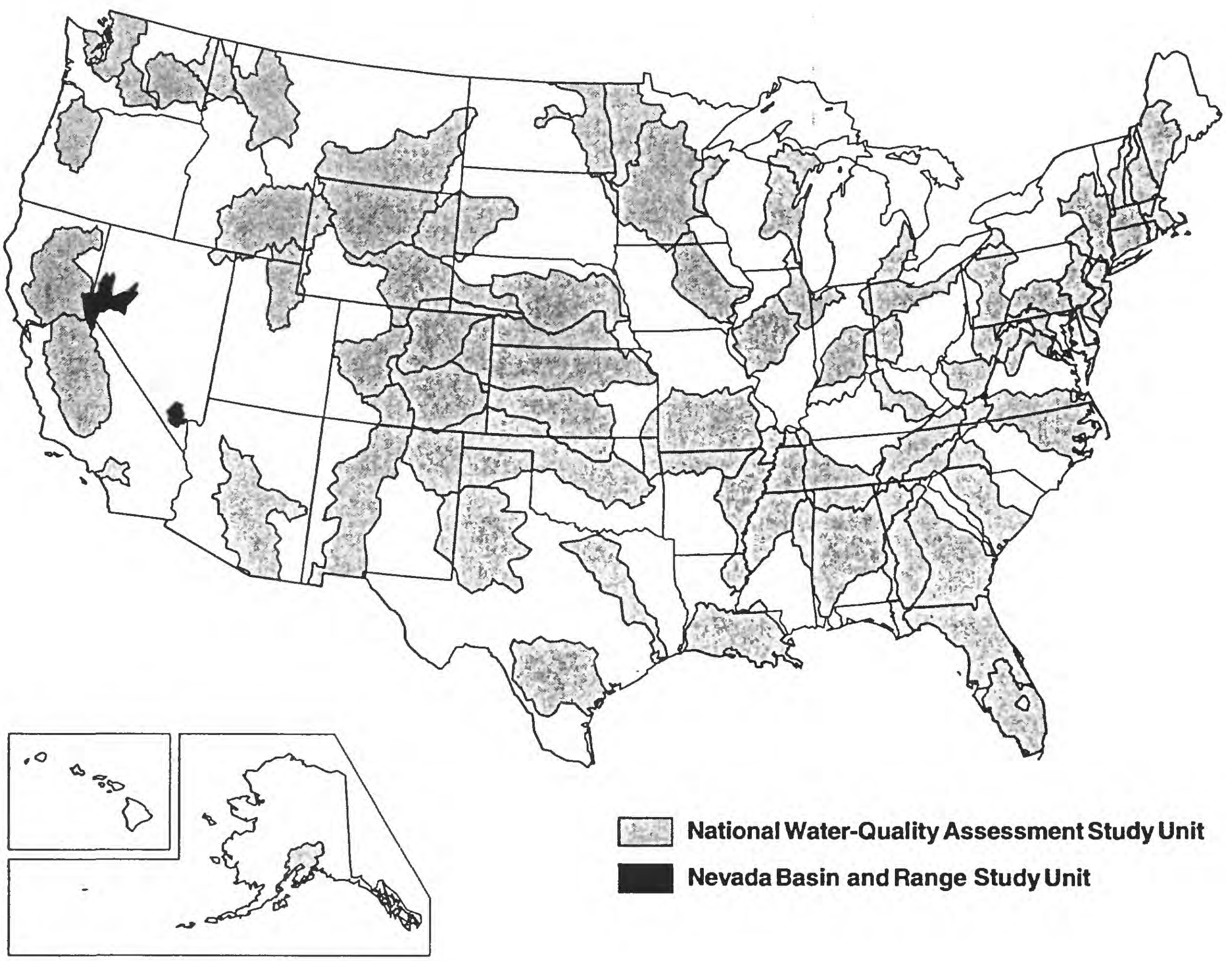
ENVIRONMENTAL AND HYDROLOGIC SETTINGS OF THE LAS VEGAS VALLEY AREA AND THE CARSON AND TRUCKEE RIVER BASINS, NEVADA AND CALIFORNIA

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 96-4087



NATIONAL WATER - QUALITY ASSESSMENT PROGRAM

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FOREWORD

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

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

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

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

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

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

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

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

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre	0.4047	square hectometer
acre-foot per year (acre-ft/yr)	1233.4	cubic meter per year
cubic foot per second (ft^3/s)	0.002832	cubic meter per second
foot (ft)	0.3048	meter
gallon (gal)	0.003785	cubic meter
million gallons per day (Mgal/d)	3.78530	million liters per day
inch (in)	25.39999	millimeter
feet per year (ft/yr)	0.30480	meters per year
inch per year (in/yr)	25.399	millimeter per year
mile (mi)	1.60934	kilometer
square mile (mi^2)	2.58992	square kilometer

Temperature: Degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the formula °F = [1.8(°C)]+32.

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

Additional abbreviations:

µg/L (microgram per liter)
µS/cm (microsiemens per centimeter at 25°C)
mg/L (milligram per liter)
mg/kg (milligram per kilogram)

Environmental and Hydrologic Settings of the Las Vegas Valley Area and the Carson and Truckee River Basins, Nevada and California

By Kenneth J. Covay, Juliana M. Banks, Hugh E. Bevans, *and* Sharon A. Watkins

ABSTRACT

In 1991, the U.S. Geological Survey began a full-scale National Water-Quality Assessment (NAWQA) program to describe the status of and trends in the quality of the Nation's water resources and to provide a scientific understanding of the primary natural and human factors that affect water quality. The NAWQA program consists of 60 proposed study units representing more than two-thirds of the Nation's water use and population served by public water supplies. The Nevada Basin and Range (NVBR) was selected as one of the first 20 study units to be investigated as part of the full-scale program.

This report uses available information and data to describe the environmental and hydrologic settings of the NVBR study unit, which includes the Las Vegas Valley area and the Carson and Truckee River Basins. It includes descriptions of landforms, geology, climate, soils, vegetation, land use, water use, surface-water and ground-water hydrology, and water-quality issues for the three areas.

The Las Vegas Valley area in southeastern Nevada encompasses about 1,640 square miles of the Basin and Range Physiographic Province. The Carson and Truckee River Basins in west-central Nevada and east-central California encompass an area of about 7,200 square miles. The basins include parts of both the Sierra Nevada and Basin and Range Provinces. More than 90 percent of Nevada's population resided in the NVBR study unit in 1990.

Land use in the Las Vegas Valley area is about 79 percent range, 14 percent forest, 5 percent urban, 1 percent open water and wetlands, and 1 percent barren. Total water use in 1990 was about 317,000 acre-feet; 91 percent was used for public supplies. Land use in the Carson and Truckee River Basins is 50 percent range, 22 percent forest, 13 percent open water and wetlands, 10 percent barren, 4 percent irrigated agriculture, and 1 percent urban. Water use in 1990 was about 538,000 acre-feet in the Carson River Basin, and about 262,000 acre-feet in the Truckee River Basin. About 95 percent of the water used in the Carson River Basin was for irrigation. About 59 percent of the water used in the Truckee River Basin was for irrigation.

Las Vegas Wash is the major drainage in Las Vegas Valley area. Its flow in and downstream from Las Vegas is perennial because of urban runoff and, in the lower reaches, tertiary treated sewage effluent, industrial drainage, and discharge of saline ground water. Las Vegas Wash transports contaminants from these point and nonpoint sources to Las Vegas Bay of Lake Mead. Other washes in Las Vegas Valley are either intermittent or ephemeral.

The Carson and Truckee Rivers are perennial and originate in headwater areas in the Sierra Nevada. The basins are hydrologically closed, with the Carson River terminating in the Carson Sink and the Truckee River terminating in Pyramid Lake. The Truckee River receives urban drainage and tertiary treated sewage effluent from the Reno-Sparks urban area. Irrigation in the

Carson Desert has resulted in high concentrations of dissolved solids, boron, arsenic, selenium, molybdenum, lithium, and un-ionized ammonia in water, bottom sediments, and biota. Historical mining activities have contaminated lower reaches of the Carson River, Lahontan Reservoir, and Stillwater Marsh with mercury.

Principal unconsolidated basin-fill aquifers in Las Vegas Valley are more than 3,000 feet thick. Deeper consolidated carbonate-rock aquifers are present beneath the valley. The ground-water quality deteriorates from headwater areas in the Spring Mountains to discharge areas in the southeast. Water quality of the shallow aquifer system underlying Las Vegas Valley is affected primarily by urban land use. The shallow aquifer system in the central and southeastern parts of the valley receives secondary recharge from landscape irrigation. Downward hydraulic gradients, with downward recharge potential, from the shallow aquifer to deeper aquifers have resulted from withdrawals for public water supplies from deeper principal aquifers. This has created a potential for contaminated shallow ground water to affect deeper potable supplies.

Principal aquifers in the Carson and Truckee River Basins are unconsolidated basin-fill deposits of interbedded gravel, sand, silt, and clay. Aquifers within the basins readily receive, transmit, and store large volumes of water. Ground water in headwater recharge areas within the Carson and Truckee River Basins generally is a calcium bicarbonate type with less than 200 mg/L of dissolved solids. Ground water in terminal areas contains increased concentrations of sodium, chloride, and sulfate; concentrations of dissolved solids can exceed 10,000 mg/L. Shallow ground-water recharge in the Carson Desert primarily is by irrigation infiltration in the Fallon agricultural area.

INTRODUCTION

National Water-Quality Assessment Program

In 1986, Congress appropriated funds for the U.S. Geological Survey (USGS) to begin a pilot National Water-Quality Assessment (NAWQA) program. The purpose of the pilot NAWQA program was to test, develop, and refine methods of assessing the quality of the Nation's water resources. The National Academy of Sciences (NAS) Water and Technology Board reviewed the NAWQA pilot program in 1987 and reported that implementation of a full-scale program was in the Nation's best interest. The NAS recommended that Congress appropriate the necessary funds to proceed with a full-scale NAWQA program in fiscal year 1991.

The full-scale NAWQA program will provide data and information on the status, trends, and major natural and human factors that affect the quality of the Nation's water resources. The program will focus on large-scale, persistent conditions to provide current information to resource managers and policy makers at the Federal, State, and local levels. A total of 60 proposed study units (fig. 1) composed of interrelated surface- and ground-water systems will be examined. These study units represent more than two-thirds of the Nation's water use and population served by public water supplies.

The first group of 20 study-unit investigations (fig. 1) began in 1991, the second group began in 1994, and the third group will begin in 1997. The basic study plan allows for 2 years of planning and retrospective analysis, followed by 3 years of intensive data collection and 5 years of less intensive activities. Selected issues of national concern for the first group of 20 study units are pesticides, nutrients, and suspended sediment. The status and trends of these water-quality constituents and relations among water quality, human activities, and natural factors will be investigated by evaluating physical, chemical, and biological components of hydrologic systems.

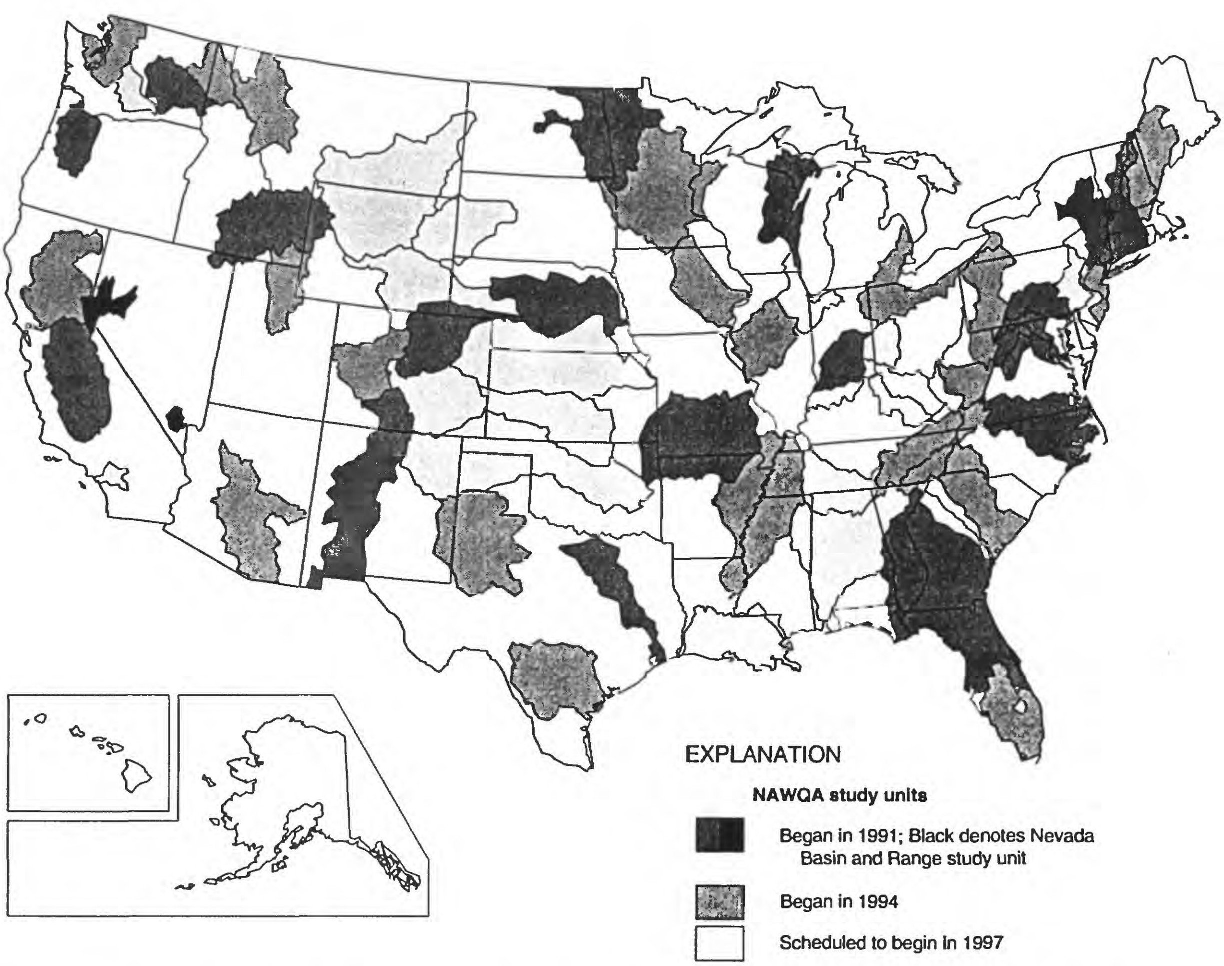

Figure 1. National Water-Quality Assessment study units, including Nevada Basin and Range Study unit.

Nevada Basin and Range Study Unit

Water quality in the Nevada Basin and Range study unit (fig. 2) is affected primarily by urbanization and agriculture. Local issues were defined in NVBR liaison committee meetings with representatives from agencies and organizations concerned with water-resource management. The committee helped identify persistent and widespread water-quality issues affected by human activities such as urbanization, agriculture, industry, and mining. The principal natural water-quality issues identified were the presence of radionuclides and arsenic in ground water, intrusion or discharge of geothermal water, and salinity. The NVBR study will provide data and interpretation needed to address water-quality issues at national, regional, and local scales.

Report Purpose and Scope

This report provides an overview of the NVBR study unit. It includes a description of environmental and hydrologic conditions for the Las Vegas Valley area and the Carson and Truckee River Basins. Available information and data are used to describe physiography, geology, climate, soils, vegetation, urbanization, land use, water use, surface-water and ground-water hydrology, and water-quality issues.

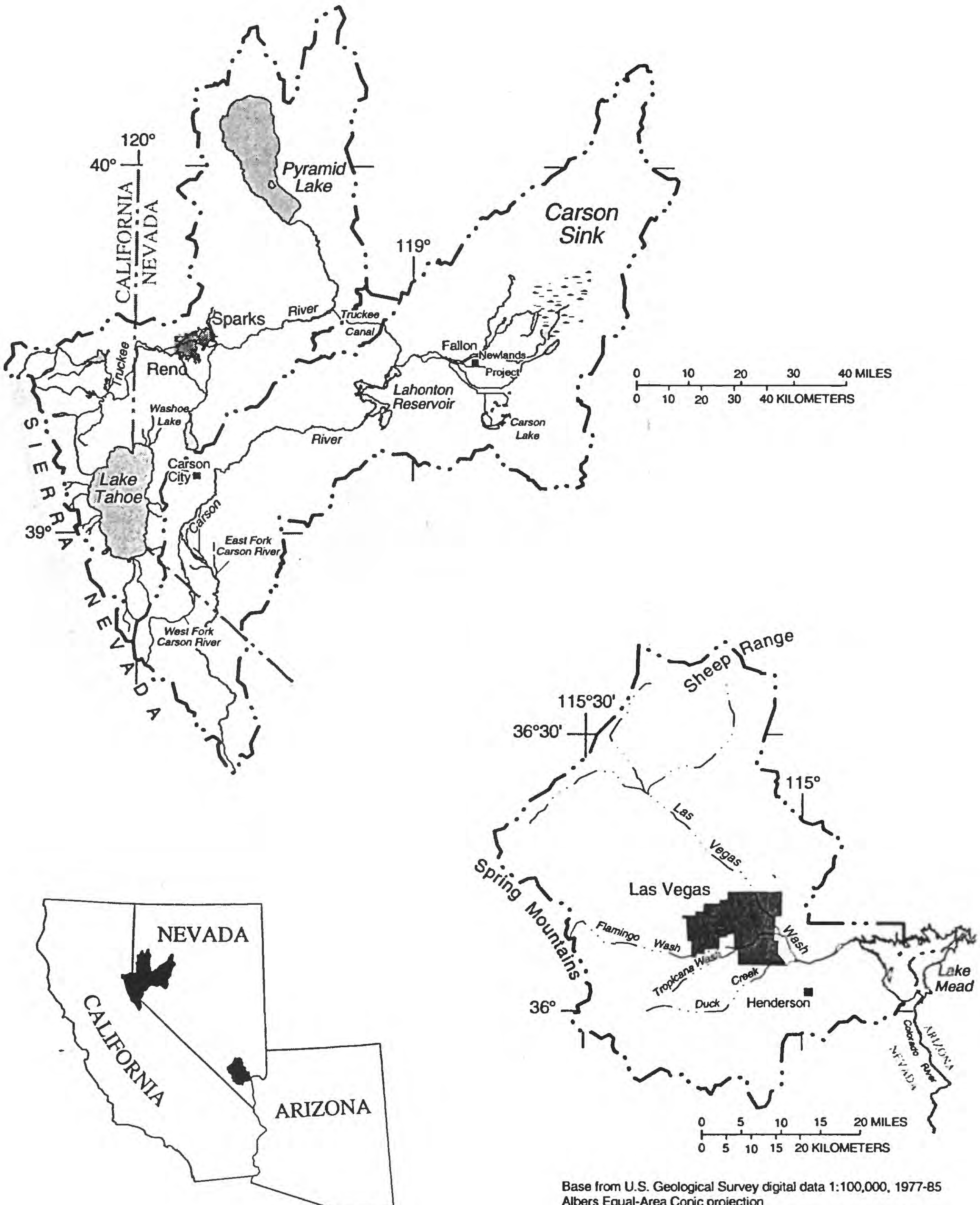

Figure 2. Nevada Basin and Range study unit.

ENVIRONMENTAL SUBAREAS

The information in this report was used to develop a strategy for further study. The investigation strategy is based on subdividing the study area (fig. 2) into subareas that are generally homogeneous with respect to environmental conditions, both human and natural, that influence water quality. This process facilitates the evaluation of significant relations among water-quality conditions and selected, important human and natural factors that otherwise might be obscured.

A conceptual model of basin and range hydrology was used to develop a framework of primary subareas. The conceptual model designates the Sierra Nevada and Spring Mountains, and other high mountains and adjacent areas, where precipitation is sufficient, as headwater areas that provide water for streamflow and ground-water recharge. Headwater areas are defined as yielding about 0.2 in. or more of annual runoff, as delineated by Gebert and others (1987). Valleys along the eastern slopes of the Sierra Nevada (Carson, Eagle, and Washoe Valleys and the Truckee Meadows) are included as headwater areas. Basin areas are low mountains and valleys that yield less than 0.2 in. of annual runoff. Basin-area valleys that receive runoff or recharge from adjacent headwater areas can have both surface- and ground-water resources. Discharge in the terminal areas of the basins is by evapotranspiration and streamflow in the Las Vegas Valley and by evapotranspiration in the Carson and Truckee River Basins.

Secondary subareas were delineated by subdividing the two primary subareas (headwater areas and basin areas) into water-resources categories (rivers, lakes, wetlands, and aquifers). Rivers and aquifers will be investigated during this cycle of the NVBR NAWQA. Aquifer resources were then subdivided into unconsolidated basin-fill deposits, carbonate rocks, and noncarbonate rocks. This cycle of the investigation will consider factors that may influence water quality of the principal unconsolidated basin-fill aquifers that have about 100 ft or more of saturated thickness (Vasey and others, 1972; White and others, 1979; Maurer, 1986) and ground water with less than 1,000 mg/L of dissolved solids (Thompson and others, 1984).

The water-resources subareas were then further subdivided into selected land uses that either represent natural conditions (forest and range) or important human effects (urban and suburban land use and agriculture). Headwater areas have forest and range as primary land uses; urban and suburban land use and agriculture (irrigated pasture and alfalfa) are the principal non-point sources that affect water resources. Basin areas are dominated by sparsely vegetated rangeland; irrigated agriculture, urban, and suburban areas affect water resources. The environmental subareas for the Las Vegas Valley area are shown in figure 3; subareas for the Carson and Truckee River Basins are shown in figure 4.

ENVIRONMENTAL SETTING

Physiography and Geology

Las Vegas Valley Area

Physical and Geologic Settings

The Las Vegas Valley area (fig. 5) in southeastern Nevada encompasses about 1,640 mi^2 and includes the Las Vegas Valley Hydrographic Area[1] and that part of the Black Mountains Hydrographic Area that includes Las Vegas Bay. Altitudes range from about 11,900 ft in consolidated-rock headwater areas in the Spring Mountains, to about 1,600 ft in unconsolidated basin-fill deposits of Las Vegas Valley, and to about 1,200 ft at Las Vegas Bay of Lake Mead. Las Vegas Valley topography is typical of the Basin and Range Physiographic Province with northward-trending mountain ranges and valleys. Las Vegas Valley, however, trends northwest to southeast. The northern part of the valley is within a structurally controlled zone of deformation known as the Las Vegas Valley Shear Zone.

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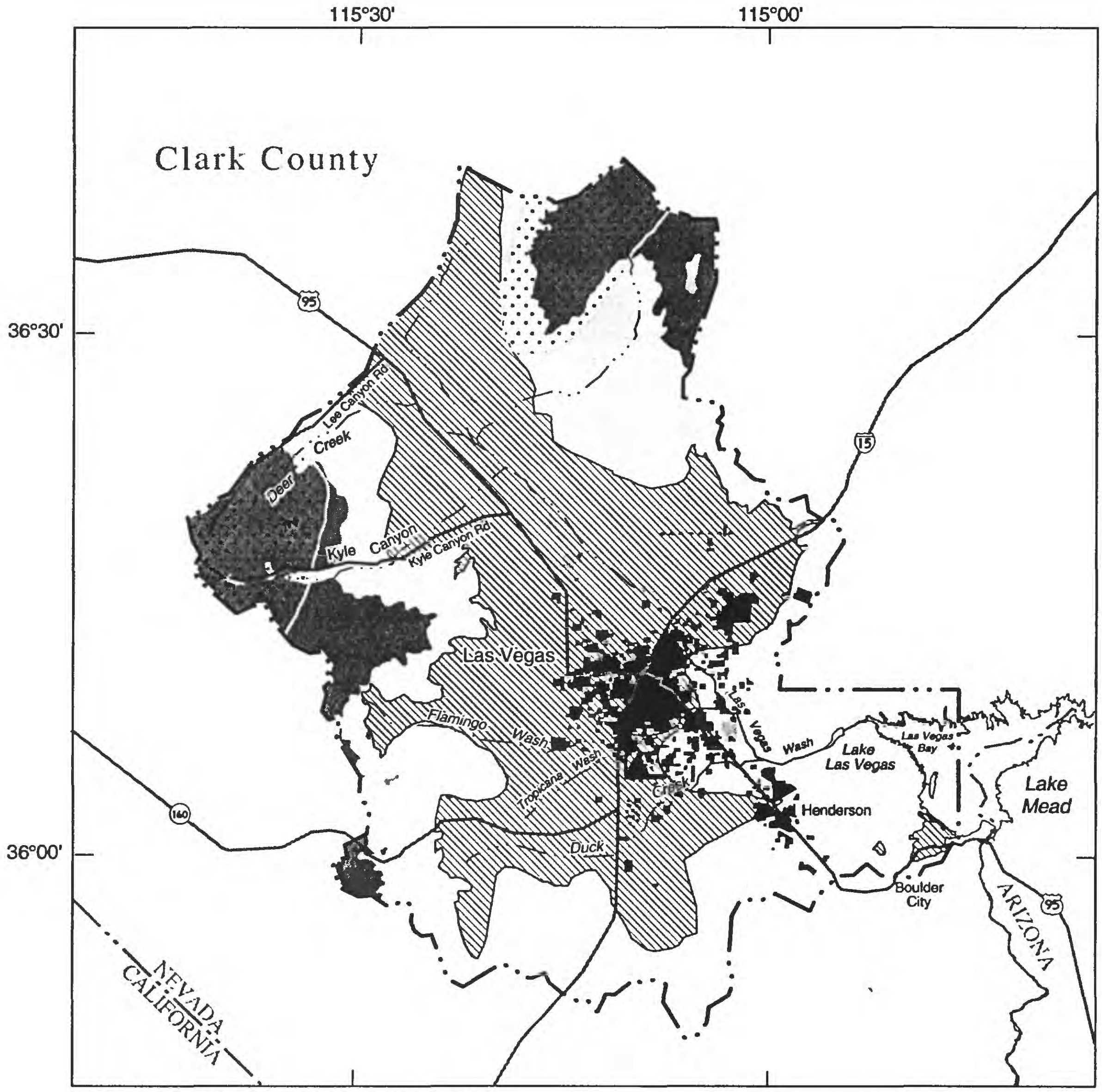
[1]Formal Hydrographic Areas in Nevada were delineated systematically by the U.S. Geological Survey and the Nevada Division of Water Resources in the late 1960's for scientific and administrative purposes (Rush, 1968; Cardinalli and others, 1968). The official Hydrographic Area names, numbers, and geographic boundaries continue to be used in U.S. Geological Survey reports and Nevada Division of Water Resources administrative activities.



Base from U.S. Geological Survey digital data 1:100,000, 1981-88
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -115°00'

0 5 10 15 20 MILES
0 5 10 15 20 KILOMETERS

EXPLANATION

General area underlain by principal basin-fill aquifers—Saturated thickness is 100 feet or more (Vasey and others, 1972). Ground water has less than 1,000 mg/L of dissolved solids (Thompson and others, 1984)

Headwater area—Annual runoff of 0.02 inch or more (Gebert and others, 1987)

Land use—Modified from U.S. Geological Survey digital data; 1:250,000 scale; 1973-83

Range—Includes barren and other

Irrigated agriculture

Forest

Urban

Study area boundary

Figure 3. Environmental subareas for Las Vegas Valley area.

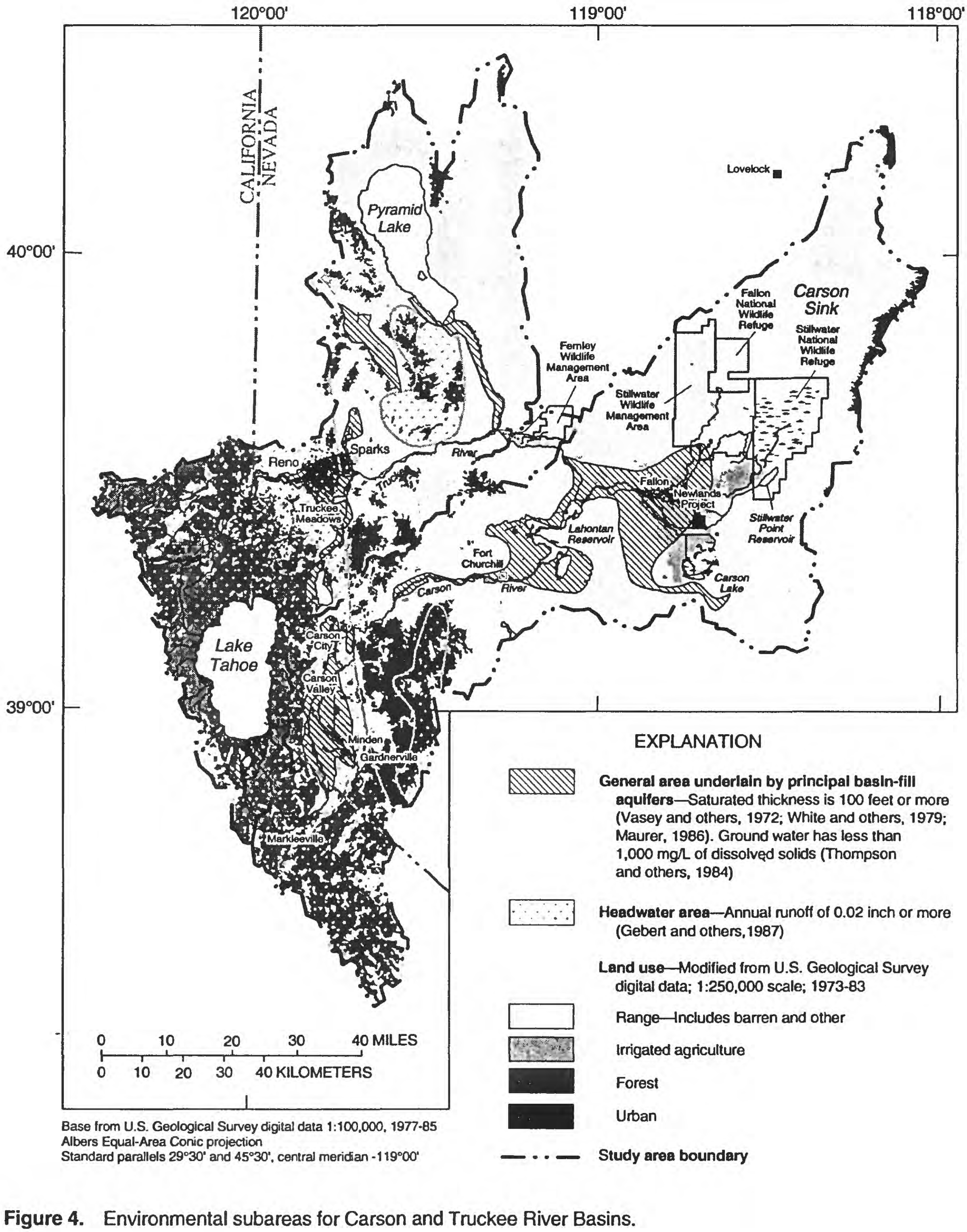
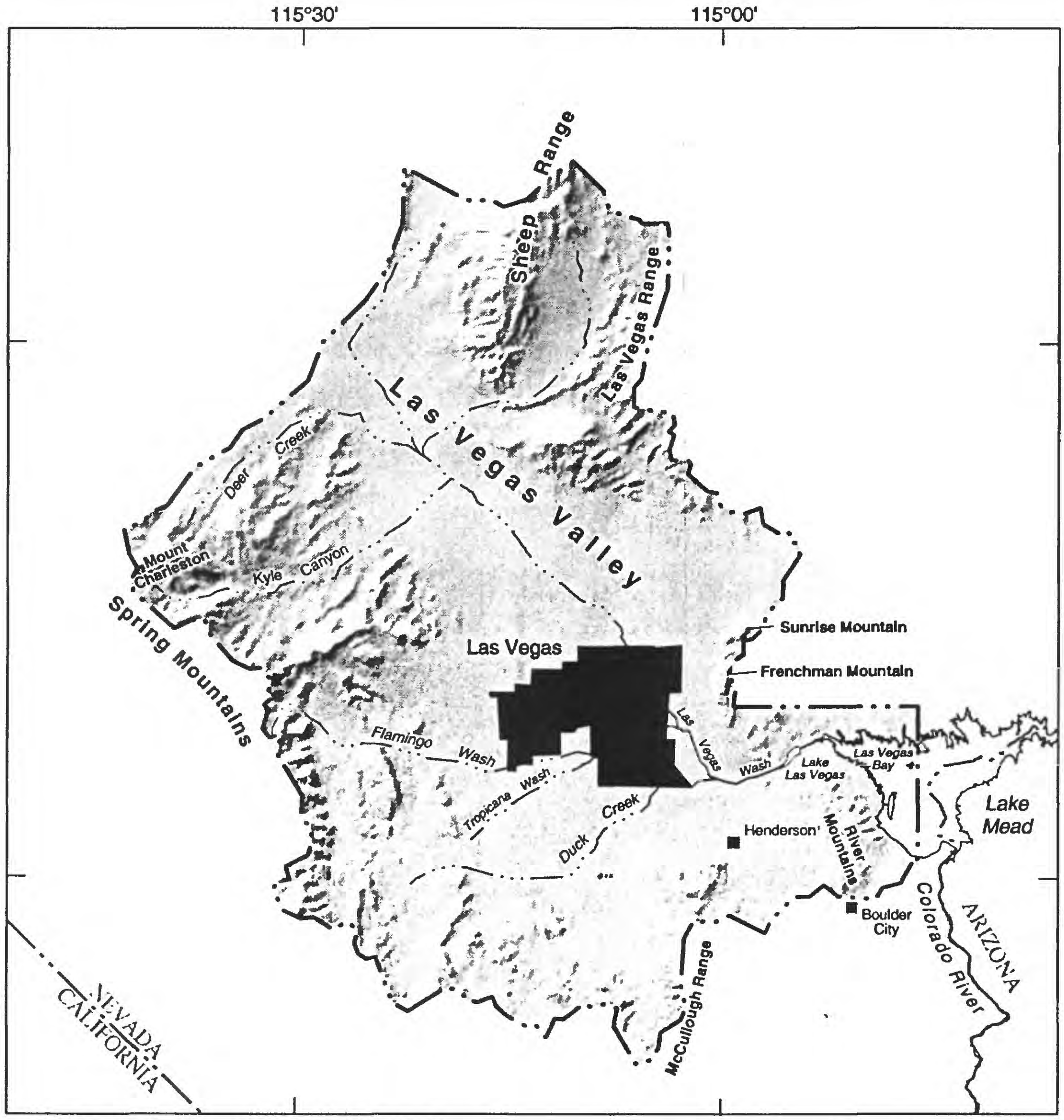


Figure 4. Environmental subareas for Carson and Truckee River Basins.



Base from U.S. Geological Survey digital data 1:100,000, 1981-88 Albers Equal-Area Conic projection. Standard parallels 29°30' and 45°30', central meridian -115°00'. Shaded relief from 1:24,000-scale Digital Elevation Model; sun illumination from northeast at 30° above horizon

EXPLANATION

— · · — Study area boundary

Figure 5. Physiography of Las Vegas Valley area.

Mountains surrounding the valley are elevated sharply above the moderately sloping valley floor. The mountains are fractured by many faults. Dark gray limestone, dolomite, and quartzite form high, rugged, steep slopes and less resistant sandstones and shales form subdued ridges or valleys (Longwell and others, 1965).

Valley lowlands are surrounded by coalescing, gently sloping alluvial fans. Large amounts of alluvial material are eroded during rainstorms and are continually cut and reworked by gullying. Sediments underlying the alluvium have fluvial, lacustrine, and eolian origins.

Drainage from the Las Vegas Valley area is southeastward into Lake Mead and the Colorado River system. Drainage is primarily ephemeral or intermittent except that the lower reach of Las Vegas Wash is perennial because of urban drainage and effluent releases. In mountainous areas, channels are narrow and steep, but in the valley they are flat and wide. Cemented gravels of the late Cenozoic often form cliffs along wash channels. Geologic time divisions are shown in table 1.

Geologic history of Las Vegas Valley is represented by the development of the Basin and Range Physiographic Province. Generalized locations of consolidated rocks and un-consolidated deposits in Las Vegas Valley are shown in figure 6. Repeated periods of volcanic activity, uplift, erosion, and deposition took place throughout the Paleozoic and Mesozoic, with sedimentation interrupted by orogenic activity. Volcanic flows were extruded over broad areas and were followed by faulting. Tectonic activity was prevalent in the mid to late Tertiary and is evident in geologic structures (Bell, 1981).

The Spring Mountains (fig. 5) are the highest features in the valley with an altitude at Mount Charleston of about 11,900 ft. Dominant geologic features in these mountains are large faults and associated folds.

The rugged Sheep Range is northwest of Las Vegas (fig. 5) and has a maximum altitude of about 9,900 ft. Carbonate rocks are in the northern and southern parts of the range; clastic rocks are near the west side. The Sheep Range overlies a thrust fault that is exposed in the Las Vegas Range.

The Las Vegas Range (fig. 5) reaches altitudes greater than about 7,000 ft with foothills at its base. Thrust faults and folds are within the range, but most are covered by alluvium. To the east of Las Vegas are Frenchman and Sunrise Mountains (fig. 5). Frenchman Mountain is steep, trends northward, and has an altitude of about 2,000 ft. Sunrise Mountain is similar to Frenchman Mountain, but is slightly smaller, and trends northeast. These mountains are bound on the west by numerous faults.

North of Sunrise Mountain is the Las Vegas Valley Shear Zone. This zone may be a regional ground-water flow path, containing water that discharges from carbonate-rock aquifers (Mifflin, 1968; Naff and others, 1974; Hess and Mifflin, 1978; Noack, 1988). This zone trends northwestward from Sunrise Mountain and corresponds with the deepest part of the bedrock within the basin (Plume, 1989).

The River Mountains (fig. 5), southeast of Las Vegas, have moderate relief and a rugged surface. The River Mountains probably have been faulted to their present position from the east (Duebendorfer and others, 1990). The northern part of the McCullough Range (fig. 5) borders part of Las Vegas Valley on the south. This part of the range primarily consists of Tertiary volcanic rocks. The consolidated rocks that underlie the volcanic rocks are mostly limestone. The eastern edge of this range is cut by a steep escarpment.

Consolidated Rocks

Mountains surrounding the valley are composed primarily of Precambrian to Tertiary consolidated carbonate rocks, sedimentary rocks, and some igneous and metamorphic rocks. Consolidated rocks (fig. 6), except for carbonate rocks, usually are a barrier to ground-water flow. Locally, carbonate rocks can transmit large quantities of water through solution channels formed along faults and joints (Plume, 1985).

The most common types of consolidated rocks (fig. 6) are carbonate rocks, siltstone, and sandstone in mountain ranges on the west, north, and east sides of the valley. The mountains to the south and southeast are composed of Tertiary volcanic rocks that overlie Precambrian metamorphic and granitic rocks. Throughout the area, there are layers of cemented gravel and lenses of caliche.

Unconsolidated Deposits

Beginning in the Miocene, terrestrial and lacustrine sediments accumulated in Las Vegas Valley to thicknesses of about 3,000 to 5,000 ft (Longwell and others, 1965). Active wash channels, including Las Vegas Wash, cut through poorly sorted sediment ranging in size from clay and sand to cobbles and boulders.

Table 1. Divisions of geologic time—major geochronologic units

Subdivisions				Age estimates of boundaries in millions of years [1]
Era	Period or System		Epoch	
Cenozoic [2]	Quaternary [2]		Holocene	0.010
			Pleistocene	1.6 (1.6-1.9)
	Tertiary		Pliocene	5 (4.9-5.3)
			Miocene	24 (23-26)
			Oligocene	38 (34-38)
			Eocene	55 (54-56)
			Paleocene	66 (63-66)
Mesozoic [2]	Cretaceous		Late	96 (95-97)
			Early	138 (135-141)
	Jurassic		Late	
			Middle	205 (200-215)
			Early	
	Triassic		Late	
			Middle	~240
			Early	
Paleozoic [2]	Permian		Late	
			Early	290 (290-305)
	Carboniferous System	Pennsylvanian	Late	
			Middle	~330
			Early	
		Mississippian	Late	
			Early	360 (360-365)
	Devonian		Late	
			Middle	410 (405-415)
			Early	
	Silurian		Late	
			Middle	435 (435-440)
			Early	
	Ordovician		Late	
			Middle	500 (495-510)
			Early	
	Cambrian		Late	
			Middle	
			Early	
Precambrian [3]				~570

[1] Ranges reflect uncertainties of isotopic and biostratigraphic age assignments. Age boundaries not closely bracketed by existing data are shown by ~. Decay constants and isotopic ratios employed are cited in Steiger and Jäger (1977).

[2] Modifiers (early, middle, late) when used with these items are informal divisions of the larger unit.

[3] Rocks older than 570 million years also called Precambrian, a time term without specific rank.

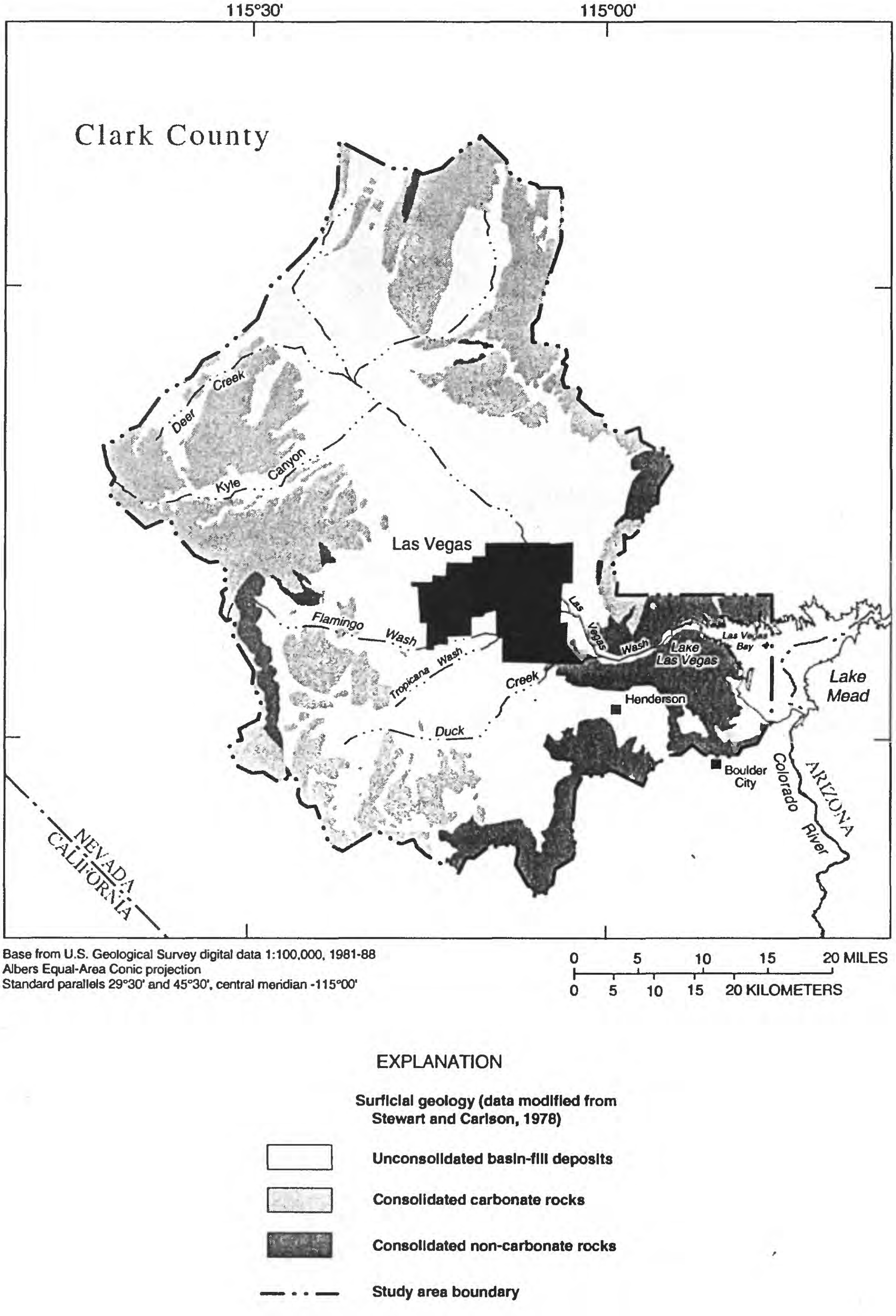


Figure 6. Surficial geology of Las Vegas Valley area.

Unconsolidated basin fill (fig. 6) is rich in carbonate material and includes Miocene clastic and sedimentary deposits of siltstone, sandstone, limestone, conglomerates, with some gypsum and lava. Cenozoic deposits consist of poorly sorted clay, silt, sand, gravel, and conglomerates that overlie older basin fill. Fine-grained siltstone and mudstone playa deposits also are in lower parts of the valley (Longwell and others, 1965; Bell, 1981; Plume, 1989). Basin-fill deposits are laterally and vertically discontinuous because of the different depositional environments. Unconsolidated sands and gravels are the most productive aquifers in the valley.

Carson and Truckee River Basins

Physical and Geologic Settings

In contrast to the primarily carbonate, sandstone, and siltstone mountains surrounding Las Vegas Valley, the mountains in the Carson and Truckee River Basins are primarily granitic and volcanic in origin. Also, the Carson and Truckee River Basins are drained by perennial streams, in contrast to intermittent streams in Las Vegas Valley.

The Carson and Truckee River Basins study area in west-central Nevada and east central California (fig. 7) encompass an area of about 7,200 mi^2. The study area includes the Carson River Basin (Carson Valley, Eagle Valley, Dayton Valley, Churchill Valley, and Carson Desert Hydrographic Areas), the Truckee River Basin (Truckee Canyon segment, Lake Tahoe Basin, Washoe Valley, Pleasant Valley, Truckee Meadows, Sun Valley, Spanish Springs Valley, Warm Springs Valley, Tracy Segment, Dodge Flat, Pyramid Lake Valley, and Winnemucca Lake Valley Hydrographic Areas.) The Fernley Hydrographic Area is included in the study area because the Truckee Canal, which diverts water from the Truckee River to Lahontan Reservoir on the Carson River, flows through it. The basins are topographically closed and extend from the mountainous Sierra Nevada Province eastward into the Basin and Range Province (fig. 7). A closed basin has no outlet and water entering such a basin discharges only by evapotranspiration. Altitudes range from about 10,900 ft in the consolidated-rock headwater areas of the Sierra Nevada, to about 3,900 ft in the unconsolidated basin-fill deposits in the Carson Sink and at Pyramid Lake.

In the western part of the Carson and Truckee River Basins, the rugged Sierra Nevada are bordered on the east by a large northwest-striking fault system that extends about 400 mi from south-central to northeastern California (Brown and others, 1986). These faults divide granitic rocks on the west from the younger volcanic rocks on the east. Vertical displacements along these faults have elevated the granitic rocks several thousand feet. Stream channels in these mountains have steep gradients in narrow, steep-walled canyons. The Sierra Nevada have been glaciated a minimum of three times (Fox, 1982). In glaciated areas, stream channels are broad and flat. Glacial features include cirques, glacial valleys, moraines, and outwash terrace deposits (Fox, 1982).

The Carson River headwaters are located in the Carson Range to the west, the Sierra Nevada to the south, and the Pine Nut Mountains to the east (fig. 7). The East Fork and West Fork (fig. 7) merge in the west-central part of the Carson Valley to form the main stem of the Carson River. Downstream from the confluence, the river flows northeastward through Carson Valley and east of Carson City. The river then flows between the Virginia Range and the Pine Nut Mountains and discharges into the Carson Sink, which is bordered by the West Humboldt Range and the Stillwater Range.

The Truckee River headwaters are in the Sierra Nevada; the river originates from Lake Tahoe (Bateman, 1976). From headwater areas, the Truckee River flows eastward to enter the Basin and Range Physiographic Province near the Truckee Meadows and Reno-Sparks urban area (fig. 7). East of the Reno-Sparks urban area, the river flows northeastward between the Pah Rah and Virginia Ranges. The river then flows northward, between the Pah Rah and Truckee Ranges, and terminates in Pyramid Lake, which is bordered by the Virginia Mountains, the Pah Rah Range, and the Lake Range (fig. 7).

There were several episodes of mountain building and volcanic activity in the Basin and Range Province during the Paleozoic and Mesozoic. Geologic time divisions are shown in table 1. Typically, mountain ranges within this province were formed during major periods of crustal extension in the Cenozoic. In the Late Jurassic, the Nevada Orogeny caused extensive eastward folding and faulting. Tectonic activity, as evidenced by widespread earthquakes, continues in the area. The Sierra Nevada are atypical of mountain ranges in that their entire length of about 350 mi is not breached by a single river (Stanley, 1989).

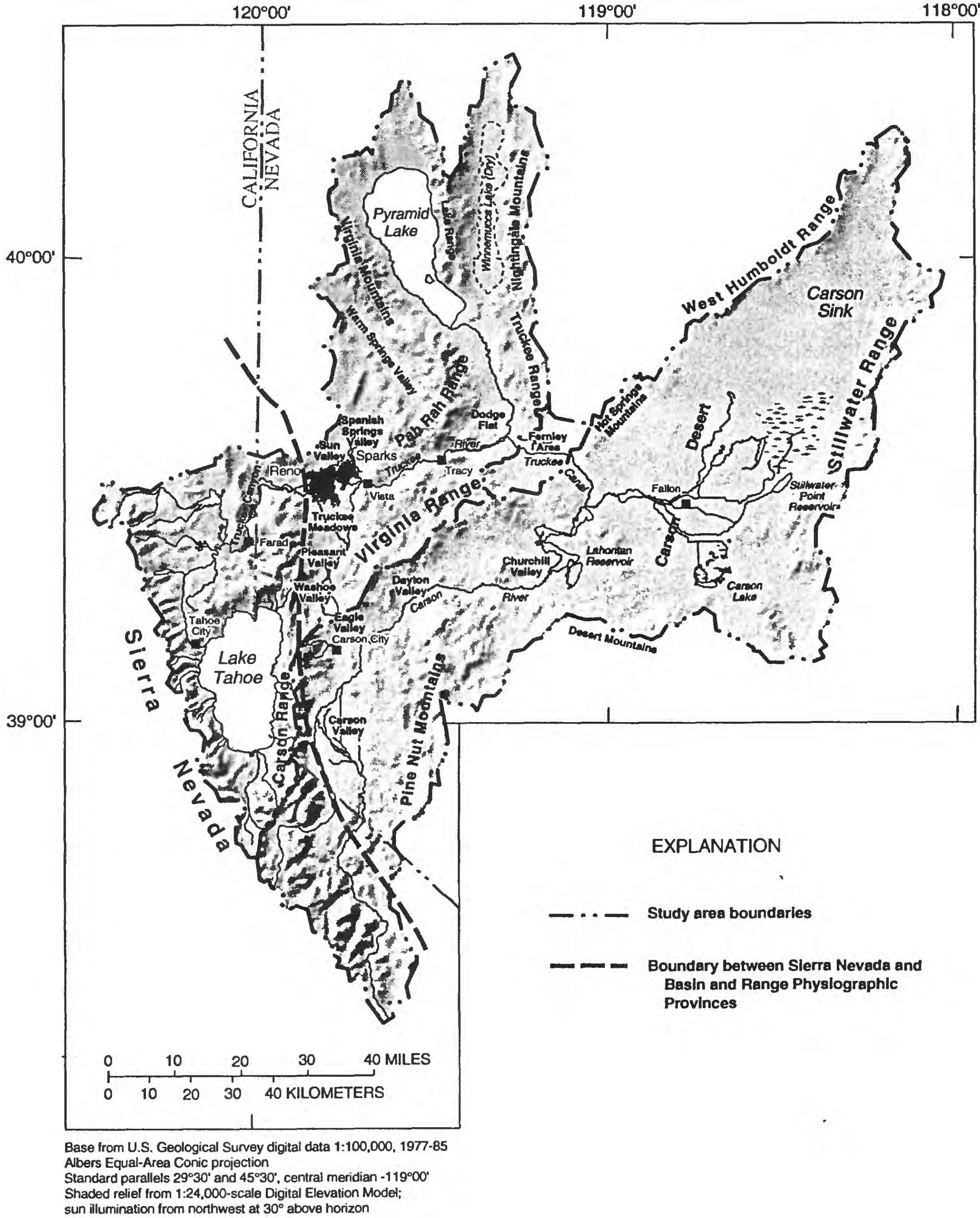


Figure 7. Physiography of Carson and Truckee River Basins.

During the Tertiary, there was volcanic activity in the Carson Sink (Morrison, 1964). During late Tertiary and early Pleistocene times, regional and local uplift and faulting helped define present-day topography. Throughout the region closed basins developed, valley sediments were deposited and volcanic activity continued. In the Carson Sink during the Pleistocene, lake sediments accumulated in Pleistocene Lake Lahonton. The lake covered a large part of the Carson and Truckee River Basins and included the present day Carson Sink and Pyramid Lake. Climatic changes resulted in reduced inflows and high temperatures and evaporation rates eventually caused desiccation of the lake.

Consolidated Rocks

Consolidated rocks in the Carson and Truckee River Basins (fig. 8) primarily are igneous and metamorphic rocks, although some localized consolidated sedimentary rocks are present. Composition and thickness of different types vary with location. Consolidated rocks usually vary from slightly permeable to completely impermeable, although where fractured can be highly permeable.

The Reno-Sparks urban area (fig. 7) is in a basin caused by faults bordering the area and is surrounded by the Sierra Nevada and the Virginia and Pah Rah mountain ranges. The consolidated rocks are mostly metasedimentary and metavolcanic in origin (Bonham, 1969). These rocks have low permeability except where they are highly fractured.

Exposed consolidated rocks around the Carson Valley (fig. 7) are primarily granitic, metavolcanic, and metasedimentary. Granite at the surface is a result of normal faulting and associated tilting and erosion. Consolidated rocks in the Carson Valley dip westward (Moore, 1969). Maurer (1986) indicates that depth to the consolidated rocks throughout the Carson Valley generally exceeds 1,000 ft, with the maximum depth exceeding 5,000 ft on the west side of the valley.

Consolidated rocks surrounding Eagle Valley (fig. 7) are primarily metamorphosed Mesozoic volcanic and sedimentary rocks, Mesozoic and Cretaceous igneous rocks, and Tertiary sandstone and volcanic rocks (Moore, 1969; Trexler, 1977). The consolidated rocks are nearly impermeable except where fractured or weathered, and have not been considered as important sources of water (Szecsody and others, 1983; Arteaga, 1986). A recent investigation by the USGS indicates that these rocks, where fractured or weathered, can be conduits for recharge to the basin-fill aquifer (David E. Prudic, U.S. Geological Survey, written commun., 1995).

In Dayton and Churchill Valleys, consolidated rocks include Jurassic to Quaternary igneous rocks, metavolcanic rocks, and sedimentary rocks (Schaefer and Whitney, 1992). Consolidated rocks within these valleys are not the primary water-bearing units, but, if highly fractured, can have high permeability.

In the Fallon area, the depth to consolidated rock often exceeds 8,000 ft. These rocks are mainly volcanic, with some metamorphic and sedimentary rocks (Willden and Speed, 1974; Hoffman, 1989).

Unconsolidated Deposits

Unconsolidated deposits (fig. 8) are in all valleys of the Carson and Truckee River Basins and are the primary water-bearing units within the study area. In the Reno-Sparks area, the basin fill is derived from the surrounding mountain ranges. Quanternary alluvial materials consist of clay, silt, sand, and gravel layers. These sediments provide most of the ground water for the area. Tertiary, semiconsolidated sediments with interbedded clay, silt, sand, gravel, and pumice do not yield large quantities of water. The basin-fill deposits in the Reno-Sparks area are as much as 4,000 ft thick (Cohen and Loeltz, 1964).

Carson Valley (fig. 7) contains unconsolidated Quaternary basin-fill sediments and semiconsolidated Tertiary sediments (Maurer, 1986). The Quaternary deposits are mostly fine- to coarse-grained Carson River alluvium and are the major water-bearing units within the Carson Valley (Maurer, 1986). The thickest section of the basin-fill deposits is west of the valley axis because of downward tilting to the west of the Pine Nut Mountains, relative to uplift along the east margin of the Carson Range. Much of the eastern part of the valley is covered by Tertiary lake and stream deposits as much as several hundreds of feet in thickness. Most of the Tertiary strata dip moderately westward and are covered by Quaternary gravel. These sediments are cut by north-trending Quaternary normal faults (Moore, 1969).

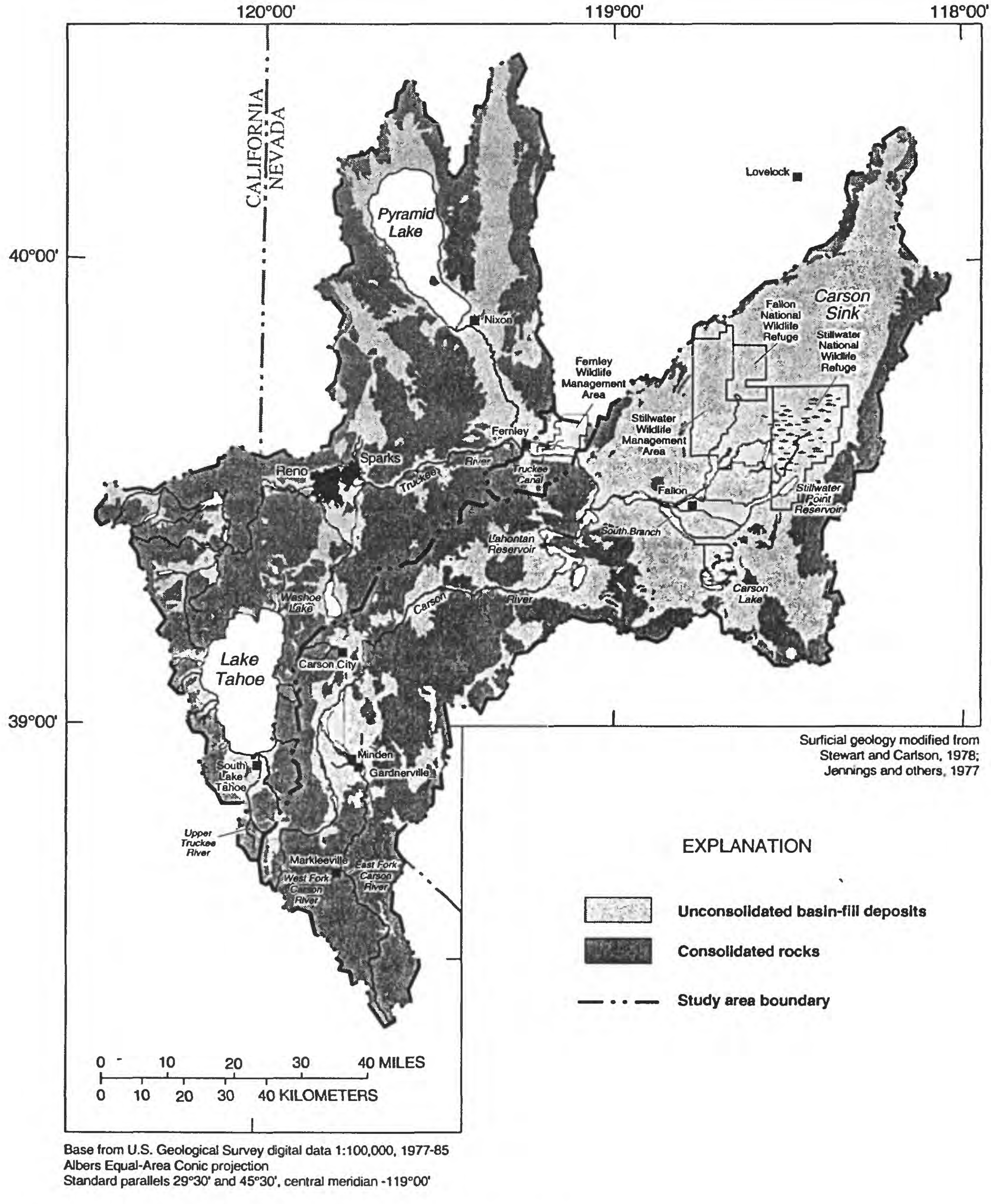


Figure 8. Surficial geology of Carson and Truckee River Basins.

Eagle Valley (fig. 7) contains Quaternary semi-consolidated and unconsolidated alluvium that is mostly granitic and metamorphic detritus of clay, silt, sand, and coarse materials deposited in alternating layers with clay layers that act as confining units (Trexler, 1977; Arteaga, 1986).

Basin-fill deposits in the Dayton and Churchill Valleys (fig. 7) consist of Cenozoic sedimentary deposits (about 500-3,000 ft thick), alluvial fans and pediments, lake, river, delta, and flood-plain deposits (Schaefer and Whitney, 1992). These depositional units consist of clays, silts, sands, and gravel.

Tertiary to Holocene sedimentary deposits are in the Fernley area (fig. 7). Lico (1992) indicates these deposits, from youngest to oldest, are Holocene eolian and alluvial deposits, lacustrine deposits from Pleistocene Lake Lahontan, pre-Pleistocene Lake Lahontan lacustrine and fluvial sediments, and Tertiary volcanic rocks. The combined thickness is approximately 1,000 ft.

In the Carson Sink (fig. 8), the unconsolidated surficial deposits are fluvial playa and lake, and some eolian sediments (Morrison, 1964). The basin floor is underlain by interbedded Holocene fluvial and eolian deposits, Pleistocene and Holocene lake sediments, Cenozoic fan gravel, deltaic deposits, and volcanic rocks, and possibly pre-Tertiary sediments. More than 300 ft of fine-grained lake sediments, consisting of deltaic deposits, shoreline sand and gravel, and deep lake sediments, were deposited when Pleistocene Lake Lahontan covered the area (Lico, 1992). The combined thickness of these deposits exceeds 8,000 ft.

Climate, Soils, and Vegetation

Las Vegas Valley Area

Climate

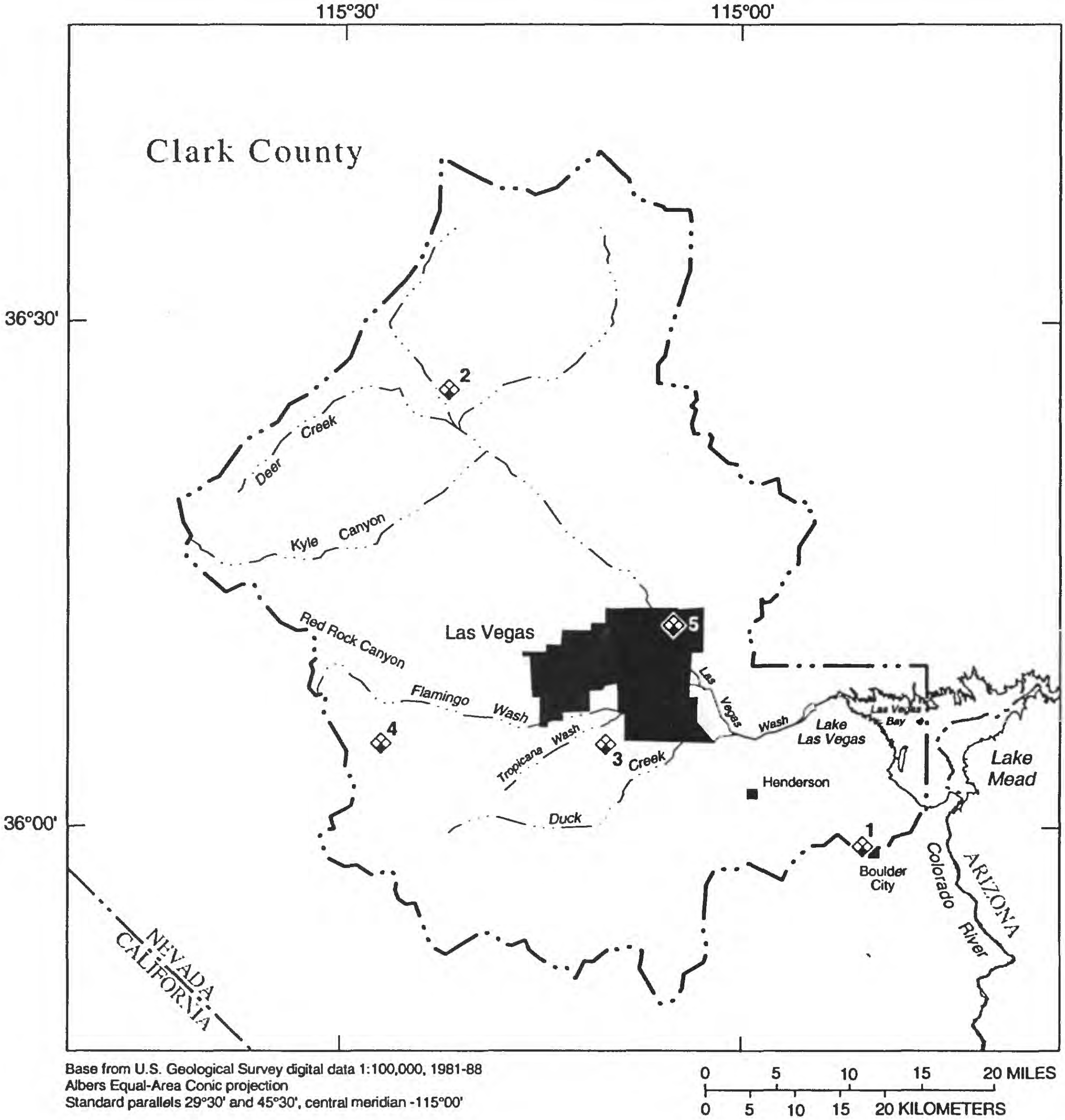
The climate in most of the Las Vegas Valley area is arid to semiarid. During 1981-91 at Las Vegas, the average monthly summer temperature maximum was 39°C and the minimum was 21°C; the average monthly winter temperature maximum was 15°C and the minimum was 0.6°C (data from National Climatic Center, 1982-92). Frost-free periods average about 240 days in the valley.

Annual precipitation for five selected locations (fig. 9) is listed in table 2. Most precipitation is during the months of December through March. The average annual precipitation of the Las Vegas Valley area is about 4 in., although higher altitudes in the mountains can receive more than 20 in. (Speck, 1985). Summer thunderstorms of short duration and high intensity cause local flooding and erosion. Intense rain storms are possible in any season and can produce torrents of water and debris. Annual precipitation, 1981-91, ranged from about 1.3 in. at McCarran Airport (station 3 in fig. 9) in 1985 to about 24 in. at Red Rock Canyon State Park (station 4) in 1983 (data from National Climatic Center, 1982-92).

Soils

Soils in Las Vegas Valley are formed from weathered basin-fill deposits and consolidated rocks. In the southeastern part of the valley, alluvial soil in the McCullough Range and River Mountains (fig. 5) is developed mainly from weathered, coarse, volcanic detritus (Carlsen and others, 1991). Soils within the valley are classified as entisols and aridisols. Entisols develop on recent alluvium and have weakly defined horizons. Aridisols form in desert environments and accumulate salts at the surface. Many soils in the valley are covered with desert pavement—pebbles and cobbles that have a dark coating of desert varnish. Surficial soils are well drained and composed of fine gravelly to fine sandy loam. At various depths below the surface throughout most of the valley, a well-cemented soil horizon of sandy, loamy, or clayey material (caliche) is present (Speck, 1985).

In the northern part of the basin, soils are formed from carbonate-enriched alluvium, siliceous enriched silt, and fine-grained sand (Sowers and others, 1988). Accumulation of calcium carbonate-rich horizons dominate these soils. Laminar calcrete is present throughout the valley and is formed when calcium carbonate percolates downward into the soil and precipitates in void spaces within the alluvium. Eventually calcium carbonate accumulation creates a hydrologic barrier. Sowers and others (1988) further suggested that the depth to this barrier is controlled by porosity and permeability of alluvium.



Base from U.S. Geological Survey digital data 1:100,000, 1981-88
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -115°00'

EXPLANATION

—·· — **Study area boundary**

◈ 5 **Precipitation measurement station**—See table 2

Figure 9. Location of precipitation measurement stations in Las Vegas Valley area.

Table 2. Precipitation data for weather stations in Las Vegas Valley area, 1981-91

[Symbol: --, full-year data not available. Data from National Climatic Center, 1982-92]

Station number (figure 9)	Station name	Altitude (feet above sea level)	Total annual precipitation (inches)											Average annual precipitation, for indicated record during 1981-91 (inches)
			1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	
1	Boulder City	2,530	7.64	6.56	7.35	13.36	4.13	5.09	7.43	3.01	3.03	5.34	8.34	6.48
2	Desert National Wildlife Range	2,922	3.26	4.87	6.34	10.38	2.58	4.66	7.21	3.12	1.51	2.82	3.66	4.58
3	McCarran Airport	2,162	3.14	3.99	4.86	6.85	1.27	2.65	6.59	2.29	2.11	3.75	3.90	3.76
4	Red Rock Canyon State Park	3,780	9.24	17.87	23.89	--	--	--	9.55	7.96	2.34	7.45	7.72	10.75
5	Sunrise Manor	1,821	3.16	4.83	6.26	--	--	2.57	7.81	--	--	--	--	4.93

Vegetation

Precipitation and altitude are major controls that influence vegetation zonation in the Las Vegas Valley area. Four plant communities are found in Las Vegas Valley area. Communities from highest to lowest altitude are (1) fir pine, (2) pinyon juniper, (3) blackbrush, and (4) creosote. Because precipitation is lacking in lower altitudes of the valley, vegetation is sparse and some areas are barren. Increased precipitation at higher altitudes supports more vegetation.

White fir, ponderosa pine, and some bristlecone pine grow above 7,000 ft on the shaded sides of canyons and on the north-facing slopes. Conifer forests and aspen grow in high altitudes within the Spring Mountains. Above 4,500 ft, wooded areas of pinyon pine and juniper are abundant.

Joshua trees and spanish bayonet grow in central parts of the alluvial fans and foothills. In this zone, blackbrush is the dominant small shrub and many cacti are present. Sagebrush typically is found in this zone.

In lower altitudes, vegetation consists of phreatophytes—plants that obtain water from or below the water table (Maxey and Jameson, 1948). Mesquite, salt grass, greasewood, and rabbit brush grow throughout the basin in the lowest, most arid altitudes. Creosote brush grows in lowland areas and on alluvial slopes where the water table is at considerable depth. Along wash channels, sagebrush, tamarisk, and creosote are dominant vegetation types, although sagebrush and tamarisk do not grow in the same community together.

Carson and Truckee River Basins

Climate

The climate of the Carson and Truckee River Basins is classified as humid and subhumid continental in headwater areas; these climates are characterized by generally cool or mild summers and cold winters. Houghton and others (1975) indicate that in more arid low-altitude areas the climate is classified as mid-latitude steppe, and is characterized by warm to hot summers and winter temperatures near or below freezing. In Reno (station 7 in fig. 10 and table 3) during 1981-91, the average monthly summer temperature maximum was 30°C and the minimum was 8.4°C; the average monthly winter temperature maximum was 8.4°C and the minimum was -6.2°C (data from National Climatic Center, 1982-92). Other climatic characteristics of this area are prevailing westerly winds, large daily temperature fluctuations, and infrequent, but severe storms (Garcia and Carman, 1986).

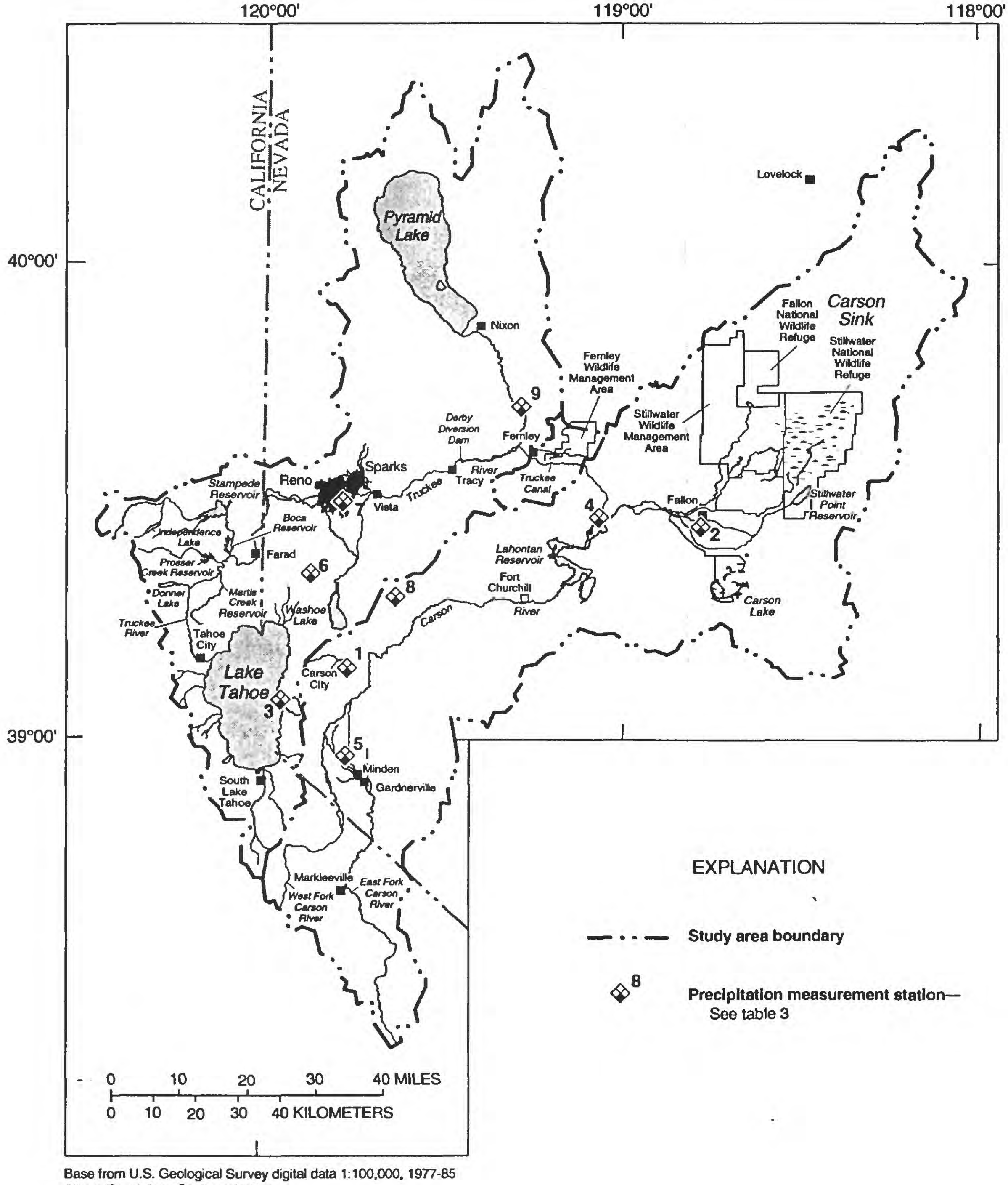
Precipitation in the Carson and Truckee River Basins is attenuated by the rainshadow of the Sierra Nevada. Average annual precipitation in the Carson Desert is less than 5 in., but high altitudes of the Sierra Nevada receive more than 30 in. Annual precipitation for nine selected locations (fig. 10) are indicated in table 2. On the eastern slopes of the Sierra Nevada and ranges to the east, annual precipitation increases with increasing altitude, but the relation varies seasonally. Annual precipitation, 1981-91, ranged from about 2.6 in. at Fallon (station 2 in fig. 10 and table 3) in 1986 to about 52 in. at Mt. Rose (station 6) in 1982 (data from National Climatic Center, 1982-92).

Soils

Carson and Truckee River Basin soils are classified primarily as aridisols and ultisols, with some entisols (U.S. Geological Survey, 1970). All soils are dry to moist and have gray to brown surface horizons, or layers. Aridisols are dry, alkaline mineral soils with light-colored surface horizons containing little organic material. Layers of calcium carbonate, gypsum or salts may accumulate beneath the surface horizon. They form mostly in semiarid to arid regions. Ultisols are highly weathered, somewhat acidic red to yellow soils underlain by clay layers. They normally develop under forest vegetation. Entisols are dry mineral soils that have formed from alluvial material without developing significant layering. All surficial soils are predominately loamy to sandy with intermixed gravel and boulders. They range from being poorly drained in flat basin areas to excessively drained on steep slopes in mountain areas (Rogers, 1974).

Vegetation

Vegetation in the Carson and Truckee River Basins can be divided into several zones that vary from barren peaks and alpine meadows in the higher altitudes of mountainous headwater areas to greasewood and barren land in the Carson Sink. Alpine meadows in higher altitudes consist of grasses and wildflowers. Below the alpine meadows, three zones of forest vegetation are in mountainous headwater areas above about



Base from U.S. Geological Survey digital data 1:100,000, 1977-85
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -119°00'

Figure 10. Location of precipitation measurement stations in Carson and Truckee River Basins.

Table 3. Precipitation data for weather stations in Carson and Truckee River Basins, 1981-91

[Leaders, (--), data not available. Data from National Climatic Center, 1982-92]

Station number (figure 10)	Station name	Altitude (feet above sea level)	Total annual precipitation (inches) 1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	Average annual precipitation, for indicated record during 1981-91 (inches)
1	Carson City	4,651	10.95	19.21	21.77	8.61	6.28	12.88	6.81	4.85	9.07	4.00	--	10.44
2	Fallon	3,966	3.80	7.92	8.45	3.76	4.94	2.55	5.27	5.83	4.82	5.69	3.38	5.13
3	Glenbrook	6,355	20.97	37.19	32.92	12.86	--	--	14.58	10.67	--	10.72	--	19.99
4	Lahontan Dam	4,150	4.22	8.73	10.92	4.57	6.10	4.19	4.23	3.15	5.14	3.81	5.37	5.49
5	Minden	4,700	6.35	13.95	17.90	5.49	--	7.65	--	3.87	--	3.41	7.16	8.22
6	Mount Rose	7,400	38.58	52.11	--	--	--	--	--	--	--	--	--	--
7	Reno-Tahoe International Airport	4,404	6.68	11.10	13.23	4.28	4.99	8.94	7.50	5.30	7.34	5.26	6.00	7.33
8	Virginia City	6,340	13.00	25.89	25.98	12.63	12.74	15.92	11.06	8.53	--	--	14.97	15.64
9	Wadsworth	4,200	4.84	--	17.36	4.56	6.26	4.88	5.65	4.54	6.52	5.29	5.52	6.54

5,500 ft (Bonham, 1969). These forest vegetation zones, from highest to lowest altitude, are (1) hemlock, white-bark pine, white pine, and red fir; (2) white and red fir; and (3) pinyon pine, Jeffrey pine, and white fir. At lower altitudes in headwater areas, sagebrush, bitterbrush, rabbit brush, and several species of grasses are common (Bateman 1976). Pinyon-juniper forest grows above altitudes of about 6,000 ft in dryer mountain ranges, including the Pine Nut mountains, Virginia Range, and Pah Rah Range.

Carson Valley and Truckee Meadows are in a sagebrush zone dominated by big sagebrush. However, agriculture (irrigated pasture and alfalfa) and urbanization (particularly in the Truckee Meadows) have replaced most of the natural vegetation. Wetland areas support plant species such as cattail, spike rush, alkali and hardstem bulrush, rushes, and sedges.

In the Carson and Truckee River Basin, downstream from Carson Valley and the Truckee Meadows, is a shadscale zone. The shadscale zone is found typically in valley bottoms where soil salt concentrations are high and precipitation is low. Dominant plant species are four-wing saltbrush, green rabbitbrush, green ephedra, winterfat, and a variety of greasewood. Near Fallon and Lahontan Reservoir, natural vegetation has been replaced by cultivated farmland and irrigated pasture.

Riparian vegetation grows along the lower Carson and Truckee Rivers, drains, and canals. Typical species are cottonwood, rabbitbrush, willow, thistle, rushes, sedges, and salt grass. Salt cedar, an introduced species, is common along the lower Carson and Truckee Rivers and other waterways.

The wetland areas downstream from Fallon support submergent, emergent, and terrestrial plant groups. Emergent plant species in the wetlands include alkali and hardstem bulrush, and cattail. Carson Lake wetland areas (southeast of Lahontan Reservoir) contain concentrations of emergent plants. Terrestrial species around the marshes include salt grass, sedge, and rushes. Away from the marsh areas, salt desert shrub species dominate. Barren areas in the Carson Sink result from decreased precipitation and increasing water and soil salinity.

Urbanization, Land Use, and Water Use

Nevada is rapidly becoming one of the most urbanized states in the Nation. The population in Nevada for 1990 was about 1,200,000. The Nevada Basin and Range study unit has about 1,090,000 people, more than 90 percent of the State's population (Nevada State Demographer, Bureau of Business and Economic Research, written commun., 1991).

Las Vegas Valley Area

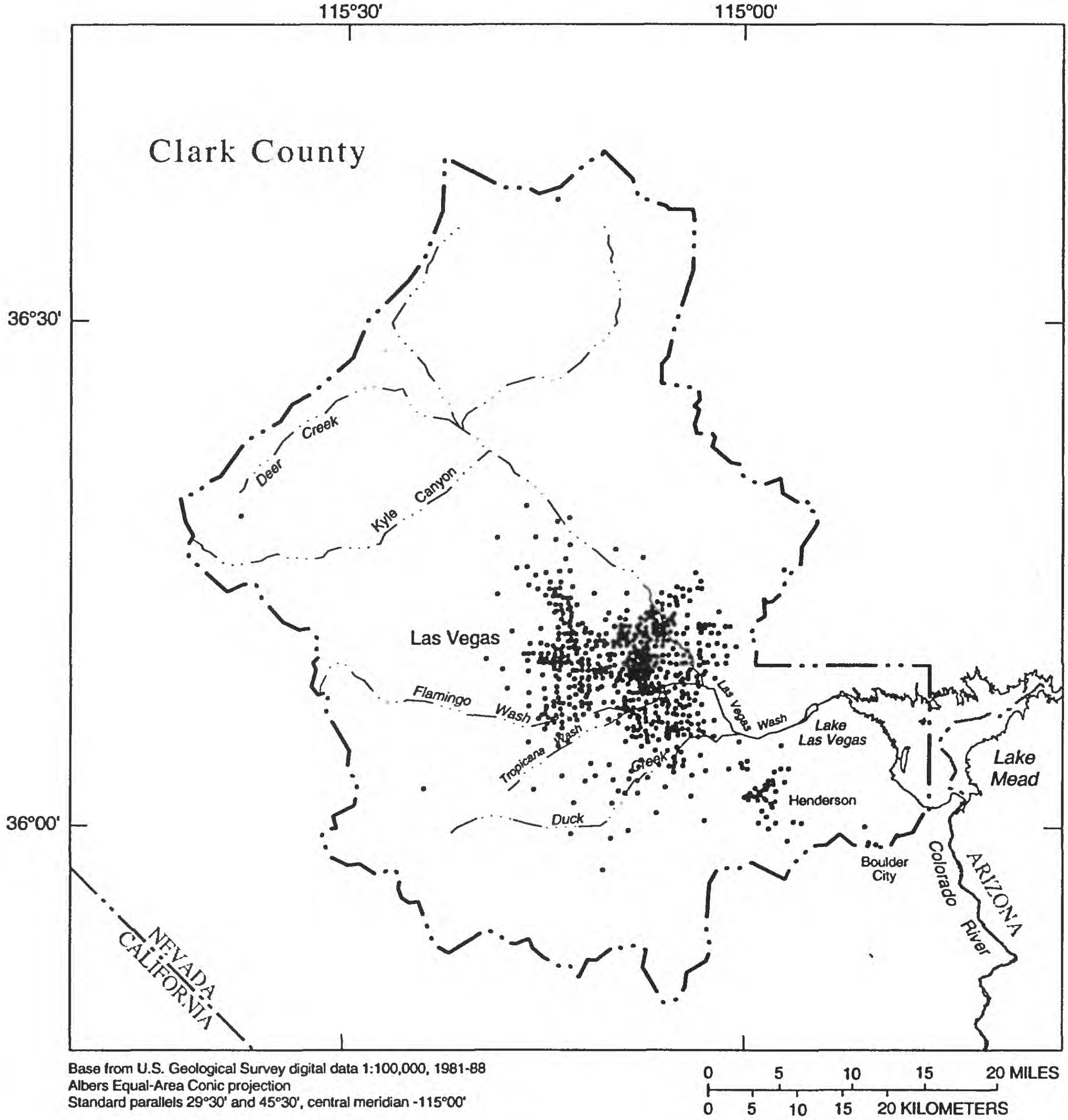
Urbanization

Most of the population resides in the southeastern part of the valley in the cities of Las Vegas and Henderson. Population density for the Las Vegas Valley area is shown in figure 11. Major reasons for population increases include growth of the gaming industry, real estate development, recreation, and favorable climate. Population for the Las Vegas Valley area was about 710,000 in 1990 (Nevada State Demographer, Bureau of Business and Economic Research, written commun., 1991).

Land Use

Figure 3 shows land-use and land-cover patterns in the Las Vegas Valley (U.S. Geological Survey, digital data, 1973-83). Land use in Las Vegas Valley area is 79 percent range, 14 percent forest, 5 percent urban, 1 percent open water and wetlands, and 1 percent barren. Outside the urban area, most of the land is federally owned.

Land in the valley that is administered by the Federal Government includes Toiyabe National Forest by the U.S. Forest Service, Lake Mead National Recreation Area by the National Park Service, and Red Rock Canyon National Conservation Area by the Bureau of Land Management. Much of the open rangeland is managed by the Bureau of Land Management. The U.S. Departments of Energy and Defense also own land within Las Vegas Valley. Privately owned land is used for residential, commercial, industrial, and warehousing developments. This activity is centered around the major cities.



EXPLANATION

— · · — **Study area boundary**

• **100 people or more**—Data from U.S. Bureau of the Census (1992)

Figure 11. Population density, based on 1990 census, in Las Vegas Valley area.

Water Use

Ground water was the main source of water for the area until 1971, when extensive importation of Colorado River water began. Analysis of 1990 water-use data for the Las Vegas Valley area indicates that the total was about 317,000 acre-ft (James E. Crompton, U.S. Geological Survey, written commun., 1992). This total included all self-supplied withdrawals and water-supply deliveries. Water use in the basin is illustrated in figure 12. About 80 percent of the water was from Lake Mead. Public water supplies accounted for about 91 percent of the water use. Self-supplied water for commercial and domestic purposes was about 4 percent of the total. Private water supplies for industrial and mining purposes were about 3 percent of the total. Water use for irrigation and agriculture from private water supplies was about 2 percent of the total. Estimated consumptive use of water in Las Vegas Valley area was about 109,000 acre-ft in 1990.

Lake Mead water is distributed for residential and commercial use throughout most of the valley by water systems in Las Vegas, North Las Vegas, and Henderson. About 113,000 acre-ft of treated sewage effluent was returned to Lake Mead (1990) and about 1,000 acre-ft was used for irrigation.

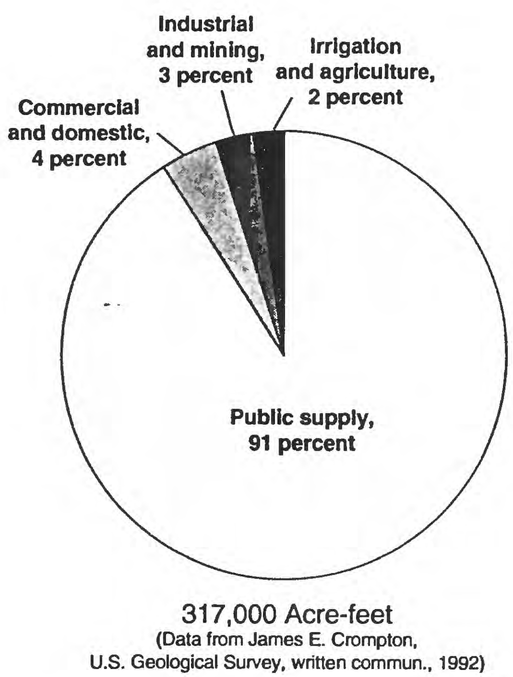


Figure 12. Water use for Las Vegas Valley, 1990.

Carson and Truckee River Basins

Urbanization

The largest urban centers are in the Reno-Sparks area, Carson City, and on the south shore of Lake Tahoe. Population densities are shown in figure 13. Population increases have shifted from a historically agrarian society to a more urban society. Most urban and suburban development has occurred on land that primarily was used for agriculture (Welch and others, 1989). Rapid urban development began in the 1950's and continues into the 1990's. Historically, surface water was the major source of public supply and ground water was used intermittently. Now, ground water is the major source of public supply used to meet the increased population demands. Population for the Carson and Truckee River Basins was about 380,000 in 1990 (Nevada State Demographer, Bureau of Business and Economic Research, written commun., 1991).

Land Use

Historically, land use in the Carson and Truckee River Basins was related to mining, logging, and agriculture. Figure 4 shows land-use and land-cover patterns in the Carson and Truckee River Basins (U.S. Geological Survey, digital data, 1973-83). Land use in the basins is about 50 percent range, 22 percent forest, 13 percent open water and wetlands, 10 percent barren, 4 percent irrigated agriculture, and 1 percent urban.

Headwater areas of the Carson and Truckee River Basins are predominantly Federal forest lands and urban development is not extensive. However, urban development of privately owned land is extensive around the north and south shores of Lake Tahoe.

Agricultural lands within the basins are mostly in the Newlands Project in the Fallon area, in the Carson Valley south of Carson City, and in the Truckee Meadows south of the Reno-Sparks area (see fig. 4). Agricultural areas in Carson Valley and the Truckee Meadows are declining because of urbanization. Few major farming communities are in other parts of the basins because of the arid climate. Small areas of agricultural land are present in the Carson City area. These areas are decreasing because of urbanization.

The Newlands Project in the Carson Desert is the largest and most intensive agricultural land-use area in the Carson and Truckee River Basins. The project was initiated with the passage of the Reclamation Act of 1902. Derby Dam and the Truckee Canal were

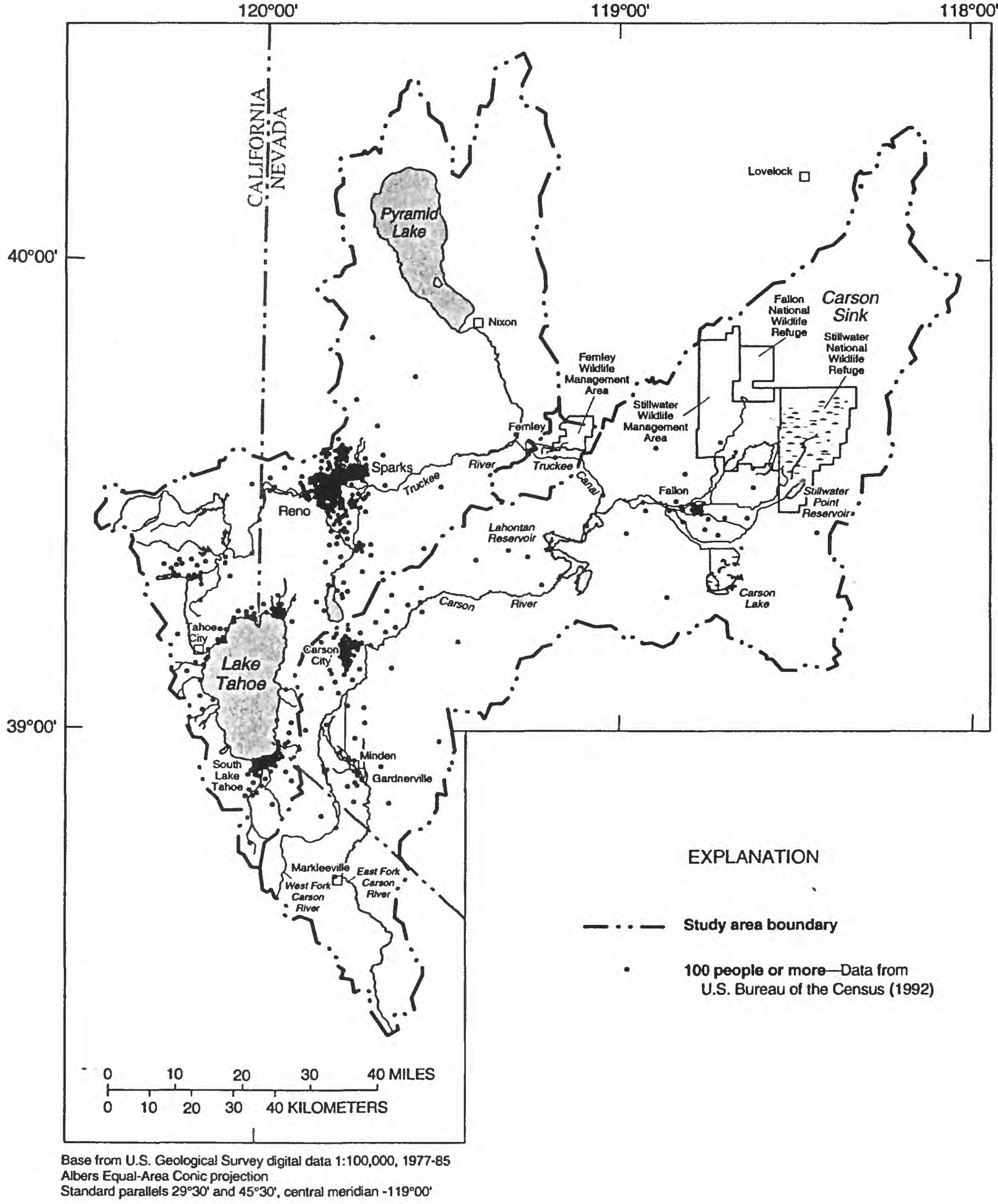
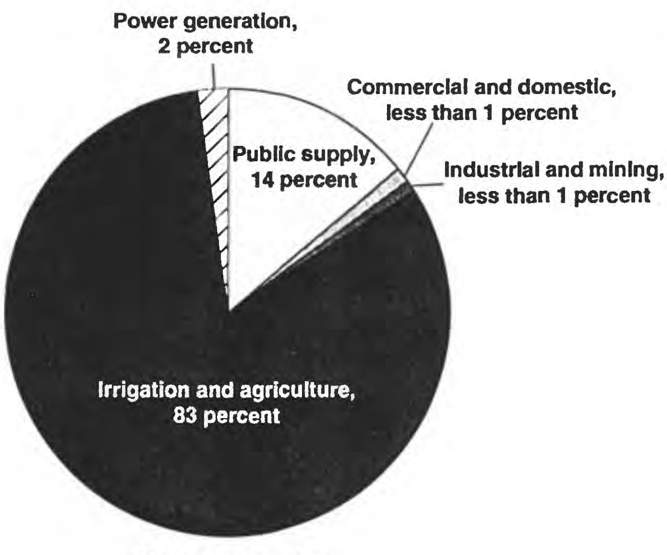


Figure 13. Population density, based on 1990 census, in Carson and Truckee River Basins.

constructed in 1905 to divert Truckee River water for irrigation in the Newlands Project. Lahontan Dam was completed on the Carson River in 1915 to provide storage for Newlands Project irrigation water from the Carson and Truckee Rivers. Alfalfa and pasture are the principal irrigated crops in the Newlands Project. About 68,000 acres of agricultural land are irrigated in the Newlands Project, and about 47,000 acres are irrigated in the Carson Valley (California Department of Water Resources, 1991b).

Water Use

Analysis of 1990 water-use data for the Carson and Truckee River Basins indicates that combined total offstream water use was about 800,000 acre-ft (James E. Crompton, U.S. Geological Survey, written commun., 1992). More than 85 percent of the water is from surface-water sources. The Carson River Basin totaled about 538,000 acre-ft; water use in the Truckee River Basin totaled about 262,000 acre-ft. These values include all self-supplied withdrawals and public-water supplies. Water use in the basins is shown in figure 14.



800,000 Acre-feet
(Data from James E. Crompton, U.S. Geological Survey, written commun., 1992)

Figure 14. Water use for Carson and Truckee River Basins, 1990.

Irrigation and agriculture was the largest use—about 662,000 acre-ft or 83 percent of the total supply; 95 percent of the water used in the Carson River Basin and 59 percent of the water used in the Truckee River Basin. Of the amount, about 92 percent was surface water, primarily from the Carson and Truckee Rivers. The largest deliveries for public supplies in the Carson and Truckee River Basins are to the Reno-Sparks and Carson City areas. Public supply used about 14 percent of the total. Water for self-supplied commercial and domestic needs was less than 1 percent of the total. Many rural homes outside the urban and suburban areas are supplied by private wells. In recent years, the quantity of ground water pumped for irrigation has decreased; the quantity pumped for domestic supply has increased. This change is a result of conversion of agricultural lands to residential developments (Garcia, 1989). Industry and mining used less than 1 percent of the total. During 1990, estimated consumptive water use in the Carson and Truckee River Basins was about 367,000 acre-ft; estimated irrigation conveyance loss was about 175,000 acre-ft. About 50,000 acre-ft of treated sewage effluent were returned to surface and ground-water systems (1990), and about 12,000 acre-ft were used for irrigation.

HYDROLOGIC SETTING

Surface Water

Las Vegas Valley Area

Lakes and Reservoirs

Two major lakes in the Las Vegas Valley area, Lake Mead and Lake Las Vegas, are shown in figure 15. Smaller real-estate lake impoundments in residential developments are not discussed in this report. No lakes of natural origin are in the Las Vegas Valley area.

Lake Mead, part of the Colorado River system, is the largest reservoir in the NVBR study unit. The lake occupies a 114 mi-long reach of the Colorado River along the Nevada-Arizona border (Baker and Paulson, 1980). Lake Mead fills a broad structural basin that was formed by faulting in the late Tertiary time (Duebendorfer and others, 1990). The lake is impounded by

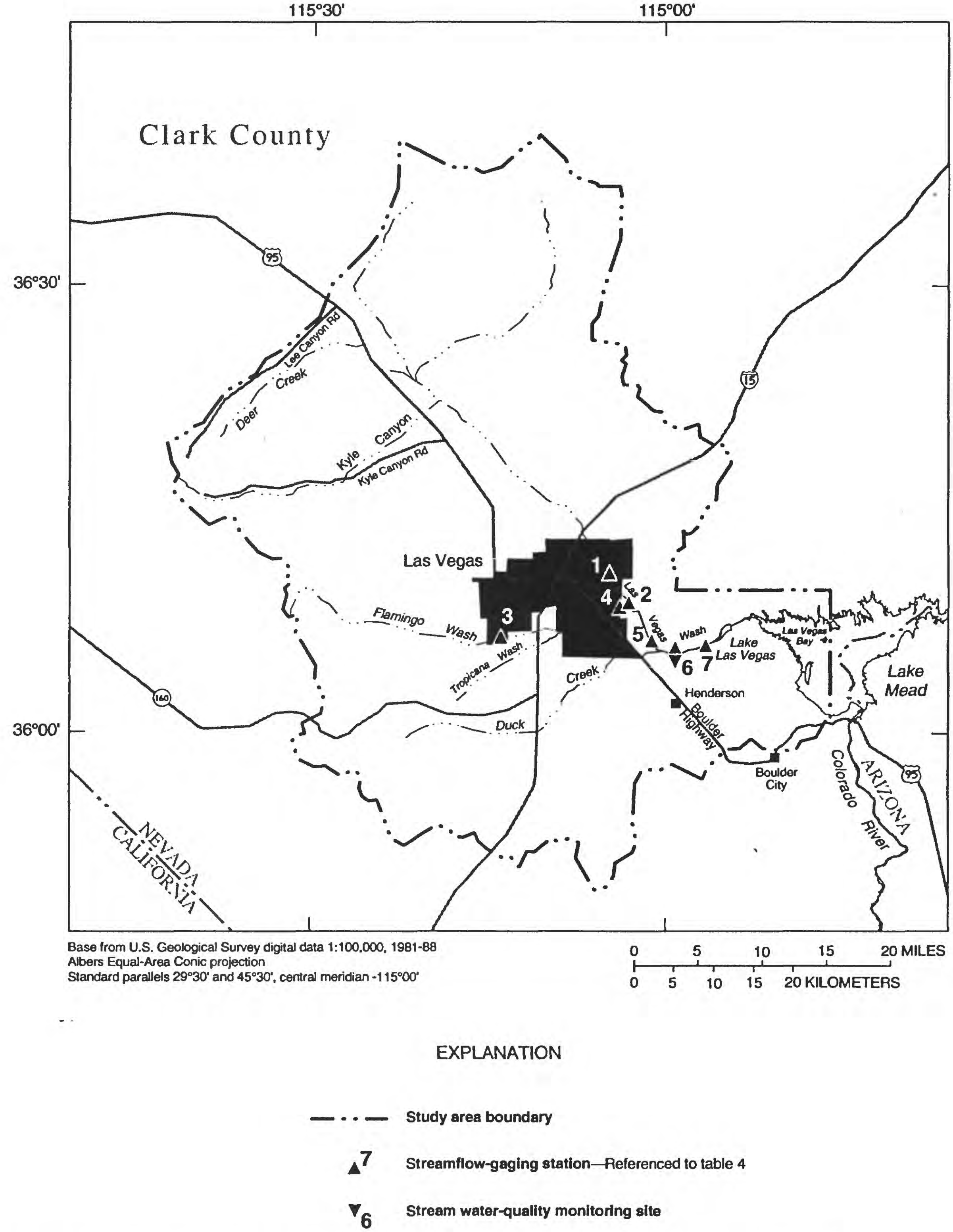


Figure 15. Streamflow-gaging stations and water-quality monitoring sites in Las Vegas Valley area.

Hoover Dam, which was completed in March 1936, by the Bureau of Reclamation. Primary uses of the lake include flood control, irrigation, public supply, power generation, and recreation. Total capacity for Lake Mead is 29,755,000 acre-ft, with a usable content of 26,159,000 acre-ft (Garcia and others, 1991).

Las Vegas Bay of Lake Mead receives urban drainage, treated sewage effluent, industrial drainage, and saline ground-water discharge from Las Vegas Wash. The discharge of Las Vegas Wash is usually more dense than the water of Las Vegas Bay. When it is much denser, the wash discharge flows mostly into the hypolimnion (below the thermocline) of the bay (Nevada Division of Environmental Protection, 1988). However, when the density difference between Las Vegas Wash discharge and Las Vegas Bay water is not large, as was observed during 1985-86, the wash discharge can introduce contaminants directly into the epilimnion of the bay (Nevada Division of Environmental Protection, 1988).

A Las Vegas development, Lake Las Vegas, was designed as a resort facility and community. The project, when completed, will include several resort hotels and golf courses built around a reservoir constructed in Las Vegas Wash about 2 mi upstream from Las Vegas Bay. The project also will incorporate commercial, residential, and recreational properties. The reservoir is impounded by an earth-fill dam with a spillway structure and is filled with water pumped from Lake Mead. It has a capacity of about 10,000 acre-ft and a surface area of 0.5 mi^2. Two 7-ft-diameter tunnels can convey about 1,800 ft^3/s of Las Vegas Wash water under the reservoir to avoid contamination of reservoir water with sewage effluent. However, during floods, Las Vegas Wash flow could exceed the capacity of the intake structure and discharge directly into the reservoir.

Flood-Control Structures

The Las Vegas Valley area can experience high-intensity, short-duration floods any time of the year. Most natural washes in Las Vegas Valley are intermittent or ephemeral, but Las Vegas Wash in and downstream from Las Vegas is perennial because of excess urban runoff and treated sewage effluent. Surface runoff from intense thunderstorms often exceeds the capacity of storm drains, and flooding occurs. Flash flooding creates serious hazards when it overflows roadways and developed lands.

A Regional Flood Control District Master Plan for Las Vegas and other metropolitan areas in the valley was adopted in 1986. Recommended flood-control measures in the plan include constructing detention basins, lining streams, building bridges, and constructing storm drains. These flood-control structures are in differing stages of completion. Detention basins have been completed on the upper reaches of Las Vegas, Flamingo, and Tropicana Washes. Channel lining of certain reaches of Las Vegas, Flamingo, Tropicana, Pittman Washes, and Duck Creek, has been completed, but substantial erosion is present in unlined reaches of these washes. Cement-lined reaches move water downstream quickly, thereby increasing velocity and turbulence (which scours the wash bed and banks) and eroding channels in unlined reaches.

Streamflow Characteristics

Las Vegas Wash is the major drainage in Las Vegas Valley. Major tributaries include Flamingo Wash, Tropicana Wash, Las Vegas Creek, and Duck Creek. Streamflow in most of the Las Vegas Valley area is ephemeral. Figure 15 shows locations of streamflow-gaging stations in the valley; selected streamflow data are listed in table 4. Las Vegas Wash near Henderson (station 6) is the only site with a long period of streamflow record (1957 to present). The stations are influenced by urban runoff, and the lower reach of Las Vegas Wash is affected by treated sewage effluent. Low-flow and high-flow characteristics were determined only for Las Vegas Wash near Henderson for water years 1970-88. The 7-day, 10-year, low flow was 23 ft^3/s and the 1-day, 25-year, high flow was 1,140 ft^3/s. A flow-duration curve for Las Vegas Wash near Henderson is shown in figure 16. The average streamflow of 58 ft^3/s is equaled or exceeded about 70 percent of the time. A daily mean streamflow hydrograph for Las Vegas Wash near Henderson (fig. 17) indicates an increasing trend in base flow, caused by increasing sewage effluent from the Las Vegas area. Peaks in the graph are caused by intense rainfall runoff. Prior to 1955, Las Vegas Wash was ephemeral except in short reaches near springs and close to points of sewage release.

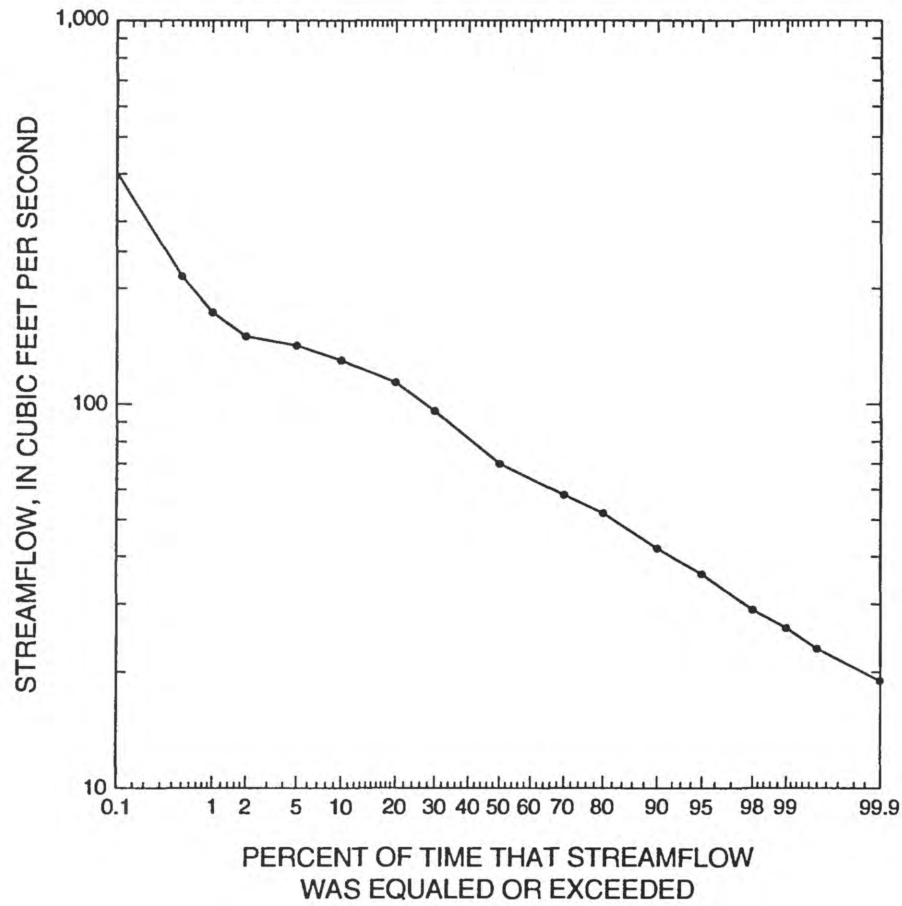


Figure 16. Flow duration curve for Las Vegas Wash near Henderson, Nev., water years 1970-88.

Stream Water-Quality Characteristics

Variations in and interrelations among chemical constituents and physical characteristics are complex in aquatic systems. Water quality can be measured in terms of chemical characteristics such as total dissolved solids and physical characteristics such as temperature. Water-quality characteristics can change considerably during short time intervals, and most measurements are instantaneous, rather than representative of long periods or average conditions.

Major-ion and dissolved-solids concentrations for Las Vegas Wash near Henderson (station 6, fig. 15) are shown in boxplots in figure 18. These boxplots show the median value and percentile distributions of ions and dissolved-solids concentrations. A percentile value is the value that is greater than or equal to the values of a specific percent of the data. Thus, if 47 is the 75th percentile of a particular set of data, the values of 75 percent of the data are less than or equal to 47. The median is the 50th percentile. As indicated in figure 18, the cations with the greatest median concentrations are sodium and calcium; potassium has the lowest. Sulfate has the greatest median concentration value for anions; bicarbonate has the lowest. The median dissolved-solids concentration is about 1,700 mg/L. Milliequivalent analyses indicate that sodium and calcium are codominant cations and sulfate is the dominant anion. The median value for pH is 7.5 at Las Vegas Wash near Henderson.

Table 4. Streamflow characteristics at selected gaging stations in Las Vegas Valley area, water years 1970-90

USGS station number (figure 15 map number)	Station name	Period of record	Drainage area (square miles)	Maximum streamflow (cubic feet per second)	Minimum streamflow (cubic feet per second)	Average annual streamflow[1] (cubic feet per second)
09419656 (1)	Las Vegas Creek at Lamb Boulevard near Las Vegas, Nev.	1988-90	46.3	1,070	0.00	--
09419658 (2)	Las Vegas Wash near Sahara Avenue near Las Vegas, Nev.	1988-90	1,146	1,960	0.58	--
09419673 (3)	Flamingo Wash near Torrey Pines Drive near Las Vegas, Nev.	1988-90	93.6	3,920	.00	--
094196781 (4)	Flamingo Wash at Nellis Boulevard near Las Vegas, Nev.	1988-90	215	4,100	4.0	--
09419679 (5)	Las Vegas Wasteway near East Las Vegas, Nev.	[2]1979-90	--	734	45	115
09419700 (6)	Las Vegas Wash near Henderson, Nev.	1970-88	1,518	6,510	4.8	58
09419753 (7)	Las Vegas Wash above Three Kids Wash below Henderson, Nev.	1988-90	1,519	4,050	114	--

[1] Average not determined for less than 10 years of record

[2] Period of record.—May 1979 to September 1983, November 1983 to May 1984, and September 1984 to present.

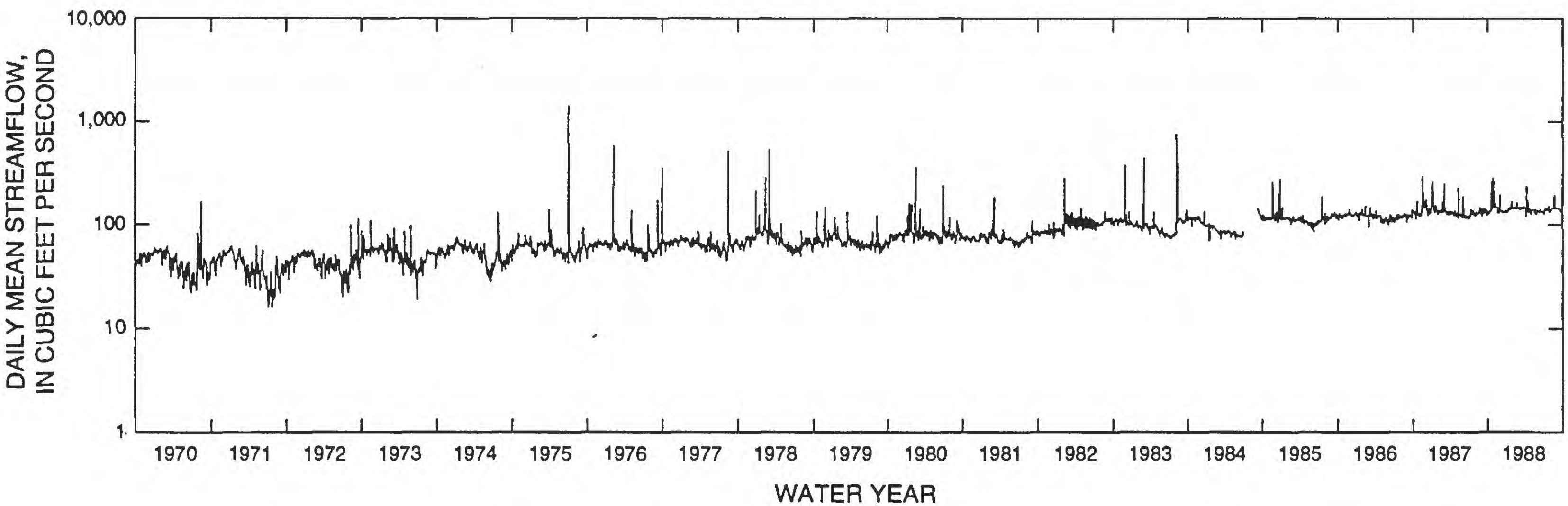


Figure 17. Daily mean streamflow for Las Vegas Wash near Henderson, Nev., water years 1970-88.

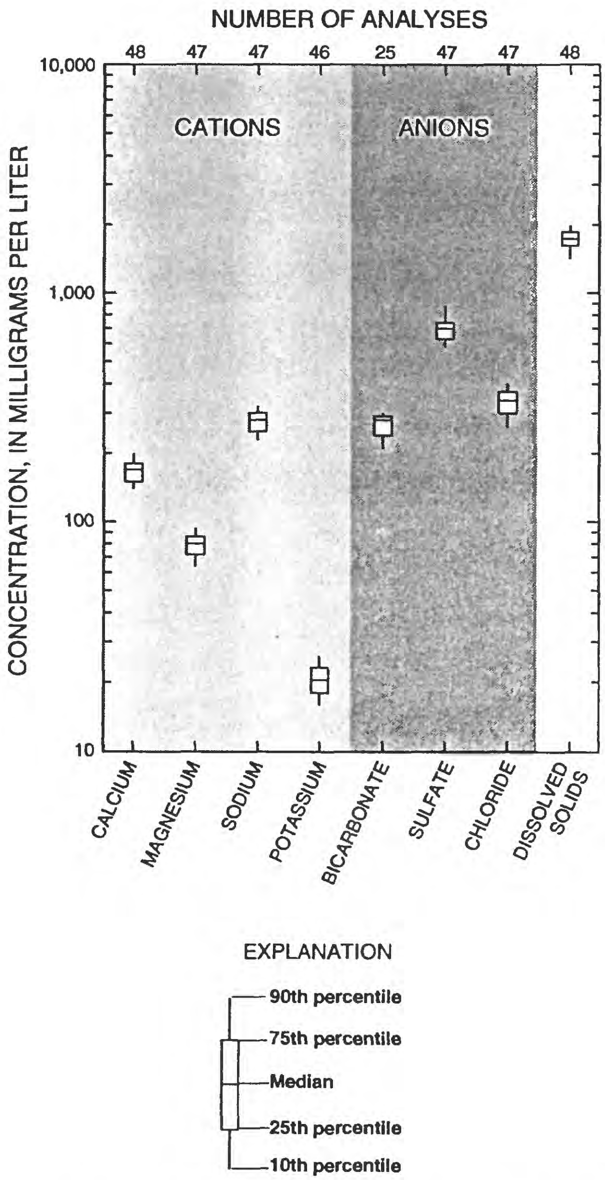


Figure 18. Boxplots for concentrations of major ions and dissolved solids for water samples from Las Vegas Wash near Henderson, Nev., water years 1988-92.

A graph relating smoothed dissolved-solids concentrations to streamflow percentiles for Las Vegas Wash near Henderson is shown in figure 19. The graph was developed by plotting dissolved-solids concentrations against streamflow percentiles determined from the distribution of long-term daily mean streamflow, and then smoothing. Smoothing is an exploratory technique that estimates the center of the data—the conditional mean of the dissolved solids concentrations as streamflow changes (Helsel and Hirsch, 1992). This graph indicates some variation in concentration with

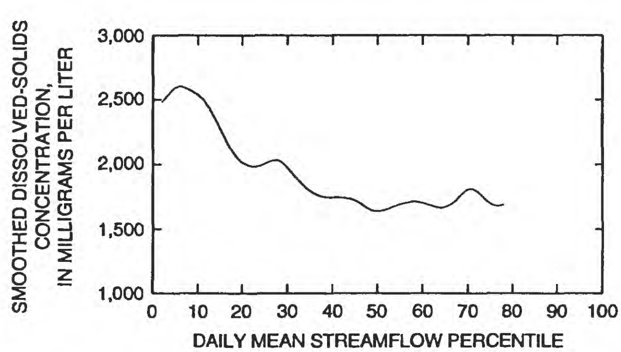


Figure 19. Relation of smoothed dissolved-solids concentrations to streamflow percentiles for Las Vegas Wash near Henderson, Nev., water years 1970-88. Daily mean streamflow values were converted to percentiles to facilitate comparison of relations among stations with different magnitudes of flow; 100th percentile corresponds to highest recorded daily mean streamflow and the 50th percentile corresponds to median daily mean streamflow.

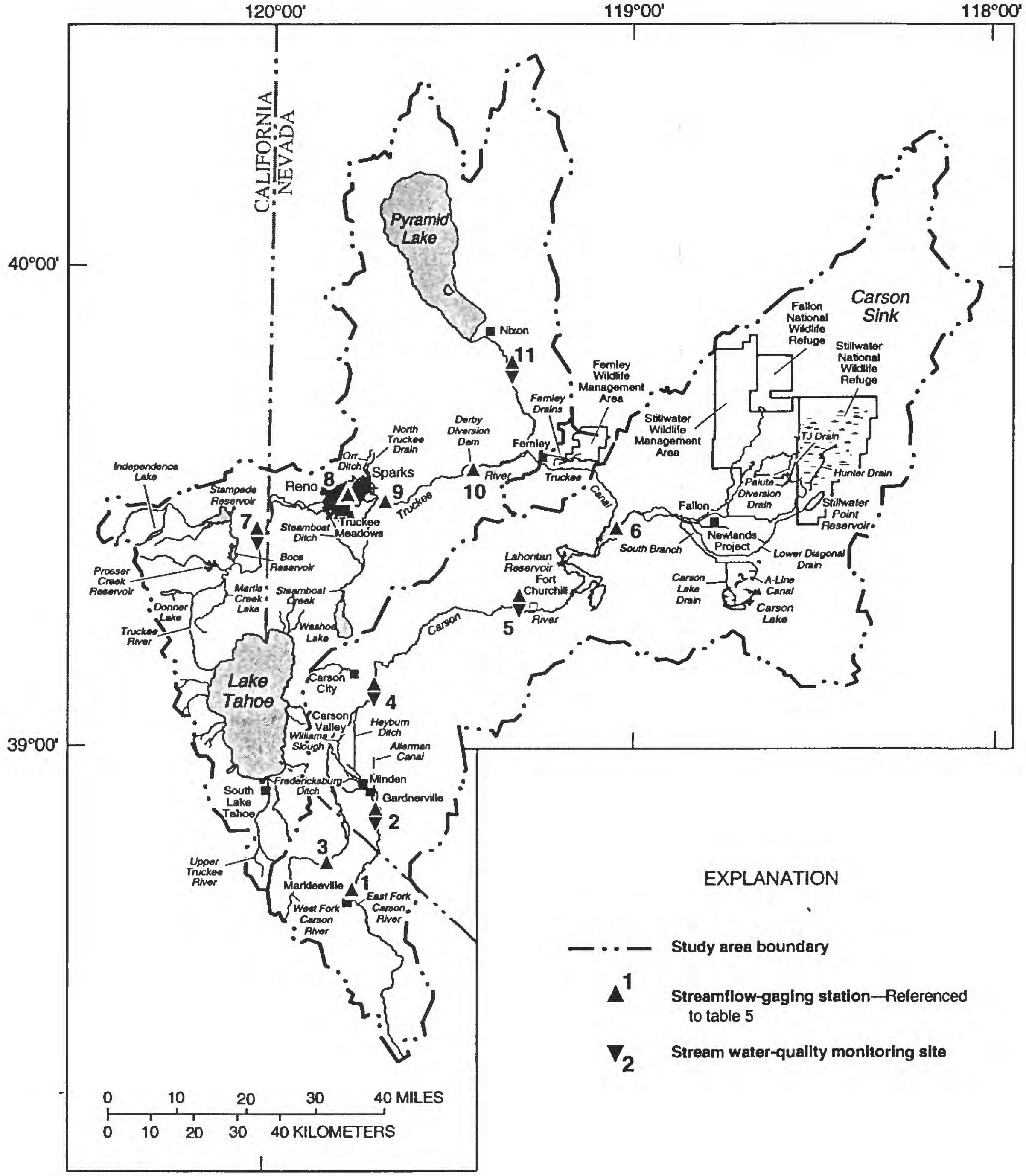
streamflow, but overall, dissolved-solids concentrations decrease as streamflow increases because of dilution. Dissolved-solids concentrations are influenced by sustained sewage-effluent discharge, intense rainfall runoff, and urban runoff. No other gaging stations in the Las Vegas Valley area have a comparable water-quality record.

Carson and Truckee River Basins

Lakes and Reservoirs

The larger lakes and reservoirs in the Carson and Truckee River Basins are shown in figure 20. Several high alpine reservoirs are located in the headwater area of the Carson River. They are very small, with storage capacities ranging from 31 to 2,948 acre-ft (California Department of Water Resources, 1991b). They are used by private parties and ditch companies to augment summer flow in the Carson River for downstream agricultural purposes in Carson and Dayton Valleys, including irrigation of alfalfa and pasture, and livestock watering.

Lahontan Reservoir (fig. 20) is the only significant storage reservoir in the Carson River Basin. It is located about 18 mi west of Fallon on the Carson River and has a drainage area of about 1,800 mi^2 (Garcia and others, 1992). The reservoir is impounded by an earth- and gravel-filled dam and has a usable storage capacity of about 295,000 acre-ft (California Department of Water Resources, 1991b). At the spillway, the surface



Base from U.S. Geological Survey digital data 1:100,000, 1977-85
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -119°00'

Figure 20. Streamflow-gaging stations and water-quality monitoring sites in Carson and Truckee River Basins.

area is about 21 mi^2 (Garcia and others, 1992). Water is supplied to this reservoir by the Carson River and the Truckee River via the Truckee Canal. The reservoir supplies approximately 87,500 acre-ft of water annually for irrigation in the Newlands Project (California Department of Water Resources, 1991b). A small 1.92 megawatt hydropower plant supplies power to the immediate vicinity. Most excess water and irrigation return flows terminate in the Stillwater Marsh area of the Carson Sink. Water from Lahontan Reservoir is a calcium sodium bicarbonate type with concentrations of dissolved solids generally less than 300 mg/L (Cooper and others, 1983; Cooper and others, 1985). The pH ranges between 6.5 to 7.5 in the winter and is uniform with depth, but can exceed 8.5 at the surface during summer. Mercury from historical silver and gold milling activities in the Virginia City area has accumulated in sediments in the lake and concentrations that exceed the recommended level for consumption of 1 mg/kg (dry weight) have been found in the tissue of numerous fish species (Cooper and others, 1983; Cooper and others, 1985).

Lake Tahoe (fig. 20), the largest lake in both basins, fills a steep-sided valley. Lake Tahoe has a drainage area of 506 mi^2 and a surface area of about 192 mi^2 (Garcia and others, 1992). Lake Tahoe is the origin of the Truckee River; outflow to the river from the upper 6.1 ft of the lake is regulated by a 17-gate concrete dam (California Department of Water Resources, 1991a). Its usable storage capacity is about 744,600 acre-ft, although its total volume is much larger (California Department of Water Resources, 1991a). Water released from Lake Tahoe is diverted, by way of Derby Dam and the Truckee Canal, for irrigation in the Carson Desert Newlands Project. Average lake depth is about 900 ft, and the maximum depth is about 1,650 ft (California Department of Water Resources, 1991a).

Chemical data for water samples from Lake Tahoe indicate that calcium is the dominant cation in solution and bicarbonate is the dominant anion. Concentrations of dissolved solids generally are less than 170 mg/L and pH is less than 8. Lake Tahoe is in the earliest stages of eutrophication. During the period 1967-86, the transparency of the lake decreased at a rate of about 1.3 ft/yr, although it still (1993) exceeds 65 ft. This decreasing transparency is directly related to increasing primary productivity of lake phytoplankton, which increased at a rate of about 6 percent per year during the same period. The sources of nutrients to Lake Tahoe include atmospheric deposition, fertilizer applications on golf courses and other developed areas, abandoned septic fields, and possible leaking sewage lines (California Department of Water Resources, 1991a).

Small lakes and reservoirs in headwater areas of the Truckee River include Donner, Independence, Martis, Prosser, Stampede, and Boca (fig. 20). These reservoirs were built for irrigation, public supply, flood control, fishery enhancement, hydropower, and recreation (California Department of Water Resources, 1991a). Donner Lake has a storage capacity of about 9,500 acre-ft; the water is used for public supply in Reno and Sparks, and for irrigation in the Newlands Project. Independence Lake has a usable storage of 17,500 acre-ft that is used for public supply in Reno and Sparks. Martis Creek Lake provides 20,400 acre-ft of temporary storage for flood control. Prosser Creek Reservoir impounds up to 29,800 acre-ft for flood control; water can be released for irrigation in the Newlands Project when traded for Lake Tahoe water, allowing more water to remain in Lake Tahoe during the summer. Stampede Reservoir can impound up to 226,500 acre-ft of water; the water is released primarily to provide fishery flows for Pyramid Lake; incidental uses include recreation, flood control, and power generation. Boca Reservoir impounds up to 41,100 acre-ft of water that is used for Truckee Meadows irrigation and public supplies for Reno and Sparks.

Pyramid Lake (fig. 20) is the terminus of the Truckee River. The drainage area for the lake is about 2,730 mi^2 (Garcia and others, 1992). The lake is a remnant of Pleistocene Lake Lahontan. The maximum water volume of the lake during water year 1992 was about 21,850,000 acre-ft (Garcia and others, 1992). Pyramid Lake is a terminal sink in the topographically lowest valley in the Truckee River Basin; water leaves the area only by evapotranspiration. Pyramid Lake is moderately saline with a dissolved-solids concentration that exceeds 5,000 mg/L. Sodium is the dominant cation in solution and chloride is the dominant anion. The pH is about 9. The water-surface altitude of Pyramid Lake has declined from about 3,865 ft in 1882 (Pyramid Lake Indian Tribal Council, 1982) to 3,800 ft in 1992. Most of this decline is the result of diversions by the Truckee Canal, which began operating in 1906, of Truckee River water for irrigation in the Carson Desert Newlands Project near Fallon. The resulting decline of surface-water inflow to the lake combined with evapotranspiration rates approaching 4 ft/yr (Galat and others, 1981), have caused the dissolved-solids concentration to increase from about 3,500 mg/L in 1882 (Pyramid Lake Indian Tribal Council, 1982) to current levels. Pyramid Lake is the habitat of the Lahontan cutthroat trout, a threatened species, and the *cui-ui* lake sucker, an endangered species.

Streamflow Diversions

Diversions of water from the Carson and Truckee Rivers have been made since the mid-1800's. Many systems have been developed to divert water throughout the basins. Controls and regulations have been established for allowable diversions from both the Carson and Truckee Rivers. Principal diversion systems and areas where the water is used, including Carson Valley, Newlands Project, Derby Dam, Truckee Canal, and Reno-Sparks areas are shown in figure 20. During 1990, approximately 196,200 acre-ft of diverted surface water were used for irrigation in the Carson Valley, about 258,300 acre-ft were used for irrigation in the Newlands Project; and about 83,300 acre-ft for irrigation and 48,400 acre-ft for public supplies were used in the Reno-Sparks area (James E. Crompton, U.S. Geological Survey, written commun., 1990).

The Alpine Decree, issued in 1980, established respective Carson River surface-water rights and reservoir storage rights in high alpine reservoirs for parties in California and Nevada (California Department of Water Resources, 1991b). The Truckee River Agreement, promulgated in 1935, is the current legal basis for operation of the Truckee River, including its tributaries and diversions from its source at Lake Tahoe to its terminus at Pyramid Lake. Upstream reservoirs are operated under supervision of the Federal Water Master, who administers requirements of the Orr Ditch Decree to achieve mandated streamflow rates (Floriston Rates) at the California-Nevada border. The Orr Ditch decree, promulgated in 1944, incorporates the Truckee River Agreement and affirms individual municipal, industrial, and agricultural water rights. The Truckee-Carson-Pyramid Lake Water Rights Settlement Act, Public Law 101-618, was passed in 1990. This law provides a foundation for developing operating criteria for interstate allocation of water for irrigation, public supplies, fish and wildlife, and recreational uses, and to meet water-quality standards (Bohman and others, 1995).

Streamflow Characteristics

The two largest rivers in the study unit, in terms of drainage area and streamflow, are the Carson and Truckee Rivers. In contrast to Las Vegas Wash, the Carson and Truckee Rivers are natural, perennial flowing streams. Statistics for selected streamflow characteristics for 11 Carson and Truckee River streamflow-gaging stations during water years 1970-90 (fig. 20) are listed in table 5. These stations were selected to represent a range of climate, geology, vegetation, and human effects. Table 5 includes period of record; drainage area; maximum observed streamflow; minimum observed streamflow; average annual flow; 7-day, 10-year low flow; and 1-day, 25-year high flow.

Low-flow statistics are used to evaluate the adequacy of a stream to assimilate industrial- or public-supply wastes. These data are needed to help preserve a suitable aquatic environment and to fulfill water-supply requirements. A common low-flow statistic used is the 7-day, low flow that occurs, on average, once every 10 years. This low-flow statistic varied considerably among the analyzed stations. The 7-day, 10-year, low flow values for the Carson River stations are slightly higher in the western part of the basin than in the eastern part because of diversions and drought conditions. The 7-day, 10-year, low flow values for the Truckee River stations vary less than those for the Carson River stations, because of streamflow regulation by reservoirs in the headwater area.

High-flow statistics are used to evaluate flood-flow frequencies. High flows result from spring snowmelt or intense rainfall. The 1-day, high flow values that occur, on average, once every 25 years, vary throughout both basins. Maximum annual streamflows usually result from snowmelt, but may result from storm runoff.

Flow-duration curves, showing the percentage of time that streamflow rates are equaled or exceeded, are presented for selected streamflow-gaging stations in Carson (fig. 21*A*) and Truckee (fig. 21*B*) River Basins. The shape of a flow-duration curve gives an indication of the streamflow conditions. For unregulated streams, a steep sloping curve indicates a highly variable streamflow, which is caused primarily by overland runoff; a flat sloping curve indicates that substantial

Table 5. Streamflow characteristics at selected gaging stations in Carson and Truckee River Basins, water years 1970-90

USGS station number (figure 20 map number)	Station name	Period of record	Drainage area (square miles)	Maximum streamflow (cubic feet per second)	Minimum streamflow (cubic feet per second)	Average streamflow (cubic feet per second)	7-day, 10-year low streamflow (cubic feet per second)	1-day, 25-year high streamflow (cubic feet per second)
10308200 (1)	East Fork Carson River below Markleeville Creek, near Markleeville, Calif.	1970-90	276	9,520	9.5	352	21	6,640
10309000 (2)	East Fork Carson River near Gardnerville, Nev.	1970-90	356	7,910	7.8	366	25	5,810
10310000 (3)	West Fork Carson River at Woodfords, Calif.	1970-90	65.4	2,290	5.3	105	8.9	1,610
10311000 (4)	Carson River near Carson City, Nev.	1970-90	886	13,200	.94	413	3.2	10,700
10312000 (5)	Carson River near Fort Churchill, Nev.	1970-90	1,302	16,600	.00	386	0.00	10,000
10312150 (6)	Carson River below Lahontan Reservoir near Fallon, Nev.	1970-90	1,801	2,970	.81	532	1.6	2,450
10346000 (7)	Truckee River at Farad, Calif.	1970-90	932	9,550	33	851	117	7,990
10348000 (8)	Truckee River at Reno, Nev.	1970-90	1,067	14,400	12	748	67	9,770
10350000 (9)	Truckee River at Vista, Nev.	1970-90	1,430	16,100	38	883	121	12,100
10351600 (10)	Truckee River below Derby Dam near Wadsworth, Nev.	1970-90	1,676	16,900	1.9	562	4.5	12,000
10351700 (11)	Truckee River near Nixon, Nev.	1970-90	1,827	12,100	11	614	20	11,500

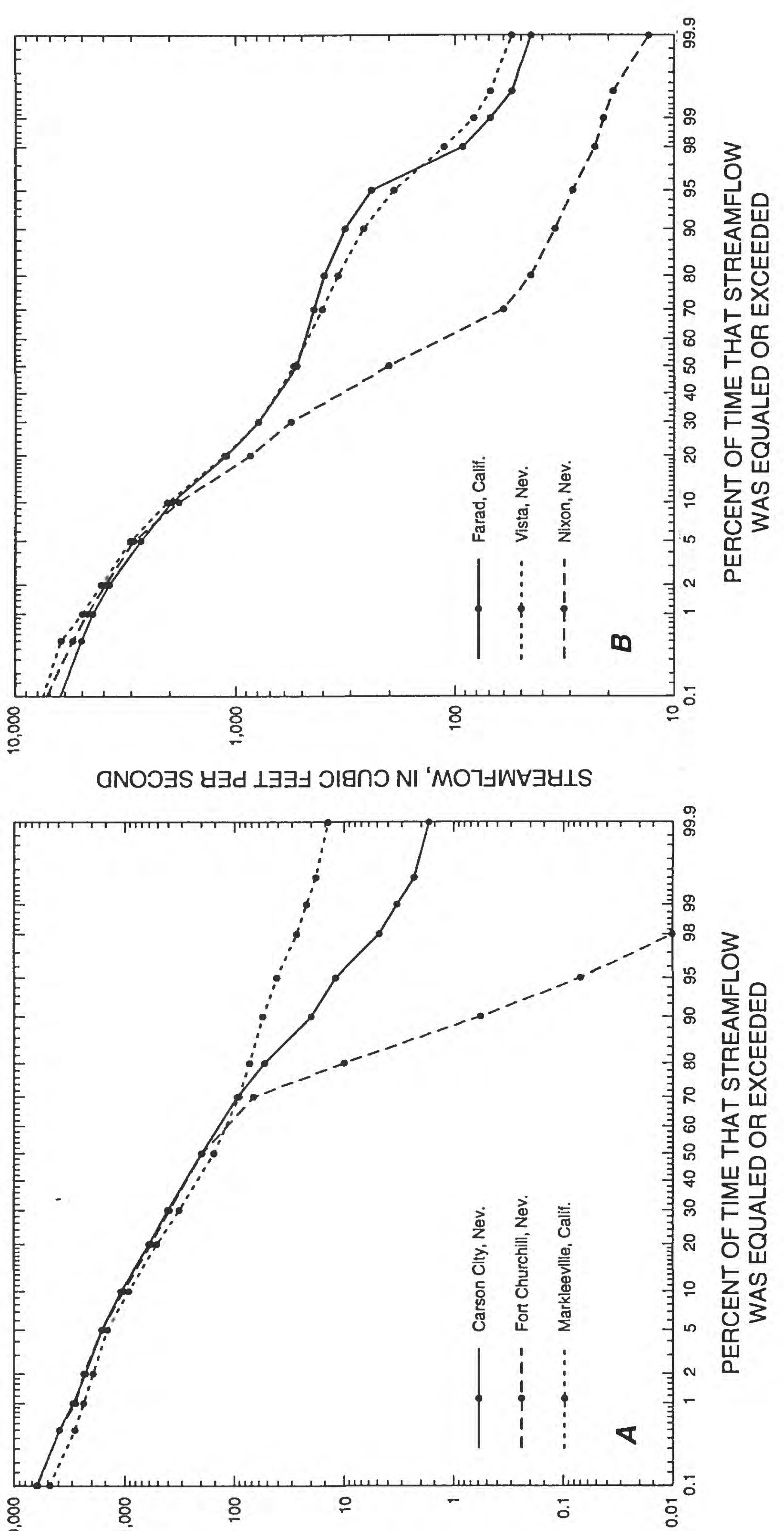


Figure 21. Flow-duration curves for selected streamflow-gaging stations in (*A*) Carson and (*B*) Truckee River Basins, water years 1970-90.

contributions come from ground-water or surface-water storage. For a regulated stream, a steep slope at the lower end of the curve indicates a minor ground-water contribution to base flow or streamflow depletion by diversions; a flat slope at the lower end indicates a substantial ground-water contribution to base flow or the effects of low-flow releases from reservoirs.

Slopes of the flow-duration curves for the Carson River stations (fig. 21*A*) are similar at the upper end, and represent the influence of direct runoff from snowmelt. The curves for the Markleeville and Carson City stations are flat throughout the middle sections and lower ends, indicating some sustained base flow. Divergence of the curves at the lower end is due primarily to irrigation diversions in Carson Valley and downstream.

Slopes of flow-duration curves for the Truckee River stations (fig. 21*B*) are influenced by regulated reservoirs in headwater areas, irrigation diversions and return flow, and treated sewage effluent in the lower reaches. The break in slope between steep upper sections and flat middle sections of the curves for Farad and Vista probably are the result of reservoir storage and release. The slope of the lower section of the curve (50 to 99 percent of the time) is affected by public supply and irrigation diversions and discharge of treated sewage from the Reno-Sparks urban area. The absence of reservoir-release effects on the slope of the flow-duration curve for Nixon is the result of substantial diversions of water to the Truckee Canal by Derby Dam for irrigation in Carson Desert; the flatter slope for that part of the curve, representing streamflow equaled or exceeded more than 70 percent of the time at Nixon probably is caused by ground-water inflow downstream of Derby Dam.

Generally, streamflow is low in late summer and gradually increases through autumn and winter to a peak during spring snowmelt; peak discharges usually are in May or June. Daily mean streamflow hydrographs are shown for selected long-term gaging stations in the Carson (fig. 22*A*) and Truckee (fig. 22*B*) River Basins. These hydrographs indicate seasonal flow patterns and longer-term trends in discharge at different locations within the basins. Streamflow hydrographs reflect not only the natural factors of snowmelt and rainfall, but also the influences of irrigation diversions, return flows, and sewage-effluent contributions. The available snowpack is a major factor influencing streamflow patterns.

Streamflow trends for the East and West Fork Carson River stations are similar for the period illustrated (fig. 22*A*). During water years 1976 and 1977, there appears to have been a slight decrease in streamflow probably caused by a regional drought. The hydrograph for the Carson River near Carson City station indicates the greatest decreases in streamflow were during water years 1977, 1981, 1987, 1988, and 1989. The decreases in streamflows during the late 1980's at these stations is attributed to below normal snowpacks in the Sierra Nevada. The highest streamflows at Carson City during water years 1970-90 were in 1979, 1980, 1982, 1983, and 1986. Streamflow at the Fort Churchill station is strongly influenced by irrigation during the summer. The Carson River below Lahontan Reservoir near Fallon is highly regulated by releases from Lahontan Reservoir for irrigation and the flow record does not match those of other stations.

Streamflow hydrographs for Truckee River gaging stations (fig. 22*B*) show the effects of severe droughts that caused outflow from Lake Tahoe to cease during periods in water years 1978 and 1989. Hydrographs for stations at Farad, Reno, and Vista (fig. 22*B*) are comparable in streamflow trends and patterns. At the stations below Derby Dam and near Nixon, the larger variations in streamflow are most likely caused by diversions of water by Derby Dam to the Truckee Canal for irrigation.

Stream Water-Quality Characteristics

Five U.S. Geological Survey stream water-quality monitoring sites in the Carson and Truckee River Basins, where water-quality samples were collected during water years 1970-90, are shown in figure 22. Statistical summaries, in the form of boxplots (fig. 23) for concentrations of selected cations, selected anions, pH, and dissolved solids are based on data that have been published in numerous annual reports by USGS. The boxplots indicate that median values for all constituents and pH at the three Carson and two Truckee River sites increase in the downstream direction. Calcium, sodium, bicarbonate, and sulfate concentrations show the largest increase. Dissolved-solids concentrations, for at least 90 percent of the data, are less than 500 mg/L for all five stations.

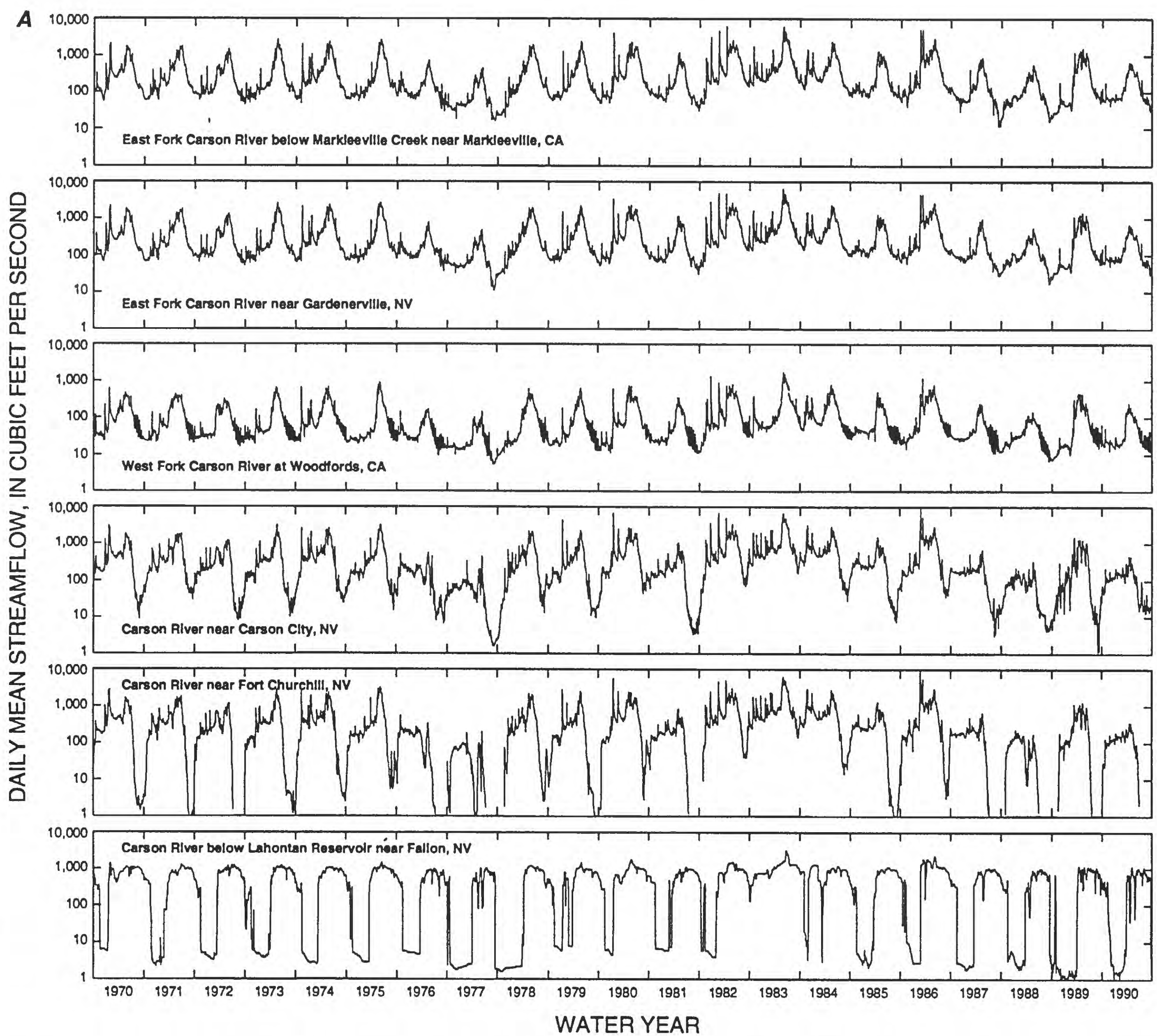


Figure 22. Daily mean streamflow for selected gaging stations in (*A*) Carson and (*B*) Truckee River Basins, water years 1970-90.

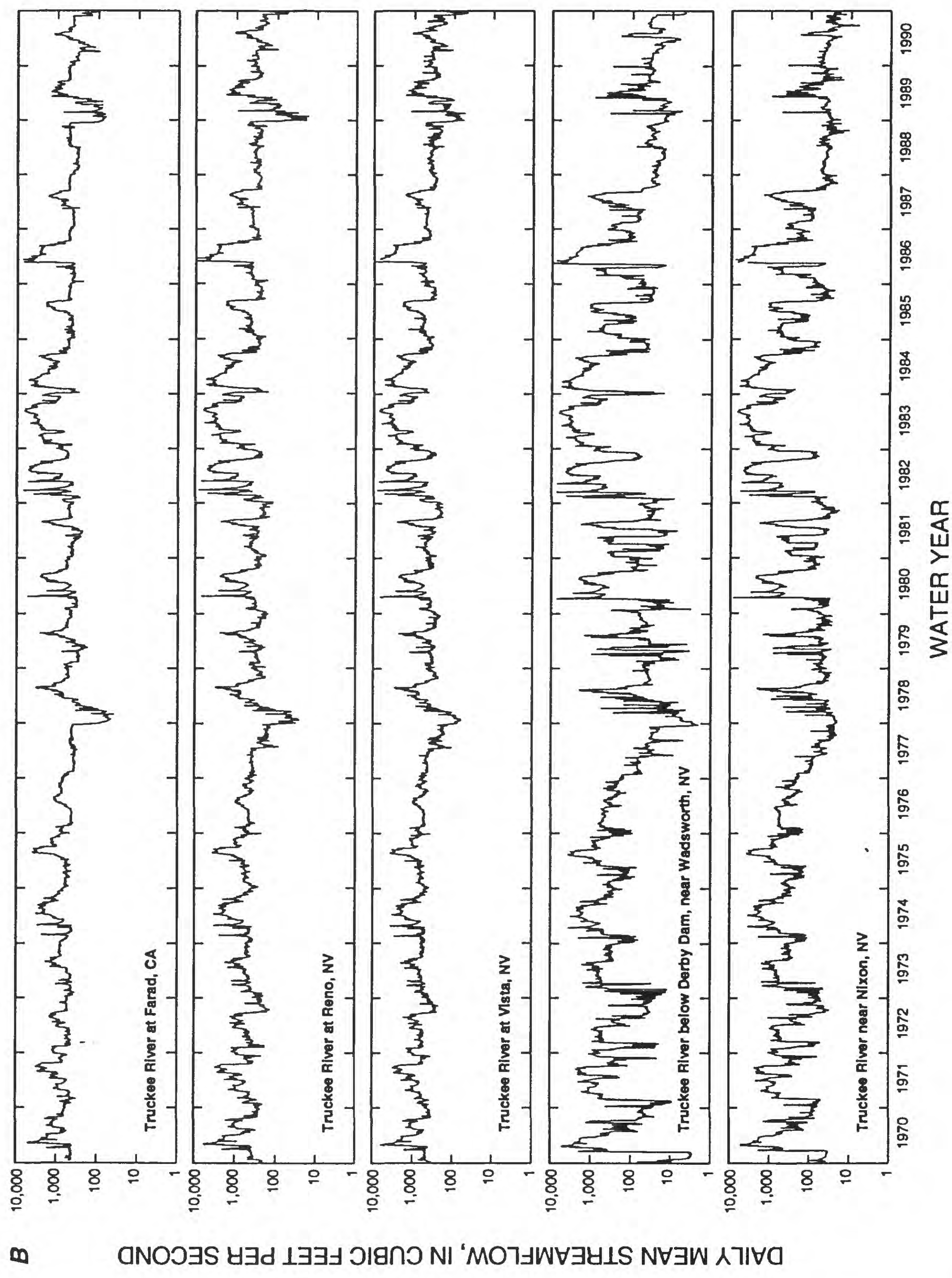


Figure 22. Continued.

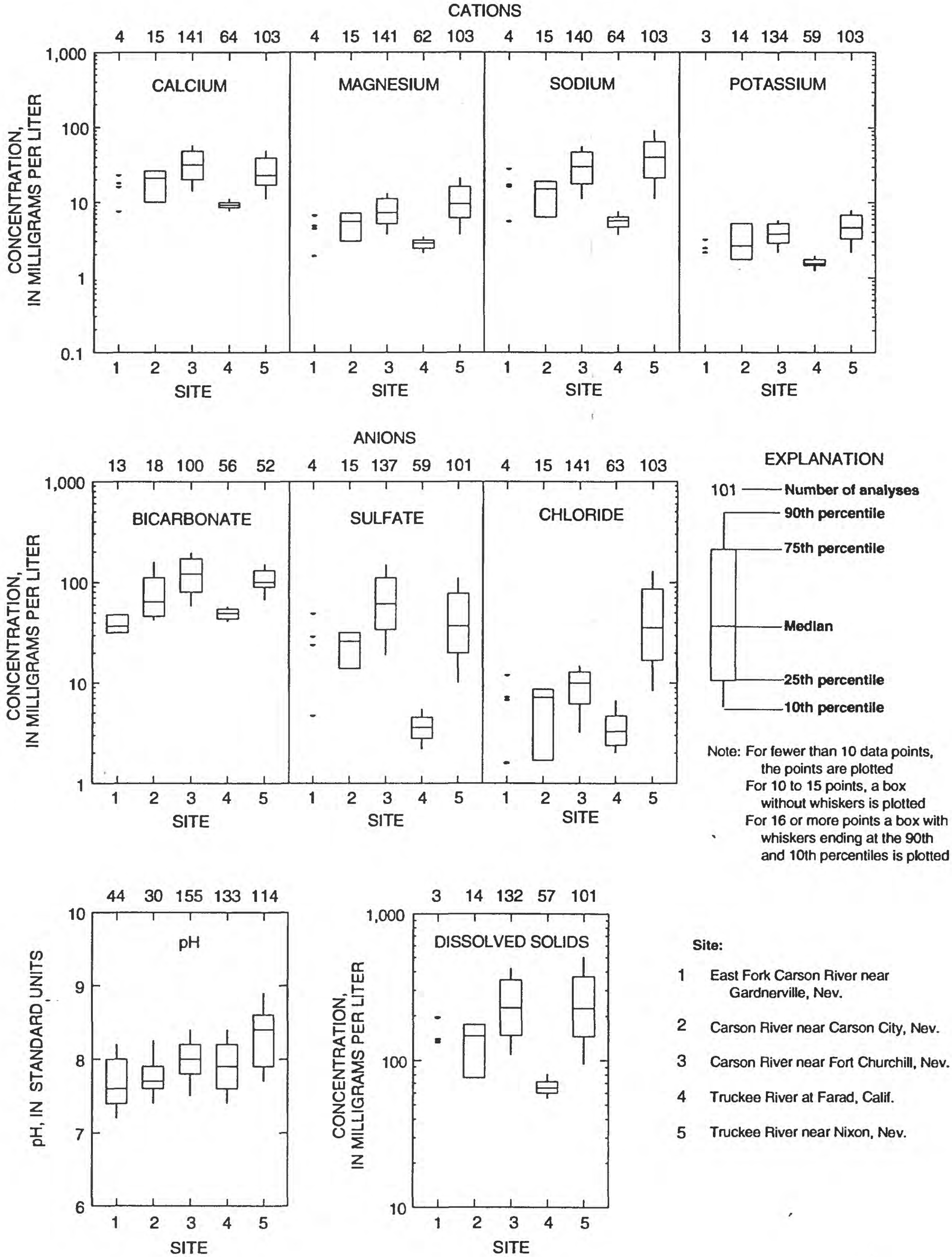


Figure 23. Boxplots for concentrations of major ions and dissolved solids, and pH for water samples from selected stream-water-quality monitoring sites in Truckee and Carson River Basins, water years 1961-92.

Graphs of smoothed dissolved-solids concentrations versus streamflow percentiles are shown in figures 24*A* and 24*B* for sites within the basins. The graphs were developed by plotting dissolved-solids concentrations against streamflow percentiles determined from the distribution of long-term, daily mean streamflow values, and then smoothing. Concentrations present during median streamflow increase from less than 100 mg/L for the East Fork Carson River near Gardnerville, the West Fork Carson River at Woodfords, and the Truckee River at Farad, to 200 mg/L or more for the Carson River at Fort Churchill and the Truckee River near Nixon.

Graphs for the Carson River sites (fig. 24*A*) indicate that at the West Fork site dissolved-solids concentrations decrease slightly as streamflow increases. At the East Fork site, concentrations decrease as streamflow increases. The curve for the Fort Churchill site indicates that dissolved-solids concentrations decrease greatly as streamflow increases. The curves for sites at Carson City and below Lahontan Reservoir show wide fluctuations, most likely attributable to irrigation diversions and reservoir releases. Overall, all curves show decreases in dissolved-solids concentrations as streamflow increases.

Garcia and Carman (1986) investigated nutrient and sediment loads in the Carson River during 1980. The investigation showed that annual nutrient loads contributed by the East and West Forks of the Carson River, upstream of agricultural activities, were about 490 tons of total nitrogen and about 130 tons of total phosphorus. At Carson City, downstream from the agricultural Carson Valley, the annual loads in the Carson River had increased to about 670 tons of total nitrogen and about 230 tons of total phosphorus. Nutrient loads remained fairly constant from Carson City to Fort Churchill. The annual sediment load upstream of agricultural activities was about 200,000 tons, increasing to about 210,000 tons at Carson City and 230,000 tons at Fort Churchill.

Historical silver and gold ore milling activities have resulted in elevated concentrations of mercury in bed sediments and tissues of aquatic organisms in the Carson River downstream from Carson City. This part of the Carson River is being investigated as a U.S. Environmental Protection Agency Superfund Site.

Intensive agricultural activities in the Carson Desert near Fallon have resulted in contamination of water, bottom sediments, and biota by irrigation drainage. High concentrations of dissolved solids, boron, arsenic, selenium, molybdenum, lithium, and un-ionized ammonia were detected in areas affected by irrigation drainage (Hoffman and others, 1990).

Graphs for Truckee River sites (fig. 24*B*) at Tahoe City and Farad indicate that dissolved-solids concentrations are fairly consistent over the range of streamflow. Flow at Tahoe City is predominantly outflow from Lake Tahoe. Flow at Farad is from Lake Tahoe and releases from headwater area reservoirs. The curve for Truckee River near Nixon indicates much greater dissolved-solids concentrations at lower streamflow. As streamflow increases, concentrations of dissolved solids decrease, indicating a dilution effect. At the 30th percentile of flow, dissolved-solids concentrations for Tahoe City and Farad are about 60 and 80 mg/L, respectively, whereas at Nixon, the concentration is about 380 mg/L. At the 80th percentile of flow, dissolved-solids concentrations for Tahoe City and Farad are still about the same, but at Nixon, the concentration has decreased to about 140 mg/L.

The U.S. Geological Survey Truckee-Carson River Quality Assessment in 1979 and 1980 investigated loading in the Truckee River. A steady-state, one-dimensional, water-quality transport model was used to assess the sources of loadings and processes controlling water quality (Nowlin, 1987). Principal sources of dissolved-solids loads from Reno to Derby Dam (fig. 20) were the North Truckee Drain, Steamboat Creek, and sewage treatment plant effluent. The Reno-Sparks Wastewater Treatment Facility was the major source of nutrient loadings to the river, followed by Steamboat Creek.

Downstream from Derby Dam local nonpoint sources of dissolved solids and nutrients are increasingly significant during low to median flows (Nowlin, 1987) primarily because a substantial part of the flow and upstream loads are diverted into the Truckee Canal. Local agricultural return flows and ground-water discharge are principal contributors of dissolved solids and nutrients to the river, particularly in the vicinity of Wadsworth and Dead Ox Wash (about 10 mi downstream from Wadsworth).

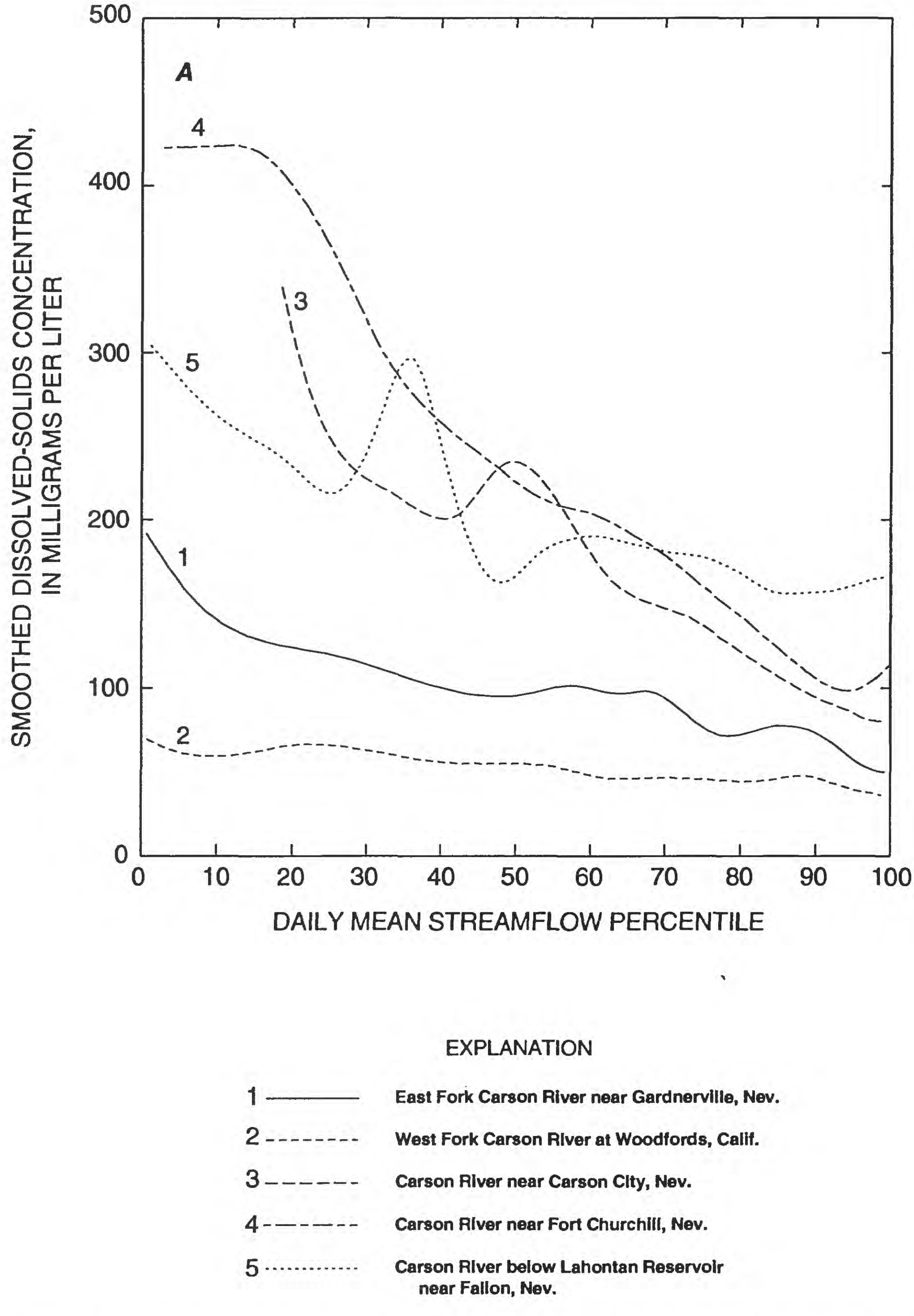


Figure 24. Relation of smoothed dissolved-solids concentrations to streamflow percentiles for selected stream-water-quality monitoring sites in (*A*) Carson and (*B*) Truckee River Basins, water years 1970-90. Daily mean streamflow values were converted to percentiles to facilitate comparison of relations among stations with different magnitudes of flow; 100th percentile corresponds to highest recorded daily mean flow and 50th percentile corresponds to median daily mean streamflow.

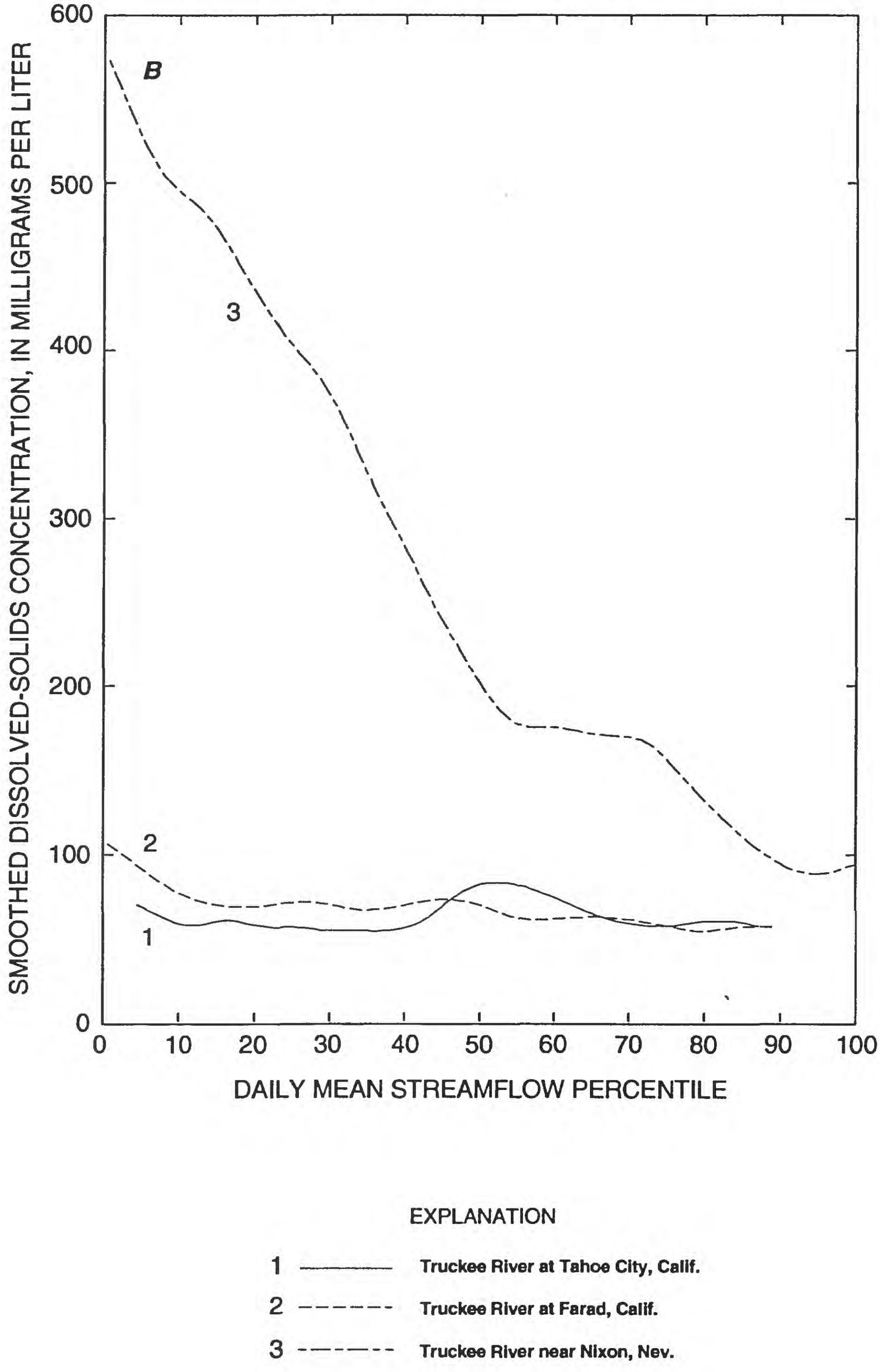


Figure 24. Continued.

Water temperature influences physical, chemical, and biological processes in water. Elevated stream temperature can create undesirable aquatic conditions such as a decrease in dissolved oxygen content, putrefaction of sludge, and obnoxious odors. Temperature greatly influences the biological "health" of a stream. Higher water temperatures increase metabolic and respiration rates and influence reproduction, mortality, and growth rates of aquatic organisms. The quantity of benthic organisms and their distribution also decrease when temperature increases beyond tolerable levels. The upper temperature tolerance limit for a well-balanced benthic community is about 32°C.

Duration curves of water temperature for three sites in the Carson and Truckee River Basins are shown in figure 25. Observed temperatures do not appear to be in the range considered harmful to the biological community. Eighty percent of temperatures were 20°C or less.

Ground Water

Las Vegas Valley Area

Principal Aquifers

The general area of principal aquifers (fig. 26) in the Las Vegas Valley area is defined for this report as where the saturated thickness is 100 ft or more (Vasey and others, 1972) and the ground water has less than 1,000 mg/L of dissolved solids (Thompson and Chappell, 1984). These aquifers are within a 550 mi^2 area of basin-fill deposits that are thousands of feet thick and consist primarily of unconsolidated sediments. Consolidated carbonate-rock aquifers are present beneath basin-fill deposits, but are not currently used as sources of water supply. Prior to development most ground water flowed eastward and southeastward through Las Vegas Valley, down the hydraulic gradient that is perpendicular to the water-level contours shown in figure 27.

The ground-water hydrology of the Las Vegas Valley aquifer system is complex because the basin-fill aquifer is composed of discontinuous beds of clay, silt, sand, gravel, and caliche. The following description of the Las Vegas Valley aquifer system is based primarily on reports by Maxey and Jameson (1948), Malmberg (1965), Harrill (1976), Van Denburgh and others (1982), Hines and others (1993), and Morgan and Dettinger (1996). In the valley, three general aquifer zones have been described as (1) shallow aquifers, (2) near-surface aquifers, and (3) deep aquifers. All aquifers may be either confined or unconfined depending on local conditions.

The shallow aquifers have been described as the upper 30 ft of saturated sediments (Van Denburgh and others, 1982). In northwest Las Vegas, the shallow aquifers are perched due to ground-water withdrawals that have caused declining water levels in deeper aquifers. The shallow perched aquifers were first described by Harrill (1976). The perched aquifers developed from secondary recharge due to large amounts of landscape irrigation; secondary recharge during 1979 was estimated at 44,000 acre-ft (Morgan and Dettinger, 1996). Water levels in the central part of Las Vegas are shallow and have fluctuated little during 1979-89. Shallow ground water discharges by the downgradient movement of water into Las Vegas Wash and its tributaries (fig. 27). Discharge also is by evapotranspiration, and possibly by downward percolation to deeper aquifers.

The near-surface aquifers occur from about 30 to 200 ft beneath the water table (Van Denburgh and others, 1982). Recharge for these aquifers is mostly by upward flow from deeper aquifers, with some secondary recharge from sewage, irrigation, and industrial wastewater (Harrill, 1976). Discharge from the near-surface aquifers is mainly through evapotranspiration. These aquifers are semiconfined and confined. Boundaries and flow directions for these aquifers are not fully understood; however, these aquifers have the potential of transmitting lesser quality water to deeper principal aquifers, especially in areas where pumping rates from the deeper principal aquifers are high (Hines and others, 1993).

The principal aquifers are more than about 200 ft beneath the water table and are semiconfined and confined. These principal aquifers correspond with the "shallow, middle, and deep zones" described by Maxey and Jamison (1948), the "principal aquifers" described by Harrill (1976), and "developed-zone aquifers" and "deep-zone aquifers" described by Morgan and Dettinger (1996). The upper and middle zones of these aquifers have been affected by pumping because they are primary sources for public-supply water. The deep zones of these aquifers, below about 1,000 ft, may contain large amounts of water, but do not yield it readily.

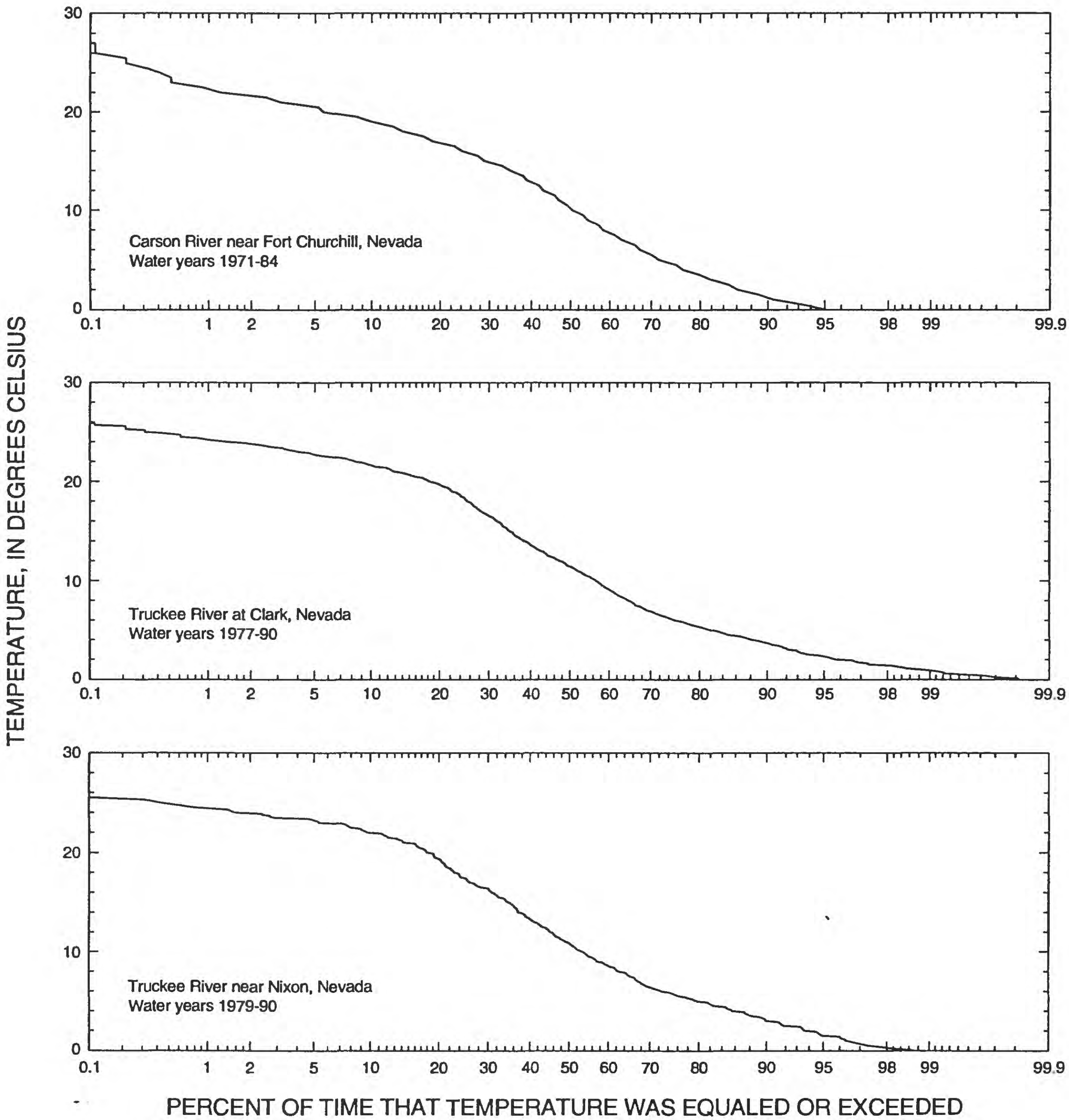


Figure 25. Temperature duration curves for selected sites in Carson and Truckee River Basins.

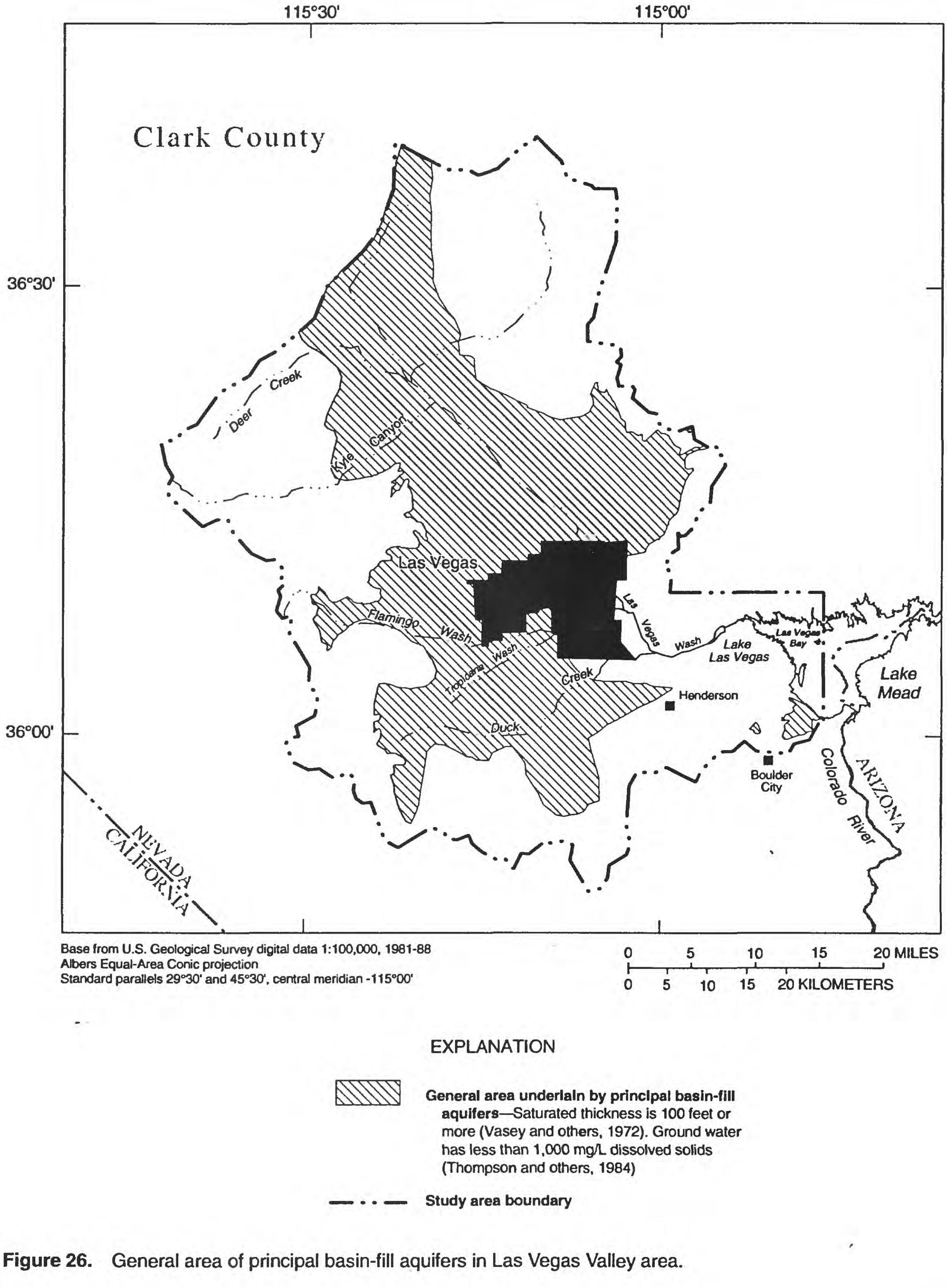
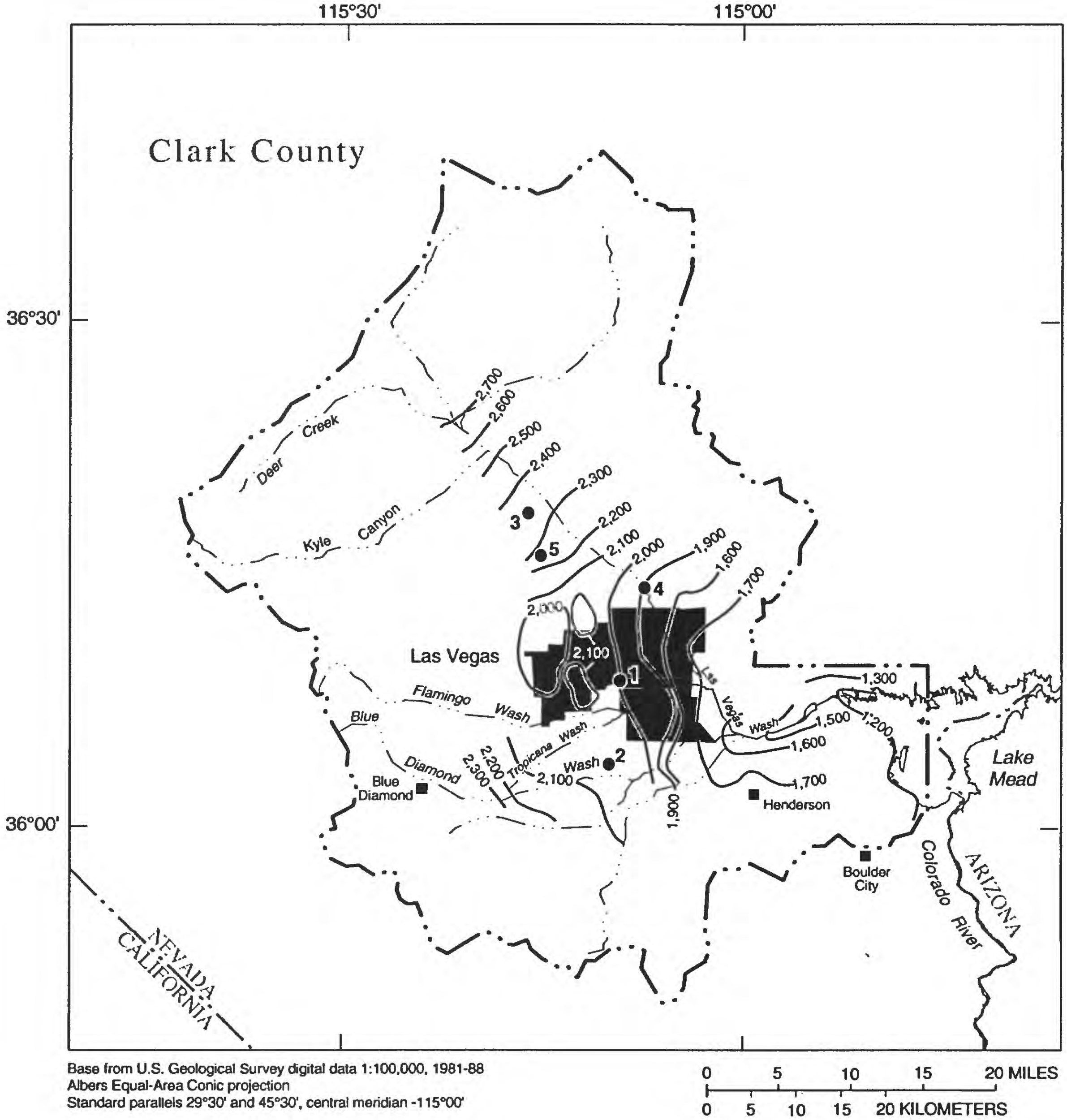


Figure 26. General area of principal basin-fill aquifers in Las Vegas Valley area.



EXPLANATION

— · · — **Study area boundary**

—2,100— **Water-level contour**—Shows altitude, in feet above sea level (from Bedinger and others, 1984)

● 1 **Water-level monitoring well and identifier**

Figure 27. Water-level altitude and selected water-level monitoring wells in Las Vegas Valley area.

Prior to urban development in Las Vegas Valley, annual recharge to aquifers was by precipitation in headwater areas of mountains to the northwest and totaled about 33,000 acre-ft (Morgan and Dettinger, 1996). Surface water from Lake Mead is injected as artificial recharge at an annual rate of about 16,000 acre-ft (Coache, 1991). Natural discharge was by aquifer leakage, springflow, and subsequent evapotranspiration (Harrill, 1976; Bell, 1981; Morgan and Dettinger, 1996). Currently, discharge primarily is by ground-water withdrawals for public supply, which was about 38,400 acre-ft in 1990 (James E. Crompton, U.S. Geological Survey, written commun., 1992).

Under natural conditions, ground water flows from recharge areas in the northwest toward discharge areas in the southeast. Ground-water withdrawals caused the water level in northwest Las Vegas to decline about 125 ft during 1944-90 (Coache, 1991). Large cones of depression have developed in near-surface and deep aquifers around major pumping centers. These cones of depression are deep enough to disrupt the natural ground-water flow. As a result, horizontal gradients controlling ground-water flow in the near-surface and deep aquifers have reversed along a linear area that extends approximately north and south through the center of the valley. Ground water, which under natural conditions generally flowed east and southeast toward natural discharge areas, now flows toward the pumping centers. Natural hydraulic gradients caused ground water to flow upward from the near-surface and deep aquifers into shallower aquifers, but now gradients are downward in areas of large drawdown (Dettinger, 1987). In addition to water-level declines and cessation of springflow, there has been local, irreversible land subsidence (Bell, 1981).

The deep aquifers (more than about 1,000 ft beneath the land surface) consist of basin-fill sediments that have relatively low permeability (Morgan and Dettinger, 1996). The deep aquifers yield little water to wells; however, they have large storage capacities (Malmberg, 1965). Discharge from these aquifers is by upward leakage and underflow.

In addition to the basin-fill aquifers, ground water also flows in fractures and solution channels within Paleozoic carbonate rocks underlying the valley. Lyles and others (1986) indicate that ground-water flow within these carbonate rocks is part of a regional flow system. Regionally, carbonate-rock aquifers currently are not heavily pumped and provide water for numerous springs along the western edge of the valley. Spring discharge provides some local irrigation water, but if these regional carbonate-rock aquifers are developed and pumped heavily for other uses, springs may cease to flow (Moosburner and Harrill, 1985).

Figure 28 compares imported Colorado River water and ground-water withdrawals in the Las Vegas Valley area. Prior to 1971, ground water was the primary source of supply. In order to reduce ground-water level declines and subsidence that resulted from heavy ground-water pumping, increasing amounts of Colorado River water were imported beginning in 1971. While ground-water withdrawals have declined slightly since about 1974, importation of Colorado River water has more than tripled. Approximately 268,000 acre-ft of Colorado River water were imported into the Las Vegas Valley area in 1990 (Coache, 1991).

Table 6 describes principal aquifer and well characteristics and figure 27 shows ground-water-level contours in feet above sea level for the Las Vegas Valley area. Water-level depths below land surface for five selected wells (fig. 27) in the Las Vegas Valley area are plotted in figure 29 for water years 1970-90. All wells tap the basin-fill aquifers. These water-level graphs indicate the variations of water levels throughout the area and their response to different effects. Three of the wells (wells 2, 3, and 5 in fig. 27) show a continuing decline in water levels during the period of record.

Ground-Water-Quality Characteristics

Ground-water-quality characteristics in Las Vegas Valley have been influenced by the pumping induced reversal of the pre-development vertical hydraulic gradients, which was upward from the principal aquifer to the overlying shallow and near-surface aquifer zones. Because the quality of shallow ground water commonly is poor, there is now a potential for water quality to be degraded at depth. Principal aquifers are most susceptible to degradation from shallow ground water in parts of the valley where there are no confined layers to impede downward movement and mixing or where pumping is heavy. The local release of poor-quality water through compaction of fine-grained sediment caused by land subsidence occurring in the Las Vegas Valley could also affect these deeper aquifers. The potential for interaction between poor-quality water in the shallow aquifer and water in deeper aquifers has not been fully determined.

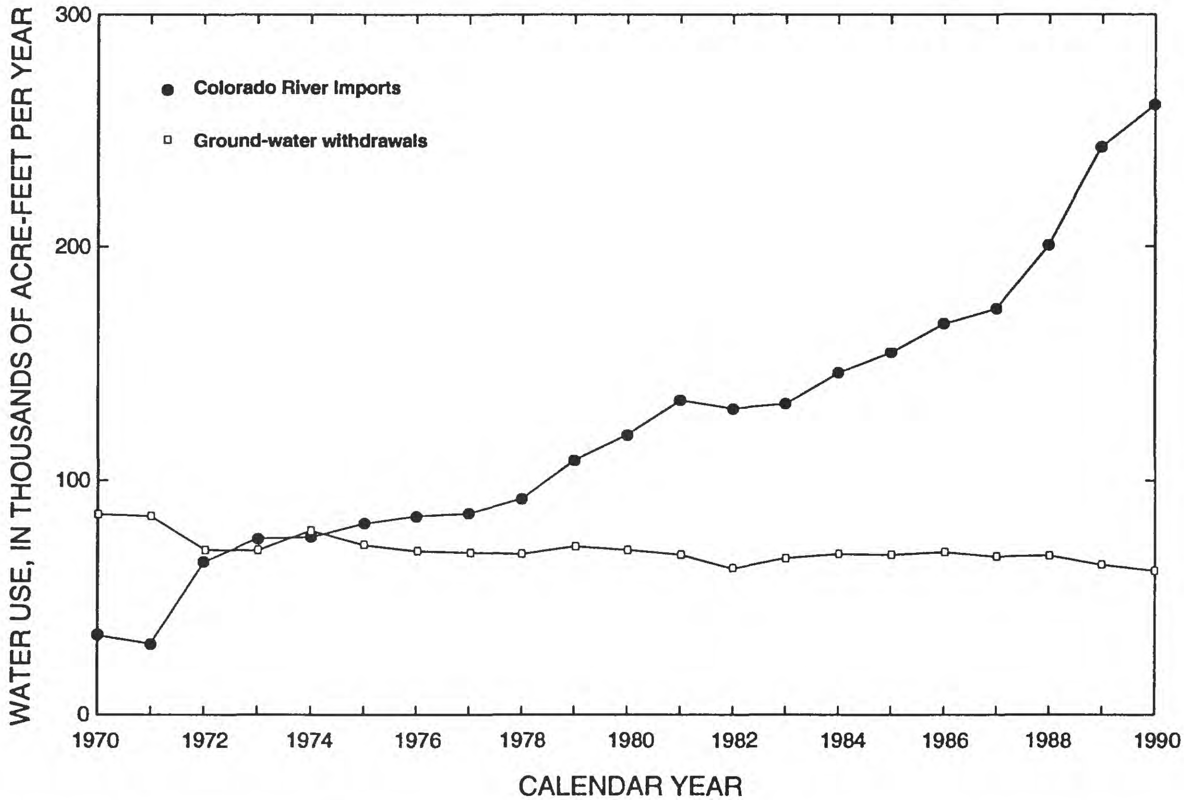


Figure 28. Total Colorado River and ground-water use for Las Vegas Valley area, 1970-90. Data from Coache (1991). See figure 27 for well locations.

In the northern Spring Mountains, the primary recharge area, ground-water quality is good. In 1981, ground-water quality in this area met established Nevada State drinking-water standards for all determined constituents (Plume, 1985). However, septic-tank effluent has locally affected ground water in the Kyle Canyon area of the Spring Mountains where urban development is expanding (Plume, 1985).

Dissolved-solids concentrations in ground waters in the northwest part of the valley range from 200 to 400 mg/L; dominant ions are calcium, magnesium, and bicarbonate, with only small amounts of sulfate. Throughout much of the valley, calcium and magnesium are codominant and bicarbonate concentrations range from 100 to 300 mg/L. Along the northern and western margins of the valley, no obvious chemical distinction is discernible between shallow and deep water, and generally water quality is good.

Ground water in the southwestern part of the valley is derived primarily from the southern Spring Mountains. It is influenced chemically by clastic sandstone, conglomerate, shale, limestone, iron-rich red beds, and gypsum deposits (Dettinger, 1987; Plume, 1989). In this part of the valley, ground water contains more sulfate and chloride than ground water in the northwestern area. The ground water in the southwestern part has slightly more calcium than magnesium, and slightly more sulfate than bicarbonate. Chloride is only a small fraction of the total anion concentrations in the water. Water obtained from intermediate and deep wells in the southern part of the valley has dissolved-solids concentrations ranging from 700 to 1,500 mg/L.

Fluoride exceeds drinking-water standards in water from some wells in the northeastern part of the valley. Fluoride in well water probably originates from the mineral fluorite in this part of Las Vegas Valley. Fluorite is present in igneous and sedimentary rocks (Dettinger, 1987). Nitrate concentrations in the shallow ground water are spatially variable and are related to the local wastewater disposal, landscape irrigation, and fertilizer use in developed areas.

Table 6. Principal aquifers and well information in the Nevada Basin and Range study unit

Aquifer	Well information			Remarks
		Depth (feet)	Yield (gallons per minute)	
Basin-fill aquifers: Alluvial and lacustrine deposits, confined and unconfined	Common range May exceed	100-500 1,200	200-1,000 5,000	Upper 500-1,000 feet most permeable and generally contains fresh water. Provides almost all water pumped by major users in State.
Volcanic rock aquifers: confined and unconfined	Common range May exceed	100-1,200 1,800	20-1,000 3,000	Provides public water to Fallon area.
Carbonate rock aquifers: limestone and dolomite, generally confined	Common range May exceed	600-2,000 5,000	50-1,000 3,400	Aggregate thickness of carbonate sections ranging from 10,000 to 30,000 feet. Aquifer not heavily pumped, although it supplies water to springs

The concentrations of dissolved solids in shallow ground water of Las Vegas Valley are affected by large volumes of secondary-recharge water that contribute additional dissolved solids. Secondary recharge and rising water levels infiltrate unsaturated soil and sediment containing large amounts of evaporites and other soluble minerals, particularly in the southeastern part of the valley. Dissolution of these evaporite and soluble minerals further degrades ground-water quality. Evapotranspiration also increases chemical-constituent concentrations in discharge areas and, subsequently, degrades ground-water quality from about 20 to 50 ft below land surface.

Dettinger (1987) indicates that average concentrations in water from wells throughout the valley in the shallow aquifers are 310 mg/L for calcium, 310 mg/L for chloride, 1,500 mg/L for sulfate, and 3,000 mg/L for dissolved solids. In shallow wells in the central and southeastern parts of the valley, dissolved-solids concentrations range from 2,000 to more than 7,000 mg/L (Dettinger, 1987). Along Las Vegas Wash, in the southeastern part of the valley, chloride concentrations exceed State drinking-water standards. Upward flow gradients in the southeastern part of the valley and low permeability of the near-surface aquifers limit downward transport of dissolved solids from the shallow aquifer, unless the gradient is reversed. Water chemistry in deep wells in the southeastern part of the valley may reflect interaction with volcanic rock. Water samples from these deep wells have low concentrations of bicarbonate and do not contain large amounts of sulfate or chloride.

Boxplots of selected water-quality constituents are shown for water samples from Las Vegas basin-fill aquifers in figure 30. The plots are derived from chemical analyses of water samples collected from 1970 to 1990. Locations of the wells where samples were collected are indicated in figure 31.

Almost 50 percent of the analyses exceeded the Nevada secondary maximum contaminant level (SMCL) of 250 mg/L for sulfate, and about 50 percent of the analyses exceeded the SMCL of 500 mg/L for dissolved solids (fig. 30). Natural dissolved-solids concentrations greater than 2,000 mg/L in the basin-fill aquifers principally result from dissolution of gypsum and other evaporite salts (Thomas and Hoffman, 1988). Dissolution of gypsum also results in increased sulfate concentrations.

Carson and Truckee River Basins

Principal Aquifers

General areas of principal aquifers in the Carson and Truckee River Basins, where saturated thickness is 100 ft or more (Vasey and others, 1972; White and others, 1979; Maurer, 1986) and concentrations of dissolved solids in ground water are less than 1,000 mg/L (Thompson and others, 1984; fig. 32) are in unconsolidated basin-fill deposits and are dependable sources of water. In the Fallon area, a consolidated volcanic-rock (basalt) aquifer also is a principal source of public water supplies. Hydraulic characteristics differ among the different types of aquifers.

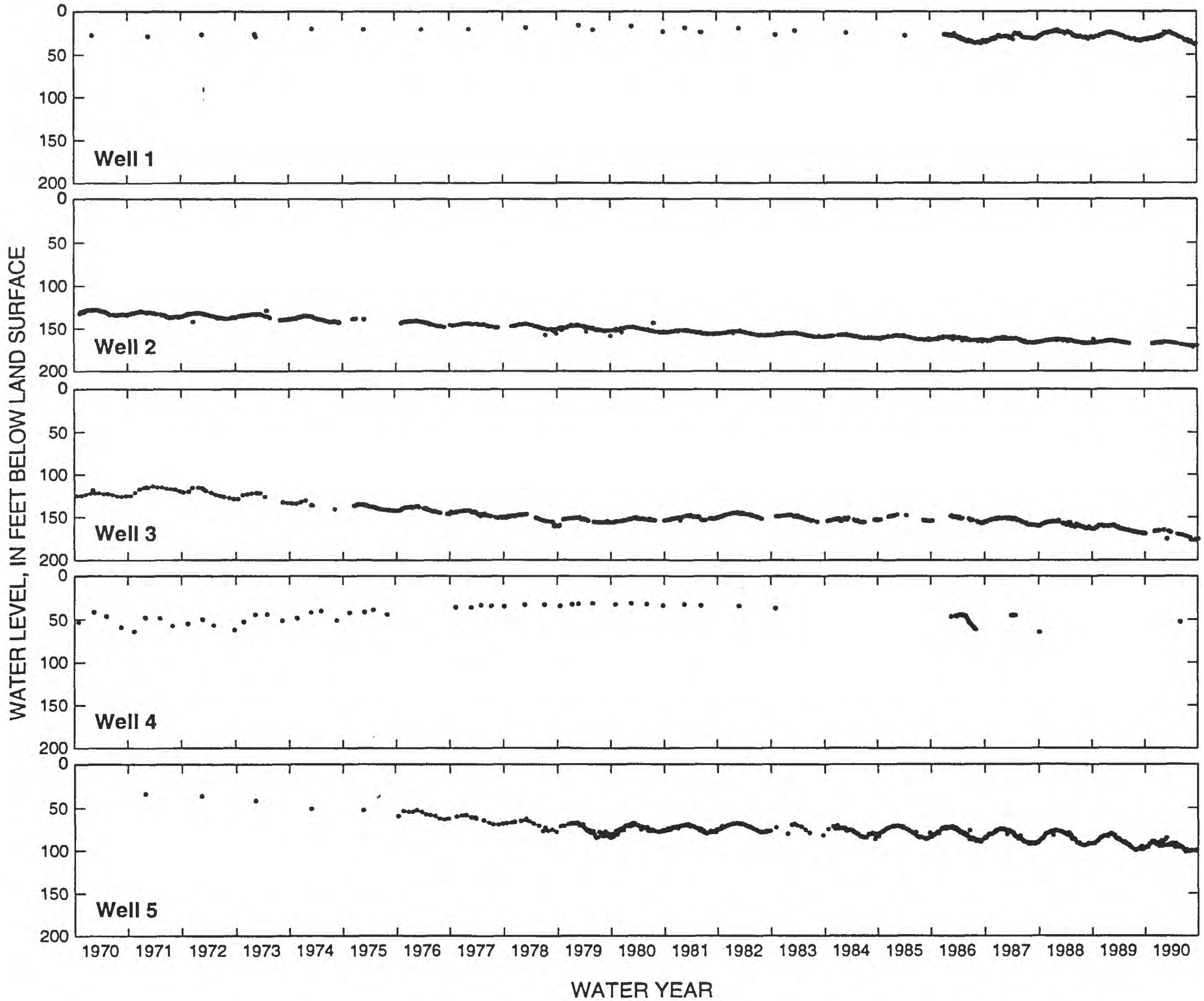


Figure 29. Ground-water levels for selected wells in Las Vegas Valley area, water years 1970-90. See figure 27 for well locations.

Principal aquifers and well characteristics are in table 6 and ground water-level contours are shown in figure 33 for the Carson and Truckee River Basins. Basin-fill aquifers readily receive, transmit, and may store large volumes of water (Glancy, 1986). Basin-fill deposits consist of layers of discontinuous clay, silt, sand, and gravel. Highest water yields are from aquifers composed of sand or gravel and are usually within 500 to 1,500 ft of land surface, although some can be less than 500 ft (Moosburner and Harrill, 1984).

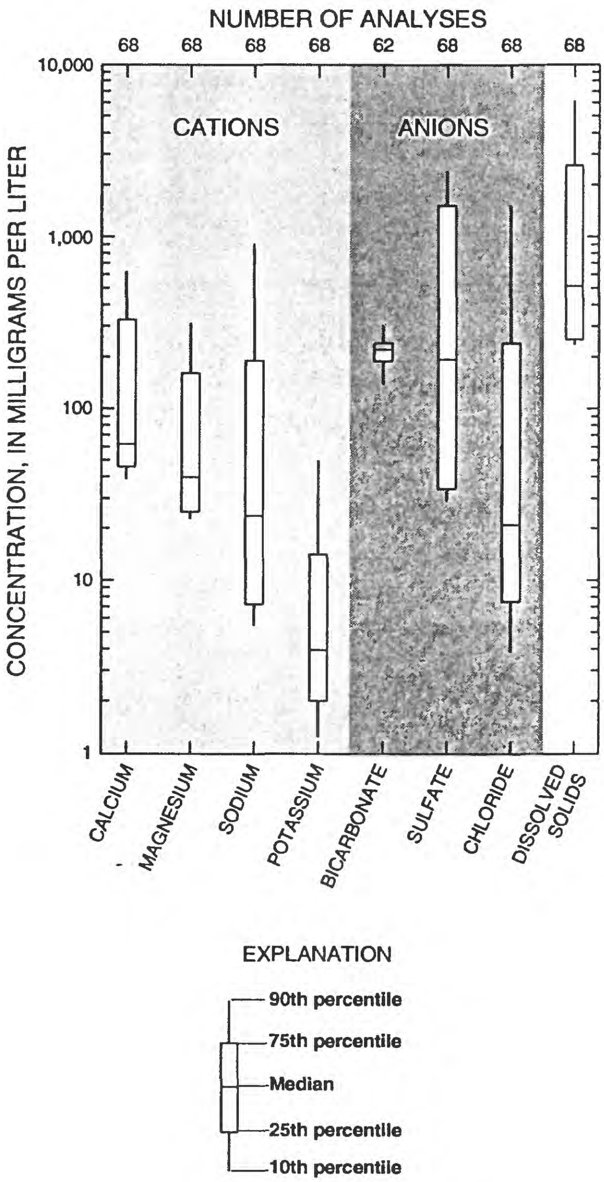


Figure 30. Boxplots for concentrations of major ions and dissolved solids in ground-water samples from Las Vegas Valley area, water years 1975-87.

Aquifers in headwater areas of the Carson and Truckee River Basins are in alluvium along canyon bottoms, where ground-water levels are controlled by adjacent streams (Welch and others, 1989). In mountainous headwater areas, the presence of some ground water depends on the permeability of consolidated rock. Permeability and saturation of consolidated rock are controlled by rock type and the extent of weathering and fracturing. Water can be found in fractured consolidated rock within most of the area, although the more known productive aquifers are restricted to alluvial fill in valley bottoms.

Locations of five wells completed in basin-fill deposits and one well near Fallon (well number 5), in a basalt aquifer are shown in figure 33. Water-level hydrographs for these six wells are shown in figure 34 and indicate areal and temporal variations of water-level depth and varying responses to hydrologic conditions such as withdrawals, recharge, and periods of drought.

Major water-bearing units in Carson Valley (fig. 32) are unconsolidated Quaternary basin fill and semiconsolidated Tertiary sediments. Quaternary deposits are fine- to coarse-grained alluvium deposited by the ancestral Carson River and are about 3,000 to 4,000 ft thick (U.S. Geological Survey, 1988). Tertiary sediments crop out in long ridges on the east side of the valley and are mostly fine-grained lake and fluvial deposits (U.S. Geological Survey, 1988). Total thicknesses are greater than 1,000 ft and the deposits probably underlie most of the valley. Ground water in Carson Valley is under confined and unconfined conditions, although there is no single confining layer that extends across the entire valley. Depth to water in unconfined aquifers ranges from about 5 to 100 ft (Maurer, 1986). Artesian flow is present in coarse Carson River and alluvial fan deposits that are confined under fine-grained sediment. Wells in confined aquifers usually flow; confined heads range from 5 to 20 ft above land surface (Maurer, 1986). More than 1,000 acre-ft of ground water was discharged from approximately 100 flowing wells in 1982 (U.S. Geological Survey, 1988).

The unconfined water table in the Carson Valley seasonally rises about 3 to 5 ft during spring runoff and in areas where flood irrigation methods are used. Water levels decline near the end of the summer because of decreased streamflow and high rates of evapotranspiration, which is estimated to be about 80,000 acre-ft/yr (U.S. Geological Survey, 1988). In the eastern part of

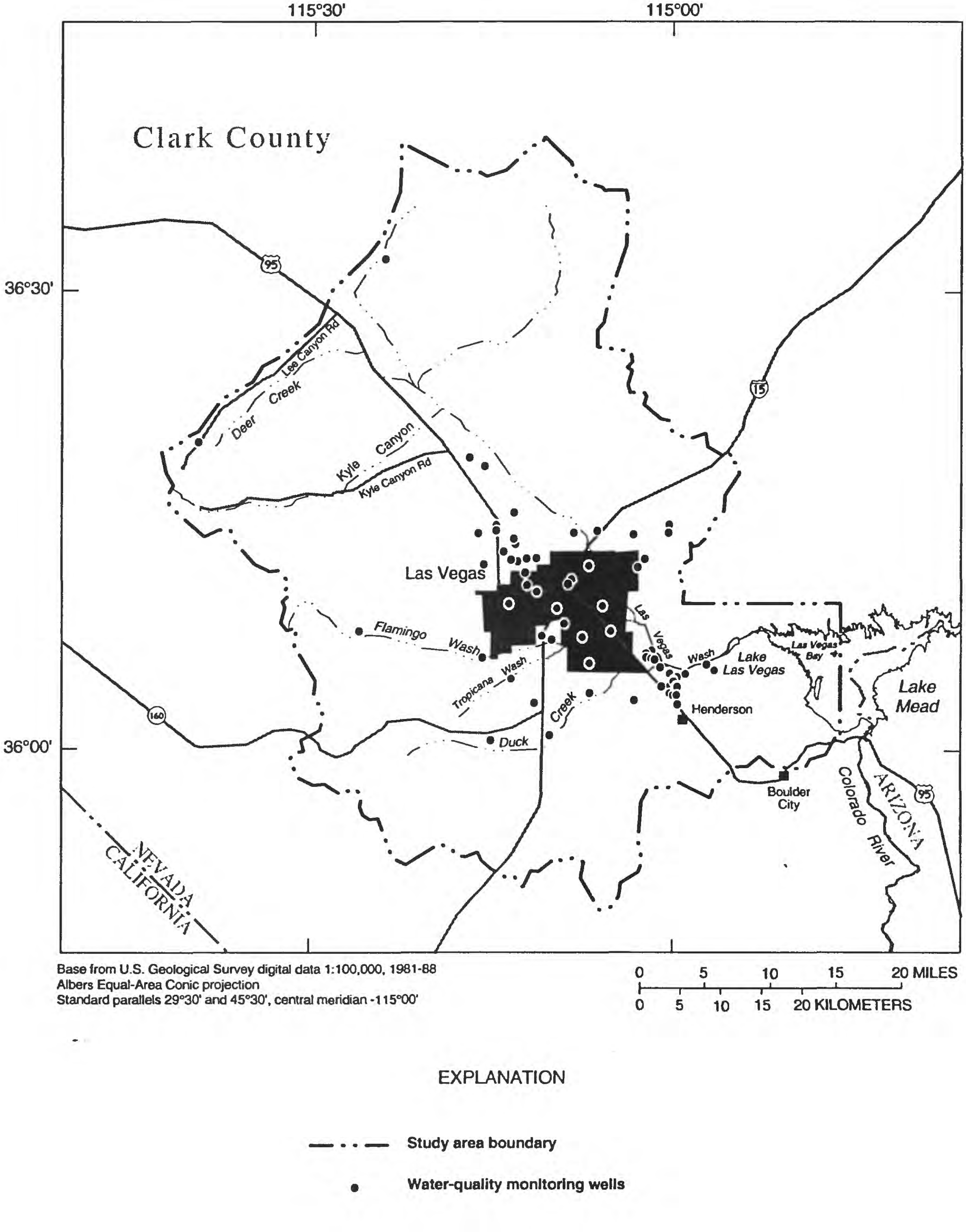
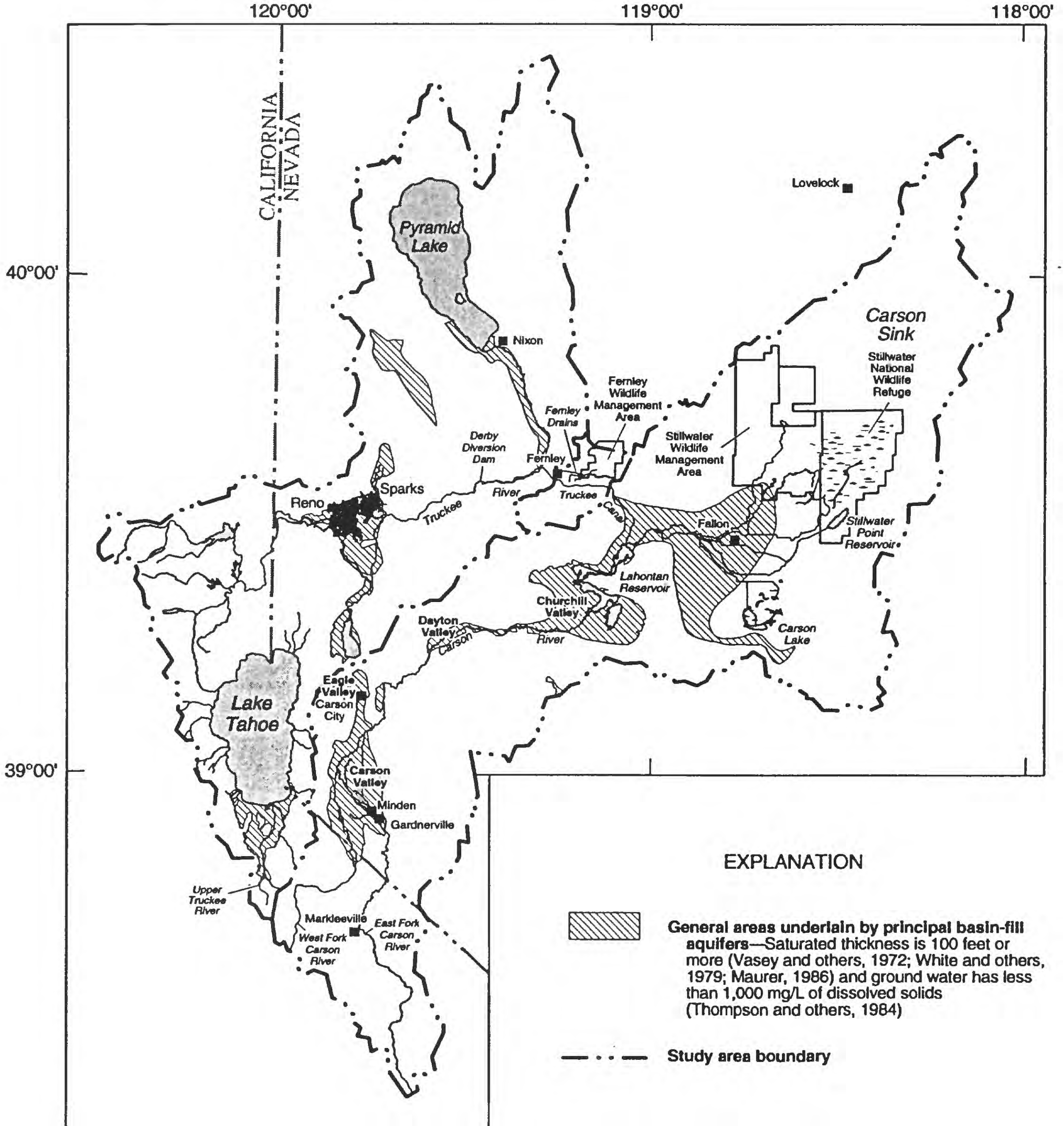
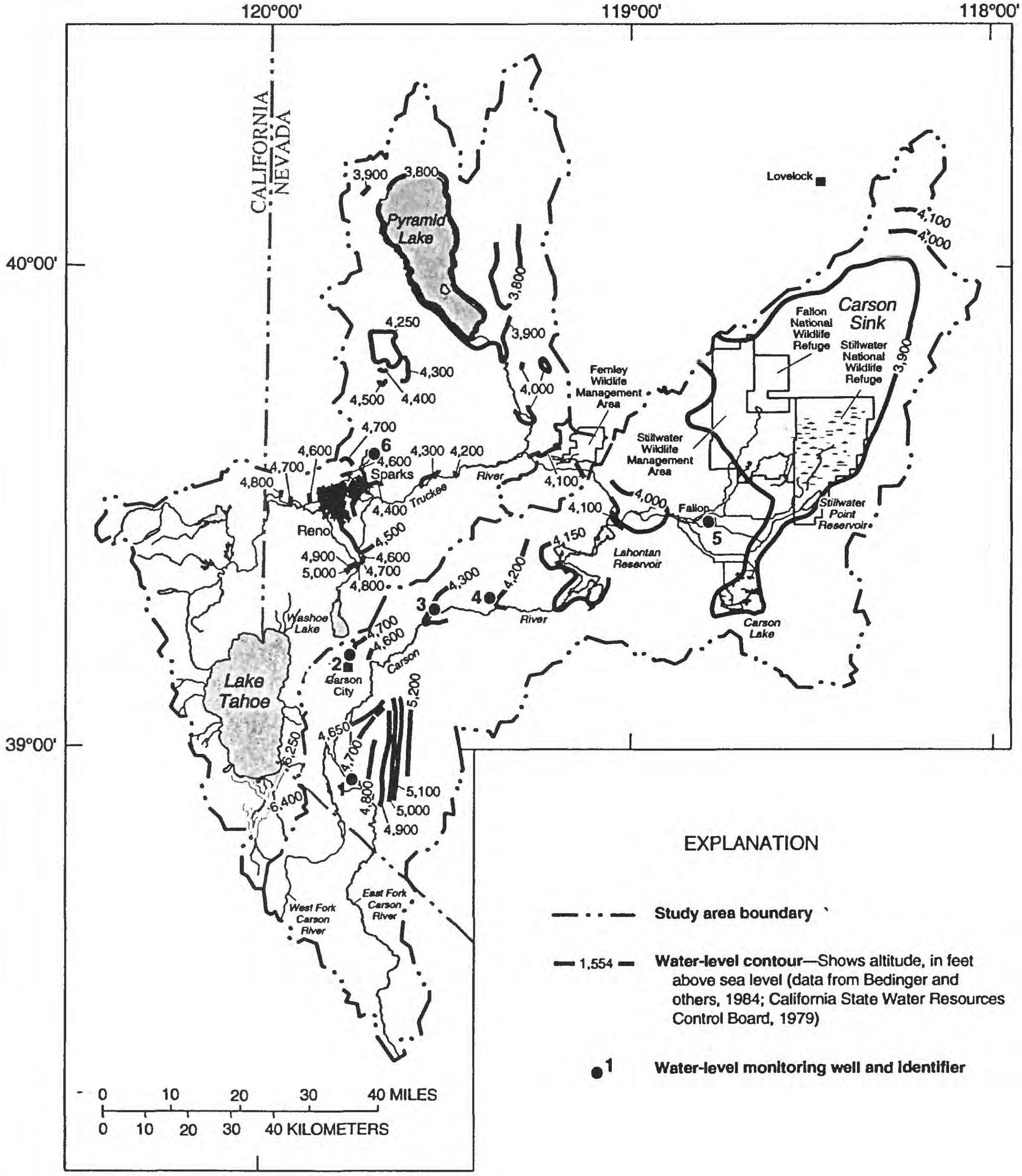


Figure 31. Location of selected water-quality monitoring wells in Las Vegas Valley area.



Base from U.S. Geological Survey digital data 1:100,000, 1977-85
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -119°00'

Figure 32. General areas of principal basin-fill aquifers in the Truckee and Carson River Basins.



Base from U.S. Geological Survey digital data 1:100,000, 1977-85
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -119°00'

Figure 33. Water-level altitude and selected water-level monitoring wells in Carson and Truckee River Basins.

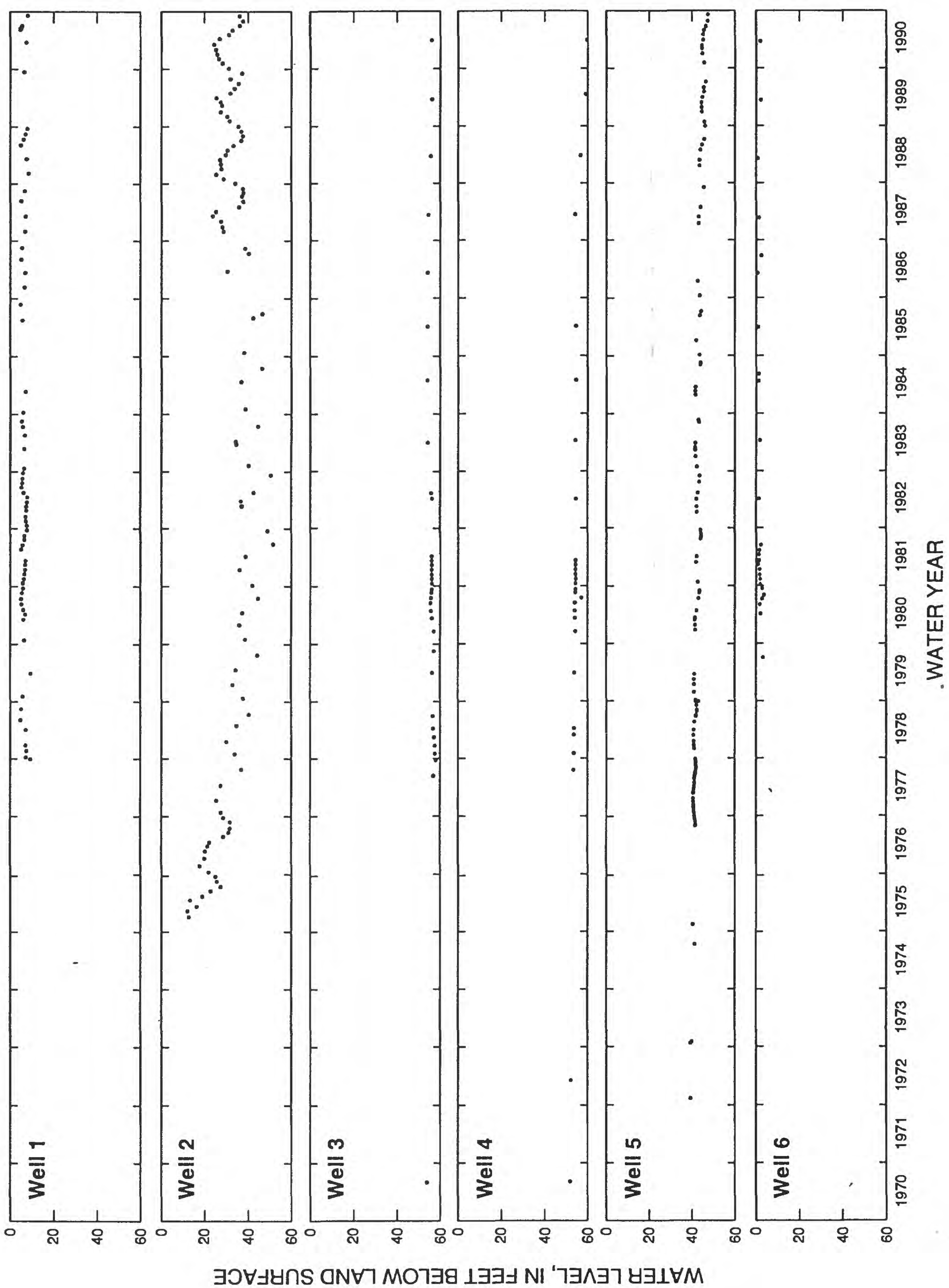


Figure 34. Ground-water levels for selected wells in Carson and Truckee River Basins, water years 1970-90. See figure 33 for well locations.

Carson Valley, ground water flows toward the center of the valley and then northward (Maurer, 1986). Depths to water in most areas of the valley are shallow, but depths increase beneath alluvial fans at the base of the Sierra Nevada and at the base of the Pine Nut Mountains to the east.

Eagle Valley (fig. 32) is underlain by unconsolidated and semiconsolidated deposits ranging from less than 100 ft to more than 800 ft in thickness. The unconsolidated deposits of sand and coarse sediments are derived from nearby granitic and metamorphic rocks, and form a generally unconfined aquifer that yields large quantities of water. Semiconsolidated alluvial deposits are heterogeneous mixtures of sand, silt, and clay, with discontinuous clay layers that serve as confining beds; finer grained sediments yield less water.

The Eagle Valley ground-water basin was described by Arteaga (1986) as a two-layer aquifer system. The upper layer, 0 to 50 ft below land surface, is unconfined. The lower layer, deeper than 50 ft, has semi- or completely confined conditions. However, Szecsody and others (1983) indicate the ground-water system in Eagle Valley is unconfined.

Ground-water flow directions in Eagle Valley are complicated by consolidated-rock barriers, but flow generally is eastward toward the Carson River (Welch and others, 1989). The valley ground-water basin is divided structurally into west and east sections by an uplifted section of consolidated rock; also by several north-northeast trending faults. These structural features influence flow directions and movement of ground water. Maximum depths to bedrock for the western and eastern sections are about 1,200 and 2,000 ft, respectively.

Total ground-water withdrawals in Eagle Valley were estimated to be 9,000 acre-ft/yr by Arteaga and Durbin (1978); withdrawals that large might lower the potentiometric surface and increase depth to water. Comparisons of depth-to-ground-water maps from 1966 to 1980 indicate a net valley-wide decline of 10 to 20 ft (Szecsody and others, 1983).

Principal aquifers in Dayton and Churchill Valleys (fig. 32) have been described by Schaefer and Whitney (1992) as basin-fill deposits with thicknesses to about 3,000 ft. Ground-water flow in Dayton and Churchill Valleys is eastward, along the same general course as the Carson River. Water levels have declined since irrigation and public-supply withdrawals have increased (Schaefer and Whitney, 1992). Depth-to-water ranges from about 200 ft below land surface near mountain fronts, to near surface in areas close to the Carson River. Agriculture along the Carson River primarily uses surface water rather than ground water.

Basin-fill aquifers in the Fallon area (fig. 32), described by Glancy (1986), are in unconsolidated sedimentary deposits originating as fluvial, pluvial, and eolian detritus. These aquifers are grouped as (1) a shallow alluvial aquifer from near land surface to about 50 ft below land surface, (2) an intermediate-depth alluvial aquifer extending from about 50 ft to depths of about 500 ft at Fallon, (3) a basalt aquifer that is exposed at the surface near Fallon but normally ranges in depth from about 60 to 1,000 ft below land surface, and (4) a deep-alluvial aquifer that underlies the intermediate-alluvial and basalt aquifers, at depths of 500 to 1,000 ft (Glancy, 1986).

Alluvial aquifers consist primarily of sand and gravel deposits within the basin fill. These aquifers contain water-bearing deposits that are hydraulically separate, during short periods of time; but during long periods of time are hydraulically dependent upon each other (Glancy, 1986). The basalt aquifer is surrounded by basin fill and transmissivity is highly variable. Hydraulically, the basalt and basin-fill aquifers are not separated; basalt aquifer transmissive zones are in partial contact with the highly transmissive zones of the basin-fill aquifers. Because of the partial contact, major stresses on either alluvial or basalt aquifers will cause them to react hydraulically with each other (Glancy, 1986). The basalt aquifer near Fallon is the most heavily pumped volcanic rock aquifer in the state, although it is not as heavily pumped as the alluvial aquifers (Moosburner and Harrill, 1984).

Ground-water flow in the shallow alluvial aquifer in the Carson Desert (less than about 50 ft deep) is generally eastward and discharges into the Stillwater Wildlife Management Area, the Carson Sink, and Carson Lake. Flow directions and magnitudes differ within the aquifer and are influenced by drains, canals, and irrigation practices (Lico, 1992).

A principal aquifer in the southern part of Lake Tahoe Basin is unconfined basin-fill composed of glacial outwash material that exceeds 600 ft in thickness (Loeb, 1987). Ground water flows toward the lake with a general gradient of about 15 ft/mi and discharges into the lake at a rate of 1,400 acre-ft/yr (Loeb, 1987).

In the Reno-Sparks area (fig. 32), much of the basin fill consists of alternating fluvial deposits of clay, silt, sand, and gravel (Sierra Pacific Power Company, 1986). General flow directions of ground water are from southwest to northeast toward the Truckee River. Fine-grained alluvium stores large amounts of ground water because of porosity and thickness, but yields small amounts of water. Alluvium of medium- to coarse-grained sand or gravel stores and transmits the largest volumes of ground water.

Ground-Water-Quality Characteristics

Concentrations of dissolved solids increase from less than 200 mg/L in most headwater areas to greater than 10,000 mg/L in terminal discharge areas of the Carson Sink. The increase in dissolved-solids concentrations (primarily sodium, chloride, and sulfate) is caused by increasingly longer contact with aquifer deposits, evapotranspiration, geothermal influences, the presence of evaporite deposits in downstream valleys, and the effects of human activities (agricultural and urban drainage). The following is a summary of reports on ground-water quality within the Carson and Truckee River Basins.

The NAWQA pilot study of the Carson River Basin evaluated available ground-water-quality data through 1987. In a report by Welch and others (1989), chemical constituents with 30 or more samples in each of the Carson River Basin hydrographic areas were evaluated with respect to Nevada State maximum contaminant levels (MCL's) and secondary maximum contaminant levels (SMCL's). In headwater areas, dissolved-solids concentrations were less than 200 mg/L; fluoride exceeded the MCL in 2 of 10 samples. In Carson Valley, dissolved-solids concentrations generally were less than 500 mg/L; fluoride exceeded the MCL in 10 of 302 samples, arsenic in 4 of 276 samples, and nitrate in 3 of 265 samples. In Eagle Valley, dissolved-solids concentrations generally were less than 200 mg/L; fluoride exceeded the MCL in 3 of 114 samples and arsenic exceeded the MCL in 3 of 99 samples. In Dayton Valley, dissolved-solids concentrations ranged from 200 to 2,000 mg/L; fluoride exceeded the MCL in 15 of 158 samples, arsenic in 4 of 113 samples, and dissolved solids exceeded the SMCL in 58 of 184 samples, primarily because of sulfate, which exceeded the SMCL in 53 of 194 samples. In Churchill Valley, dissolved-solids concentrations generally ranged from 200 to 1,000 mg/L; arsenic exceeded the MCL in 6 of 55 samples and dissolved solids exceeded the SMCL in 7 of 70 samples, because of sulfate, which exceeded the SMCL in 6 of 72 samples. In Carson Desert, dissolved-solids concentrations ranged from near 1,000 to more than 10,000 mg/L; fluoride exceeded the MCL in 10 of 186 samples; arsenic in 107 of 190 samples, and dissolved solids exceeded the SMCL in 72 of 190 sites, because of chloride, which exceeded the SMCL in 69 of 209 samples.

In Carson Valley, calcium bicarbonate, sodium bicarbonate, and calcium sodium or sodium calcium bicarbonate are the most common water types, although other chemical types of water are present (Garcia, 1989). Ground-water quality differs from west to east, with lower dissolved-solids concentrations on the west side of the valley (Maurer, 1986). The effects of rapid population growth and subsequent development of ground-water resources in Carson Valley are concerns for State and county officials (Garcia, 1989). Most ground water in Carson Valley is acceptable for public and agricultural uses. Further development of residential areas using septic systems may result in more frequent occurrences of high nitrate concentrations in ground water. Treated sewage from urban areas and effluent from the Lake Tahoe Basin are used to irrigate golf courses and agricultural land at several locations within the valley.

Ground water in Carson Valley near a regional landfill and near the airport has been affected by organic compounds. However, limited valley-wide monitoring indicates that contamination by organic compounds is not a widespread problem (U.S. Geological Survey, 1988).

Worts and Malmberg (1966) investigated water from aquifers within Eagle Valley to identify potential water-quality concerns. Samples from 22 wells were analyzed for major ions and were considered to be good water quality. In nonthermal water, calcium and sodium are the dominant cations and carbonate is the dominant anion in the valley. Thermal waters in Eagle Valley are sodium sulfate or calcium sulfate types. Both sodium sulfate and calcium sulfate enriched waters are widespread throughout the Carson and Truckee River Basins. Chemical similarities of these water types suggest that deposits of gypsum and anhydrite may be the source of calcium and sulfate (Szecsody and others, 1983). Some ground water within Eagle Valley has chemical compositions that indicate mixing of thermal and nonthermal water.

Water-quality concerns for Eagle Valley include locally high concentrations of iron, manganese, sulfide, fluoride, nitrate, and arsenic. Other water-quality concerns include gasoline leaking from underground storage tanks and industrial spills of synthetic organic compounds (U.S. Geological Survey, 1988). High nitrate concentrations in ground water of areas where septic systems have been used for the disposal of domestic sewage has become a major concern in the early 1990's.

Boxplots for concentrations of selected ions in ground water in the Carson River Basin are shown in figures 35-38. Boxplots are arranged by constituent with respect to hydrographic area, and allow for analysis of distribution in and comparison of concentrations in the hydrographic areas. Locations of the wells from which these boxplots are derived are shown on figure 39.

In the Carson River Basin (fig. 35), median concentrations of calcium, magnesium, sodium, and potassium are less than 100 mg/L in ground water; except the median concentration of sodium is about 700 mg/L in the Carson Desert. Median concentrations of bicarbonate are less than 200 mg/L (fig. 36), except in the Carson Desert, where the median concentration approaches 400 mg/L. Median sulfate concentrations increase from less than 30 mg/L in Carson Valley to more than 100 mg/L in the Carson Desert (fig. 36). Median chloride concentrations increase from less than 10 mg/L in Carson Valley to more than 500 mg/L in the Carson Desert (fig. 36).

Van Denburgh and others (1973) determined that ground water in headwater recharge areas within the Truckee River Basin is a calcium bicarbonate type, except where there are increased dissolved-solids concentrations. Water with high dissolved-solids concentrations is commonly a sodium bicarbonate type. As ground water flows away from recharge areas, dissolved-solids concentrations increase and water becomes a sodium chloride type. In some geothermal areas, sulfate is the dominant anion. Ground water in most of the Truckee River Basin, except in the Tracy area, is suitable for agricultural purposes. Ground-water quality is poor north of Reno and near Fernley, Wadsworth, and Nixon.

Ground-water quality in the basin-fill aquifers beneath the southern part of the Lake Tahoe Basin was described by Loeb (1987). Loeb reported that concentrations of nitrate as nitrogen ranged from 0.006 mg/L to 2.55 mg/L and were higher in water from shallow wells and in downgradient wells closer to the lake. Measurements of specific conductance ranged from about 70 to 400 µS/cm (microsiemens per centimeter). The higher specific conductance values were associated with higher chloride concentrations measured in wells near the junction of major highways. Chloride sources could be from road salt applied to remove snow and ice from the highways.

Ground-water samples collected from shallow test wells in unconsolidated deposits along the eastern shore of Lake Tahoe by Thodal (1992) had specific conductance values ranging from 131 to 1,560 µS/cm. Dissolved-solids concentrations ranged from 82 to 994 mg/L. High specific conductance and dissolved-solids concentrations also were associated with high chloride concentrations.

Ground-water quality in the southern part of the Reno-Sparks area ranges from poor to excellent (William F. Guyton Assoc., 1986). In the Reno-Sparks area, arsenic, manganese and iron concentrations can approach or exceed SMCL's or MCL's. The poorest quality water is primarily to the east near the Virginia Range. In the southern part of the Reno-Sparks area, dissolved-solids concentrations range from 669 to 2,670 mg/L. Water of good quality, with low dissolved-solids concentrations and moderate to high total hardness, is in the north-central and western part of the area. Analytical results indicate that dissolved-solids concentrations in the western part of the Reno-Sparks area range from 168 to 262 mg/L and total hardness ranges from 83 to 208 mg/L. Arsenic concentrations in ground water in much of the central Reno-Sparks area approach the MCL of 50 µg/L for public supply (Van Denburgh and others, 1973; William F. Guyton Assoc., 1986).

In the Truckee River Basin (figs. 37 and 39), median concentrations of calcium, magnesium, sodium, and potassium are less than 30 mg/L, except in the Tracy area, where median concentrations of calcium, magnesium, and sodium exceed 30 mg/L and in the Fernley area where the median concentrations of sodium exceed 200 mg/L. Median bicarbonate concentrations increase from less than 90 mg/L in the Lake Tahoe Basin, to about 300 mg/L in the Tracy area. Median sulfate concentrations increase from less than 2 mg/L in the Lake Tahoe Basin to more than 100 mg/L in the Tracy area.

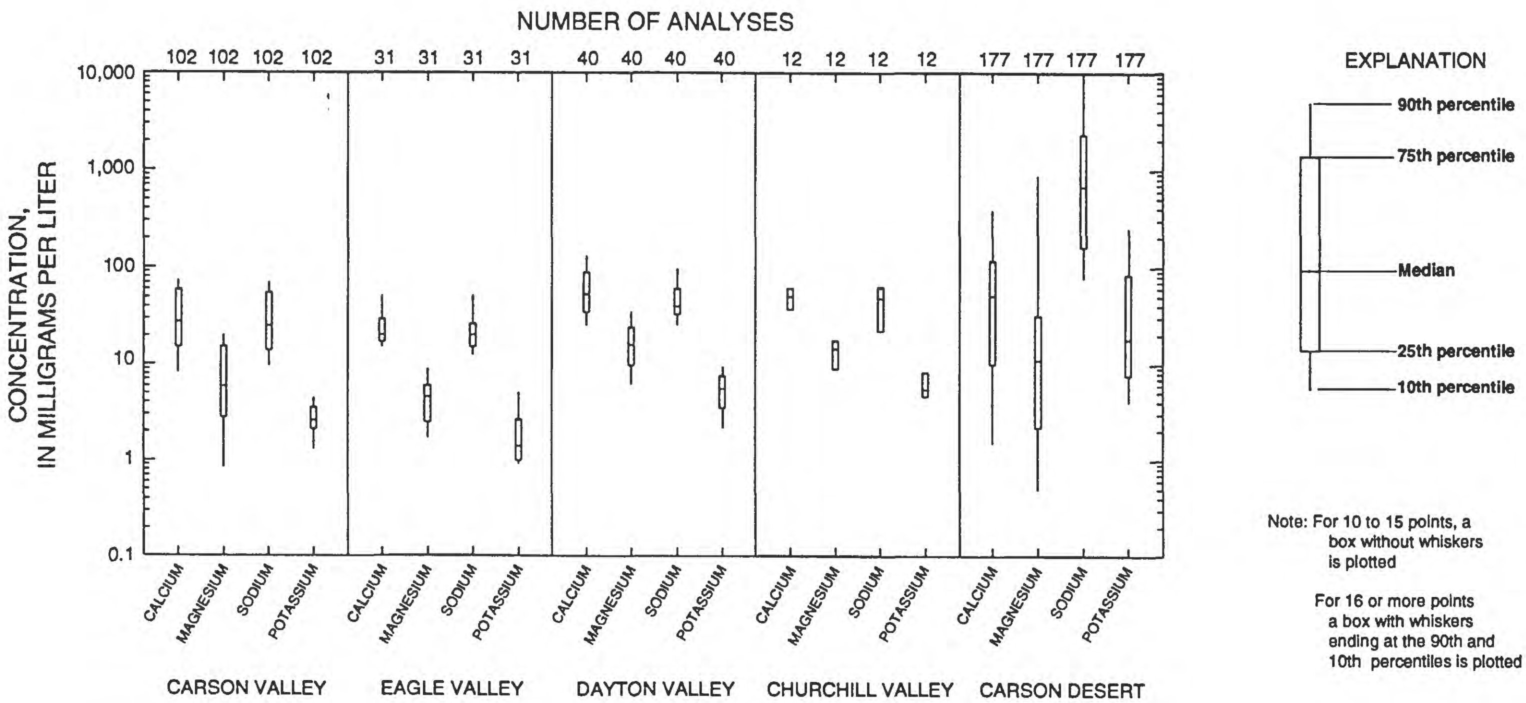


Figure 35. Boxplots for concentrations of selected cations in ground-water samples from Carson River Basin, water years 1958-89.

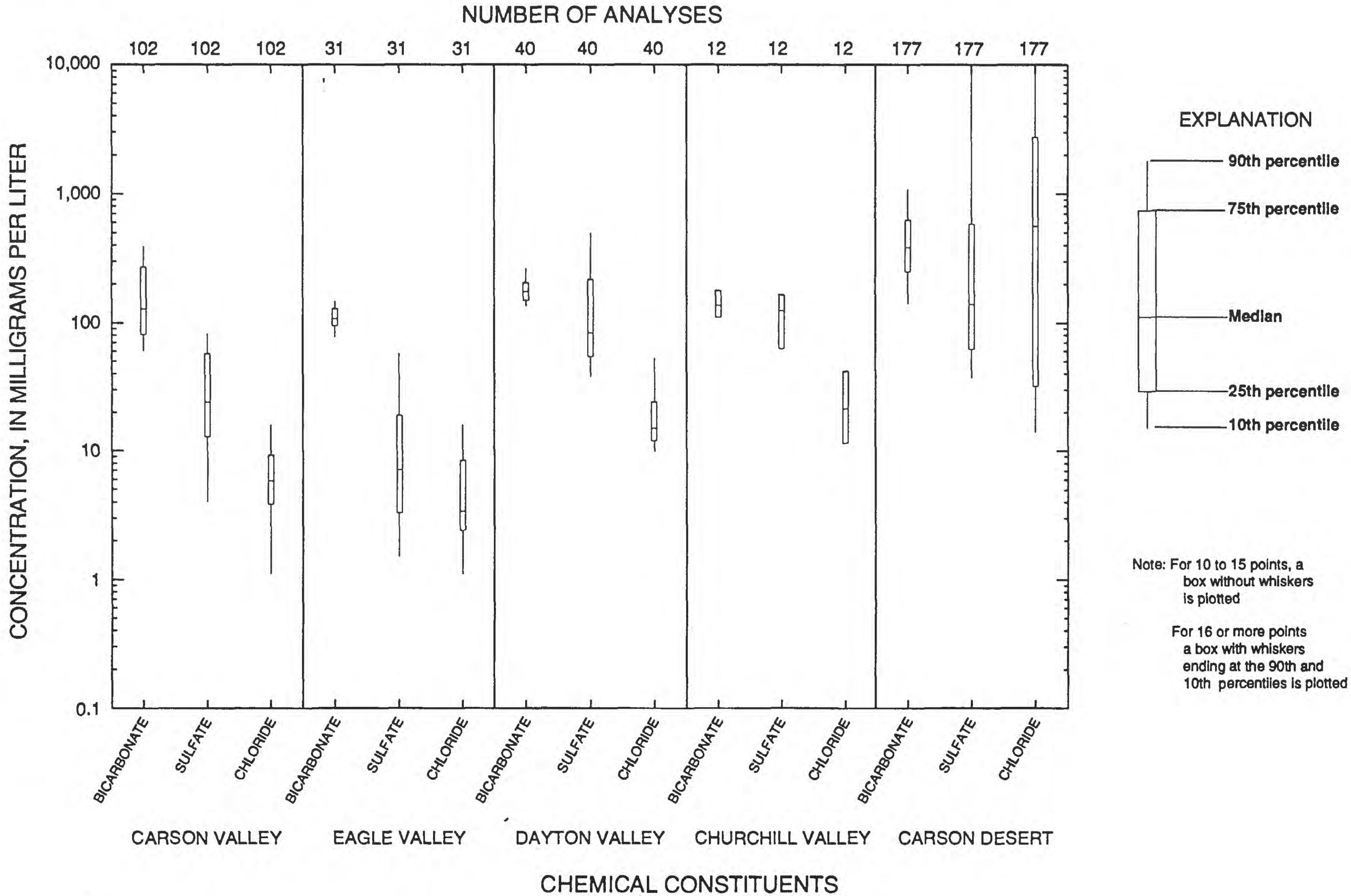


Figure 36. Boxplots for concentrations of selected anions in ground-water samples from Carson River Basin, water years 1958-89.

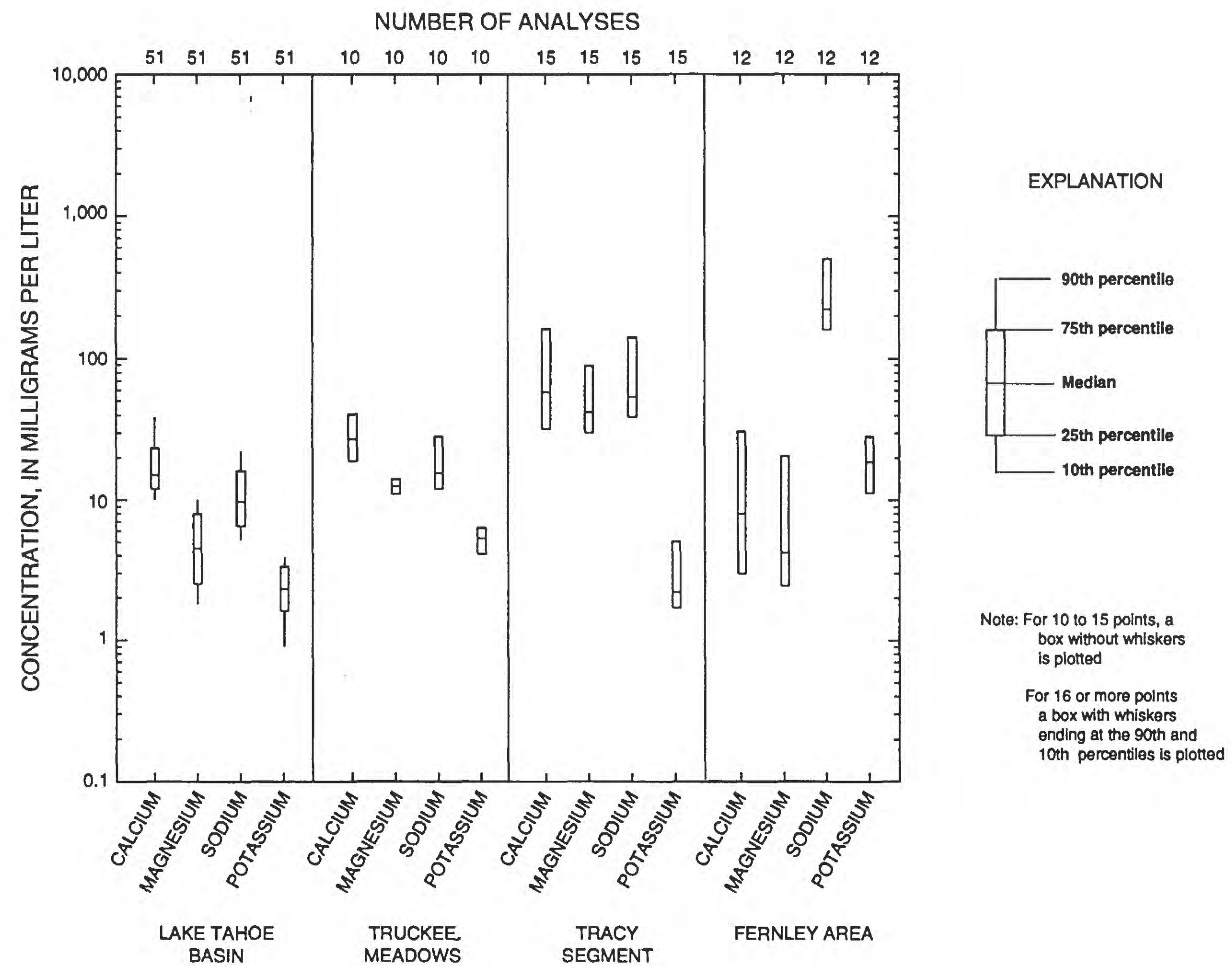


Figure 37. Boxplots for concentrations of selected cations in ground-water samples from Truckee River Basin, water years 1972-91.

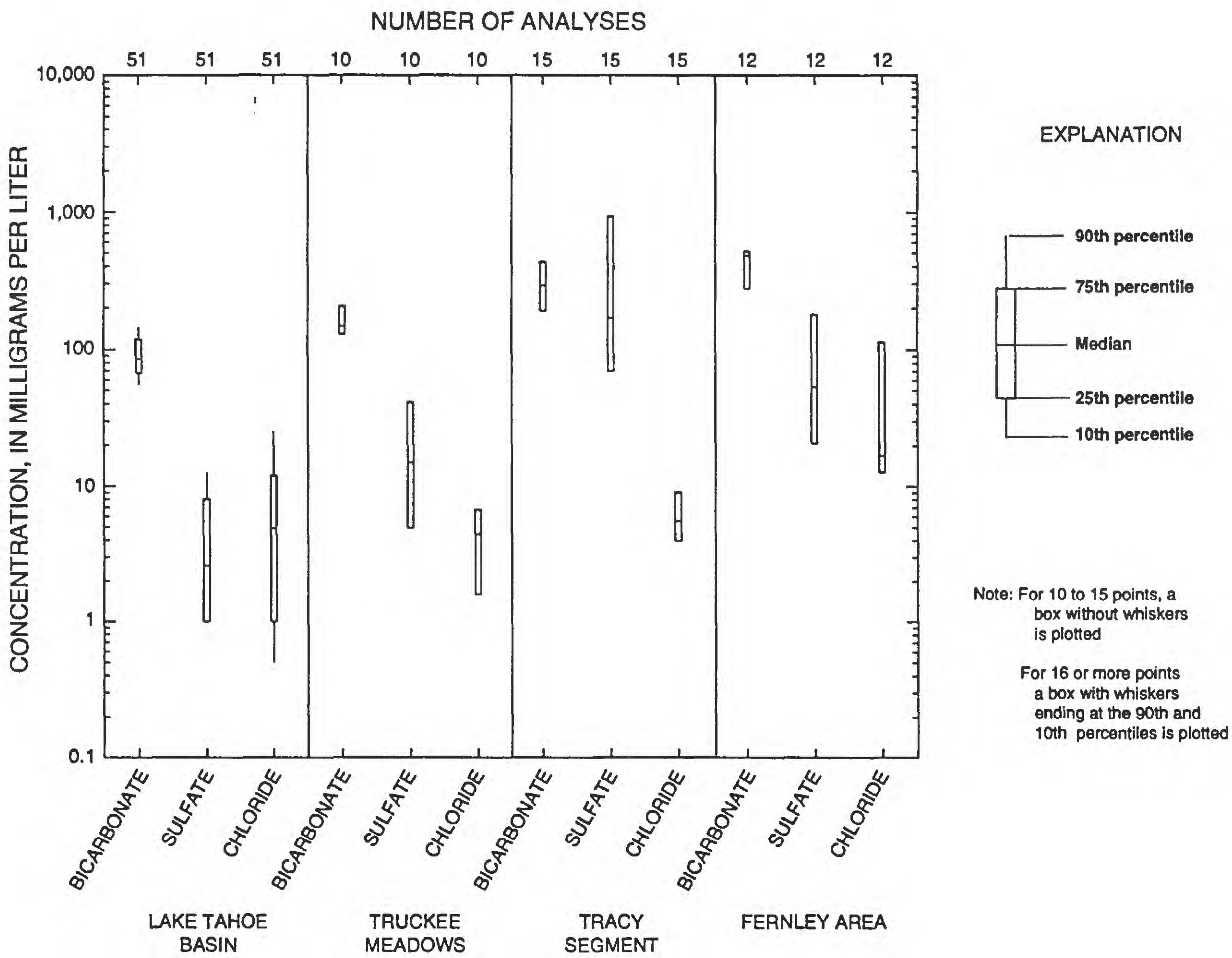


Figure 38. Boxplots for concentrations of selected anions in ground-water samples from Truckee River Basin, water years 1972-91.

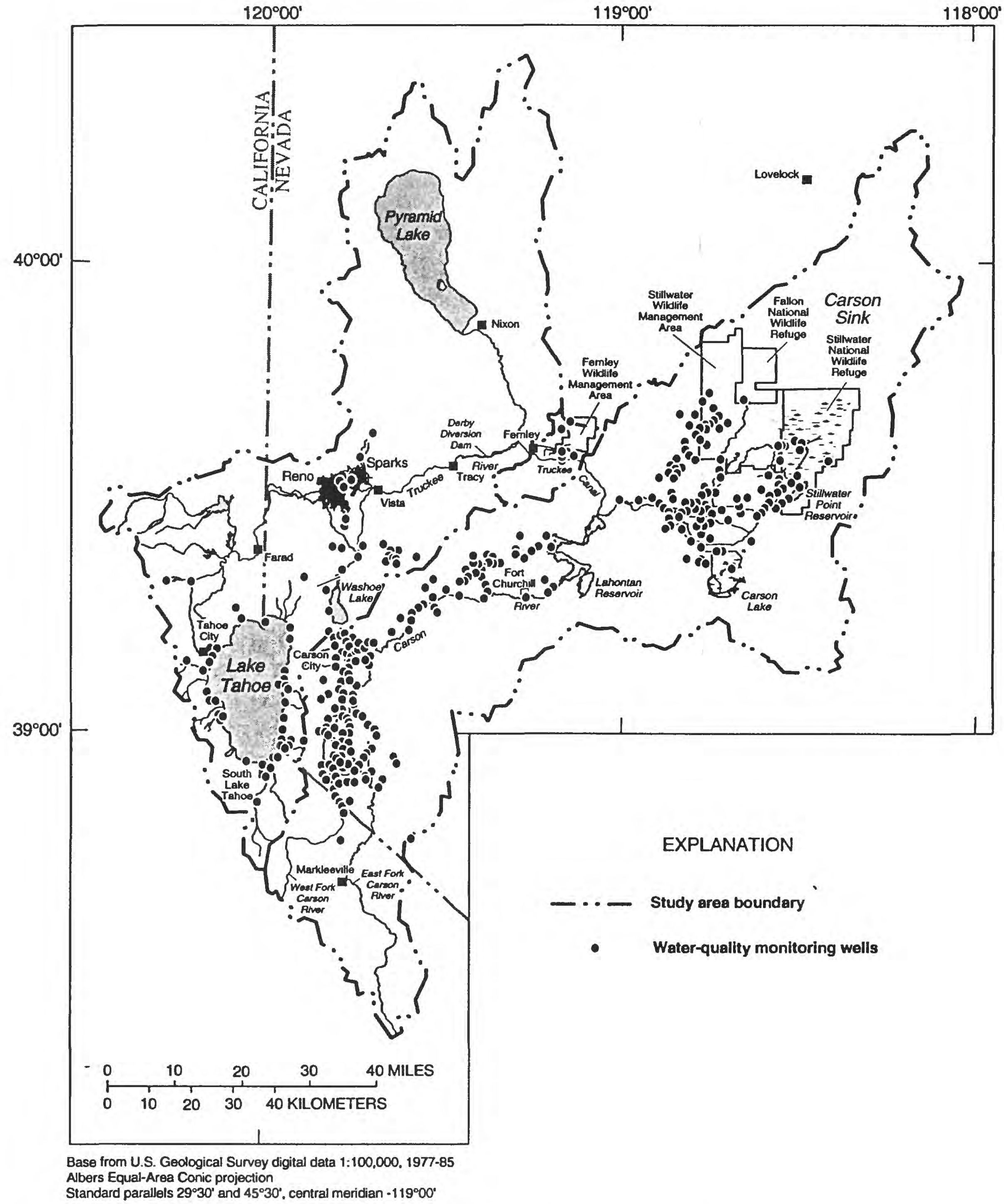


Figure 39. Location of selected water-quality monitoring wells in Carson and Truckee River Basins.

Water-Quality Issues

Las Vegas Valley Area

Las Vegas Wash conveys treated effluent from sewage-treatment plants, industrial drainage, urban runoff, storm runoff, and sediment to Las Vegas Bay of Lake Mead. In Las Vegas Bay, phytoplankton growth, pathogenic bacteria, and viruses also are potential problems (William Burke, National Park Service, oral commun., 1993). The presence of these organisms creates a nuisance and health hazard for recreational users of Lake Mead.

In Las Vegas Valley, water quality of the shallow aquifers is affected by urban land use. Rapid population growth and associated water use in the Las Vegas area have contributed to shallow perched aquifers. The shallow perched aquifer water is of poor quality (nonpotable) and has the hydraulic potential to percolate downward and possibly contaminate deeper principal aquifers that provide water for public supply (Brothers and Katzer, 1988). The shallow aquifers presently discharge in the southeastern part of the valley into Las Vegas Wash.

Carson and Truckee River Basins

Water quality is adversely affected by human activities in parts of the Carson and Truckee River Basins. Urbanization introduces sewage, industrial wastes, fertilizers, pesticides, and sediment to the environment. Agriculture introduces irrigation drainage with elevated levels of dissolved solids, trace elements, and agricultural chemicals. Mining practices have introduced acid mine drainage, metals, and sediment to water resources (Bevans and Kilroy, 1991).

In the Carson River Basin, there are major concerns about contamination of shallow ground water by nitrate from septic systems in some urban and suburban areas. There also are concerns about mercury contamination in the Carson River caused by historical ore-milling activities. There is contamination of wetlands in the Carson Desert and Carson Sink by irrigation drainage that contains high concentrations of dissolved solids, boron, arsenic, selenium, molybdenum, lithium, and un-ionized ammonia. Documented effects of irrigation drainage and mercury on biota in the Fernley and Stillwater Wildlife Management Areas include (1) water in TJ and Hunter Drains, which discharge to the Stillwater Wildlife Management Area, was acutely toxic to freshwater daphnids and flathead minnows, and to saltwater myriad shrimp, sheephead minnows, and striped bass, (2) samples of juvenile migratory birds from several sites had levels of boron, mercury, and selenium that could affect survival, (3) nest success was poor, and (4) concentrations of mercury and selenium in waterfowl exceeded criteria for human consumption (Hallock and Hallock, 1993).

In the Truckee River Basin, the principal water-quality issues are the introduction of nutrients and sediment into Lake Tahoe by human activities and the discharge of treated sewage effluent into the Truckee River downstream from the Reno-Sparks urban area. In the Truckee River downstream from the Reno-Sparks area, principal water-quality issues include instream concentrations of dissolved oxygen and nutrients, with respect to management of the threatened Lahontan cutthroat trout and the endangered *Cui-ui* sucker, and nutrient loads transported to Lahontan Reservoir by way of the Truckee Canal and to Pyramid Lake (Nowlin, 1987). Septic fields in suburban areas and application of treated sewage effluent for irrigation is increasing in the Truckee River Basin and is a potential source of ground-water and surface-water contamination.

In 1990, about 1,000 acre-ft of treated effluent were used for irrigation in Las Vegas Valley, 7,000 acre-ft were used in the Carson River Basin, and 5,000 acre-ft were used in the Truckee River Basin (James E. Crompton, U.S. Gèological Survey, written commun., 1992).

SUMMARY

In 1991, Congress appropriated funds for the U.S. Geological Survey to begin a National Water-Quality Assessment (NAWQA) program. The NAWQA program will provide data and information on the status, trends, and major factors that affect the quality of the Nation's water resources. The program will focus on large scale, persistent conditions, and provide information to resource managers and policy makers at the Federal, State, and local levels. Surface- and ground-water systems will be investigated in 60 proposed river-basin study units. The first group of 20 study-unit investigations began in 1991, the second

group began in 1994, and the third group is scheduled to begin in 1997. The Nevada Basin and Range (NVBR) study-unit investigation, which includes the Las Vegas Valley area and the Carson and Truckee River Basins, is part of the first study-unit group.

This report provides an overview of the environmental and hydrologic settings in the NVBR study unit. Available data and information were used to describe physiography, geology, climate, soils, vegetation, urbanization, land use, water use, surface- and ground-water hydrology, and water-quality issues.

The Las Vegas Valley area in southeastern Nevada encompasses about 1,640 mi^2. Altitudes range from about 11,900 ft in headwater areas of the Spring Mountains, to about 1,600 ft in Las Vegas Valley, and to about 1,200 ft at Las Vegas Bay of Lake Mead. The area is typical of basin and range topography with the northwest-trending valley bounded by mountain ranges, including the Spring Mountains on the west and the Sheep and Las Vegas Ranges on the north. Consolidated rocks in the mountains primarily are carbonate rocks, siltstone, and sandstone. Unconsolidated basin-fill deposits in Las Vegas Valley are more than 3,000 ft thick.

The Carson and Truckee River Basins in west-central Nevada and east-central California are closed basins that encompass an area of about 7,200 mi^2. Altitudes range from about 10,900 ft in headwater areas of the Sierra Nevada to about 3,900 ft in the Carson Sink and at Pyramid Lake. The area primarily is composed of north-trending basins bounded by mountain ranges. Major basins include Carson Valley, Carson Desert and Sink, Lake Tahoe, Truckee Meadows, and Pyramid Lake. Major mountain ranges include the Sierra Nevada, Carson Range, Stillwater Range, Virginia Range, Pah Rah Range, Lake Range, Truckee Range, Virginia Mountains, and Pine Nut Mountains. Consolidated rocks in the mountains are primarily granitic and volcanic. Unconsolidated deposits in major basins are 4,000 to 8,000 ft thick.

Average annual precipitation in the Las Vegas Valley area ranges from more than 20 in. in the higher altitudes of the mountainous headwater areas to about 4 in. on the valley floor. Soils in the valley have formed from weathered alluvial deposits and consolidated rocks. Entisols have developed on alluvium and are characterized by weakly defined horizons. Aridisols have developed in desert areas and are characterized by accumulated salts in the surface horizon. Laminar calcrete, formed by the precipitation of calcium carbonate that has percolated downward into the soil, is found throughout the valley and can be a hydrologic barrier. Vegetation is primarily controlled by precipitation and communities include fir pine in areas of shaded canyon sides and north-facing slopes above an altitude of 7,000 ft, pinyon juniper in areas above 4,500 ft, blackbrush on foothills and alluvial fans, and creosote in lowlands. Phreatophytes grow in lowland areas where the depth to the water table is shallow. There are some barren areas at low altitudes.

Headwater areas in the Sierra Nevada of the Carson and Truckee River Basins receive an annual average precipitation greater than 30 in.; Carson Desert receives less than 5 in. Soils are primarily aridisols and ultisols, with some entisols. Aridisols have developed in arid and semiarid areas; ultisols have developed in forested areas and are characterized as highly weathered acidic soils underlain by clay layers; and entisols have developed in alluvial areas. In headwater areas of the Sierra Nevada, vegetation includes alpine meadows with barren peaks at the highest altitudes, fir pine forests above 5,500 ft, and lower altitude communities of sagebrush, bitterbrush, rabbit brush, and grasses. Headwater riparian areas support willows, sedges, aspen, and cottonwood. Dryer mountain ranges—including the Pine Nut Mountains, the Virginia Range, and the Pah Rah Range—support pinyon-juniper forests at higher altitudes. Greasewood is the dominant natural vegetation in the Carson Desert. Riparian and wetland areas in the lower Carson and Truckee River Basins support a variety of vegetation including cottonwoods, willows, grasses, rushes, sedges, bulrushes, and cattails. Barren land is present in some parts of the Carson Sink.

Nevada is rapidly becoming one of the most urban States in the Nation. The 1990 population for Nevada was about 1,200,000. About 1,090,000 people, more than 90 percent of Nevada's 1990 population, resided in the NVBR study unit. In 1990, the Las Vegas Valley area had an estimated population of about 710,000. Las Vegas is the largest urban area. Land use was 79 percent range, 14 percent forest, 5 percent urban, 1 percent water and wetland, and 1 percent barren. In 1990, approximately 317,000 acre-ft of water were used in Las Vegas Valley. Most of the water is from Lake Mead (80 percent). Public water supplies accounted for 91 percent of the water used, self-supplied commercial and domestic uses were 4 percent, self-supplied industrial and mining uses were 3 percent, and irrigation and agricultural uses were 2 percent.

The estimated 1990 population for the Carson and Truckee River Basins was 380,000. The Reno-Sparks urban area had the greatest concentration of people. Land use was 50 percent range, 22 percent forest, 13 percent water and wetlands, 10 percent barren, 4 percent irrigated agriculture, and 1 percent urban. Of the approximately 800,000 acre-ft of water used in 1990, more that 85 percent was from surface-water sources. Irrigation used 83 percent of the water, public supplies used 14 percent, self-supplied commercial and domestic uses were less than 1 percent. Self-supplied industrial and mining uses also were less than 1 percent.

Streamflow in the Las Vegas Valley area is ephemeral. Flow in Las Vegas Wash downstream from Las Vegas is perennial because of urban runoff from landscape irrigation and treated sewage effluent. Streamflow for Las Vegas Wash near Henderson has increased steadily during 1970-88 because of increasing discharge of treated sewage and urban runoff. The average streamflow for this station during 1970-88 was 58 ft^3/s; the 7-day, 10-year, low flow was 23 ft^3/s; and the 1-day, 25-year, high flow was 1,140 ft^3/s. The median concentration of dissolved solids for Las Vegas Wash near Henderson was about 1,700 mg/L. The principal ions in solution are sodium, calcium, and sulfate. Concentrations of dissolved solids decrease as streamflow increases, as a result of dilution by overland runoff from storms. Lake Mead on the Colorado River is the principal surface-water resource in the Las Vegas Valley area. It has a total capacity of 29,755,000 acre-ft and is used for flood control, irrigation, public supply, power generation, and recreation. Las Vegas Bay of Lake Mead receives urban runoff and treated sewage effluent from Las Vegas Wash.

The Carson and Truckee Rivers are perennial and originate in headwater areas in the Sierra Nevada; they flow to their respective termini in the Carson Sink and Pyramid Lake. Snowmelt is the principal source of flow in these streams, which receive no perennial tributary flow from areas outside the Sierra Nevada. The Carson River is unregulated in the Sierra Nevada, but is affected by irrigation diversions and return flows in the Carson Valley and is highly regulated by Lahontan Reservoir in its lower reaches. Combined average flow of the East and West Forks of Carson River upstream from Carson Valley during 1970-90 was about 471 ft^3/s; respective 7-day, 10-year low flows were 25 and 8.9 ft^3/s; and respective 1-day, 25-year high flows were 5,810 and 1,610 ft^3/s. The average streamflow downstream from the Carson Valley for the Carson River near Carson City was 413 ft^3/s; the 7-day, 10-year low flow was 3.2 ft^3/s; and the 1-day, 25-year high flow was 10,700 ft^3/s. The highly regulated Carson River below Lahontan Reservoir (which also stores diverted water from the Truckee River for irrigation) had an average flow of 532 ft^3/s; a 7-day, 10-year low flow of 1.6 ft^3/s; and a 1-day, 25-year high flow of 2,450 ft^3/s.

The Truckee River originates as outflow from Lake Tahoe and is highly regulated by Lake Tahoe and other major impoundments in the Sierra Nevada. Average flow (1970-90) for the Truckee River at Farad, downstream from all major regulating impoundments, was 851 ft^3/s; the 7-day, 10-year low flow was 117 ft^3/s; and the 1-day, 25-year high flow was 7,990 ft^3/s. Downstream from urban and agricultural activities in the Truckee Meadows, average flow of the Truckee River at Vista was 883 ft^3/s; 7-day, 10-year low flow was 121 ft^3/s; and 1-day, 25-year high flow was 12,100 ft^3/s. Downstream from Derby Dam, where Truckee River water is diverted to Lahontan Reservoir for irrigation use, the average flow was 562 ft^3/s; the 7-day, 10-year low flow was 4.5 ft^3/s; and the 1-day, 25-year high flow was 12,000 ft^3/s.

Water-quality conditions in the Carson and Truckee Rivers are similar. In headwater areas, represented by the East and West Forks of Carson River and the Truckee River at Farad, the concentrations of dissolved solids are less than 100 mg/L during median streamflow. Downstream from agricultural and urban influences, concentrations of dissolved solids are more than 200 mg/L during median streamflow near Fort Churchill and Nixon. Calcium, sodium, bicarbonate, and sulfate concentrations increase appreciably in the downstream direction. Water temperatures for the Carson River near Fort Churchill and the Truckee River at Clark and near Nixon are not in the range considered to be stressful to aquatic organisms. Treated sewage effluent is not directly discharged into the Carson River, but effluent from the Reno-Sparks area is discharged into the Truckee River. The Carson River downstream from Carson City is being investigated as a U.S. Environmental Protection Agency Superfund Site because of mercury contamination from historical silver- and gold-ore milling activities. Irrigation in the Carson Desert has resulted in high concentrations of dissolved solids, boron, arsenic, selenium, molybdenum, lithium, and un-ionized ammonia.

Reservoirs and lakes have a prominent role in both the Carson and Truckee River systems. Lahontan Reservoir impounds the Carson River and diverted Truckee River water for irrigation use in the Carson Desert. The reservoir has a surface area of about 21 mi^2 and has a storage capacity of about 295,000 acre-ft. Calcium, sodium, and bicarbonate are the principal ions in solution and concentrations of dissolved solids generally are less than 300 mg/L. Mercury from upstream historical ore milling activities has accumulated in bottom sediments and fish tissues. Lake Tahoe, the source of the Truckee River, is a natural body of water with a surface area of about 192 mi^2 and an average depth of about 900 ft. The upper 6.1 ft of Lake Tahoe is regulated by a dam in the outlet to supply irrigation water to the Newlands Project for irrigation in the Carson Basin. Calcium and bicarbonate are the principal ions in solution and the concentration of dissolved solids generally is less than 170 mg/L. Lake Tahoe is in the early stages of eutrophication and controlling nutrient contributions to the lake is an important concern. During 1967-86, the transparency of Lake Tahoe decreased at about 1.3 ft/yr, although it still exceeds 65 ft. Pyramid Lake is a natural body of water that is the terminus of the Truckee River. Sodium and chloride are the principal ions in solution and the concentration of dissolved solids exceeds 5,000 mg/L. The water surface of Pyramid Lake has declined from an altitude of 3,865 ft in 1882 to 3,800 ft in water year 1992; primarily due to Truckee Canal diversions. Pyramid Lake is the habitat for the threatened Lahontan cutthroat trout and the endangered *cui-ui* lake sucker.

Principal aquifers in the NVBR study unit consist of unconsolidated basin-fill deposits. In the Las Vegas Valley area these aquifers receive recharge from headwater areas primarily in the Spring Mountains—about 33,000 acre-ft/yr. Ground water flows from recharge areas in the northwest part of the valley to discharge areas in the southeast. Prior to development, ground water was discharged primarily by leakage, springs, and evapotranspiration. However, most ground water currently is discharged by withdrawals for public water supplies. A water-level decline (caused by withdrawals) of about 125 ft was measured in northwest Las Vegas during 1944-90. This decline caused compaction of clay layers and resulted in land subsidence. A shallow perched aquifer has developed under the Las Vegas urban area as a result of secondary recharge by landscape irrigation, which was estimated to be 43,000 acre-ft/yr in 1979. The perched aquifer discharges into Las Vegas Wash and subsequently to Las Vegas Bay of Lake Mead. Also, there is potential for contaminated water in shallow perched aquifers to percolate downward to deeper aquifers.

Dissolved-solids concentrations in ground water of principal aquifers in the northern part of Las Vegas Valley range from 200 to 400 mg/L; calcium, magnesium, and bicarbonate are the dominant ions. In the southern part of the valley, dissolved-solids concentrations range from 700 to 1,500 mg/L; concentrations of sulfate and chloride are higher than in the northwestern part. In the shallow aquifer, leaching and rising water levels caused by secondary recharge have resulted in dissolution of evaporite minerals. Subsequent evapotranspiration has further concentrated the shallow water resulting in average concentrations of 3,000 mg/L for dissolved solids, 1,500 mg/L for sulfate, 310 mg/L for calcium, and 310 mg/L for chloride. Results of available water-quality analyses indicate that concentrations of sulfate and dissolved solids exceed SMCL's (250 and 500 mg/L, respectively) in about one-half of the samples.

Principal basin-fill aquifers are present in most major valleys in the Carson and Truckee River Basins. In the Carson River Basin, principal aquifers are in Carson, Eagle, Dayton, and Churchill Valleys, and Carson Desert. In the Truckee River Basin, principal aquifers are in the Lake Tahoe Basin, Washoe Valley, Truckee Meadows, Spanish Springs Valley, and Warm Springs Valley. In basin-fill aquifers in or adjacent to mountainous headwater areas, ground water flows toward major streams. Ground-water recharge in the Carson Desert is provided by the major delivery ditches and streams; ground water flows away from the recharge sources and is discharged in the Carson Sink by evapotranspiration. Ground water generally is shallow, ranging from less than 5 ft in some areas on valley floors to more than 100 ft on alluvial fans. Ground-water gradients are upward in central parts of valleys and deeper wells often are artesian. Concentrations of dissolved solids range from less than 200 mg/L in most headwater-area aquifers, where calcium and bicarbonate are dominant ions, to more than 10,000 mg/L in parts of the Carson Desert, where sodium and chloride are the dominant ions.

The most important and pervasive water-quality issues in the NVBR study unit result from effects of human activities. Urban, agricultural, and mining activities have caused or have the potential to cause water-quality contamination in the study unit. Landscape irrigation in the Las Vegas urban area has resulted in the development of a shallow perched aquifers with high concentrations of dissolved solids. Water from these shallow aquifers has the potential to contaminate deeper aquifers. Effluent from sewage-treatment plants from the Las Vegas and Reno-Sparks urban areas has the potential to degrade water quality in Las Vegas Bay of Lake Mead and the lower Truckee River, respectively. Septic systems in urban and suburban areas can contaminate shallow ground-water systems. The ground application of treated sewage effluent for irrigation in urban and agricultural areas is becoming a widespread practice and has the potential to degrade water quality. Irrigation drainage has affected wetlands in the Carson Desert and Carson Sink. Historical milling of gold and silver ore has contaminated the Carson River system downstream from Carson City with mercury.

REFERENCES CITED

Arteaga, F.E., 1986, Mathematical model analysis of the Eagle Valley ground-water basin, west-central Nevada: Nevada Division of Water Resources Bulletin 45, 53 p.

Arteaga, F.E., and Durbin, T.J., 1978, Development of a relation for steady-state pumping rate for Eagle Valley ground-water basin, Nevada: U.S. Geological Survey Open-File Report 79-261, 44 p.

Baker, J.R., and Paulson, L.J., 1980, Influence of Las Vegas Wash density current on nutrient availability and phytoplankton growth in Lake Mead, *in* Proceedings of the Symposium on Surface Water Impoundments: Minneapolis, Minn., American Society of Chemical Engineers, p. 1638-1647.

Bateman, R.L., 1976, Influence of watershed characteristics on water quality behavior of streams in the eastern Sierra Nevada: Reno, University of Nevada, Ph.D. dissertation, 159 p.

Bedinger, M.S., Harrill, J.R., Langer, W.H.,Thomas, J.M., and Mulvihill, D.A., 1984, Maps showing ground-water levels, springs, and depth to ground water, Basin and Range Province, Nevada: U.S. Geological Survey Water-Resources Investigation Report 83-4119-B, 2 sheets, scale 1:500,000.

Bell, J.W., 1981, Subsidence in Las Vegas Valley: Nevada Bureau of Mines and Geology Bulletin 95, 84 p.

Bevans, H.E., and Kilroy, K.C., 1991, National Water-Quality Assessment Program; Nevada Basin and Range: U.S. Geological Survey Open-File Report 91-154, 2 p. (Water Fact Sheet).

Bohman, L.R., Berris, S.N., and Hess, G.W., 1995, Interactive computer program to simulate and analyze streamflow, Truckee and Carson River Basins, Nevada and California: U.S. Geological Survey Fact Sheet, FS-165-95, 4 p.

Bonham, H.F., 1969, Geology and mineral deposits of Washoe and Storey Counties, Nevada: Nevada Bureau of Mines and Geology Bulletin 70, 140 p.

Brothers, Kay, and Katzer, Terry, 1988, Ground-water chemistry changes resulting from stressed aquifer systems in Las Vegas Valley, Clark County, Nevada: Nevada Department of Conservation and Natural Resources, Division of Environmental Protection, 66 p.

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.

California Department of Water Resources, 1991a, Truckee River atlas: Sacramento, Calif., 127 p.

———1991b, Carson River atlas: Sacramento, Calif., 132 p.

California State Water Resources Control Board, 1979, Report on water use and water rights, Lake Tahoe Basin, 203 p.

Cardinalli, J.L., Rouch, L.M., Rush, F.E., and Vasey, B.J., 1968, State of Nevada hydrographic areas: Nevada Division of Water Resources map, scale 1:500,000.

Carlsen, C.L., Lunnis, R.C., and Prudic, D.E., 1991, Changes in water levels and water quality in shallow ground water, Pittman-Henderson area, Clark County, Nevada, resulting from diversion of industrial cooling water from ditch to pipeline in 1985: U.S. Geological Survey Water-Resources Investigations Report 89-4093, 69 p.

Coache, R., 1991, Las Vegas Valley water usage report, Clark County, Nevada: Nevada Division of Water Resources, 110 p.

Cohen, Philip, and Loeltz, O.J., 1964, Evaluation of hydrogeology and hydrogeochemistry of Truckee Meadows area, Washoe County, Nevada: U.S. Geological Survey Water-Supply Paper 1779-S, p. S1-S63.

Cooper, J.J., Thomas, R.O., and Reed, S.M., 1985, Total mercury in sediment, water, and fishes in the Carson River drainage, west-central Nevada: Nevada Division of Environmental Protection, 96 p.

Cooper, J.J., Vigg, S., Bryce, R.W., and Jacobson, R.L., 1983, Limnology of Lahontan Reservoir, Nevada: University of Nevada, Desert Research Institute Publication 50021, 187 p.

Dettinger, M.D., 1987, Ground-water quality and geochemistry of Las Vegas Valley, Clark County, Nevada, 1981-83—Implementation of a monitoring network: U.S. Geological Survey Water-Resources Investigations Report 87-4007, 69 p.

Duebendorfer, E.M., Sewall, A.J., and Smith, E.I., 1990, The Saddle Island detachment; an evolving shear zone in the Lake Mead area, Nevada, *in* Basin and Range extensional tectonics near the latitude of Las Vegas, Nevada: Geological Society of America, Memoir 176, p. 77-99.

Fox, F.L., 1982, Chemical variations of the Truckee River from Lake Tahoe to Truckee, California during low flow: Reno, University of Nevada, M.S. thesis, 108 p.

Galat, D.L., Lider, E.L., Vigg, S., and Robertson, S.R., 1981, Limnology of a large, deep North American terminal lake, Pyramid Lake, Nevada, U.S.A.: Hydrobiologia, v. 82, p. 281-317.

Garcia, K.T., 1989, Ground-water quality in Douglas County, western Nevada: U.S. Geological Survey Water-Resources Investigations Report 87-4269, 107 p.

Garcia, K.T., and Carman, R.L., 1986, Water quality characteristics and nutrient and suspended-sediment loads, Carson River and Truckee Canal, western Nevada, water year 1980: U.S. Geological Survey Water-Resources Investigations Report 85-4147, 107 p.

Garcia, K.T., Gortsema, G.C., Pennington, R.N., and Preissler, A.M., 1992, Water resources data, Nevada, water year 1991: U.S. Geological Survey Water-Data Report NV-91-1, 481 p.

Gebert, W.A., Graczyk, D.J., and Krug, W.R., 1987, Average annual runoff in the United States, 1951-80: U.S. Geological Survey Hydrologic Investigations Atlas HA-710, 1 plate.

Glancy, P.A., 1986, Geohydrology of the basalt and unconsolidated sedimentary aquifers in the Fallon Area, Churchill County, Nevada: U.S. Geological Survey Water-Supply Paper 2263, 62 p.

Hallock, R.J., and Hallock, L.L., eds., 1993, Detailed study of irrigation drainage in and near wildlife management areas, west-central Nevada: U.S. Geological Survey Water-Resources Investigations Report 92-4024-B, 84 p.

Harrill, J.R., 1976, Pumping and ground-water storage depletion in Las Vegas Valley, Nevada, 1955-74: Nevada Division of Water Resources, Bulletin 44, 70 p.

Helsel, D.R., and Hirsch, R.M., 1992, Studies in environmental science 49, statistical methods in water resources: Amsterdam, Elsevier Science Publishers, 522 p.

Hess, J.W., and Mifflin, M.D., 1978, A feasibility study of water production from deep carbonate aquifers in Nevada: University of Nevada, Desert Research Institute Publication 41054, 125 p.

Hines, W.G., Cole, E.D., and Donovan, D.J., 1993, Ground-water quality in the Las Vegas Valley, Clark County, Nevada; an update and analysis of recent trends; Las Vegas Valley Water District, Las Vegas, Nevada: Nevada Division of Environmental Protection, 43 p.

Hoffman, R.J., 1989, Preliminary report of potentially toxic trace elements and pesticides in water, sediment, and biota in and near the Stillwater Wildlife Management Area, Churchill County, Nevada, 1986-1987, Department of the Interior Irrigation Drainage Program, *in* Howard, A.Q., ed., Selenium and agricultural drainage—Implications for San Francisco Bay and the California environment: Fourth Selenium Symposium, Berkeley, Calif., March 1987, Proceedings, p. 163-167.

Hoffman, R.J., Hallock, R.J., Rowe, T.G., Lico, M.S., Burge, H.L., and Thompson, S.P., 1990, Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in and near Stillwater Wildlife Management Area, Churchill County, Nevada, 1986-87: U.S. Geological Survey Water Resources Investigations Report 89-4105, 150 p.

Houghton, J.G., Sakamoto, C.M., and Gifford, R.O., 1975, Nevada's weather and climate: Nevada Bureau of Mines and Geology Special Publication 2, 78 p.

Jennings, C.W., Strand, R.G., and Rogers, T.H., 1977, Geologic map of California: California Department of Conservation California Geologic Data Map Series, Map No. 2, 1:750,000 scale.

Lico, M.S., 1992, Detailed study of irrigation drainage in and near wildlife management areas, west-central Nevada, 1987-90—Part A. Water quality, sediment composition, and hydrogeochemical processes in Stillwater and Fernley Wildlife Management areas: U.S. Geological Survey Water-Resources Investigations Report 92-4024 A, 65 p.

Loeb, S.L., 1987, Groundwater quality with the Tahoe basin: Davis, University of California, Institute of Ecology, 265 p.

Longwell, C.R., Pampeyan, E.H., Bowyer, Ben, and Roberts, R.J., 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bureau of Mines Bulletin 62, 218 p.

Lyles, B.F., Jacobsen, R.L., and Hess, J.W., 1986, Reconnaissance of groundwater quality in southern Nevada: University of Nevada, Desert Research Institute Publication 41101, 87 p.

Malmberg, G.T., 1965, Available water supply of the Las Vegas ground-water basin, Nevada: U.S. Geological Survey Water-Supply Paper 1780, 116 p.

Maurer, D.K., 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.

Maxey, G.B., and Jameson, C.H., 1948, Geology and water resources of Las Vegas, Pahrump, and Indian Springs Valleys, Clark and Nye Counties, Nevada: Nevada State Engineer, Water Resources Bulletin 5, 292 p.

Mifflin, M.D., 1968, Delineation of ground-water flow systems in Nevada: University of Nevada, Desert Research Institute Technical Report H-W 4, 112 p.

Moore, J.G., 1969, Geology and mineral deposits of Lyon, Douglas, and Ormsby Counties, Nevada: Nevada Bureau of Mines Bulletin 75, 46 p.

Moosburner, Otto, and Harrill, J.R., 1985, Nevada ground-water resources, *in* National water summary 1984—Hydrologic events, selected water-quality trends and ground-water resources: U.S. Geological Survey Water-Supply Paper 2275, p. 297-302.

Morgan, D.S., and Dettinger, M.D., 1996, Ground-water conditions in Las Vegas Valley, Clark County, Nevada—Part II, Geohydrology and simulation of ground-water flow: U.S. Geological Survey Water-Supply Paper 2320-B, 124 p.

Morrison, R.B., 1964, Lake Lahontan—Geology of southern Carson Desert, Nevada: U.S. Geological Survey Professional Paper 401, 156 p.

Naff, R.L., Maxey, G.B., and Kaufman, R.F., 1974, Interbasin ground-water flow in southern Nevada: Nevada Bureau of Mines and Geology Report 20, 28 p.

National Climatic Center, 1982-92, Climatological data, annual summary, Nevada, 1981-91: Asheville, N.C., U.S. National Oceanic and Atmospheric Administration, v. 96-106, no. 13 (published annually).

Nevada Division of Environmental Protection, 1988, Nevada water quality assessment (305B) report: Nevada Department of Conservation and Natural Resources, p. 16-27.

Noack, R.E., 1988, Sources of ground water recharging the principal alluvial aquifers in Las Vegas Valley, Nevada: University of Nevada, Las Vegas, M.S. thesis, 160 p.

Nowlin, J.O., 1987, Modelling nutrient and dissolved-oxygen transport in the Truckee River and Truckee Canal downstream from Reno, Nevada: U.S. Geological Survey Water-Resources Investigations Report 87-4037, 487 p.

Plume, R.W., 1985, Ground-water resources in Kyle and Lee Canyons, Spring Mountains, Clark County, Nevada: U.S. Geological Survey Open-File Report 84-438, 47 p.

——— 1989, Ground-water conditions in Las Vegas Valley, Clark County, Nevada—Part 1, Hydrogeologic framework: U.S. Geological Survey Water-Supply Paper 2320-A, 15 p.

Pyramid Lake Indian Tribal Council, 1982, Review of existing surface water quality data base for the lower Truckee River and Pyramid Lake, Task VI, *in* Pyramid Lake 208 Program Studies: Pyramid Lake Indian Tribal Council report.

Rogers, J.H., 1974, Soil survey of the Tahoe basin area, California and Nevada: Soil Conservation Service, 84 p.

Rush, F.E., 1968, Index of hydrographic areas in Nevada: Nevada Division of Water Resources, Information Report 6, 38 p.

Schaefer, D.H., and Whitney, Rita, 1992, Geological framework and ground-water conditions in basin-fill aquifers of the Dayton Valley and Churchill Valley hydrographic areas, western Nevada: U.S. Geological Survey Water-Resources Investigations Report 91-4072, 12 p.

Sierra Pacific Power Company, 1986, 1985-2005—Water resource plan: Reno, Nev., interim progress report appendix - volume 2, 148 p.

Sowers, J.M., and others, 1988, Geomorphology and pedology on the Kyle Canyon alluvial fan, Southern Nevada, *in* Weide, D.L., and Faber, M.L., eds., This extended land, geological journeys in the southern Basin and Range: Geological Society of America, Cordilleran Section, Field Trip Guidebook, p. 137-157.

Speck, R.L., 1985, Soil survey of Las Vegas Valley basin, Nevada part of Clark County: Soil Conservation Service, 194 p.

Stanley, S.M., 1989, Earth and life through times: San Francisco, W.H. Freeman, 689 p.

Steiger, R.H., and Jäger, E., 1977, Subcommission on geochronology—Convention on the use of decay constants in geo- and cosmochronology: Earth and Planetary Science Letters, v. 36, no. 3, p. 359-362.

Stewart, J.H., and Carlson, J.E., comps., 1978, Geologic map of Nevada: U.S. Geological Survey, 1:500,000 scale.

Szecsody, J.E., 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.

Thodal, C.E., 1992, Geophysical, hydrogeologic, and water-quality data for areas tributary to Lake Tahoe in Douglas County and Carson City, Nevada, through 1987: U.S. Geological Survey Open-File Report 89-263, 32 p.

Thomas, J.M., and Hoffman, R.J., 1988, Nevada ground-water quality, *in* Moody, D.W., Carr, Jerry, Chase, E.B., and Paulson, R.W., comps., National Water Summary 1986—Hydrologic events and ground-water quality: U.S. Geological Survey Water-Supply Paper 2325, p. 355-362

Thompson, T.H., Chappell, Richard, Harrill, J.R., and Welch, A.H., 1984, Maps showing distribution of dissolved solids and dominant chemical type in ground water, Basin and Range Province, Nevada: U.S. Geological Survey Water-Resources Investigations Report 84-4119-C, 11 p.

Trexler, D.T., 1977, Geologic map, Carson City quadrangle: Nevada Bureau of Mines and Geology Urban Map Series, Carson City Folio, Map 1Ag, scale 1:24,000.

U.S. Bureau of the Census, 1992, Idaho, Montana, Nevada, Wyoming computer file, *in* 1990 census of population and housing: U.S. Bureau of the Census Summary Tape File CD 90-3A-15 (1 computer laser optical disk, 4-3/4 in.).

U.S. Geological Survey, 1970, The national atlas of the United States of America: U.S. Geological Survey, 417 p.

———1988, Water-quality assessment of the Carson River ground-water basin, Nevada and California: U.S. Geological Survey, Field-Trip Guide, May 1988, 13 p.

Van Denburgh, A.S., Lamke, R.D., and Hughes, J.L., 1973, A brief water-resources appraisal of the Truckee River basin, western Nevada: Nevada Division of Water Resources Reconnaissance Report 57, 122 p.

Van Denburgh, A.S., Seitz, H.R., Durbin, T.J., and Harrill, J.R., 1982, Proposed monitoring network for ground-water quality, Las Vegas Valley, Nevada: U.S. Geological Survey Open-File Report 80-1286, 25 p.

Vasey, B.J., Scott, Bruce, Roach, Lawrence, Jr., and Rush, F.E., 1972, Hydrologic atlas: Nevada Division of Water Resources, Water for Nevada Report, 21 maps.

Welch, A.H., Plume, R.W., Frick E.A., and Hughes, J.L., 1989, 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.

White, C.A., Rhinehart, Ben, Williams, Ryan, Jr., Landon, Robert, Parson, Jim, Garcia, Ann, Wilds, Ed, and Oliver, Dale, 1979, Report on water use and water rights, Lake Tahoe basin: California State Water-Resources Control Board, 203 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.

William F. Guyton Associates, 1986, Report on ground-water availability in the south Truckee Meadows area, Washoe County, Nevada: Austin-Houston, Texas, William F. Guyton Associates, 35 p.

Worts, G.F., Jr., and Malmberg, G.T., 1966, Hydrologic appraisal of Eagle Valley, Ormsby County, Nevada: Nevada Department of Conservation and Natural Resources, Water Resources - Reconnaissance, Report 39, 55 p.

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