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Sources of Phosphorus to the Carson River Upstream from Lahontan Reservoir, Nevada and California, Water Years 2001–02

Scientific Investigations Report 2004–5186

Prepared in cooperation with
CARSON WATER SUBCONSERVANCY DISTRICT

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(Back of Cover)

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by Nancy L. Alvarez and Ralph L. Seiler

U.S. GEOLOGICAL SURVEY

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Carson City, Nevada
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CONVERSION FACTORS, ACRONYMS, AND ABBREVIATIONS

Multiply	By	To obtain
acre	0.4047	hectare (ha)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
foot (ft)	0.3048	meter (m)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
inch (in.)	2.54	centimeter (cm)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.5899	square kilometer (km^2)
pound (lb)	0.454	kilogram (kg)
pound per day (lb/d)	0.454	kilogram per day (kg/d)
pound per acre (lb/acre)	1.12	kilogram per hectare (kg/ha)
pound per acre per year (lb/acre/yr)	1.12	kilogram per hectare per year (kg/ha/yr)
ton	0.9072	megagram (Mg)
ton per day (ton/d)	0.9072	megagram per day (Mg/d)
ton per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton per acre (ton/acre)	2.242	megagram per hectare (Mg/ha)

Temperature: Degrees Celsius (^oC) can be converted to degrees Fahrenheit (^oF) by using the formula $^oF = 1.8(^oC)+ 32$. Degrees Fahrenheit can be converted to degrees Celsius by using the formula $^oC = 0.556(^oF-32)$.

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.

Water-quality units and related units used in this report:

cm	centimeter
g	gram
g/kg	gram per kilogram
L	liter
mg/L	milligram per liter
mg/kg	milligram per kilogram
mm	millimeter
µm	micrometer
µS/cm	microsiemens per centimeter at 25 degrees Celsius
N	Normal
NTU	Nephelometer turbidity units

Abbreviations and acronyms:

CWSD	Carson Water Subconservancy District
n	Number of samples
NAD	North American Datum
NAWQA	National Water-Quality Assessment
NDEP	Nevada Division of Environmental Protection
NRCS	Natural Resources Conservation Service
NSHL	Nevada State Health Laboratory
NURP	Nationwide Urban Runoff Program
NWQL	National Water Quality Laboratory
SLR	Simple linear regression
SSC	Suspended-sediment concentration
STATSGO	State Soil Geographic
STPUD	South Tahoe Public Utility District
TMDL	Total maximum daily load
TSS	Total-suspended solids
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WY	Water year

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by Nancy L. Alvarez and Ralph L. Seiler

ABSTRACT

Discharge of treated municipal-sewage effluent to the Carson River in western Nevada and eastern California ceased by 1987 and resulted in a substantial decrease in phosphorus concentrations in the Carson River. Nonetheless, concentrations of total phosphorus and suspended sediment still commonly exceed beneficial-use criteria established for the Carson River by the Nevada Division of Environmental Protection. Potential sources of phosphorus in the study area include natural inputs from undisturbed soils, erosion of soils and streambanks, construction of low-head dams and their destruction during floods, manure production and grazing by cattle along streambanks, drainage from fields irrigated with streamwater and treated municipal-sewage effluent, ground-water seepage, and urban runoff including inputs from golf courses. In 2000, the U.S. Geological Survey (USGS), in cooperation with Carson Water Subconservancy District, began an investigation with the overall purpose of providing managers and regulators with information necessary to develop and implement total maximum daily loads for the Carson River. Two specific goals of the investigation were (1) to identify those reaches of the Carson River upstream from Lahontan Reservoir where the greatest increases in phosphorus and suspended-sediment concentrations and loading occur, and (2) to identify the most important sources of phosphorus within the reaches of the Carson River where the greatest increases in concentration and loading occur.

Total-phosphorus concentrations in surface-water samples collected by USGS in the study area during water years 2001–02 ranged from <0.01 to 1.78 mg/L and dissolved-orthophosphate concentrations ranged from <0.01 to 1.81 mg/L as phosphorus. In streamflow entering Carson Valley from headwater areas in the East Fork Carson River, the majority of samples exceeding the total phosphorus water-quality standard of 0.1 mg/L occur during spring runoff (March, April, and May) when suspended-sediment concentrations are high. Downstream from Carson Valley, almost all samples exceed the water-quality standard, with the greatest concentrations observed during spring and summer months.

Estimated annual total-phosphorus loads ranged from 1.33 tons at the West Fork Carson River at Woodfords to 43.41 tons at the Carson River near Carson City during water years 2001–02. Loads are greatest during spring runoff, followed by fall and winter, and least during the summer, which corresponds to the amount of streamflow in the Carson River. The estimated average annual phosphorus load entering Carson Valley was 21.9 tons; whereas, the estimated average annual phosphorus load leaving Carson Valley was 37.8 tons, for an annual gain in load across Carson Valley of 15.9 tons. Thus, about 58 percent of the total-phosphorus load leaving Carson Valley on an annual basis could be attributed to headwater reaches upstream from Carson Valley. During spring and summer (April 1–September 30) an average of 85 percent of the total-phosphorus load leaving Carson Valley could be attributed to headwater reaches. During fall and winter (October 1–March 31) only 17 percent of the phosphorus load leaving Carson Valley could be attributed to headwater reaches.

The composition of the phosphorus changes during summer from particulate phosphorus entering Carson Valley to dissolved orthophosphate leaving Carson Valley. Particulate phosphorus entering Carson Valley could be settling out when water is applied to fields and be replaced by dissolved orthophosphate from other sources. Alternatively, the particulate phosphorus could be converted to dissolved orthophosphate as it travels across Carson Valley. Data collected during the study are not sufficient to distinguish between the two possibilities.

Eagle Valley and Dayton–Churchill Valleys may act as sinks for phosphorus. On an annual basis, during water years 2001–02, about 90 percent of the phosphorus entering Eagle Valley left the valley. Similarly, only about 85 percent of the phosphorus entering Dayton–Churchill Valleys was discharged from the valleys.

Total-phosphorus concentrations and load increased substantially between Brockliss Slough at Highway 88 and Brockliss Slough upstream from the confluence with the Carson River. Between 10 and 22 percent of the total-phosphorus load measured at Carson River near Genoa during summer could be attributed to this reach. During summer, all phosphorus loads contributed to the river by the West Fork Ditch originated in the 8.7 mi reach downstream of Highway 88 and accounted for 27–36 percent of the load measured at Carson River near

Genoa. Similarly, between 11 and 20 percent of the total-phosphorus load at Carson River near Genoa during summer could be attributed to the 1.5 mi reach between the East Fork Carson River at Muller Lane and the East Fork Carson River at the confluence of the West Fork Carson River. The combined load from Ambrosetti Pond Outlet and Williams Slough contributed between 6.7 and 11 percent of the total-phosphorus load at the Carson River near Carson City site.

The relation between suspended-sediment concentrations and phosphorus concentrations in water indicates that phosphorus from particulate phosphorus alone can exceed the State phosphorus standard when suspended-sediment concentrations exceed about 50 mg/L.

Little change occurred in water quality in the East Fork Carson River between the Markleeville and Dresslerville sites, implying that phosphorus and sediment entering Carson Valley in the East Fork originates upstream of the Markleeville gage. Large increases in phosphorus loads occur in the East Fork, West Fork/Brockliss Slough, and West Fork Ditch systems during summer and are caused principally by increases in dissolved orthophosphate. The source of dissolved orthophosphate in these reaches likely is agricultural. Because treated municipal-sewage effluent contains elevated phosphorus concentrations, drainwater from fields irrigated with this effluent is a potentially large source of phosphorus. Ambrosetti Pond, which stores drainwater from irrigated fields, can be a source of substantial amounts of phosphorus in the Carson River, particularly during winter.

INTRODUCTION

Potential sources of phosphorus in the study area include natural inputs from undisturbed soils, erosion of soils and streambanks, construction of low-head dams and their destruction during floods, manure production and grazing by cattle along streambanks, drainage from fields irrigated with streamwater and treated municipal-sewage effluent (hereafter referred to as treated effluent or effluent), ground-water seepage, and urban runoff including inputs from golf courses.

Phosphorus problems such as nuisance algal growth occur when a phosphorus source is available and a mechanism exists for its transport to a sensitive location (Gburek and others, 2000). Gburek and others emphasized the importance of defining, targeting, and remediating source areas that coincide with high surface runoff and erosion potential. Sharpley and others (1995) stated that general measures to minimize phosphorus transfer that are implemented over a broad area are less effective than targeting the most vulnerable areas within a watershed. Thus, identification of specific reaches of the river where phosphorus increases substantially, followed by identification of phosphorus sources that contribute to those reaches is critically important in efforts to manage the river and prevent or reverse phosphorus related water-quality problems.

Background

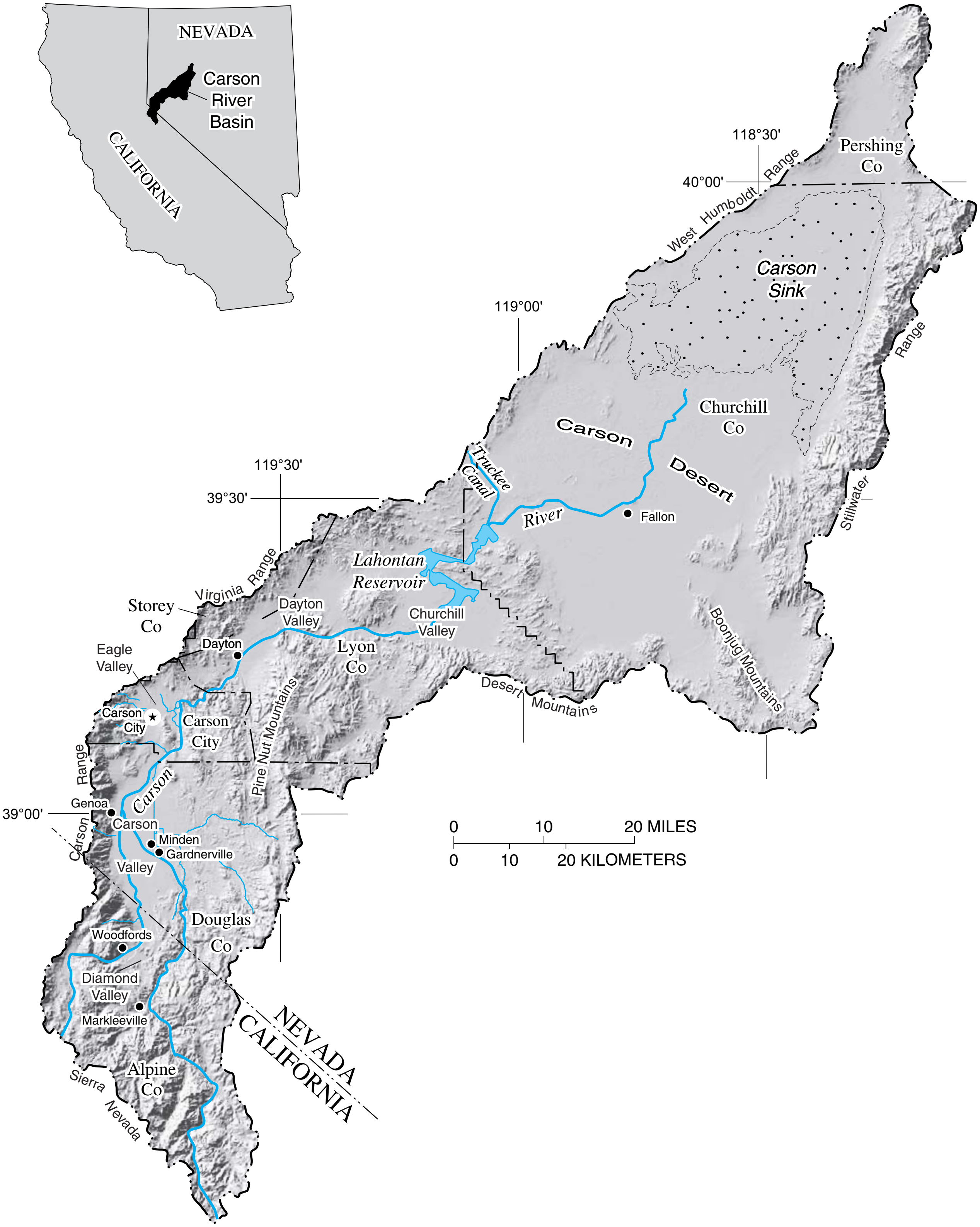
In areas where phosphorus is the major limiting nutrient in freshwater streams, inputs of phosphorus can stimulate growth of phytoplankton, macroalgae, and macrophytes. Increases in the growth of these plants can result in low dissolved-oxygen concentrations in streams at night and adversely affect invertebrate and fish populations. During the summer of 1980, an algal bloom caused by the cyanobacteria *Aphanizomenon flos-aquae* occurred in Lahontan Reservoir and, at that time, diatoms and cyanobacteria were the codominant groups upstream from Lahontan Reservoir (Garcia and Carman, 1986). Because cyanobacteria can fix atmospheric nitrogen, they typically become the dominant groups in nitrogen-limited, phosphorus-enriched water bodies. Concerns that additions of phosphorus to the Carson River in Nevada and California may be having adverse effects on invertebrate and fish populations have led to intensive data collection and research by Federal, State, and university scientists.

The highest quality water in the Carson River Basin (fig. 1) is in the headwater areas. Water quality tends to deteriorate in a downstream direction as a result of natural processes and man-caused effects (Glancy and Katzer, 1975). Previous studies have shown that total-phosphorus and suspended-sediment concentrations increase in a downstream direction (Glancy and Katzer, 1975; Garcia and Carman, 1986) and that these concentrations commonly exceed beneficial-use criteria for the Carson River (Nevada Division of Environmental Protection, 2002b). Many potential sources of phosphorus exist along the Carson River drainage and the distribution of these sources is rapidly changing as urban development increases.

Purpose and Scope

The Federal Clean Water Act of 1972 requires States to set water-quality standards to protect the beneficial uses of waters, assess the quality of those waters, generate a list of waters that do not meet water-quality standards, and formulate plans to bring impaired waters into compliance with the State standards. The list of impaired water bodies is called the 303(d) list and is updated every 2 years. Nevada’s 303(d) list for 2002 includes the entire reach of the Carson River from the California–Nevada border to Lahontan Reservoir because of excessive phosphorus concentrations and high levels of turbidity (Nevada Division of Environmental Protection, 2002b).

Once on a 303(d) list, the State must develop a plan, or total maximum daily loads (TMDLs), to bring a water body into compliance with water-quality standards. The overall objective of this investigation is to provide managers and regulators with the information necessary to develop and implement TMDLs for the Carson River. A key component in the development of TMDLs is the identification of sources of pollutant loading to a water body and their characterization by type, magnitude, and location (U.S. Environmental Protection Agency, 1999). The purpose of this report is twofold: (1) to identify those reaches of



Base from U.S. Geological Survey digital data, 1:100,000-scale, 1979-82
Universal Transverse Mercator projection, zone 11

Figure 1. Location of Carson River Basin, Nevada and California.

the Carson River upstream from Lahontan Reservoir where the greatest increases in phosphorus and suspended-sediment concentrations and loading occur, and (2) to identify the most important sources of phosphorus within the reaches of the Carson River where the greatest increases in concentration and loading occur.

The emphasis of this investigation is determining sources and source areas for phosphorus upstream from Lahontan Reservoir (fig. 1) because the State does not list the reach downstream from Lahontan Reservoir as an impaired reach for phosphorus. In addition, several major investigations have examined water quality, including phosphorus, in the Carson River system downstream of Lahontan Reservoir.

This report describes the results of a 3½-year investigation of sources of phosphorus in the Carson River watershed. USGS personnel collected samples during water years (WY) 2001–02. A water year is the 12 month period October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 2001, is called “water year 2001.” This report documents the concentrations of suspended sediment in water, in addition to total-phosphorus and dissolved-orthophosphate (hereafter referred to as orthophosphate) concentrations in water, streambed sediment, and sediment from erodible streambanks. Appendixes of selected historical data collected by the Nevada Division of Environmental Protection (NDEP) and the South Tahoe Public Utility District (STPUD) also are included.

Acknowledgments

The authors wish to thank residents of the study area for access to their property and for permission to collect data. Many Federal, State, and local agencies provided chemical data, maps, and information and their collaboration is greatly appreciated. Paul Pugsley (Carson Valley Conservation District) and Kevin Piper (Dayton Valley Conservation District) provided useful information about their Districts and helped to obtain permission to sample at some sites.

STUDY AREA

Location and General Features

The Carson River watershed extends from the headwaters in the eastern Sierra Nevada of California to its terminus in the Carson Desert of Nevada (fig. 1). The Carson River Basin covers an area of about 4,000 mi^2, most of which is in Nevada. The river originates on the eastern slopes of the Sierra Nevada and flows in a northeasterly direction through five valleys (Carson, Eagle, Dayton, and Churchill Valleys, and terminates in the Carson Desert, which is known locally as Lahontan Valley; fig. 1).

Agriculture is by far the largest use of Carson River water. Carson Valley is Nevada’s second largest agricultural area with about 47,000 acres (California Department of Water Resources, 1991). Much smaller areas of irrigated agriculture are found in Eagle and Dayton Valleys where agriculture has been developed on bottomlands near the river (California Department of Water Resources, 1991). In California, the majority of irrigated agriculture is at the upstream end of Carson Valley in an area called Diamond Valley (fig. 1). Water supply for irrigation in Carson Valley comes from diversions of surface water through an extensive system of ditches, stored water in the upper alpine reservoirs, effluent from municipal-sewage treatment plants within the basin, and treated effluent imported from the Lake Tahoe Basin.

The Sierra Nevada is the dominant mountain range in the basin and precipitation is the major source of streamflow in the Carson River (fig. 1). On the valley floors, precipitation ranges from about 10 in/yr in Carson Valley to 5 in/yr in the Carson Desert. In the headwaters, precipitation averages as much as 45 in/yr. Most precipitation falls during the winter months; 67 percent of the annual precipitation falls during November–March in Minden and 70 percent in Carson City (National Climate Data Center, 2002). During the summer, intense thunderstorms occur in the study area.

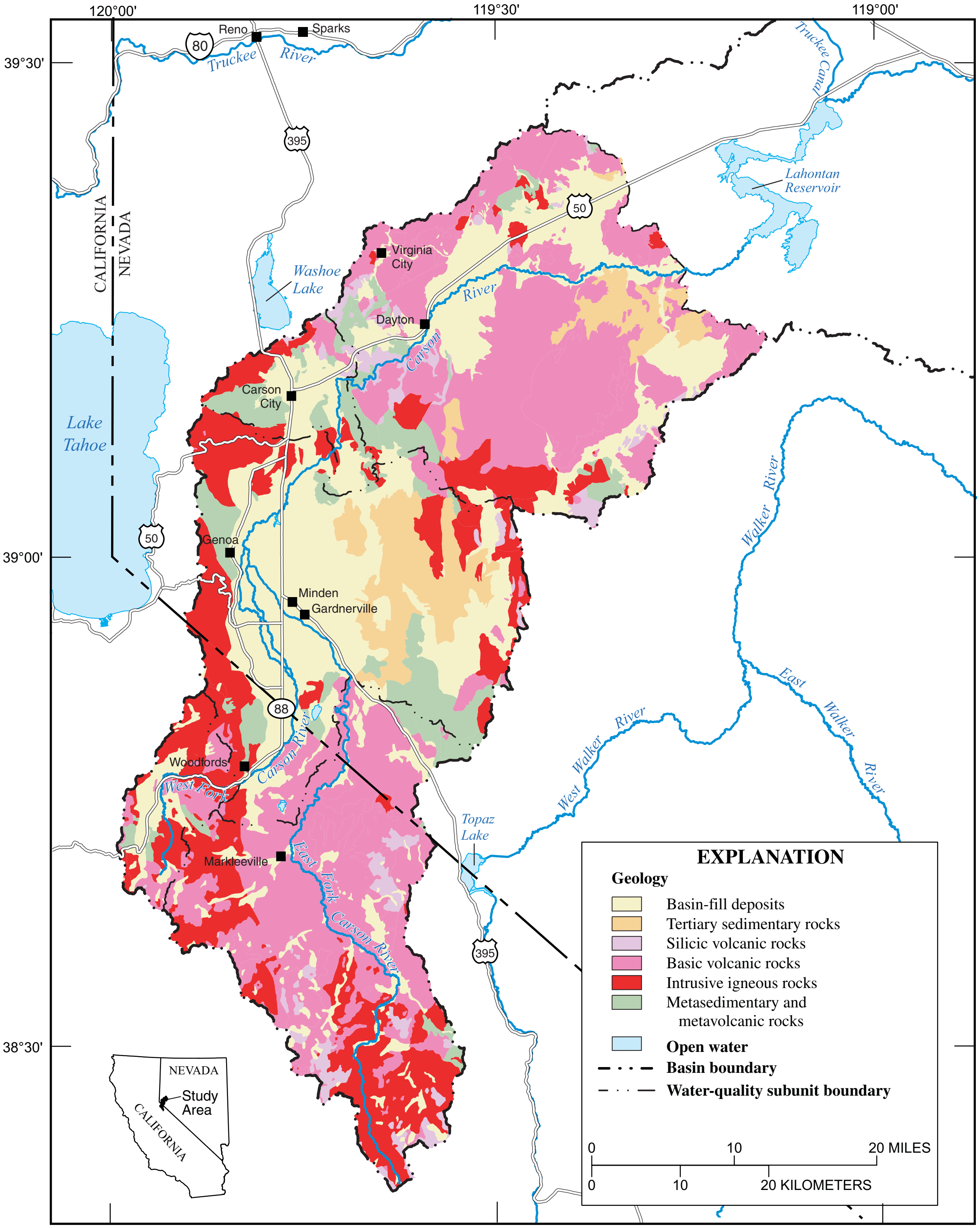
Except for mountainous areas in the headwaters of the Carson River in Alpine County, CA, the study area has an arid to semiarid climate characterized by cool to occasionally cold winters and hot summers. Forests dominated by Jeffrey pine and red fir are found in higher mountain areas, while piñon-juniper forests occur in lower mountain areas. Valley floors and alluvial fans are sparsely covered with sagebrush, bitterbrush, and rabbitbrush. Cottonwood and willows are found in areas of high soil moisture along the river corridor and tributary streams.

Geology

The geologic history of the study area has been described by Stewart (1980). The generalized geology of the Carson River Basin upstream from Lahontan Reservoir is shown in figure 2. The geologic data are provided as geospatial-digital data and are available at URL <http://water.usgs.gov/lookup/getspatial?sir2004-5186_geol250>.

Volcanic and intrusive igneous rocks make up most of the consolidated rocks exposed in the study area (fig. 2). The Sierra Nevada is composed mainly of intrusive granitic rocks that likely form the bedrock beneath Carson and Eagle Valleys. The Pine Nut Mountains (fig. 1) are composed of intrusive granitic rocks and Tertiary age volcanic and sedimentary rocks. Other mountain ranges in the basin are composed primarily of volcanic rocks with varying amounts of intrusive granitic rocks and other rock types.

The valleys are filled with Late Tertiary and Quaternary age deposits of clay, silt, sand, gravel, and cobbles derived from adjacent mountains and from mountains in the headwaters.



Base from U.S. Geological Survey digital data, 1:100,000- and 1:24,000-scale, 1979-82
Universal Transverse Mercator projection, zone 11
North American Datum 1927

Geology modified from Bonham (1969), Moore (1969),
Willden and Speed (1974), Johnson (1977), and Stewart (1983)

Figure 2. Generalized geology of the Carson River Basin upstream from Lahontan Reservoir.

These unconsolidated and semiconsolidated deposits form basin-fill aquifers which are the principal source of drinking water for residents of the study area.

Soils

The soils data used in this report are from the USSOILS coverage (Schwarz and Alexander, 1995). The coverage was compiled from individual State coverages contained in the October 1994 U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), State Soil Geographic (STATSGO) Database. Two important characteristics of soils that affect their ability to contribute phosphorus to surface waters are their clay content and erodibility. These soil characteristics are shown in figure 3.

Clay content and erodibility are important soil characteristics that affect the phosphorus content of the soils and the ease with which they can be mobilized and transported in surface waters. Areas with high clay content may be important sources for phosphorus because clays are formed by the weathering of primary minerals, which may have a high phosphorus content in the study area, and because of the affinity of the clays themselves for phosphorus. The erodibility of soils in the study area was assessed using the soil-erodibility factor used in the Universal Soil Loss Equation.

Surface-Water Hydrology

The East and West Forks Carson River (hereafter referred to as the East Fork and West Fork) originate on the eastern slopes of the Sierra Nevada and join in Carson Valley near the town of Genoa to form the Carson River (fig. 4). The Carson River flows in a northeasterly direction and terminates in the Carson Sink. A schematic diagram of flow in the Carson River system upstream from Lahontan Reservoir is shown in figure 5.

The West Fork becomes the Brockliss Slough about 3 mi north of the Nevada–California State line, and the Brockliss Slough becomes the principal watercourse along the west side of Carson Valley. The reach between sites 4 and 9 (fig. 5) is sometimes called West Fork Ditch to emphasize that this reach is no longer the principal watercourse. After the West Fork becomes the Brockliss Slough, some water is diverted to West Fork Ditch; however, it is consumed prior to Highway 88 (fig. 4). Downstream of Highway 88, the water in West Fork Ditch is derived from the Rocky Slough, Home Slough, and other ditches that originate from the East Fork and flow to the west.

No surface water is exported from the basin, but a substantial amount of water is imported into the basin upstream of Lahontan Reservoir. Carson Valley receives treated effluent from the Lake Tahoe Basin and Eagle Valley imports water for municipal use from Marlette Lake also in the Lake Tahoe Basin.

Stream Characteristics

Runoff from snowpack in the Sierra Nevada contributes most of the flow to the Carson River, which generally flows perennially throughout most of its reaches. The number of perennial tributaries decreases in a downstream direction. Downstream of the head of Dayton Valley, all tributaries are ephemeral near their confluence with the Carson River (Glancy and Katzer, 1975). In late summer, diversions for irrigation and consumption of water by evapotranspiration result in periods of low flow in the main channel of the river downstream from Carson Valley. During droughts there have been periods of zero flow (table 1).

Streamflow at gaging stations along the Carson River varies greatly from year to year (fig. 6). On the West and East Forks, three of the five wettest years and three of the five driest years for the period of record occurred between 1982 and 1995.

The gradient of the river influences flow velocity, and hence many other stream characteristics such as time of travel and sediment transport. The gradient between the headwaters and the confluence of the West and East Forks is about 125 ft/mi for the West Fork and 92 ft/mi for the East Fork (California Department of Water Resources, 1991). Between the confluence of the West and East Forks and Lahontan Reservoir, the gradient is much gentler at about 10 ft/mi. Diversion structures along the river locally flatten the stream gradient and create large pools (fig. 7), which trap sediment and provide water to riparian vegetation during summer periods of low flow. Many of these diversions are not permanent structures and are rebuilt annually; they are washed out during floods and are sources of phosphorus and sediment to downstream reaches.

Mean and Peak Streamflow

Annual mean discharge at five gaging stations along the Carson River for their period of record is listed in table 1. Because average values may differ substantially depending on the period of record used, mean discharge for the stations were compared using the longest common period of record 1940–2002. Mean annual flow entering Carson Valley from the West and East Forks for this period is 472 ft^3/s (fig. 6) and leaving Carson Valley is 409 ft^3/s. The difference corresponds to an average annual consumption of about 45,600 acre-ft of water in Carson Valley. Between the Carson River near Carson City (site 34; fig. 5) and Carson River near Fort Churchill (site 42a; fig. 5), mean annual flow decreases about 24 ft^3/s, which corresponds to an average annual consumption of about 17,400 acre-ft.

More than half of the total annual flow in the Carson River occurs during April, May, and June during snowmelt runoff (fig. 8). At the four sites along the Carson River with 60 years or more of record, about 20 percent of the annual discharge occurs during June and about 25 percent of the annual discharge occurs during May.