay of radioactive progeny of uranium-238, both in granitic rocks of the Sierra Nevada and in aquifer material of the principal aquifers beneath the western part of Carson Valley. The high radon-222 concentrations in the

Table 11. Concentrations of radionuclides in ground water at selected sites in Carson and Eagle Valleys

[Uranium values (natural) in pCi/L are calculated from corresponding uranium values in µg/L by assuming that activity ratio of U-234 to U-238 is 1. Units of measure and symbols: mg/L, milligrams per liter; pCi/L, picocuries per liter; --, not determined; <, less than; µg/L, micrograms per liter; Cs-147, cesium-147; Sr-90/Y-90, strontium-90/yttrium-90]

Site (figs. 3 and 4)	Date	Radon-222, dissolved (pCi/L)	Radium-226, dissolved, radon method (pCi/L)	Radium-228, dissolved as Ra-228 (pCi/L)	Uranium, dissolved as U (µg/L)	Uranium, dissolved (pCi/L)	Gross alpha, dissolved as U, natural (µg/L)	Gross alpha, dissolved (pCi/L)	Gross beta, dissolved as Sr-90/Y-90 (pCi/L)
CARSON VALLEY									
Upland aquifers									
78	08-27-87	380	--	--	--	--	--	--	--
104	06-09-88	790	--	--	2.5	1.7	2.1	1.4	2.2
Shallow aquifers									
1	07-19-88	5,200	--	--	<0.40	<0.27	1.0	.68	2.3
29	08-23-88	550	--	--	5.5	3.7	5.3	3.6	5.0
56	08-09-88	1,200	--	--	26	18	25	17	15
59	07-06-88	--	--	--	21	14	28	19	12
59	08-15-89	550	0.10	<1.0	30	20	--	.27	9.7
67	08-09-88	--	--	--	6.4	4.3	4.7	3.2	8.2
83	07-14-88	560	--	--	<.40	<.27	1.8	1.2	6.7
96	07-20-88	880	--	--	36	24	35	24	21
Principal aquifers—east side of valley									
14	08-24-87	<100	--	--	--	--	--	--	--
27	08-20-87	440	--	--	--	--	--	--	--
39	06-16-88	860	--	--	3.6	2.4	6.2	4.2	4.3
46	05-09-88	--	--	--	<.40	<.27	<.40	<.27	3.3
87	08-04-88	850	--	--	<.40	<.27	.70	.48	3.8
90	08-25-87	460	--	--	--	--	--	--	--
93	05-05-88	280	--	--	4.5	3.1	6.7	4.5	5.3
Principal aquifers—west side of valley									
3	07-28-88	3,200	--	--	--	--	4.0	2.7	4.8
12	06-16-88	700	--	--	3.6	2.4	.80	.54	1.5
15	07-07-87	760	--	--	--	--	--	--	--
17	08-10-88	1,500	--	--	6.1	4.1	7.9	5.4	5.5
18	05-05-88	1,200	--	--	.80	.54	1.3	.88	2.3
21	07-21-88	1,400	--	--	.50	.34	.60	.41	2.0
28	07-14-88	1,100	--	--	.50	.34	<.40	<.27	2.0
30	05-04-88	760	--	--	1.5	1.0	2.0	1.4	3.6
31	06-15-88	7,000	--	--	15	10	10	6.8	14
32	07-25-88	1,300	--	--	.80	.54	1.1	.75	2.9
34	08-23-88	940	--	--	3.2	2.2	4.9	3.3	5.0
38	07-21-88	1,200	--	--	5.7	3.9	7.2	4.9	4.2
43	07-27-88	710	--	--	1.1	.75	1.4	.95	2.5
47	07-25-88	690	--	--	2.0	1.4	2.8	1.9	3.8
81	06-09-88	1,400	--	--	<.40	<.27	4.3	2.1	3.9
105	07-28-88	940	--	--	--	--	6.2	4.2	2.0

Table 11. Concentrations of radionuclides in ground water at selected sites in Carson and Eale Valleys—Continued

Site (figs. 3 and 4)	Date	Radon-222, dissolved (pCi/L)	Radium- 226, dissolved, radon method (pCi/L)	Radium- 228, dissolved as Ra-228 (pCi/L)	Uranium, dissolved as U (µg/L)	Uranium, dissolved (pCi/L)	Gross alpha, dissolved as U, natural (µg/L)	Gross alpha, dissolved (pCi/L)	Gross beta, dissolved as Sr-90/ Y-90 (pCi/L)
EAGLE VALLEY									
Upland aquifers									
129	06-02-89	14,000	0.15	--	29	20	--	--	--
141	09-08-88	3,600	--	--	1.6	1.1	3.5	2.4	3.6
176	09-07-88	14,000	--	--	39	26	41	28	21
176	07-12-89	10,000	.20	<1.0	--	--	--	--	--
Shallow aquifers									
131	05-31-89	1,100	--	--	--	--	--	--	--
134	03-07-89	1,000	--	--	--	--	--	--	--
136	08-30-88	1,100	--	--	1.5	1.0	2.5	1.7	2.9
146	06-02-89	5,100	--	--	--	--	--	--	--
155	05-31-89	5,100	--	--	--	--	--	--	--
156	01-12-89	3,200	--	--	--	--	--	--	--
171	03-07-89	660	--	--	--	--	--	--	--
Principal aquifers—east side of valley									
148	06-08-88	360	--	--	2.7	1.8	3.9	2.6	3.8
165	09-20-88	2,100	--	--	12	8.1	21	14	7.8
172	08-24-88	630	--	--	.50	.34	1.1	.75	5.9
179	08-19-88	240	--	--	<.40	<.27	.60	.41	4.7
180	08-30-88	1,900	--	--	56	38	52	35	28
180	08-09-89	--	0.30	<1.0	--	--	--	--	--
Principal aquifers—west side of valley									
106	05-03-88	1,800	--	--	2.9	2.0	2.8	1.9	3.1
111	08-27-87	1,200	--	--	--	--	--	--	--
113	08-17-88	2,200	--	--	4.3	2.9	6.2	4.2	3.1
116	08-15-88	2,300	--	--	2.8	1.9	4.3	2.9	3.6
122	05-24-88	1,100	--	--	3.2	2.2	2.7	1.8	2.5
126	08-16-88	830	--	--	.60	.41	1.4	.95	1.3
127	05-24-88	1,200	--	--	2.7	1.8	2.7	1.8	2.1
130	08-18-88	1,300	--	--	1.2	.81	3.1	2.1	3.6
138	09-08-88	1,700	--	--	1.1	.75	1.1	.75	1.9
157	08-25-88	--	--	--	30	20	36	24	16
	07-12-89	2,100	--	--	--	--	--	--	--
160	08-26-87	--	0.18	4.0	--	--	--	--	--
162	05-11-88	4,900	--	--	13	8.8	12	8.1	8.1
174	09-02-88	2,800	--	--	37	25	38	26	19
182	05-25-88	2,400	--	--	25	17	19	13	9.9
184	08-17-88	2,000	--	--	2.2	1.5	3.5	2.4	2.3
185	08-12-88	2,500	--	--	38	26	42	28	18

Sierra Nevada are a result of the presence of uranium and radium along fracture surfaces, which allow rapid release of radon-222 to the ground water. Prehistoric flooding of the Carson Valley by the Carson River resulted in the inclusion of riparian vegetation into the basin-fill sediments as sedimentary organic matter. The presence of this material on the west side of Carson Valley is a result of the Carson River being continually displaced because of greater vertical movement along the base of the Sierra Nevada than on the east side of the valley. Details of the model are described by Thomas and others (1993).

Synthetic Organic Compounds

Some synthetic organic compounds pose a potential health hazard if released into the environment. Of particular concern are synthetic organic compounds including volatile constituents and pesti-

cides. The various aquifer systems in Carson and Eagle Valleys were sampled for volatile organic compounds as part of the Carson River Basin NAWQA project. In addition, the shallow aquifers were sampled for selected pesticides beneath both agricultural and urban areas because of their greater susceptibility to contamination from surface sources. The shallow-aquifer sampling as part of the NAWQA project included 10 sites in agricultural areas and 20 sites within the urbanized part of Eagle Valley (S.J. Lawrence, U.S. Geological Survey, written commun., 1992). Results of ground-water sampling for volatile organic compounds prior to 1988 have been summarized by Welch and others (1990). Table 14 summarizes the results of the more recent NAWQA sampling for organic compounds that have MCL's. Because only the most recent analysis was used for this summary, the maximum concentrations observed at all sites are not necessarily included.

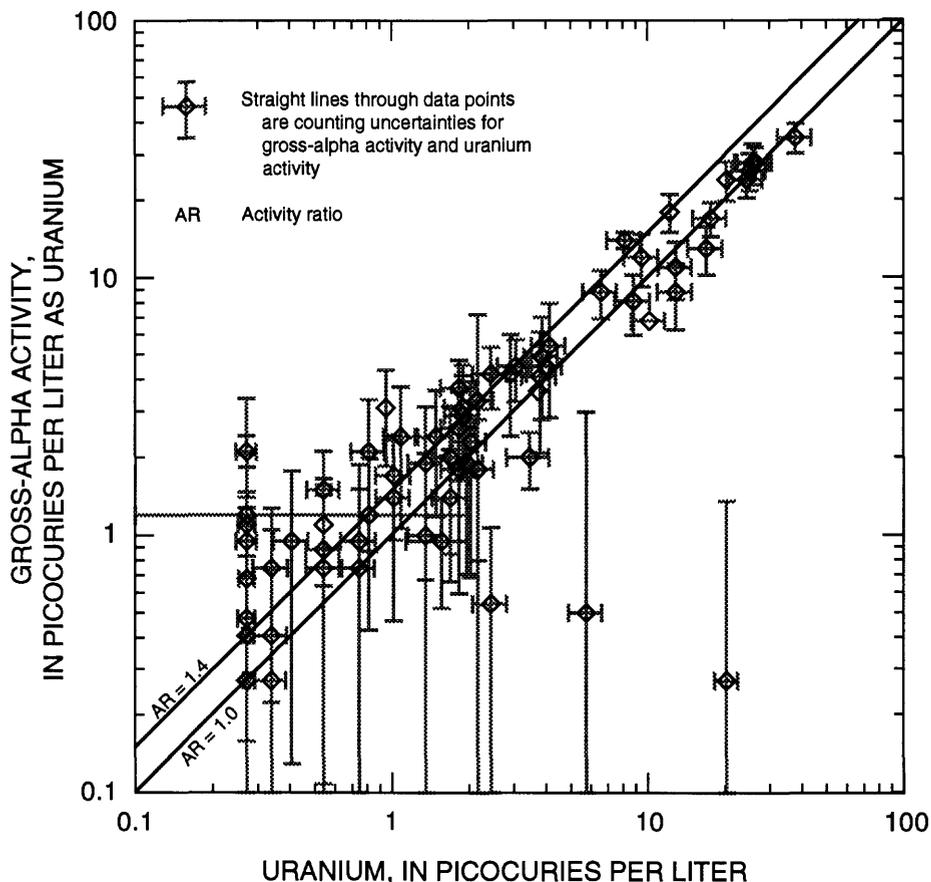


Figure 28. Relation between gross-alpha and uranium activity in ground water of Carson and Eagle Valleys.

Table 12. Uranium-isotope data for ground water in Carson and Eagle Valleys

[Units of measure and symbol: pCi/L, picocuries per liter; --, not determined]

Site (figs. 3 and 4)	Uranium-234, dissolved (pCi/L)	Uranium-235, dissolved (pCi/L)	Uranium-238, dissolved (pCi/L)
6	0.7	--	0.6
158	0.4	0.01	.4
176	17.	--	15.
183	5.1	--	5.1
147	7.5	.26	7.0
160	7.4	.27	6.9
162	4.7	.31	4.6

As indicated by analyses in table 14, samples from the upland and principal aquifers indicate that volatile organic compounds have not been found at concentrations above the laboratory minimum. Shallow aquifers in some areas contain water that exceeds the MCL's for some organic compounds. Shallow aquifers underlying agricultural land generally do not contain concentrations of synthetic organic compounds above the reporting level. Analytical results for water from 10 shallow wells sampled as part of the NAWQA project show that compounds listed in table 14 are not present at concentrations that exceed the MCL's. As previously discussed (Welch and others, 1990a, p. 45-46), volatile organic compounds, including trichloroethylene and 1,1,1-trichloroethane, have been reported in wells tapping the shallow aquifers in the vicinity of the Douglas County Airport in northern Carson Valley at concentrations that exceed MCL's.

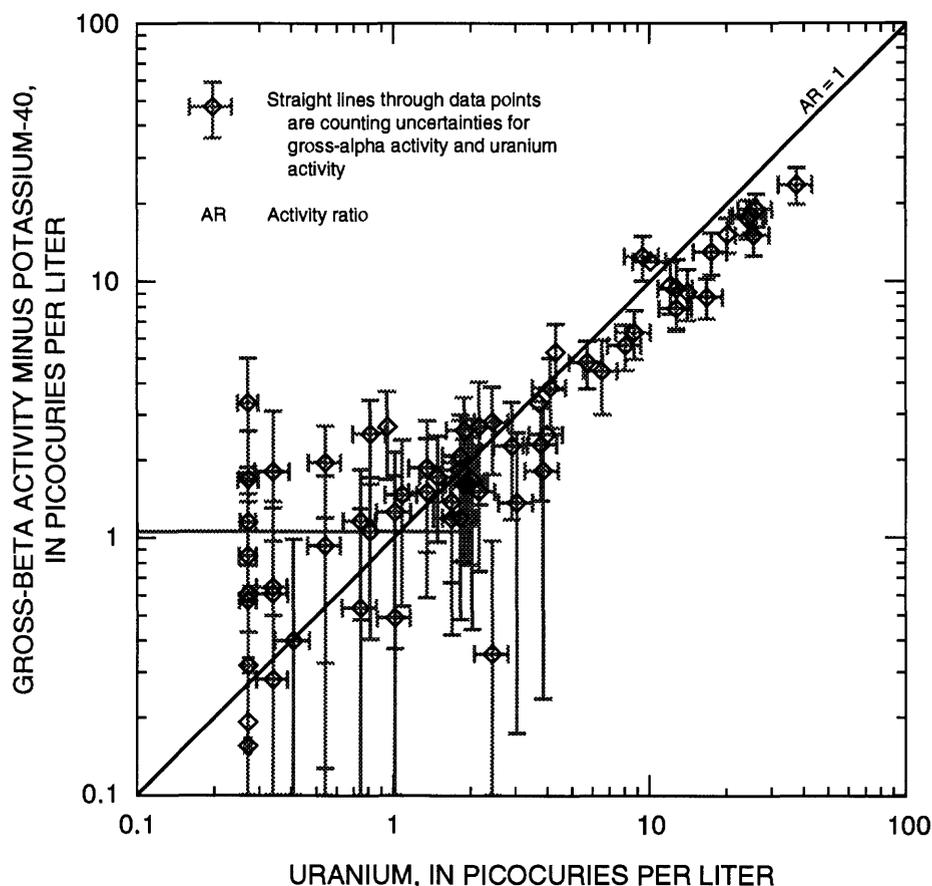


Figure 29. Relation between gross-beta activity minus gross-beta contribution from potassium-40 and uranium activities in ground water from principal aquifers in Carson and Eagle Valley.

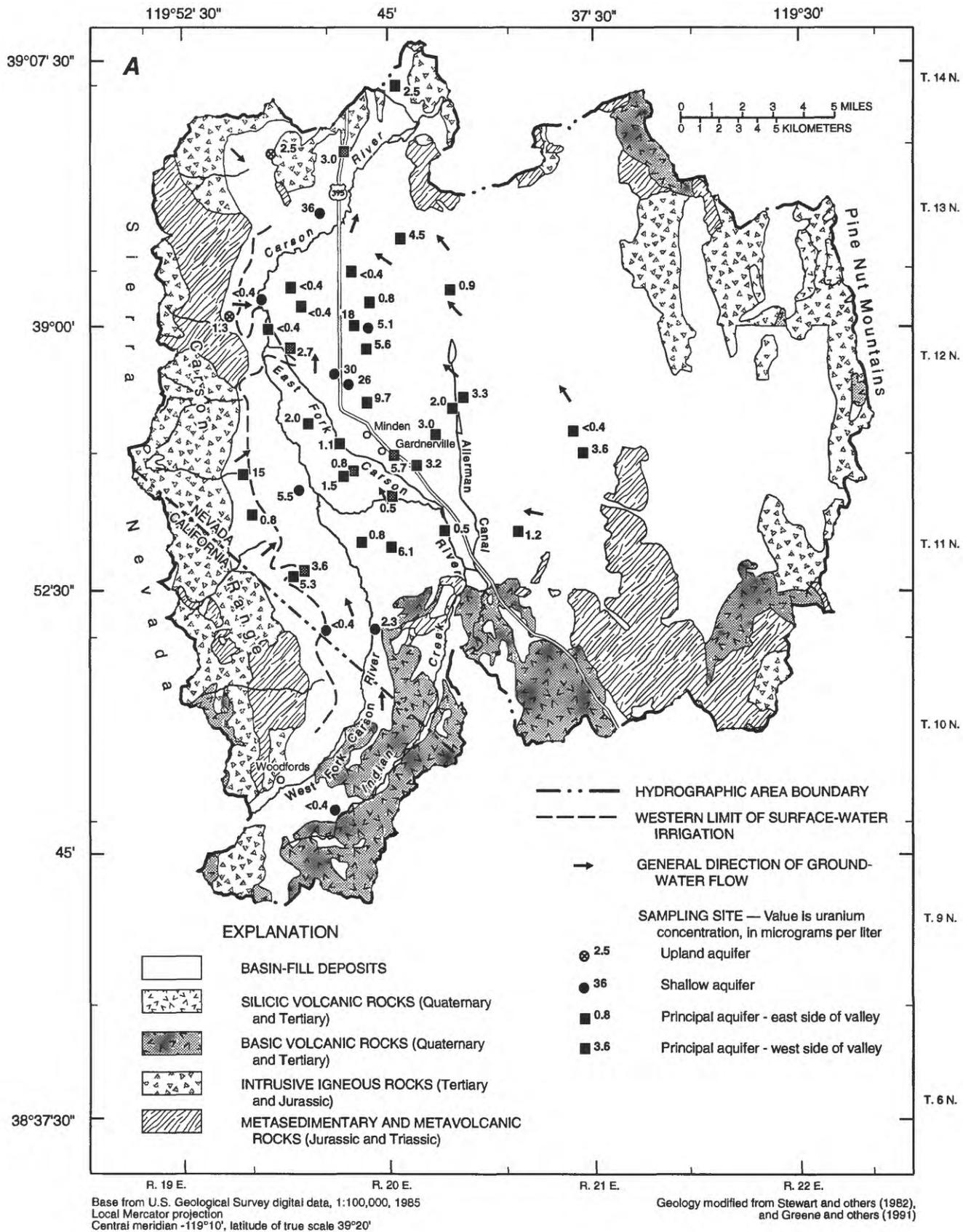


Figure 30. Uranium concentrations in ground water at selected sites in **A**, Carson and **B**, Eagle Valleys.

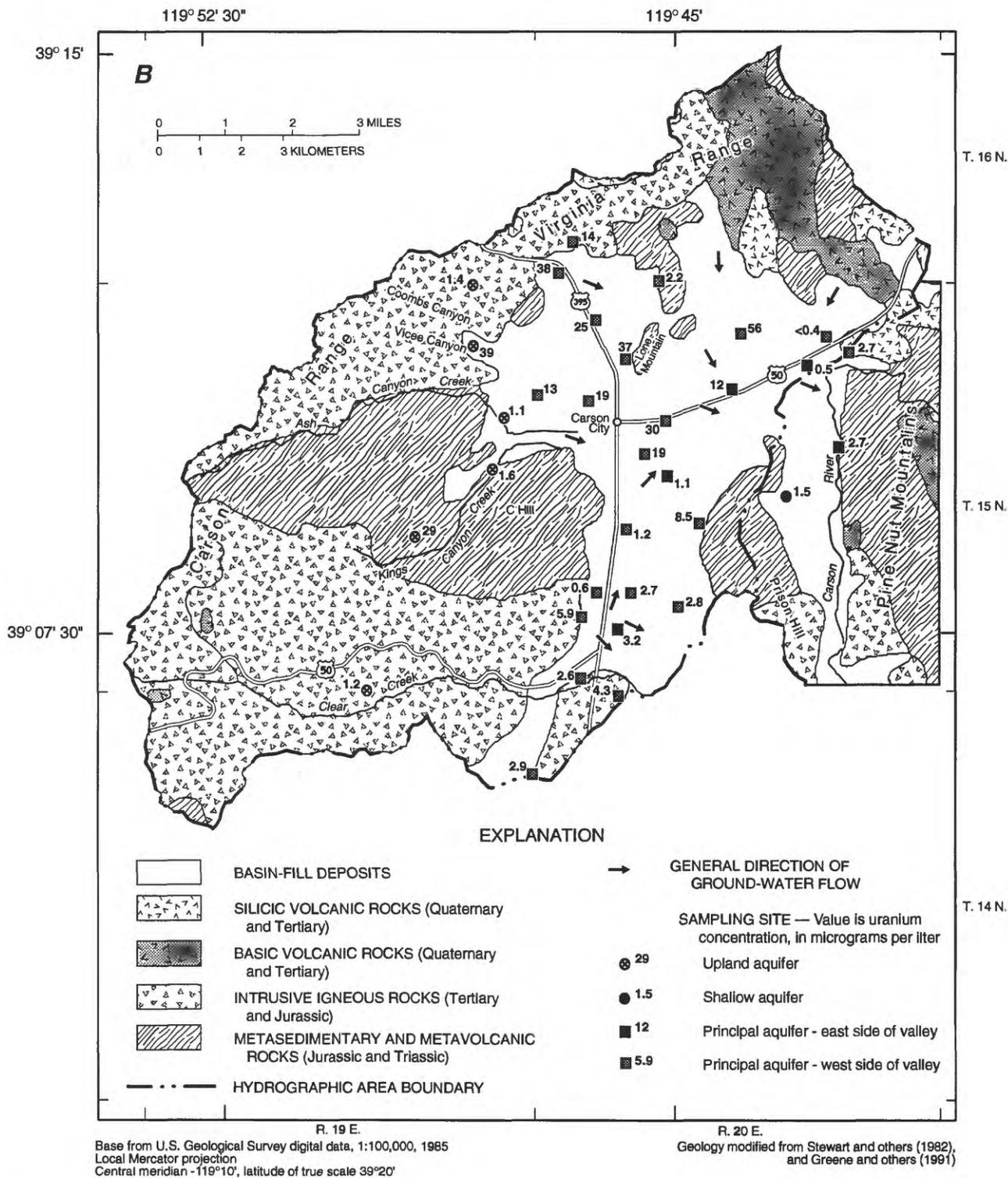


Figure 30. Uranium concentrations in ground water at selected sites in A, Carson and B, Eagle Valleys—Continued.

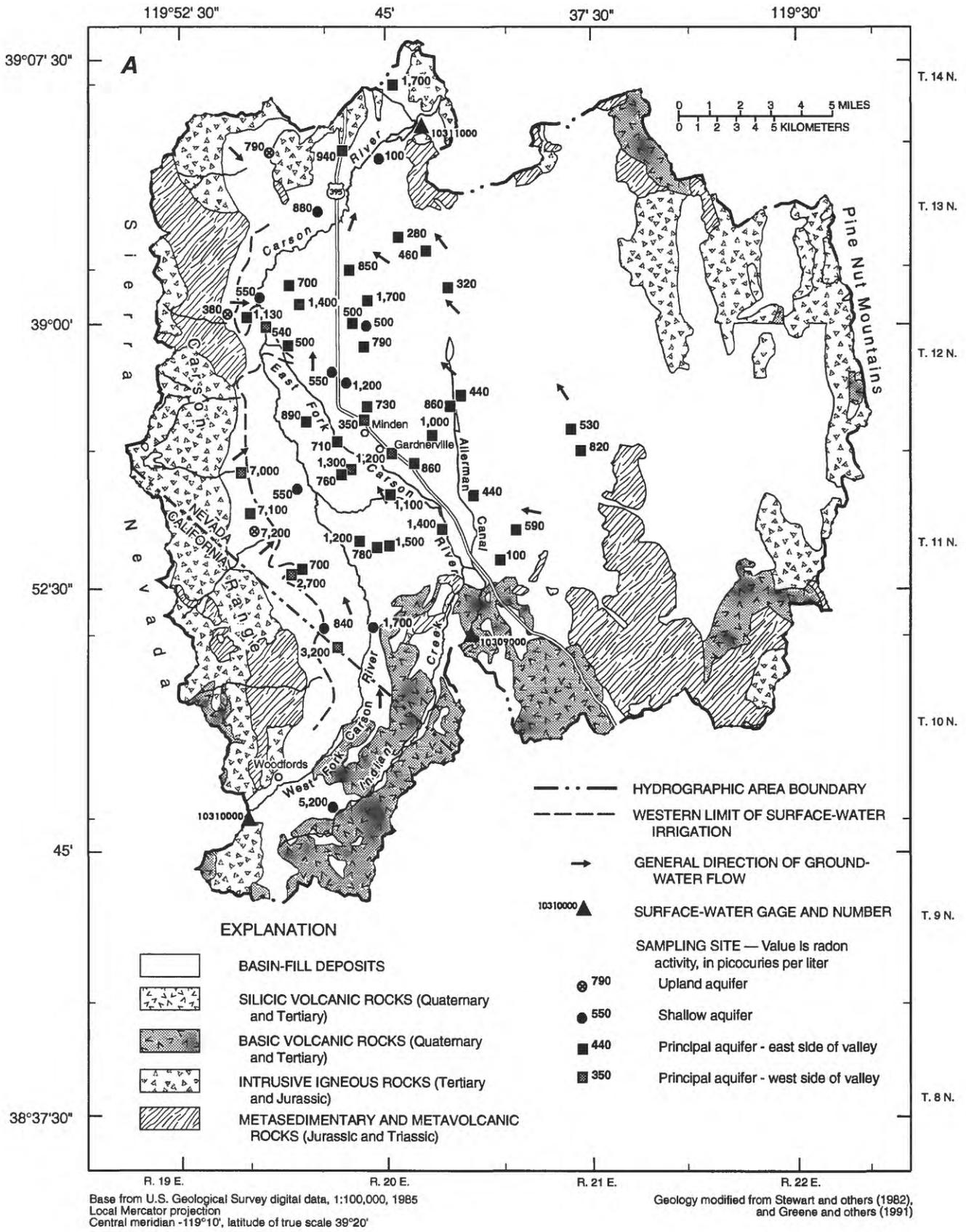


Figure 31. Radon-222 activities in ground water at selected sites in A, Carson and B, Eagle Valleys.

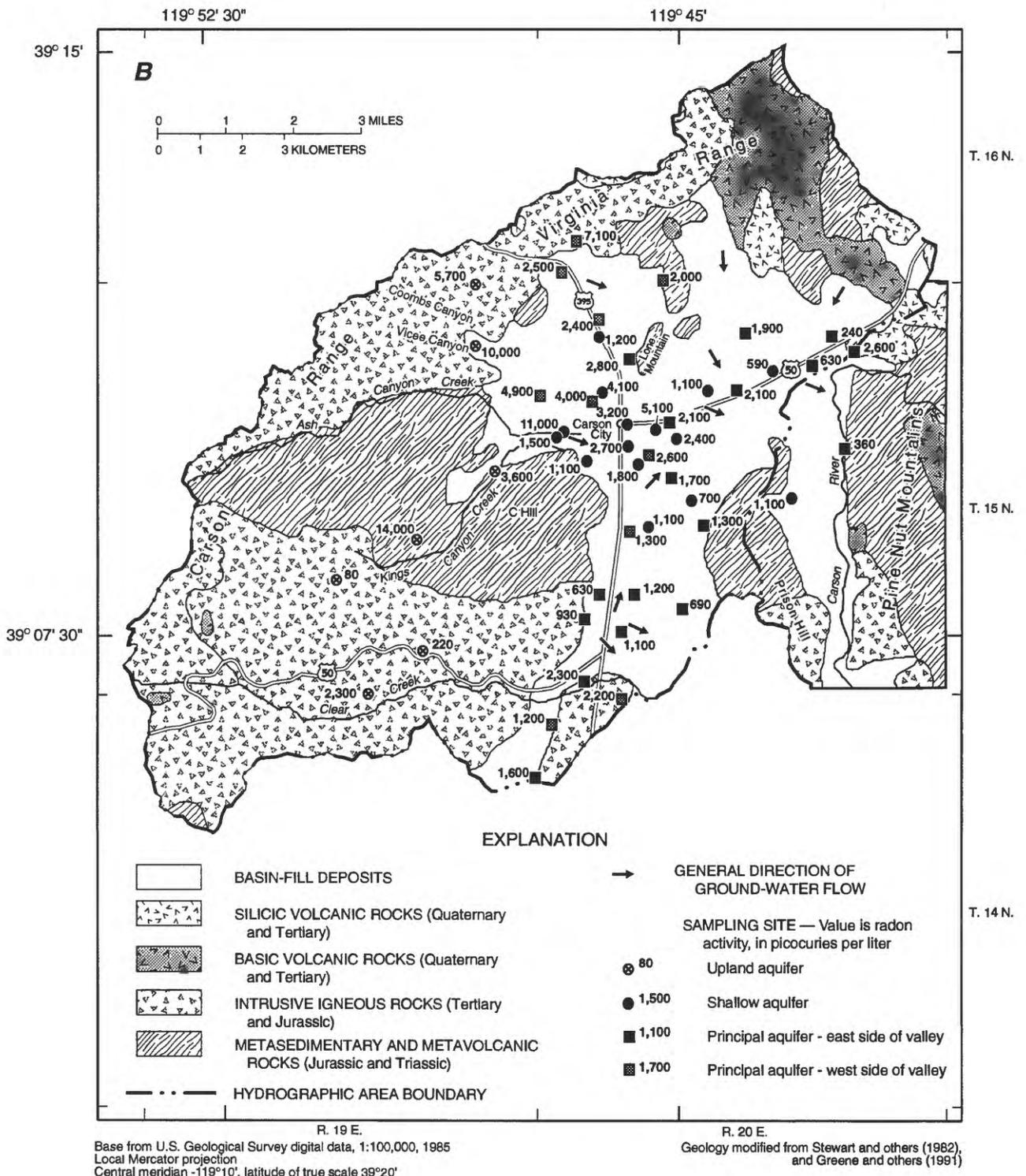


Figure 31. Radon-222 activities in ground water at selected sites in A, Carson and B, Eagle Valleys—Continued.

In ground water from one site in the Carson City urban area, concentrations of benzene, tetrachloroethylene, and trichloroethylene have been found with maximum concentrations of 23, 20, and 7 µg/L, respectively. Prometone, a triazine herbicide without an established MCL, also was reported in 5 of 20 sites in the urban part of Carson City. The maximum concentration at these locations was 3.8 µg/L. Prometone was not detected at 10 sites in agricultural areas.

Volatile organic compounds have been previously reported in ground water in the vicinity of a gasoline leak, at an industrial site, and in an area where septic tanks are used (Welch and others, 1990, p. 51). Samples of ground water from the principal aquifers did not contain organic compounds for which drinking-water standards have been established at concentrations greater than the reporting levels.

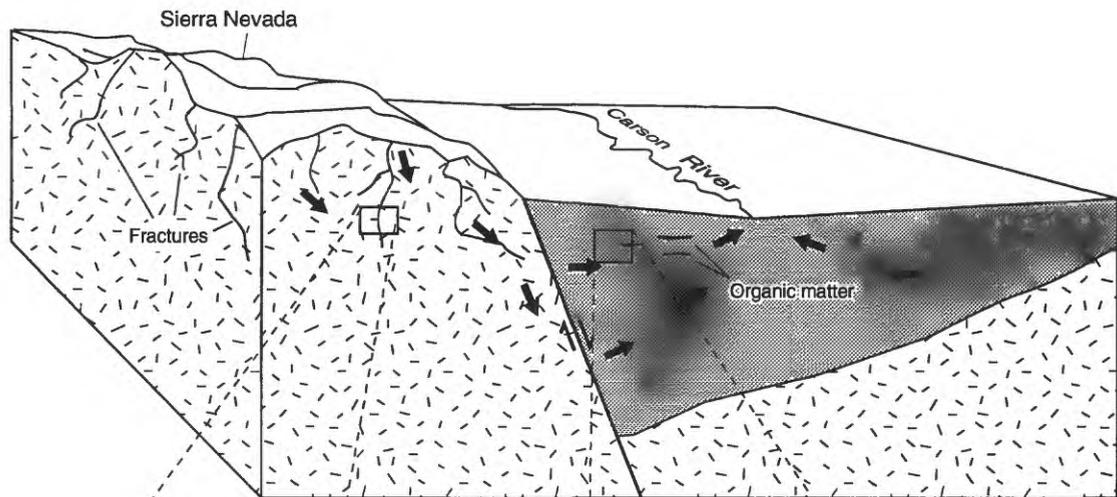
Table 13. Summary of number of radionuclide sites with analyses that exceed and do not exceed Nevada State maximum contaminant levels (MCL's) and MCL's proposed by U.S. Environmental Protection Agency (1991) in ground water of Carson and Eagle Valleys

[See table 2 and text for explanation of MCL's. Units of measure: mg/L, milligrams per liter; pCi/L, picocuries per liter]

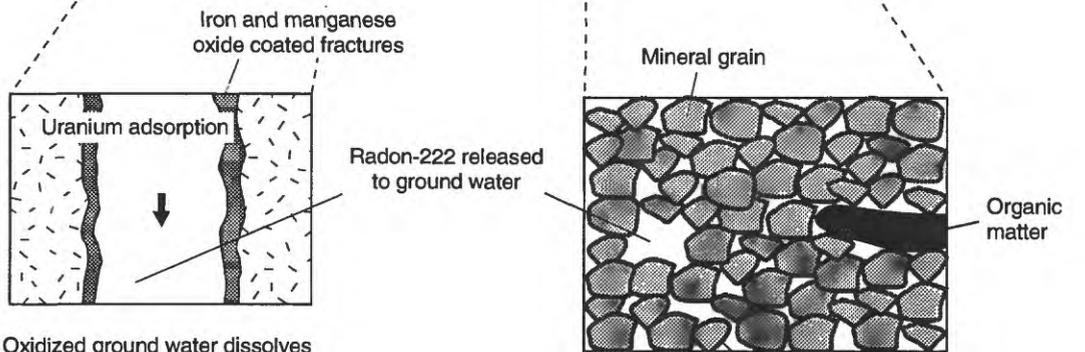
Constituent or gross measurement with and MCL	Upland aquifers		Shallow aquifers		Principal aquifers		All aquifers	
	Total number of sites	Number of sites with analyses exceeding MCL	Total number of sites	Number of sites with analyses exceeding MCL	Total number of sites	Number of sites with analyses exceeding MCL	Total number of sites	Number of sites with analyses exceeding MCL
Gross alpha ^a	5	1	10	2	55	5	70	8
Adjusted gross alpha (radium-226, excluding radon-222 and uranium), 20 pCi/L	5	0	10	0	55	0	70	0
Radium-226 and -228 (combined), 5 pCi/L	2	0	3	0	3	0	8	0
Radium-226, 20 pCi/L ^b	6	0	3	0	11	0	20	0
Radium-228, 20 pCi/L ^b	2	0	3	0	3	0	8	0
Radon-222, 300 pCi/L ^b	10	8	26	25	67	64	103	97
Uranium, 0.02 mg/L ^b	8	2	10	3	59	5	77	10

^aNumber of exceedances represents number of values greater than 15 pCi/L and does not exclude contribution due to uranium and radium-226.

^bValue proposed by U.S. Environmental Protection Agency (1991).



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



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.

EXPLANATION

-  BASIN-FILL DEPOSITS
-  PLUTONIC ROCKS
-  BASIN-BOUNDING FAULT —
Arrows show direction of movement
-  DIRECTION OF GROUND-WATER FLOW

Figure 32. Major processes affecting distribution of uranium and radon-222 in ground water in Carson and Eagle Valleys.

Table 14. Summary of selected organic constituents that exceed and do not exceed Nevada State drinking-water maximum contaminant levels (MCLs) in ground water of Carson and Eagle Valleys

[Samples were collected from 1987 through 1989. See table 2 and text for explanation of MCL's. Units of measure and symbol: µg/L, micrograms per liter; --, not determined]

Constituents with an established MCL	Upland aquifers			Shallow aquifers			Principal aquifers			Minimum reporting level, in (µg/L)
	Total number of sites	Number of sites exceeding MCL	Number of sites with reported concentrations	Total number of sites	Number of sites with reported concentrations	Number of sites exceeding MCL	Total number of sites	Number of sites exceeding MCL	Number of sites with reported concentrations	
Benzene	6	0	0	34	2	0	62	0	0	0.2
Carbon tetrachloride	6	0	0	35	1	0	62	0	0	.2
Edrin	0	--	--	17	0	0	0	0	0	.01
Lindane	0	--	--	17	1	0	0	0	0	.01
Methoxychlor	0	--	--	17	0	0	0	0	0	.01
Prometon	0	--	--	30	5	--	--	--	--	--
Trichloroethylene	6	0	0	35	3	0	62	0	0	.2
Toxaphene	0	--	--	17	0	0	0	0	0	1
Vinyl chloride	6	0	0	35	3	1	62	0	0	.2
1,2-Dichloroethane	5	0	0	32	1	0	41	0	0	.2
1,1-Dichloroethylene	6	0	0	35	1	0	62	0	0	.2
1,4-Dichlorobenzene	6	0	0	35	1	0	62	0	0	.2
1,1-Trichloroethane	6	0	0	35	1	0	62	0	0	.2
2,4-Dichlorophenoxyacetic acid (2,4-D)	0	--	--	28	1	0	0	0	0	.01
2,4,5-Trichlorophenoxypropionic acid (2,4,5-T)	0	--	--	28	2	0	0	0	0	.01

SUMMARY AND CONCLUSIONS

Carson and Eagle Valleys are valley lowlands surrounded by mountains. To the west and south of these lowlands are scenic ranges that receive most of the water that recharges the local ground- and surface-water systems. The mountains are virtually undeveloped and sparsely populated, whereas the lowlands are used primarily for agriculture and urban purposes.

Basin-fill aquifers are the primary source of ground water in the basins that underlie Carson and Eagle Valleys. Water from the principal aquifers is an important source of municipal and agricultural supply. The basin-fill sediments are as much as 5,000 ft thick, with greater thicknesses beneath the western sides of the basins. The basins are surrounded by mountains composed primarily of granitic and basaltic igneous rocks and lesser amounts of metamorphosed sedimentary and volcanic rocks. Basin-bounding mountains and the Headwaters Area constitute the primary source of sediment to the basins.

Other aquifers are less developed in Carson and Eagle Valleys. Thermal water, and some ground water in the higher altitudes, flows through consolidated rocks that underlie and contain the basin-fill sediments. Thermal water is used for aquaculture and recreation. Upland aquifers are sources for both municipal and domestic supply.

Rapid infiltration from streams draining the Sierra Nevada, and to a much lesser extent, other mountains bounding the valleys, is an important source of recharge to the basin-fill sediments. Recharge of water from the Carson River appears to be induced locally by pumping of principal aquifers in south-central Carson Valley. In areas of agricultural and urban irrigation, shallow aquifers are recharged by surface infiltration. In some areas, the water table has risen in response to irrigation. Atmospheric precipitation falling on the valley floors probably provides little recharge because of relatively high evapotranspiration rates.

Ground water in the principal aquifers of Carson and Eagle Valleys generally has pH values ranging from near neutral to alkaline, with dissolved-solids concentrations less than 1,000 mg/L. Sodium and calcium are the dominant cations and bicarbonate the dominant anion. Among the aquifers of Carson and Eagle Valleys, nonparametric statistical tests indicate that ranked concentrations of sodium, calcium, magnesium, sulfate, and bicarbonate concentrations generally

are greater in the principal aquifers than in the upland aquifers. Ranked concentrations of these same constituents in shallow aquifers are significantly higher than in principal aquifers. Generally higher ranked concentrations of these major constituents in the shallow aquifers indicate that the primary source of recharge to the principal aquifers is not flow from the shallow aquifers.

Concentrations of calcium, sodium, potassium, chloride, and sulfate in water from principal aquifers are higher in the western part of Carson and Eagle Valleys than in the eastern part of the basins. Some areal differences in the inorganic chemistry of water in the principal aquifers are influenced by the different types of bedrock that comprise the aquifers. Sulfate concentrations, sulfate to chloride ratios, and sulfate-isotope composition in water of northeastern Eagle Valley are consistent with the derivation of sulfate primarily by dissolution of gypsum originating in marine evaporites.

Concentrations of major constituents in water from the principal aquifers on the west side of Carson and Eagle Valleys appear to be a result of natural geochemical reactions with minerals derived primarily from plutonic rocks. Evaluation of the results from mass-balance models, combined with mineralogic and thermodynamic data, indicates that observed concentrations of major constituents in water are caused by overall reactions involving plagioclase feldspar, carbon dioxide, and calcite, along with (1) relatively small amounts of potassium feldspar, silica, pyrite, and sodium chloride, and (2) some combination of the silicate minerals chlorite, biotite, hornblende, and augite. The quantitatively most important minerals produced by the reactions appear to be kaolinite and beidellite.

In general, water in the principal aquifers is acceptable for drinking, on the basis of present (1990) Nevada State drinking-water MCL's. Of water collected at 89 ground-water sites and analyzed for all inorganic constituents for which MCL's or SMCL's have been established, water at 3 sites exceeds one or more MCL's and water at 10 sites has at least one constituent that exceeds either a MCL or a SMCL. Arsenic exceeds the MCL of 0.05 mg/L in water from only 1 of 91 sites where wells tap the principal aquifer and nitrate exceeds its 10 mg/L MCL in water at 3 of 93 such sites. Water pumped from wells that tap the principal aquifer containing high concentrations of nitrate is found in areas where septic systems are used. The high concentrations indicate that sewage may

be entering the wells. The only constituent that exceeds a SMCL in water from the principal aquifers is manganese, which exceeds the 0.1 mg/L drinking-water standard at 8 of 93 sites.

Water in the upland aquifers generally contains concentrations of constituents that do not exceed MCL's or SMCL's. Iron and manganese are the only constituents that exceed standards in water from the upland aquifers. Water at only one site has concentrations greater than the SMCL's.

Constituents with concentrations greater than a MCL in water in shallow aquifers are arsenic, fluoride, and nitrate; concentrations of dissolved solids, fluoride, iron, manganese, and sulfate locally exceed their SMCL's. Of 39 sites that had water analyzed for all inorganic constituents with a MCL or a SMCL, water from 6 sites exceeds one or more MCL and from 23 sites exceed at least one MCL or SMCL. The arsenic MCL is exceeded in water at 3 of 39 sites, with fluoride and nitrate each exceeding their MCL in water at 2 of 40 and 41 sites, respectively. Manganese in ground water most commonly exceeds the SMCL, with water at 21 of 40 sites having concentrations greater than the 0.1 mg/L standard. Iron exceeded the SMCL in water at 8 of 40 sites.

Water from the thermal aquifers generally has at least one constituent at a concentration that exceeds a MCL. Thermal aquifers yield water that has fluoride concentrations that exceed the MCL at 5 of 6 sites. Other constituents that exceed either a MCL or SMCL are arsenic, lead, iron, manganese, and sulfate.

Concentrations of iron and manganese greater than the drinking-water standards are present in ground water with little or no oxygen. This results in chemically reduced forms of these elements that are more soluble than the oxidized forms generally found in oxygenated water. Water with higher manganese and iron concentrations appears to be in equilibrium with the carbonate minerals siderite and rhodochrosite, indicating that concentrations of these elements are limited by the solubility of these phases.

Concentrations of naturally occurring radionuclides in water from the principal aquifers exceeded some of the proposed standards, but were not found to exceed existing standards (1990). Measured gross-alpha activities in water did not surpass the 15 pCi/L

limit that excluded uranium and radon-222 at 69 sites for which both gross alpha and uranium were determined. The uranium concentrations in the various aquifers exceeded the proposed 20 µg/L limit at 10 of 77 sites. Of 39 ground-water sites that were analyzed for uranium and all the inorganic constituents with MCL's, 6 exceeded one or more MCL. If the proposed 20 µg/L MCL for uranium were to be applied to the 39 samples, then water from 9 of the sites would exceed at least one MCL, which would represent a 50 percent increase in the frequency of exceedance. On the basis of only a few analyses for radium-226 and radium-228 (18 and 8 analyses, respectively), the activities in ground water did not exceed either the present combined MCL or the proposed 20 pCi/L for each of these radionuclides.

Activities of radon in almost all water sampled from the principal aquifers (97 of 103) exceed the 300 pCi/L proposed MCL samples. Ground-water sampling sites with the highest activities of radon in water are most common in upland aquifers in the Sierra Nevada and in principal aquifers on the western side of Carson and Eagle Valleys. The high radon-222 activities appear to be a result of uranium being concentrated on iron and manganese oxides that coat detrital grains and fractures in granitic bedrock and in sedimentary organic matter within the basin-fill sediments.

Ground water from the shallow aquifers beneath the urban part of Carson City and near the Douglas County airport contains measurable concentrations of some synthetic organic compounds. Concentrations of those compounds in water samples from the shallow aquifers beneath Carson City generally do not exceed MCL's. Water from only one site contained concentrations of trichloroethylene greater than the drinking-water MCL of 5 µg/L. Samples of water from the principal aquifers did not contain organic compounds for which drinking-water standards have been established at concentrations greater than the reporting levels. Prometone, an herbicide without an established MCL, was detected at 5 of 20 sites in the urban part of Carson City.

REFERENCES CITED

- Amundson, R.G., Chadwick, O.A., Sowers, J.M., and Doner, H.E., 1988, Relationship between climate and vegetation and the stable carbon isotope chemistry of soils in the eastern Mojave Desert, Nevada: *Quaternary Research*, v. 29, p. 245-254.
- Arteaga, F.E., 1982, Mathematical model analysis of the Eagle Valley ground-water basin, west-central Nevada: U.S. Geological Survey Open-File Report 80-1224, 55 p.
- Ball, J.W., Nordstrom, D.K., and Zachmann, D.W., 1987, WATEQ4F—A personal computer FORTRAN translation of the geochemical model WATEQ2 with revised data base: U.S. Geological Survey Open-File Report 87-50, 108 p.
- Barnes, Ivan, 1964, Field determination of alkalinity and pH: U.S. Geological Survey Water-Supply Paper 1535-H, 17 p.
- Berger, D.L., 1990, Ground-water levels in water year 1987 and estimated ground-water pumpage in water years 1986-87, Carson Valley, Douglas County, Nevada: U.S. Geological Survey Open-File Report 89-70, 9 p.
- Bingler, E.C., 1977, Geologic map of the New Empire quadrangle: Nevada Bureau of Mines and Geology Map 59, scale 1:24,000.
- Bowser, C.J., and Jones, B.F., 1990, Geochemical constraints on groundwaters dominated by silicate hydrolysis: An interactive spreadsheet, mass balance approach: *Chemical Geology*, v. 84, no. 1/4, p. 33-35.
- Brown, W.M., III, Nowlin, J.O., Smith, L.H., and Flint, M.R., 1986, River-quality assessment of the Truckee and Carson River System, California and Nevada—hydrologic characteristics: U.S. Geological Survey Open-File Report 84-576, 201 p.
- Cerling, T.E., 1984, The stable isotopic composition of modern soil carbonate and its relationship to climate: *Earth and Planetary Science Letters*, v. 71, p. 229-240.
- Claypool, G.E., Holser, W.T., Kaplan, I.R., Sakai, H., and Zak, I., 1980, The age curves of sulfur and oxygen isotopes in marine sulfate and their mutual interpretation: *Chemical Geology*, v. 28, p. 199-260.
- Cleveland, W.S., and McGill, Robert, 1984, The many faces of a scatter plot: *Journal of the American Statistical Association*, v. 79, no. 388, p. 807-822.
- Craig, Harmon, 1961, Isotopic variations in meteoric waters: *Science*, v. 133, no. 3465, p. 1702-1703.
- Deer, W.A., Howie, R.A., and Zussman, J., 1967, An introduction to the rock-forming minerals: London, Longmans, Green and Co., 528 p.
- Deines, Peter, 1980, The isotopic composition of reduced organic carbon, *in* Fritz, Peter, and Fontes, Jean-Charles, eds., 1980, *Handbook of environmental isotope geochemistry*: New York, Elsevier, v. 1, p. 329-406.
- Drever, J.I., 1982, *The geochemistry of natural waters*: Englewood Cliffs, Prentice-Hall, 388 p.
- Faure, Gunter, 1986, *Principals of isotope geology*: New York, John Wiley, 589 p.
- Feth, J.H., Roberson, C.E., and Polzer, W.L., 1964, Sources of mineral constituents in water from granitic rocks, Sierra Nevada, California and Nevada: U.S. Geological Survey Water-Supply Paper 1535-I, 70 p.
- Fishman, M.J., and Friedman, L.C., 1985, Methods for the determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chap. A1, 709 p.
- Fontes, J.C., 1980, Environmental isotopes in groundwater hydrology, *in* Fritz, Peter, and Fontes, Jean-Charles, eds., *Handbook of environmental isotope geochemistry*: New York, Elsevier, v. 1, p. 75-140.
- Friedlander, G., Kennedy, J.W., Macias, E.S., and Miller, J.M., 1981, *Nuclear and radiochemistry* (3d ed.): New York, John Wiley, 684 p.
- Fritz, Peter, and Fontes, Jean-Charles, 1980, Introduction, *in* Fritz, Peter, and Fontes, Jean-Charles, eds., *Handbook of environmental isotope geochemistry*: New York, Elsevier, v. 1, p. 1-20.
- Garcia, K.T., 1989, Ground-water quality in Douglas County, western Nevada: U.S. Geological Survey Water-Resources Investigations Report 87-4269, 107 p.
- Garrels, R.M., and Mackenzie, F.T., 1967, Origin of the chemical compositions of some springs and lakes: *American Chemical Society, Advances in Chemistry Series*, no. 67, chap. 10, p. 222-242.
- Graf von Reichenbach, H., and Rich, C.I., 1975, Fine-grained micas in soils, *in* Giesekeing, J., ed., *Soil components—Inorganic components*: New York, Springer-Verlag, v. 2, chap. 3, p. 59-88.
- Greene, R.C., Stewart, J.H., John, D.A., Hardyman, R.F., Silberling, N.J., and Sorensen, M.L., 1991, Geologic map of the Reno 1° x 2° quadrangle, Nevada and California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2154-A, scale 1:250,000.
- Hardy, M.A., Leahy, P.P., and Alley, W.M., 1989, Well installation and documentation, and ground-water sampling protocols for the pilot national water-quality assessment program: U.S. Geological Survey Open-File Report 89-396, 36 p.

- Helgeson, H.C., 1969, Thermodynamics of hydrothermal systems at elevated temperatures and pressures: *American Journal of Science*, v. 267, p. 729-804.
- Helgeson, H.C., Delany, J.M., Nesbitt, H.W., and Bird, D.K., 1978, Summary and critique of the thermodynamic properties of rock-forming minerals: *American Journal of Science*, v. 278-A, p. 1-229.
- Hirsch, R.M., Alley, W.M., and Wilber, W.G., 1988, Concepts for a National Water-Quality Assessment Program: U.S. Geological Survey Circular 1021, 42 p.
- Iman, R.L., and Conover, W.J., 1983, A modern approach to statistics: New York, John Wiley, 497 p.
- Ishihara, Shunso, and Sasaki, Akira, 1989, Sulfur isotopic ratios of the magnetic-series and ilmenite series granitoids of the Sierra Nevada batholith—A reconnaissance study: *Geology*, v. 17, no. 9, p. 788-791.
- Jenne, E.A., 1968, Controls on Mn, Fe, Co, Ni, Cu, and Zn concentrations in soils and water—The significant role of hydrous Mn and Fe oxides *in* Gould, R.F., ed., *Advances in Chemistry Series*: Washington D.C., American Chemical Society, v. 73, p. 337-387.
- Jones, B.F., and Bowser, C.J., 1978, The mineralogy and related chemistry of lake sediments, *in* Lerman, Abraham, *Lakes Chemistry Geology Physics*: New York, Springer-Verlag, chap. 7, p. 179-235.
- Krouse, H.R., 1980, Sulphur isotopes in our environment, *in* *Handbook of environmental isotope geochemistry*: Amsterdam, Elsevier, v. 1A, chap. 11, p. 435-472.
- Lico, M.S., Kharaka, Y.K., Carothers, W.W., and Wright, V.A., 1982, Methods for collection and analysis of geopressured geothermal and oil-field waters: U.S. Geological Survey Water-Supply Paper 2194, 21 p.
- Loeb, S.L., 1987, Groundwater quality within the Tahoe Basin: Davis, University of California, Institute of Ecology, 265 p.
- Maddy, D.V., Lopp, L.E., Jackson, D.L., Coupe, R.H., and Schertz, T.L., 1990, National Water Information System user's manual, volume 2, chapter 2, Water-quality system: U.S. Geological Survey Open-File Report 89-617, 216 p.
- Magaritz, Mordeckai, and Luzier, J.E., 1985, Water-rock interactions and seawater-freshwater mixing effects in the coastal dunes aquifer, Coos Bay, Oregon: *Geochimica et Cosmochimica Acta*, v. 49, p. 2515-2525.
- Mariner, R.H., Rapp, J.B., Willey, L.M., and Presser, T.S., 1974, The chemical composition and estimated minimum thermal reservoir temperature of the principal hot springs of northern and central Nevada: U.S. Geological Survey Open-File Report, 32 p.
- Mariner, R.H., Presser, T.S., Rapp, J.B., and Willey, L.M., 1975, The minor and trace elements, gas, and isotope compositions of the principal hot springs of Nevada and Oregon: U.S. Geological Survey Open-File Report, 27 p.
- Mast, M.A., and Drever, J.I., 1990, Chemical weathering in the Loch Vale Watershed, Rocky Mountain National Park, Colorado: *Water Resources Research*, v. 26, no. 12, p. 2971-2978.
- Mattraw, H.C., Jr., Wilber, W.G., and Alley, W.M., 1989, Quality-assurance plan for the pilot National Water-Quality Assessment program: U.S. Geological Survey Open-File Report 88-726, 21 p.
- Maurer, D.K., 1985, Gravity survey and depth to bedrock in Carson Valley, Nevada-California: U.S. Geological Survey Water-Resources Investigations Report 84-4202, 20 p.
- 1986, Geohydrology and simulated response to ground-water pumpage in Carson Valley, a river-dominated basin in Douglas County Nevada, and Alpine County, California: U.S. Geological Survey Water-Resources Investigations Report 86-4328, 109 p.
- Maurer, D.K., and Fischer, J.M., 1988, Recharge to the Eagle Valley ground-water basin by streamflow in Vicee Canyon, west-central Nevada: U.S. Geological Survey Water-Resources Investigations Report 88-4158, 66 p.
- May, H.M., Helmke, P.A., and Jackson, M.L., 1979, Gibbsite solubility and 75 thermodynamic properties of hydroxyl-aluminum ions in aqueous solution at 25°C: *Geochimica et Cosmochimica Acta*, v. 43, no. 6, p. 861-868.
- May, H.M., Kinniburgh, D.G., Helmke, P.A., and Jackson, M.L., 1986, Aqueous dissolution, solubilities, and thermodynamic stabilities of common aluminosilicate clay minerals—Kaolinite and smectites: *Geochimica et Cosmochimica Acta*, v. 50, no. 8, p. 1667-1677.
- Mook, W.G., 1980, Carbon-14 in hydrogeological studies, *in* Fritz, Peter, and Fontes, Jean-Charles, eds., *Handbook of environmental isotope geochemistry*: New York, Elsevier, v. 1, p. 49-74.
- Mook, W.G., Bommerson, J.C., and Staverman, W.H., 1974, Carbon isotope fractionation between dissolved bicarbonate and gaseous carbon dioxide: *Earth and Planetary Science Letters*, v. 22, p. 169-176.

- Moore, J.G., 1969, Geology and mineral deposits of Lyon, Douglas, and Ormsby Counties, Nevada: Nevada Bureau of Mines Bulletin 75, 45 p.
- Morgan, D.S., 1982, Hydrogeology of the Stillwater area, Churchill County, Nevada: U.S. Geological Survey Open-File Report 82-345, 95 p.
- Nevada Bureau of Consumer Health Protection Services, 1980, Water supply regulations—part 1, water-quality standards—monitoring, recordkeeping, and reporting: Nevada Division of Health, 16 p.; app. A, 11 p.
- Parkhurst, D.L., Plummer, L.N., and Thorstenson, D.C., 1982, BALANCE—A computer program for calculating mass transfer for geochemical reactions in ground water: U.S. Geological Survey Open-File Report 82-14, 29 p.
- Parkhurst, D.L., Thorstenson, D.C., and Plummer, L.N., 1980, PHREEQE—A computer program for geochemical calculations: U.S. Geological Survey Open-File Report 80-96, 210 p.
- Plummer, L.N., Parkhurst, D.L., and Thorstenson, D.C., 1983, Development of reaction models for ground-water systems: *Geochimica et Cosmochimica Acta*, v. 47, p. 665-686.
- Plummer, L.N., and Busenberg, Eurybiades, 1982, The solubilities of calcite, aragonite and vaterite in CO₂-H₂O solutions between 0 and 90°C, and an evaluation of the aqueous model for the system CaCO₃-CO₂-H₂O: *Geochimica et Cosmochimica Acta*, vol. 46, p. 1011-1040.
- Plummer, L.N., Prestemon, E.C., and Parkhurst, D.L., 1991, An interactive code (NETPATH) for modeling net geochemical reactions along a flow path: U.S. Geological Survey Water-Resources Investigation Report 91-4078, 227 p.
- Quade, Jay, Cerling, T.E., and Bowman, J.R., 1989, Systematic variations in the carbon and oxygen isotopic composition of pedogenic carbonate along elevation transects in the southern Great Basin, United States: *Geological Society of America Bulletin*, v. 101, p. 464-475.
- Robie, R.A., and Waldbaum, D.R., 1968, Thermodynamic properties of minerals and related substances at 298.15 K (25°C) and one atmosphere pressure (1.013 bars) and at higher temperatures: U.S. Geological Survey Bulletin 1259, 256 p.
- Rush, F.E., 1968, Index of hydrographic areas in Nevada: Nevada Division of Water Resources Information Report 6, 38 p.
- Scott, J.C., 1990, Computerized stratified random site-selection approaches for design of a ground-water-quality sampling network: U.S. Geological Survey Water-Resources Investigations Report 90-4101, 109 p.
- Spane, F.A., 1977, Evaluation of factors influencing the inorganic water-quality regimen of Carson River, Carson Valley, Nevada—California: University of Nevada, Reno, unpub. Ph. D. thesis, 205 p.
- Stauffer, R.E., 1990, Granite weathering and the sensitivity of alpine lakes to acid deposition: *Limnology and Oceanography*, v. 35, p. 1112-1134.
- Stewart, J.H., Carlson, J.E., and Johannesen, D.C., 1982, Geologic map of the Walker Lake 1° by 2° quadrangle, California and Nevada: U.S. Geological Survey Miscellaneous Field Studies Map MF-1382-A, scale 1:250,000.
- Szecsody, J., Jacobson, R.L., and Campana, M.E., 1983, Environmental isotopic and hydrogeochemical investigation of recharge and subsurface flow in Eagle Valley, Nevada: University of Nevada, Desert Research Institute Publication 42037, 120 p.
- Thacher, L.L., Janzer, V.J., and Edwards, K.W., 1977, Methods for determination of radioactive substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resource Investigations, Book 5, Chap. A5, 95 p.
- Thode, H.G., Shima, M., Rees, C.E., and Krishnamurthy, K.V., 1965, Carbon-13 isotope effects in systems containing carbon dioxide, bicarbonate, carbonate and metal ions: *Canadian Journal of Chemistry*, v. 43, p. 582-595.
- Thomas, J.M., Welch, A.H., Lico, M.S., Hughes, J.L., and Whitney, R., 1993, Radionuclides in ground water of the Carson River Basin, western Nevada and eastern California, U.S.A.: *Applied Geochemistry*, v. 8, p. 447-471.
- Thorstenson, D.C., Fisher, D.W., and Croft, M.G., 1979, The geochemistry of the Fox Hills-Basal Hell Creek aquifer in southwestern North Dakota and northwestern South Dakota: *Water Resources Research*, v. 15, p. 1479-1498.
- Tidball, R.R., Briggs, P.H., Stewart, K.C., Vaughn, R.B., and Welsch, E.P., 1991, Analytical data for soil and well core samples from the Carson River Basin, Lyon and Churchill Counties, Nevada: U.S. Geological Survey Open-File Report 91-584A, 14 p.
- Trexler, D.T., Koenig, B.A., Flynn, Thomas, and Bruce, J.L., 1980, Assessment of geothermal resources of Carson-Eagle Valleys and Big Smoky Valley, Nevada—first annual report: Nevada Bureau of Mines and Geology Report DOE/NV/10039-2, 162 p.
- U.S. Environmental Protection Agency, 1986a, Maximum contaminant levels (subpart B of part 141, National Interim Primary Drinking-Water Regulations): U.S. Code of Federal Regulations, title 40, pts. 100-149, revised as of July 1, 1986, p. 524-528.

- 1986b, Secondary maximum contaminant levels (section 143.3 of part 143, National secondary drinking-water regulations): U.S. Code of Federal Regulations, title 40, pts. 100-149, revised as of July 1, 1986, p. 587- 590.
- 1991, Proposed rule for primary maximum contaminant levels for radionuclides: U.S. Code of Federal Regulations, July 18, 1991, no. 138, p. 33050-33127.
- Welch, A.H., Lico, M.S., and Hughes, J.L., 1988, Arsenic in ground water of the western United States: *Ground Water*, v. 26, no. 3, p. 333-347.
- Welch, A.H., and Plume, R.W., 1987, Water-quality assessment of the Carson River ground-water basin, Nevada and California—Project description: U.S. Geological Survey Open-File Report 87-104, 27 p.
- Welch, A.H., and Plume, R.W., Frick, E.A., and Hughes, J.L., 1990, Ground-water quality assessment of the Carson River Basin, Nevada and California—Analysis of available water-quality data through 1987: U.S. Geological Survey Open-File Report 89-382, 115 p.
- Wershaw, R.L., Fishman, M.J., Grabbe, R.R., and Lowe, L.E., eds., 1987, *Methods for the determination of organic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chap. A3*, 80 p.
- White, D.E., Muffler, L.J.P., and Truesdell, A.H., 1971, Vapor dominated hydrothermal systems compared with hot-water systems: *Economic Geology*, v. 66, no. 1, p. 75-97.
- Whitney, Rita, 1994, Data on ground-water quality in the Carson River Basin, western Nevada and eastern California, 1987-90: U.S. Geological Survey Open-File Report 94-39, 139 p.
- Willden, Ronald, and Speed, R.C., 1974, Geology and mineral deposits of Churchill County, Nevada: Nevada Bureau of Mines and Geology Bulletin 83, 95 p.
- Zachara, J.M., Cowan, C.E., and Resch, C.T., 1991, Sorption of divalent metals on calcite: *Geochimica et Cosmochimica Acta*, v. 55, p. 1549-1562.
- Zaporozec, Alexander, 1972, Graphical interpretation of water-quality data: *Ground Water*, v. 10, no. 2, p. 32-43.



APPENDIX

Appendix—Summary statistics for ground-water quality of Carson and Eagle Valleys

[Abbreviations and symbols: mg/L, milligrams per liter; µg/L, micrograms per liter; µs/cm, microsiemens per centimeter at 25 degrees Celsius; mV, millivolts; °C, degrees Celsius; --, not determined; <, less than; pCi/L, picocuries per liter; PMC, percent modern carbon. Isotope standards: Deuterium and oxygen are relative to Vienna Standard Mean Ocean Water; carbon-13 relative to Pee-Dee Belemnite; sulfur relative to Canyon Diablo meteorite; Sr-90/Y-90, strontium-90/yttrium-90. Uranium in pCi/L is calculated from corresponding uranium values in µg/L by assuming that activity ratio of U-234 to U-238 is 1]

Constituents and properties	Specific conductance (µS/cm at 25°C)	pH (standard units)	Water temperature (°C)	Oxygen, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
Upland aquifers								
Number of samples (sites)	14	24	22	6	27	27	27	26
Minimum	77	6.2	9	<1	4.9	.05	4.6	.6
25th	120	6.9	10	--	9.2	2	6.3	1.7
Median (50th)	140	7.1	12	3.9	16	3.9	7.8	2.5
75th	250	7.4	18	--	28	4.9	12	3
Maximum	280	8.6	26	7.2	41	8.8	22	5
Shallow aquifers								
Number of samples (sites)	41	41	41	31	41	41	41	40
Minimum	92	6.3	12	<1	9.9	.73	5.5	.7
25th	440	6.8	14	<1	47	9.8	26	1.9
Median (50th)	670	7.2	15	2	68	18	52	2.7
75th	920	7.4	16	4.3	92	25	89	4.9
Maximum	4,200	7.9	19	6.6	370	53	620	13
Principal aquifers—east side of valleys								
Number of samples (sites)	33	31	30	18	33	33	33	32
Minimum	150	6.8	13	<1	4.7	.5	15	.9
25th	240	7.6	15	<1	19	2.9	25	2.2
Median (50th)	330	7.9	17	<1	30	5.5	29	2.9
75th	470	8.1	21	3.3	39	8.8	51	4.3
Maximum	1,100	8.5	23	5.9	88	31	140	6.9
Principal aquifers—west side of valleys								
Number of samples (sites)	73	73	73	37	72	72	71	71
Minimum	60	6.4	2	<1	1.7	.19	3.9	.3
25th	170	7	13	1.5	15	2.2	14	1.2
Median (50th)	210	7.5	15	2.4	20	4.5	18	2.1
75th	240	8	17	4.5	24	7	24	2.8
Maximum	1,100	9.1	28	9.8	77	15	70	5.4
Thermal aquifers								
Number of samples (sites)	2	6	6	0	6	6	6	6
Minimum	730	7.3	24	--	2.2	<.05	82	1.6
25th	--	--	--	--	--	--	--	--
Median (50th)	970	8.7	48	--	12	.06	140	2.8
75th	--	--	--	--	--	--	--	--
Maximum	1,220	8.8	61	--	170	.74	170	5

Appendix—Summary statistics for ground-water quality of Carson and Eagle Valleys—Continued

Constituents and properties	Bicarbonate (mg/L as HCO ₃)	Sulfate, dissolved (mg/L as SO ₄)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO ₂)	Solids, residue at 180 °C, (mg/L)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, nitrate, dissolved (mg/L as N)
Upland aquifers								
Number of samples (sites)	24	26	28	23	21	4	18	9
Minimum	35	.5	<3	<.1	14	74	48	<.1
25th	67	1	.42	.1	18	--	75	<.1
Median (50th)	88	2	.8	.1	23	85	91	.41
75th	110	5	1.5	.2	29	--	100	1
Maximum	190	11	7	1.4	45	170	200	1.4
Shallow aquifers								
Number of samples (sites)	40	40	41	40	41	9	40	41
Minimum	50	2	.8	.1	9.5	280	69	<.22
25th	220	26	8.6	.2	31	390	310	<.22
Median (50th)	350	50	14	.2	40	570	440	.47
75th	410	99	54	.4	53	900	590	3
Maximum	860	1800	220	7.5	63	3,300	3,200	17
Principal aquifers—east side of valleys								
Number of samples (sites)	31	33	33	32	33	16	31	31
Minimum	54	3.3	2.4	<.1	21	140	130	<.14
25th	100	22	5.6	.2	34	170	190	<.14
Median (50th)	140	37	8.4	.4	48	240	230	.31
75th	180	67	16	.87	58	280	270	1.5
Maximum	300	260	71	1.8	78	350	570	20
Principal aquifers—west side of valleys								
Number of samples (sites)	60	70	72	60	72	30	59	61
Minimum	32	1.5	.3	<.1	13	50	52	<.1
25th	80	5.1	1.7	.1	27	120	130	.12
Median (50th)	100	13	4.1	.2	33	150	160	.8
75th	120	20	5.9	.47	38	180	170	1.6
Maximum	270	44	69	2	57	520	420	19
Thermal aquifers								
Number of samples (sites)	6	6	6	6	6	1	6	4
Minimum	5	89	21	3.3	33	800	320	<.1
25th	--	--	--	--	--	--	--	--
Median (50th)	49	190	39	5.4	37	800	490	<.1
75th	--	--	--	--	--	--	--	--
Maximum	73	620	91	7.8	60	800	1,000	<.1

Appendix—Summary statistics for ground-water quality of Carson and Eagle Valleys—Continued

Constituents and properties	Nitrogen, nitrite, dissolved (mg/L as N)	Nitrogen, ammonia, dissolved (mg/L as N)	Carbon, organic, dissolved (mg/L as C)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Boron, dissolved (µg/L as B)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)
Upland aquifers								
Number of samples (sites)	9	9	9	17	9	9	9	9
Minimum	<.01	<.01	.3	<1	5	<10	<1	<10
25th	<.01	<.01	.5	<1	11	<10	<1	<10
Median (50th)	<.01	<.01	.7	9	17	10	<1	<10
75th	<.01	.01	.85	12	38	10	1	5
Maximum	.01	.03	4.5	21	90	20	1	10
Shallow aquifers								
Number of samples (sites)	41	41	41	39	40	40	40	40
Minimum	<.01	<.01	.4	<1	20	<20	<3	<15
25th	<.01	.01	1.4	<1	55	20	<3	<15
Median (50th)	<.01	.02	2.3	9	89	120	<3	<15
75th	.01	.09	3	20	120	370	<3	<15
Maximum	.06	.84	8.8	110	310	3,100	10	10
Principal aquifers beneath the east side of valleys								
Number of samples (sites)	31	31	30	31	31	31	31	31
Minimum	<.01	<.01	.3	<1	11	10	<2	<10
25th	<.01	<.01	.47	4	41	50	<2	<10
Median (50th)	<.01	.01	.6	8	69	100	<2	<10
75th	<.01	.03	.95	23	86	170	1	10
Maximum	.01	.16	2.4	49	180	340	3	16
Principal aquifers beneath the west side of valleys								
Number of samples (sites)	61	61	62	60	61	60	61	61
Minimum	<.01	<.01	.1	<1	4	<10	<1	<10
25th	<.01	<.01	.4	1	23	20	<1	<10
Median (50th)	<.01	<.01	.6	3	41	55	<1	<10
75th	<.01	.02	.72	9	63	160	<1	<10
Maximum	.03	.21	4.4	34	170	260	1	40
Thermal aquifers								
Number of samples (sites)	1	2	0	4	4	5	1	1
Minimum	<.001	.15	--	<5	<.1	1,000	1	<10
25th	--	--	--	--	--	--	--	--
Median (50th)	<.001	.26	--	15	<.1	1,400	1	<10
75th	--	--	--	--	--	--	--	--
Maximum	<.001	.38	--	75	23	2,100	1	<10

Appendix—Summary statistics for ground-water quality of Carson and Eagle Valleys—Continued

Constituents and properties	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Lithium, dissolved (µg/L as Li)	Mercury, dissolved (µg/L as Hg)	Manganese, dissolved (µg/L as Mn)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Delta deuterium (permil)	Delta oxygen-18 (permil)
Upland aquifers									
Number of samples (sites)	18	9	6	8	9	8	9	10	10
Minimum	<3	<10	<4	<.1	<1	<1	<1	-120	-16
25th	4	<10	--	<.1	<1	<1	<1	-110	-15
Median (50th)	11	<10	14	<.1	1	<1	<1	-110	-15
75th	33	<10	--	<.1	5	<1	<1	-110	-15
Maximum	1,900	10	26	.1	1,600	1	1	-100	-14
Shallow aquifers									
Number of samples (sites)	40	40	32	39	40	40	40	338	38
Minimum	<3	<30	<4	<.1	1	<1	<3	-20	-16
25th	6.3	<30	13	<.1	19	<1	<3	-110	-14
Median (50th)	21	<30	22	<.1	110	<1	<3	-110	-14
75th	300	<30	34	<.1	510	<1	1	-100	-14
Maximum	9,600	100	92	.1	3,400	2	4	-96	-13
Principal aquifers—east side of valleys									
Number of samples (sites)	32	31	19	31	32	31	31	24	24
Minimum	<14	<10	<4	<.1	<1	<1	<1	-130	-16
25th	3.3	<10	6	<.1	1	<1	<1	-120	-16
Median (50th)	8.9	<10	10	<.1	3	<1	<1	-110	-15
75th	28	10	23	.1	44	1	<1	-110	-14
Maximum	100	20	47	.1	310	5	6	-100	-13
Principal aquifers—west side of valleys									
Number of samples (sites)	61	61	38	60	61	61	61	46	46
Minimum	<5	<10	<4	<.1	<1	<1	<1	-120	-16
25th	3	<10	7	<.1	<1	<1	<1	-110	-15
Median (50th)	7	<10	12	<.1	1	<1	<1	-110	-15
75th	12	<10	25	.1	12	<1	<1	-110	-14
Maximum	140	10	140	.5	460	3	3	-100	-13
Thermal aquifers									
Number of samples (sites)	3	1	4	2	2	1	1	3	3
Minimum	<20	<10	96	<.1	<20	1	<1	-130	-16
25th	--	--	--	--	--	--	--	--	--
Median (50th)	30	<10	210	<.1	<20	1	<1	-130	-16
75th	--	--	--	--	--	--	--	--	--
Maximum	5,600	<10	350	.5	330	1	<1	-120	-15

Appendix—Summary statistics for ground-water quality of Carson and Eagle Valleys—Continued

Constituents and properties	Delta carbon-13 (permil)	Carbon-14 (PMC)	Delta sulfur-34 (permil)	Tritium (pCi/L)	Radon-222, dissolved (pCi/L)	Radium-226, dissolved, radon method (pCi/L)	Radium-228, dissolved (pCi/L)	Uranium, dissolved (µg/L as U)
Upland aquifers								
Number of samples (sites)	2	0	0	8	10	6	2	8
Minimum	-17	--	--	<7	80	.04	1	1.1
25th	--	--	--	1.1	340	--	--	1.2
Median (50th)	-16	--	--	10	3,000	.17	1.1	1.5
75th	--	--	--	27	7,900	--	--	22
Maximum	-16	--	--	49	14,000	.4	1.2	39
Shallow aquifers								
Number of samples (sites)	0	0	0	5	26	3	3	10
Minimum	--	--	--	1.8	100	.1	1	<.4
25th	--	--	--	--	670	--	--	<.4
Median (50th)	--	--	--	42	1,200	.1	1	3.7
75th	--	--	--	--	2,800	--	--	27
Maximum	--	--	--	67	11,000	.13	1.2	36
Principal aquifers—east side of valleys								
Number of samples (sites)	16	16	13	18	24	4	1	21
Minimum	-16	9	-4.3	<.3	100	.04	1	<.4
25th	-14	41	-.2	.3	440	--	--	.87
Median (50th)	-12	81	5.7	.9	660	.07	1	2.7
75th	-11	99	13	21	1,200	--	--	5
Maximum	-10	110	18	74	2,600	.3	1	56
Principal aquifers—west side of valleys								
Number of samples (sites)	23	22	19	48	43	7	2	38
Minimum	-17	52	-4.5	<14	350	.05	4	<.4
25th	-15	72	.1	<14	830	--	--	1
Median (50th)	-15	88	4.4	1.2	1,300	.18	4	2.9
75th	-13	110	5.7	36	2,400	--	--	11
Maximum	-12	120	21	140	7,100	.56	4	38
Thermal aquifers								
Number of samples (sites)	0	0	0	0	0	0	0	0
Minimum	--	--	--	--	--	--	--	--
25th	--	--	--	--	--	--	--	--
Median (50th)	--	--	--	--	--	--	--	--
75th	--	--	--	--	--	--	--	--
Maximum	--	--	--	--	--	--	--	--

**Appendix—Summary statistics for ground-water quality
of Carson and Eagle Valleys—Continued**

Constituents and properties	Uranium, dissolved (pCi/L)	Gross alpha, dissolved (pCi/L as uranium)	Gross beta, dissolved (pCi/L as Sr-90/Y-90)
Upland aquifers			
Number of samples (sites)	8	5	5
Minimum	.77	1.2	1.8
25th	.83	--	--
Median (50th)	1	2.4	3.6
75th	15	--	--
Maximum	26	30	21
Shallow aquifers			
Number of samples (sites)	10	10	10
Minimum	<.27	.27	2.3
25th	<.27	.88	2.8
Median (50th)	2.5	1.4	5.8
75th	19	6.9	12
Maximum	24	24	21
Principal aquifers—east side of valleys			
Number of samples (sites)	21	18	18
Minimum	<.27	.27	1.7
25th	.59	.68	3.2
Median (50th)	1.8	2.4	3.9
75th	3.4	4.3	5.7
Maximum	38	35	28
Principal aquifers—west side of valleys			
Number of samples (sites)	38	37	37
Minimum	<.27	<.27	<.4
25th	.69	1	2.3
Median (50th)	2	2.4	3.6
75th	7.1	7.4	7.8
Maximum	26	28	19
Thermal aquifers			
Number of samples (sites)	0	0	0
Minimum	--	--	--
25th	--	--	--
Median (50th)	--	--	--
75th	--	--	--
Maximum	--	--	--

Nov 30 15:13 1994 jaboyer Page 1

Return-Path: crompton@dnvcrl.wr.usgs.gov
Received: from localhost (d501dnvcrs [130.118.64.29]) by dnvcrl.wr.usgs.gov (8.6.8/8.6.4) with
Message-Id: <199411302057.UAA12865@dnvcrl.wr.usgs.gov>
To: cc@dnvcrl.wr.usgs.gov
Subject: Winter driving
X-Mailer: exmh version 1.4.1 7/21/94
Date: Wed, 30 Nov 1994 12:55:13 -0800
From: James Crompton <crompton>

On Wednesday, December 7, at 9:00 Tony Alvarez from the NHP will be giving a short presentation (less than 1 hour) on winter driving in the large conference room.