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

U.S. Department of the Interior
U.S. Geological Survey

(Back of Cover)

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

by Nancy L. Alvarez and Ralph L. Seiler

U.S. GEOLOGICAL SURVEY

Scientific Investigations Report 2004-5186

Prepared in cooperation with the
CARSON WATER SUBCONSERVANCY DISTRICT

Carson City, Nevada
2004

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director

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

For additional information contact:

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

Email: GS-W-NVpublic-info@usgs.gov

World Wide Web: <http://nevada.usgs.gov>

For more information about the U.S. Geological Survey and its products:

Telephone: 1-888-ASK-USGS
World Wide Web: <http://www.usgs.gov>

CONTENTS

Abstract....1
Introduction....2
Background....2
Purpose and Scope....2
Acknowledgments....4
Study Area....4
Location and General Features....4
Geology....4
Soils....6
Surface-Water Hydrology....6
Stream Characteristics....6
Mean and Peak Streamflow....6
Storage Facilities....12
Diversions and Return Flows....12
Channel Stability....17
Ground-Water Hydrology....17
Water Quality....17
Land Use....19
Cycling and Transport of Phosphorus....19
Cycling....19
Transport....21
Potential Sources of Phosphorus to the Carson River....21
Geological Sources and Forested Areas....21
Soils and Sediment....22
Atmospheric Transfers....22
Ground Water....22
Animal Grazing....22
Agriculture....24
Treated Sewage Effluent....25
Urban Runoff....27
Sample Collection and Analysis....27
Location of Sampling Sites....27
Water Samples....27
Suspended-Sediment Samples....32
Streambank- and Streambed-Sediment Samples....32
Quality Control....32
Discussion of Results....32
Water-Quality Subunits....32
Phosphorus in Water....34
Phosphorus Concentrations....34

Phosphorus Loads and Yields....34
Phosphorus in Sediment....49
Suspended Sediment....49
Streambank and Streambed Sediments....49
Relation Between Suspended-Sediment Concentration and Total-Suspended Solids....49
Changes Across Specific Reaches....53
West Fork/Brockliss Slough....53
West Fork Ditch....60
East Fork....60
Mainstem....61
Storm Runoff....61
Phosphorus Sources....61
Summary....63
Future Directions....65
References Cited....66
Appendixes:
1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02....73
2. Chemical analyses for streambed- and streambank-sediment samples collected from the study area, water years 2001–02....85
3. Chemical analyses for nitrogen species in surface-water samples collected from the study area, water year 2002....86
Supplemental Geospatial Digital Data:
Areas permitted for irrigation, storage, evaporation, and disposal of treated sewage effluent in the upper Carson River Basin, Nevada and California, by Rose L. Medina and Deborah A. Dean. Available at URL <http://water.usgs.gov/lookup/getspatial?sir2004-5186_eff_p>.
1:250,000-scale geology of the Carson River Basin, Nevada and California, by Rose L. Medina. Available at URL <http://water.usgs.gov/lookup/getspatial?sir2004-5186_geol250>.

FIGURES

1. Map showing location of Carson River Basin, Nevada and California....3
2. Map showing generalized geology of the Carson River Basin upstream from Lahontan Reservoir....5
3. Map showing soils of the Carson River Basin upstream from Lahontan Reservoir (*A*) clay content and (*B*) erodibility....7
4. Map showing hydrologic features of the Carson River Basin upstream from Lahontan Reservoir....9
5. Schematic diagram of flow in the Carson River system upstream from Lahontan Reservoir....10
6. Graphs showing mean annual discharge at sites along the Carson River....13
7. Photograph showing typical low-head dam along Carson River....15
8. Graphs showing monthly mean discharge as a percent of mean annual discharge at five sites along the Carson River....15
9. Map showing land use in the Carson River Basin upstream from Lahontan Reservoir, 1990....20
10. Map showing phosphorus concentrations in soil samples collected in 1987 from the Carson River Basin upstream from Lahontan Reservoir....23

FIGURES–Continued

11. Photograph showing unstable reach along East Fork Carson River in Carson Valley 24
12. Photograph showing cattle near tributary to Carson River in Carson Valley 25
13. Map showing areas permitted as of 2001 for storage, irrigation, evaporation, and disposal of treated sewage effluent in Carson and Eagle Valleys 26
14. Photograph showing urban runoff in Eagle Valley Creek following a winter rainstorm 28
15. Photograph showing golf course adjacent to Carson River in Carson Valley 28
16. Map showing location of sampling sites in the Carson River Basin upstream from Lahontan Reservoir 29
17. Graphs showing total-phosphorus concentrations at selected sites in the Carson River Basin, 1988–2002 36
18. Graphs showing ratio of orthophosphate to total-phosphorus concentrations at selected sites in the Carson River Basin, 1988–2002 37
19. Graphs showing relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 1, West Fork Carson River at Woodfords (10310000) 39
20. Graphs showing relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 17, East Fork Carson River near Dresslerville (10309010) 40
21. Graphs showing relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 34, Carson River near Carson City (10311000) 41
22. Graphs showing relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 39, Carson River at Deer Run Road (10311400) 42
23. Graphs showing relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 43, Carson River near Silver Springs (10312020) 43
24. Graphs showing comparison of (*A*) discharge and (*B*) total-phosphorus loads entering and leaving Carson Valley 46
25. Graphs showing comparison of (*A*) discharge and (*B*) total-phosphorus loads entering and leaving Eagle Valley 47
26. Graphs showing comparison of (*A*) discharge and (*B*) total-phosphorus loads entering and leaving Dayton–Churchill Valleys 48
27. Graphs showing relation between phosphorus and suspended-sediment concentrations in samples from the Carson River Basin upstream from Lahontan Reservoir, 2000–02 50
28. Map showing phosphorus concentrations in streambank-sediment samples in the Carson River Basin upstream from Lahontan Reservoir, 2001–02 51
29. Map showing phosphorus concentrations in streambed-sediment samples in the Carson River Basin upstream from Lahontan Reservoir, 2001–02 52
30. Graph showing relation between suspended-sediment concentration and total-suspended solids in samples from the Carson River Basin upstream from Lahontan Reservoir, 2002 54
31. Graph showing relation between sand break and percent difference between suspended-sediment concentration and total-suspended solids in samples from the Carson River Basin upstream from Lahontan Reservoir, 2002 54

FIGURES–Continued

32. Graphs showing discharge, phosphorus concentrations and loads, and suspended sediment (<0.062 millimeter fraction) at sites sampled during Winter synoptic survey (February 19–28, 2002) 55
33. Graphs showing discharge, phosphorus concentrations and loads, and suspended sediment (<0.062 millimeter fraction) at sites sampled during Spring 1 synoptic survey (April 24–May 15, 2002) 56
34. Graphs showing discharge, phosphorus concentrations and loads, and suspended sediment (<0.062 millimeter fraction) at sites sampled during Spring 2 synoptic survey (May 28–31, 2002) 57
35. Graphs showing discharge, phosphorus concentrations and loads, and suspended sediment (<0.062 millimeter fraction) at sites sampled during Summer 1 synoptic survey (July 1–12, 2002) 58
36. Graphs showing discharge, phosphorus concentrations and loads, and suspended sediment (<0.062 millimeter fraction) at sites sampled during Summer 2 synoptic survey (August 21–29, 2002) 59

TABLES

1. Summary data for streamflow at selected sites in the Carson River Basin 12
2. Summary of water-quality data for selected sites on the Carson River showing changes in water quality following cessation of treated sewage effluent discharge to the Carson River 18
3. Irrigated acreage and population trends in the Carson River Basin above Lahontan Reservoir 19
4. Location of sampling sites and gaging stations, and the types of data collected at each site 30
5. Land characteristics for Carson River water-quality subunits 33
6. Statistical summary of phosphorus concentrations for water samples collected between 1988 and 2002 35
7. Coefficients and bias correctors for total-phosphorus load regressions for samples collected between 1988 and 2002 44
8. Estimated seasonal and annual loads, and average annual yields of total phosphorus at sites on the Carson River, water years 1980, 2001, and 2002 45
9. Mass-balance calculations for the study area showing potential phosphorus loads from treated sewage effluent used for irrigation, 2000–02 63

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

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

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, groundwater 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

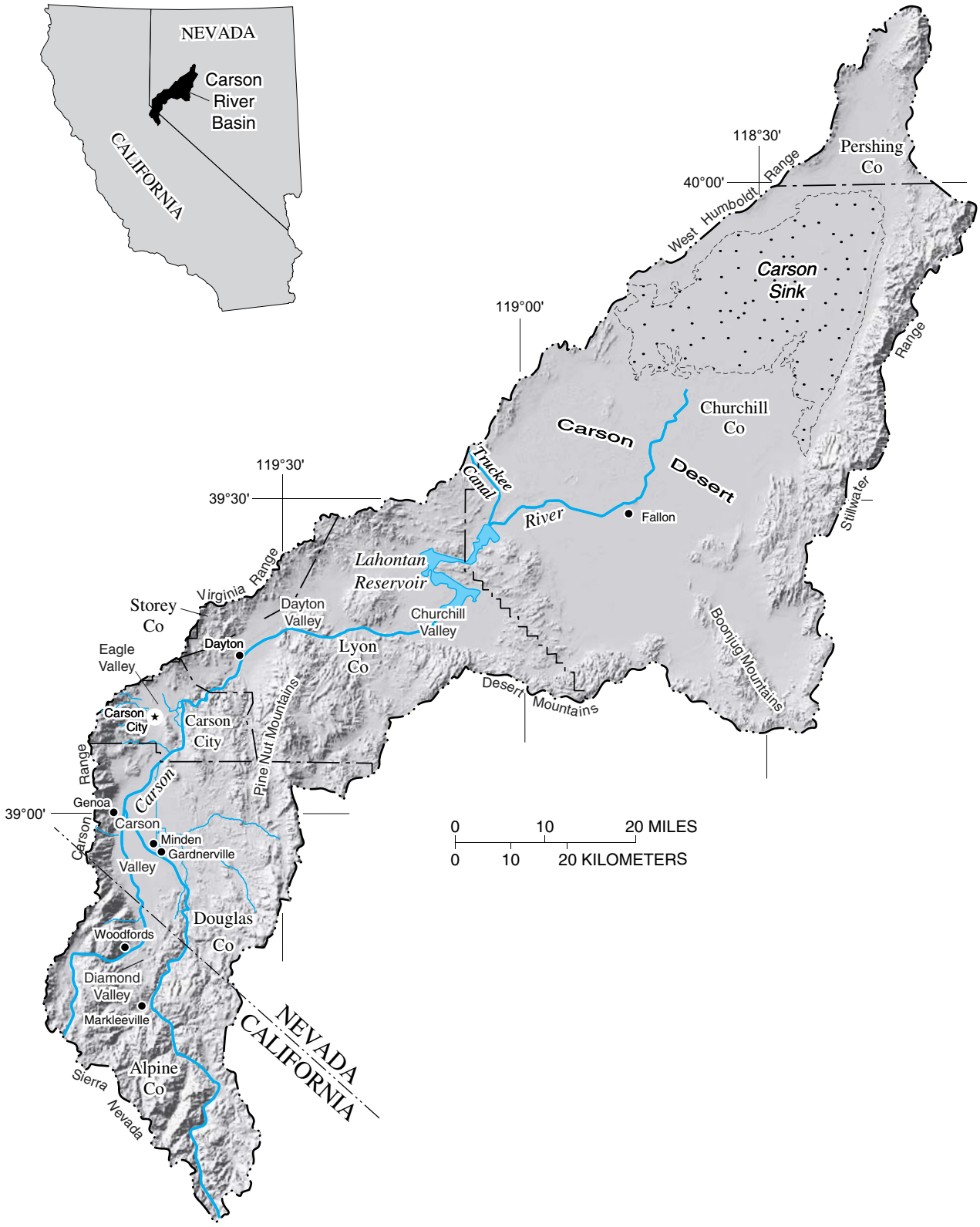
In areas where phosphorus is the major limiting nutrient in freshwater streams, inputs of phosphorus can stimulate growth of phytoplankton, macroalgae, and macrophytes. Increases in the growth of these plants can result in low dissolved-oxygen concentrations in streams at night and adversely affect invertebrate 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.

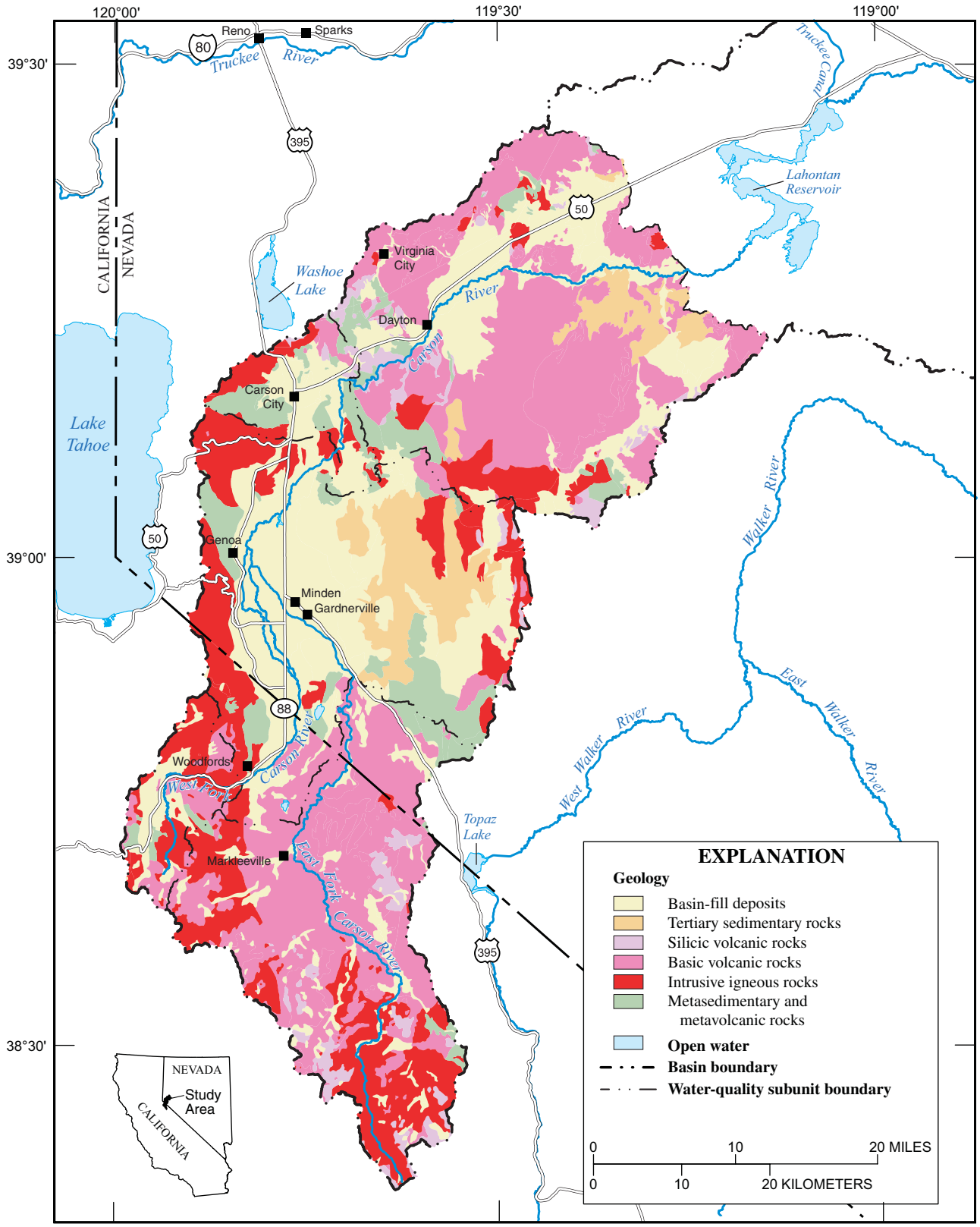
Except for mountainous areas in the headwaters of the Carson River in Alpine County, CA, the study area has an arid to semiarid climate characterized by cool to occasionally cold winters and hot summers. Forests dominated by Jeffrey pine and red fir are found in higher mountain areas, while piñon-juniper 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.

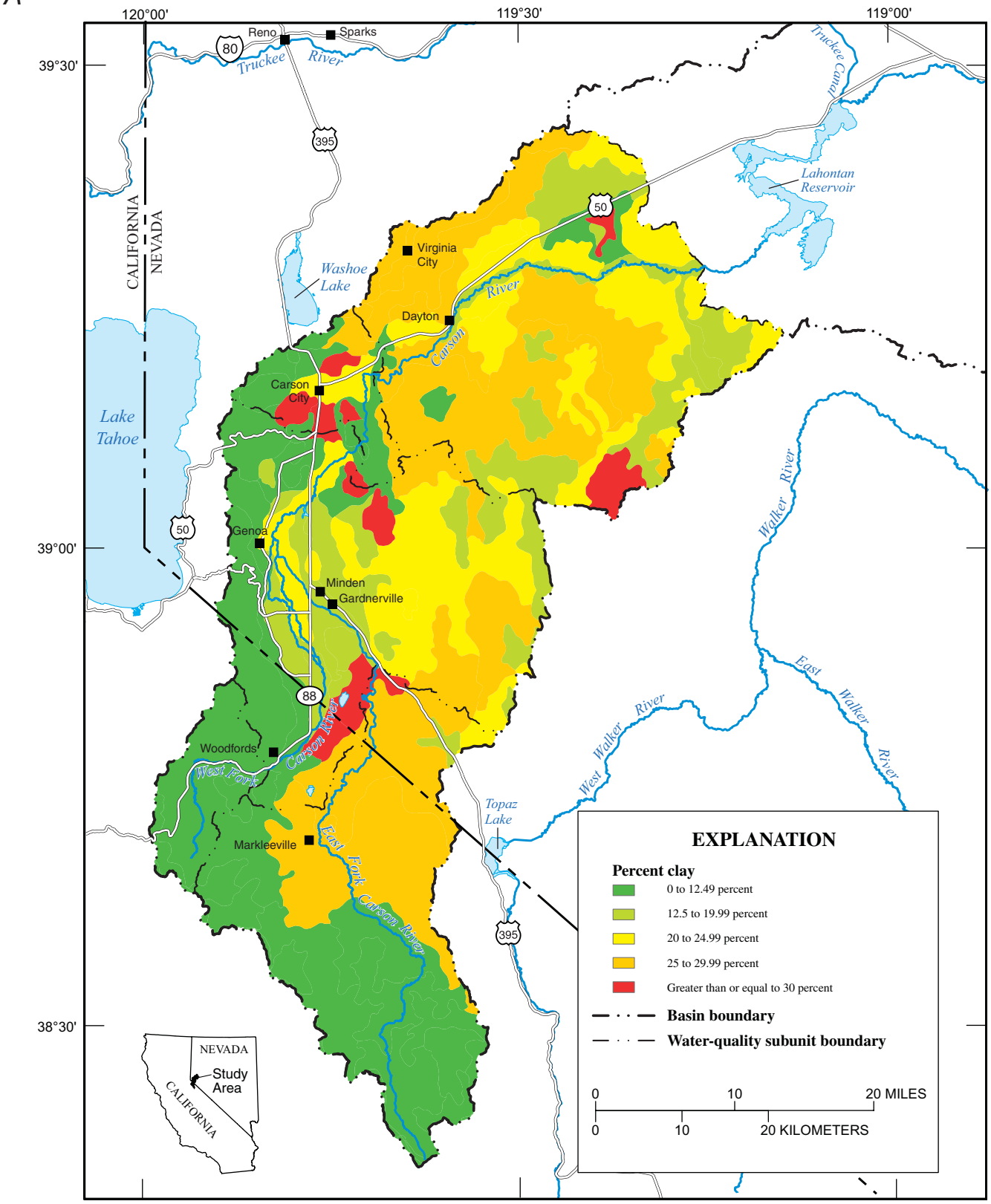
The gradient of the river influences flow velocity, and hence many other stream characteristics such as time of travel and sediment transport. The gradient between the headwaters and the confluence of the West and East Forks is about 125 ft/mi for the West Fork and 92 ft/mi for the East Fork (California 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.

A

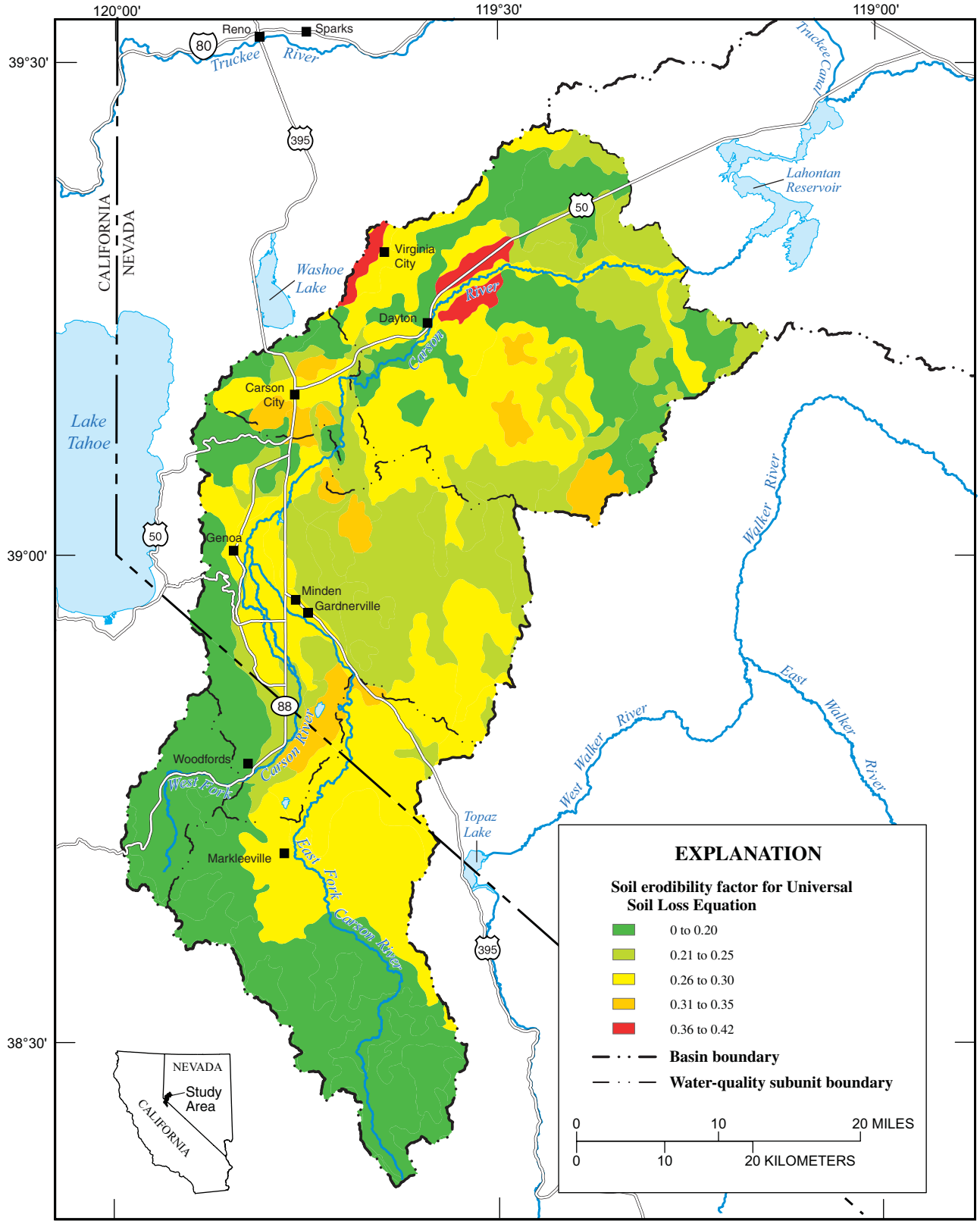


Base from U.S. Geological Survey digital data, 1:100,000- and 1:24,000-scale, 1979-82
Universal Transverse Mercator projection, zone 11
North American Datum 1927

Soil characteristics modified from Schwarz and Alexander (1995)

Figure 3. Soils of the Carson River Basin upstream from Lahontan Reservoir (*A*) clay content and (*B*) erodibility.

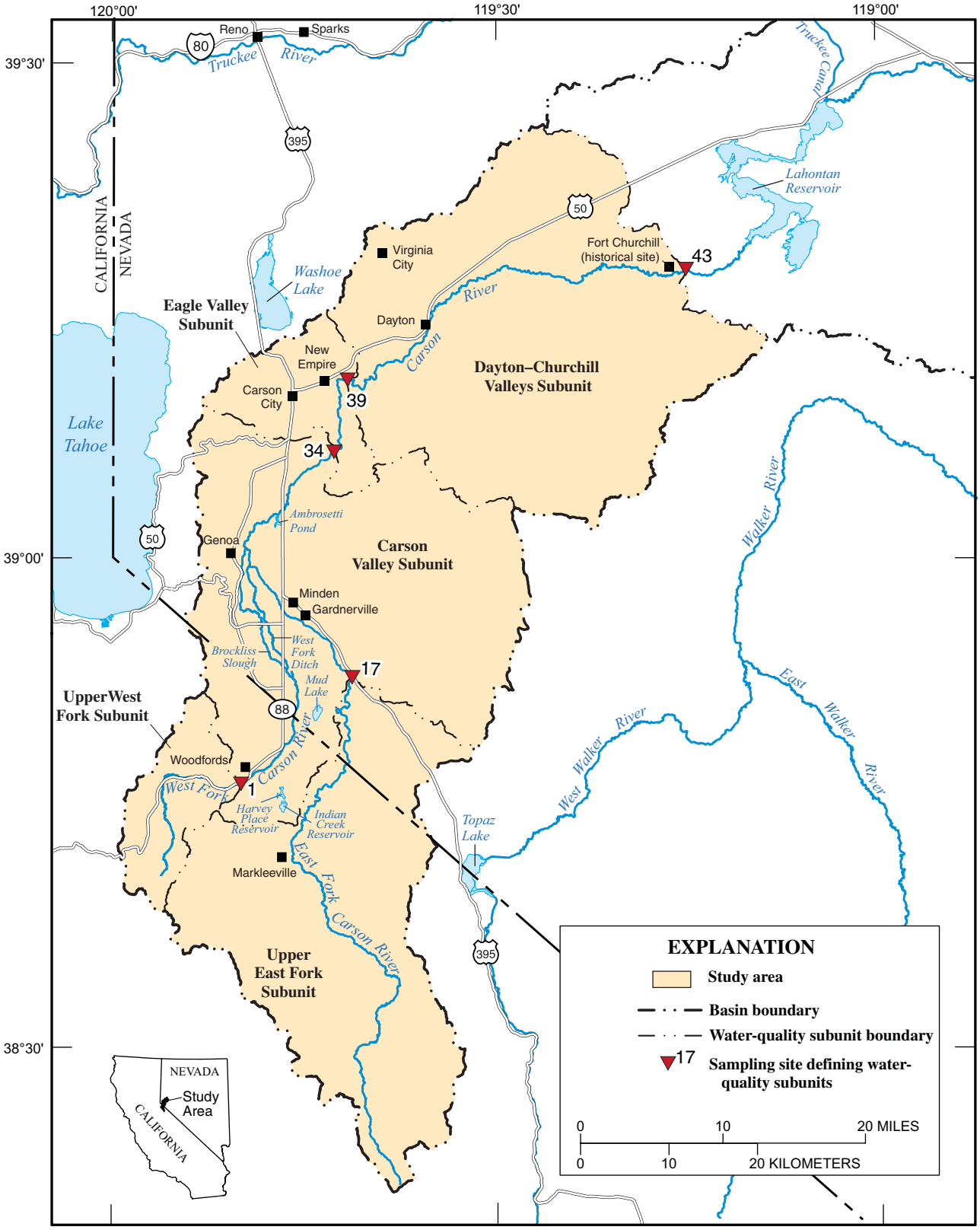
B



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

Soil characteristics modified from Schwarz and Alexander (1995)

Figure 3. Soils of the Carson River Basin upstream from Lahontan Reservoir (*A*) clay content and (*B*) erodibility—Continued.



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

Figure 4. Hydrologic features of the Carson River Basin upstream from Lahontan Reservoir.

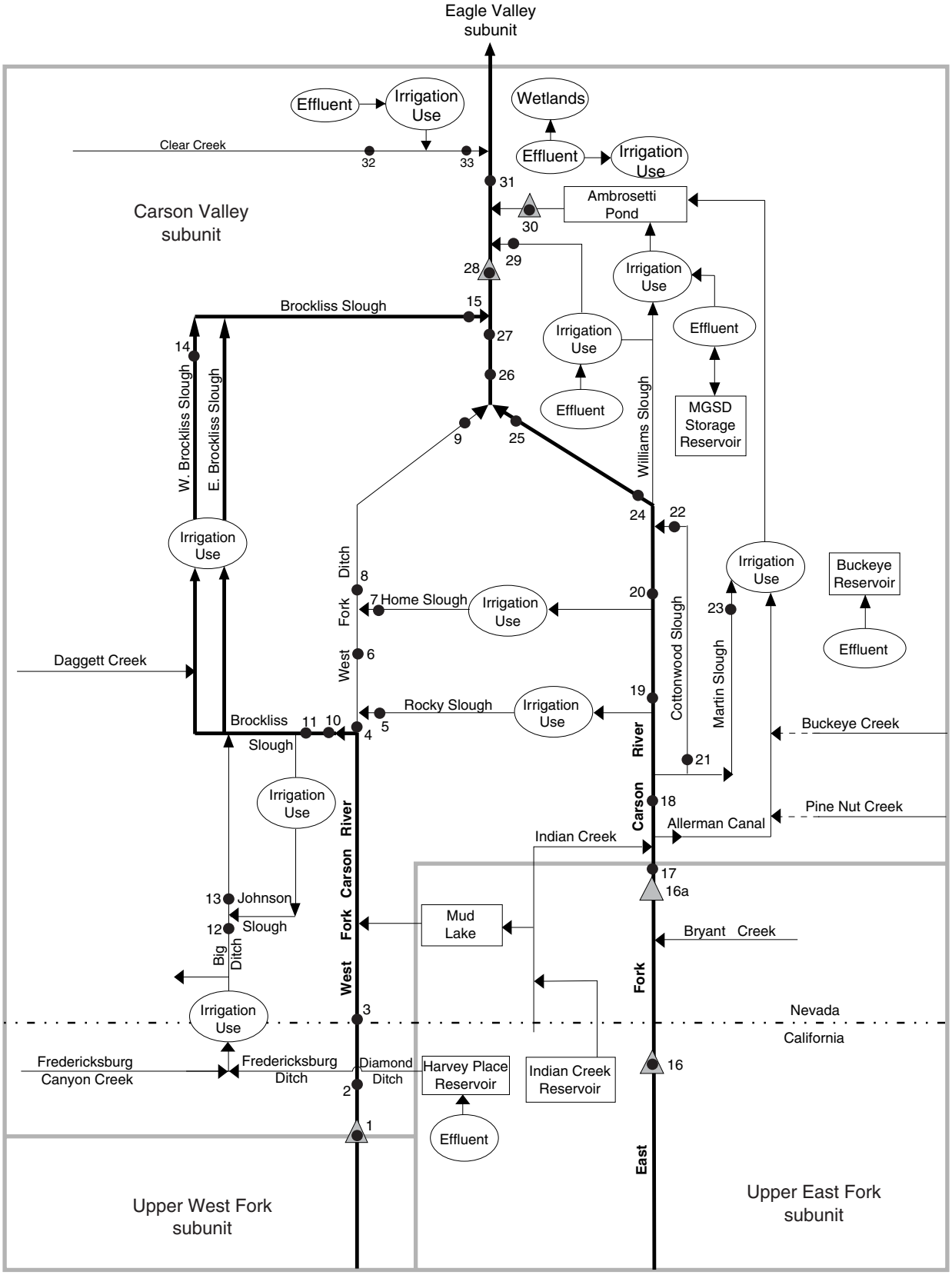


Figure 5. Schematic diagram of flow in the Carson River system upstream from Lahontan Reservoir.

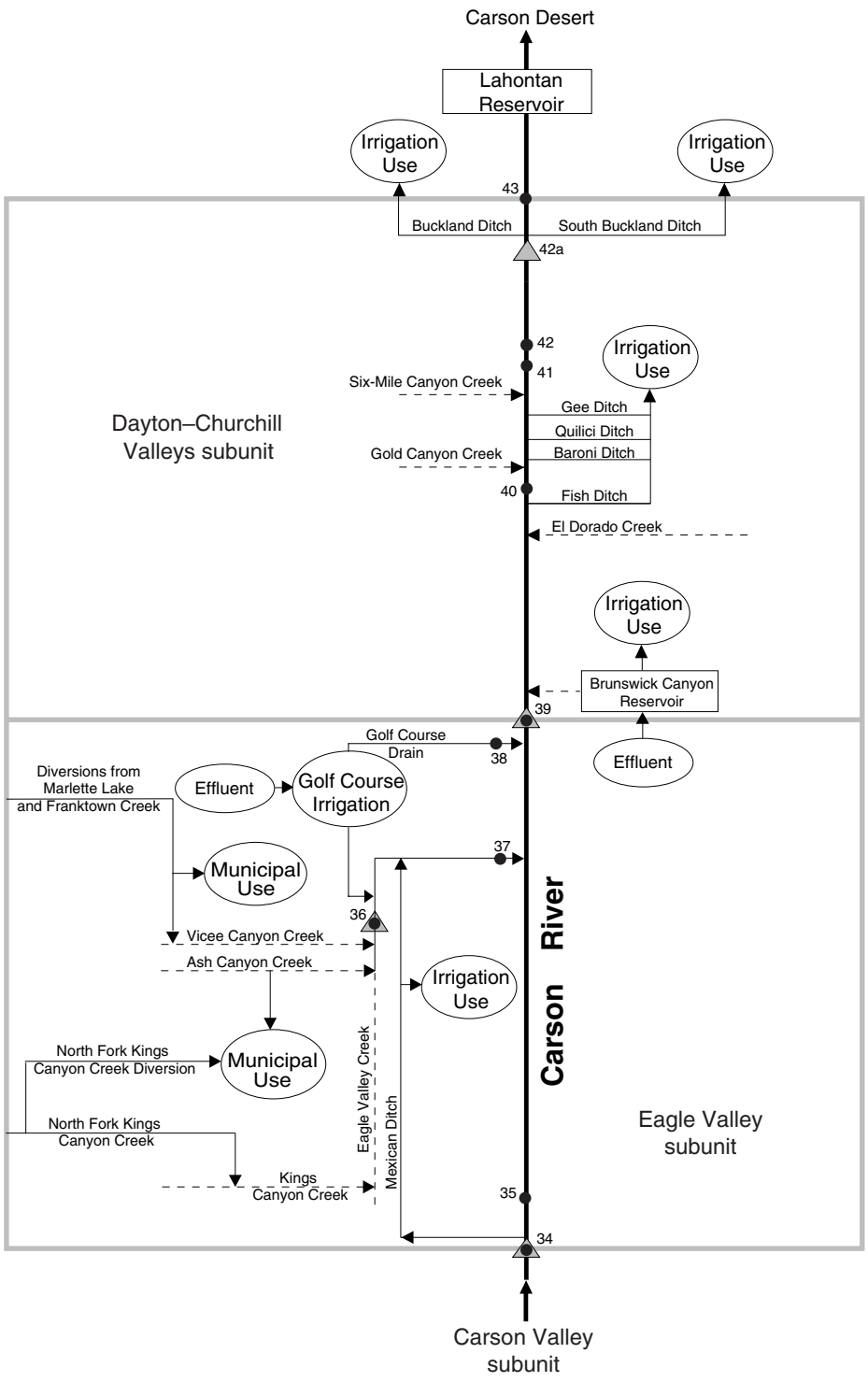


Figure 5. Schematic diagram of flow in the Carson River system upstream from Lahontan Reservoir—Continued.

Table 1. Summary data for streamflow at selected sites in the Carson River Basin

[All data are in cubic feet per second. Symbol: --, data not available]

Site no. (see fig. 16)	Station name	Period of record, water year	Range of daily mean discharge for period of record[a]	Range of mean annual discharge for period of record[a]	Mean annual discharge for period of record[a]	Mean annual discharge for 1940–2002[b]
1	West Fork Carson River at Woodfords, CA	1901–2002	5.3–5,500	26.1–290	111	105
16a	East Fork Carson River near Gardnerville, NV	1890–2002	11–17,000	91.6–905	382	367
34	Carson River near Carson City, NV	1940–2002	0–26,100	58.5–1,142	409	409
39	Carson River at Deer Run Road, NV	1979–2002	0–22,600	90.7–1,178	485	--
42a	Carson River near Fort Churchill, NV	1911–2002	0–20,000	36.3–1,111	376	385

[a]Data from Berris and others, 2003.

[b]Data from Water Resources Data of Nevada series of reports.

Peak flows along the Carson River occur during snowmelt runoff in spring and during winter storms. Many floods have occurred on the Carson River since settlement of the valley in the middle 19th century. Nearly all were winter floods caused by rain on snow (Glancy and Katzer, 1975). The greatest daily mean flow for five sites along the Carson River upstream of Lahontan Reservoir (table 1) was recorded during the New Years flood of 1997. Peak annual discharge in small streams in the basin occasionally occurs during runoff from summer storms. Summer storms over small drainages have the potential to transport large amounts of sediment and contaminants to the Carson River without greatly increasing the discharge of the river.

Storage Facilities

Numerous small natural lakes at higher altitudes exist in the watershed, a few of which have been converted to reservoirs by constructing dams across the outlets. Upstream from Markleeville, on the East Fork, reservoirs can store about 5,000 acre-ft of water. Upstream from Woodfords (fig. 4), on the West Fork, reservoirs can store about 2,000 acre-ft of water (Hess, 1996). Water stored in these reservoirs is released during summer for irrigation. Mud Lake, a 3,100 acre-ft reservoir between the East and West Forks, and Ambrosetti Pond, a small reservoir in northern Carson Valley which stores irrigation return flows, store water used to maintain instream flows during periods when Carson City wells near the river are pumping.

Several facilities have been constructed in the watershed to store and evaporate treated effluent. The stored effluent commonly is used during summer for irrigation of agricultural areas and green areas such as golf courses. The largest such storage facility, 3,800 acre-ft Harvey Place Reservoir near Woodfords (fig. 4), stores effluent generated in the Lake Tahoe Basin which is used during the growing season to irrigate crops in the Diamond Valley area (fig. 1). Other effluent-storage facilities include the Minden–Gardnerville Sanitation District storage reservoir, Buckeye Reservoir used to store effluent from Douglas County Sewer Improvement District No. 1, and Brunswick Canyon Reservoir used to store effluent from Carson City. The effluent from Incline Village General Improvement District is used for irrigation in Carson Valley, with the remainder discharging to the Incline Village General Improvement District Wetlands Enhancement Facility in northern Carson Valley for wildlife habitat and evapotranspiration.

Diversions and Return Flows

Most of the East Fork is diverted for agricultural use on entering Carson Valley. A complex system of canals, small reservoirs, diversions, and return-flow drains has been constructed in Carson Valley to distribute the water and is responsible for the lush green fields in an otherwise high-desert terrain (Hess and Taylor, 1999). An updated digital map of the water distribution system in Carson Valley has been prepared by Douglas County (Dawn Patterson, Douglas County Multi-Agency Geographic Information Center, written commun., 2003). From March through October 2002, about 61,000 acre-ft of water was diverted from the East Fork; however, some of that water returns unused to the Carson River (Dave Wathen, Carson River Annual Diversion Report for Water Year 2002, Federal Water Master's Records, written commun., May 12, 2003).

In Eagle Valley, there is only one major diversion from the Carson River; water is diverted through Mexican Ditch for irrigation of about 100 acres on the west side of the river. From March through October 2002, about 4,000 acre-ft of water was diverted into Mexican Ditch (Dave Wathen, Carson River Annual Diversion Report for Water Year 2002, Federal Water Master's Records, written commun., May 12, 2003). In Dayton and Churchill Valleys, slightly more than 20,000 acre-ft of water was diverted from the river at several locations from March through October 2002 and used to irrigate about 3,200 acres of land along the river ditch. Ditches in Eagle, Dayton, and Churchill Valleys divert continuously and the majority of the diverted water returns unused to the river.

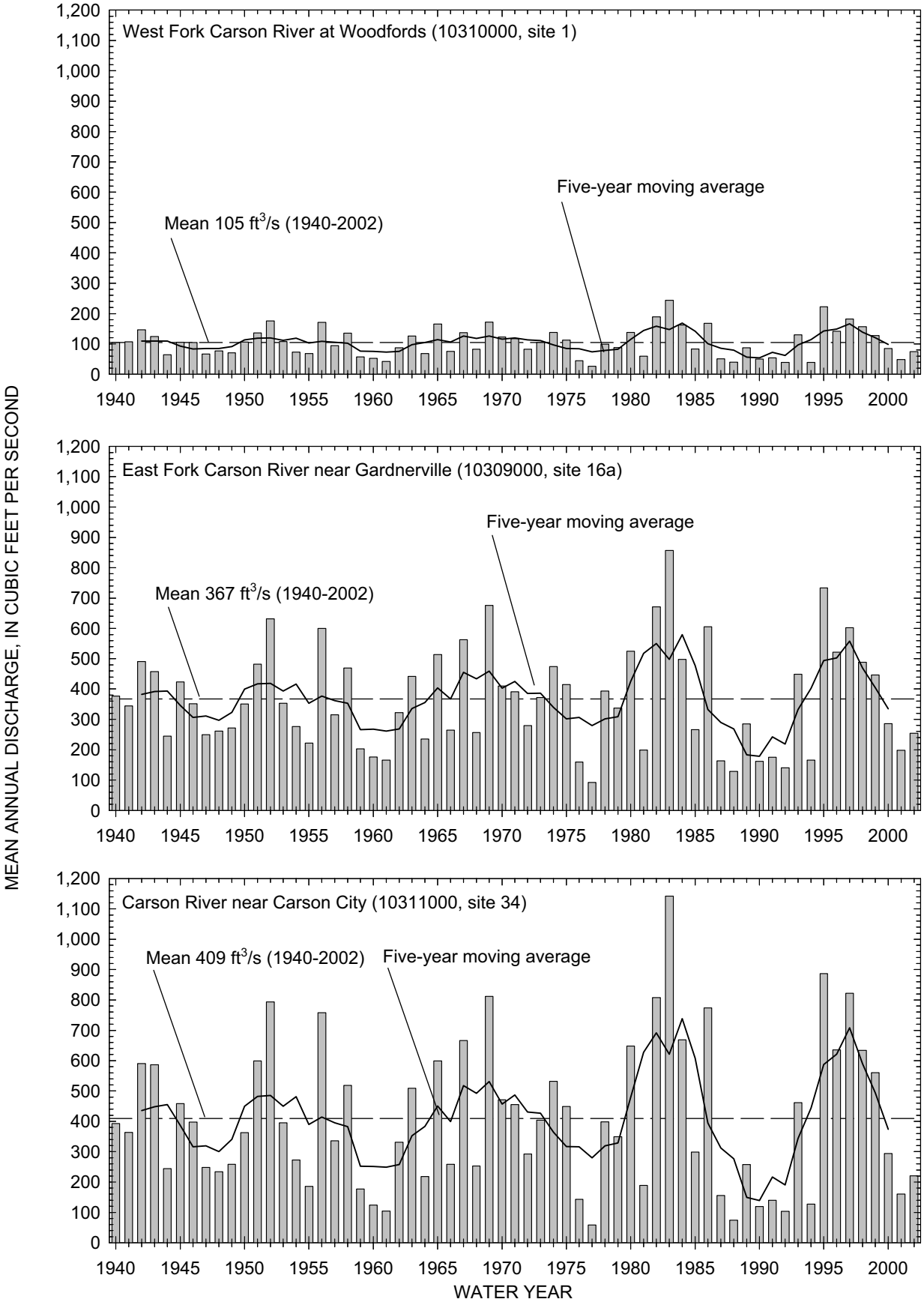


Figure 6. Mean annual discharge at sites along the Carson River.

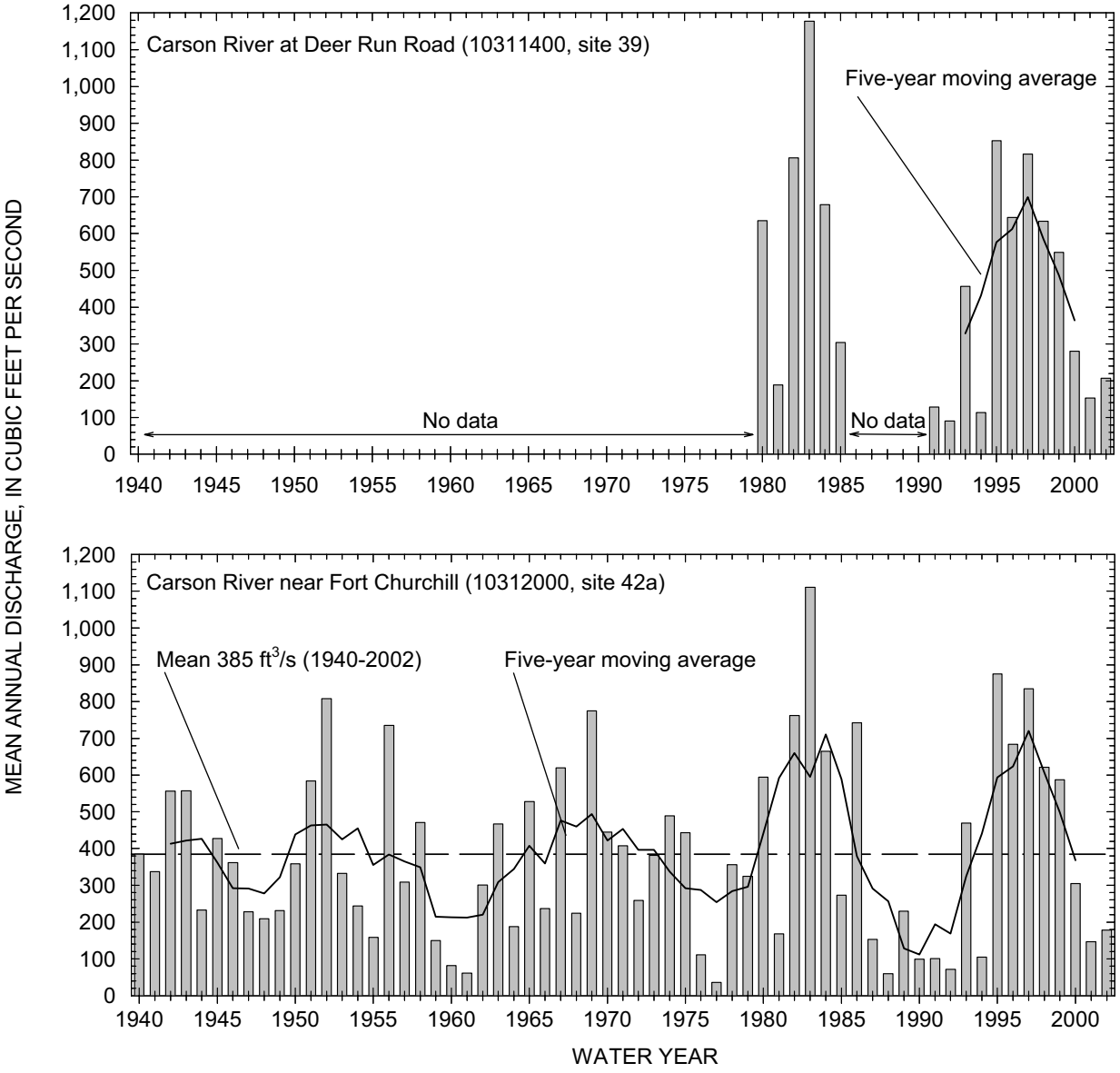


Figure 6. Mean annual discharge at sites along the Carson River—Continued.

Figure 7. Typical low-head dam along Carson River.

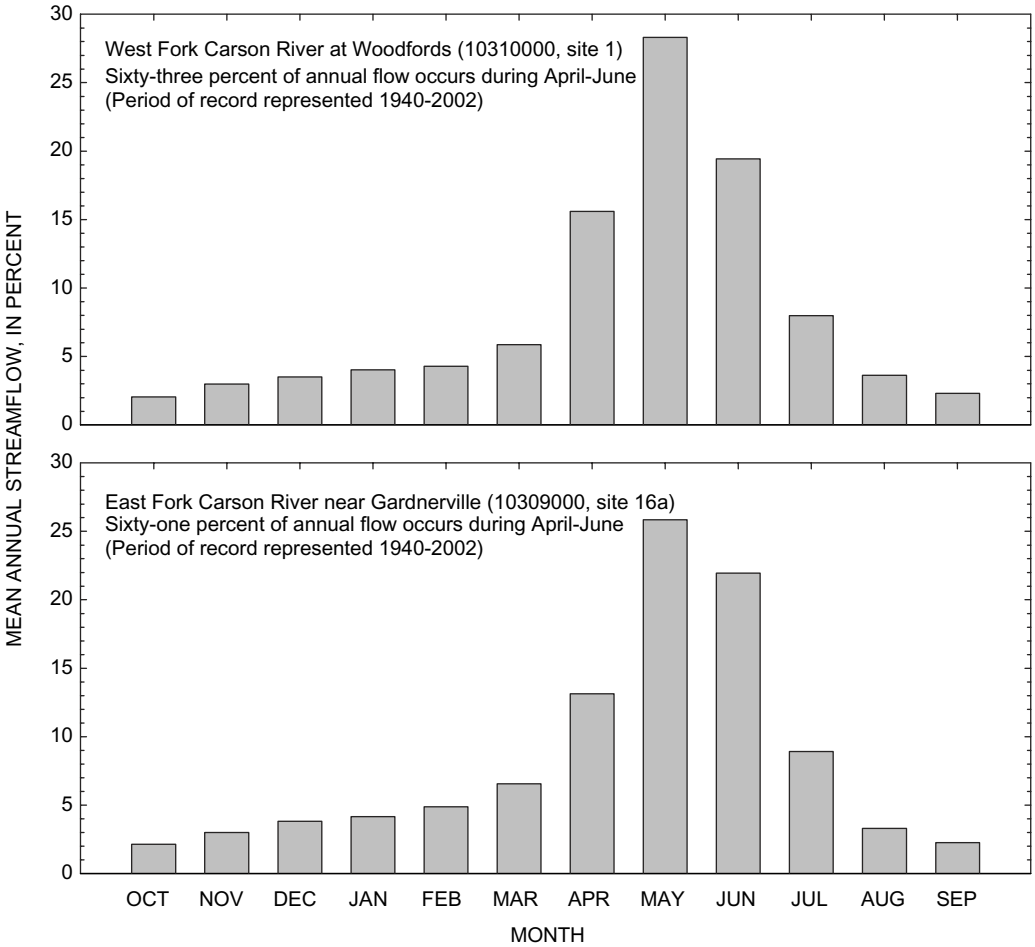


Figure 8. Monthly mean discharge as a percent of mean annual discharge at five sites along the Carson River.

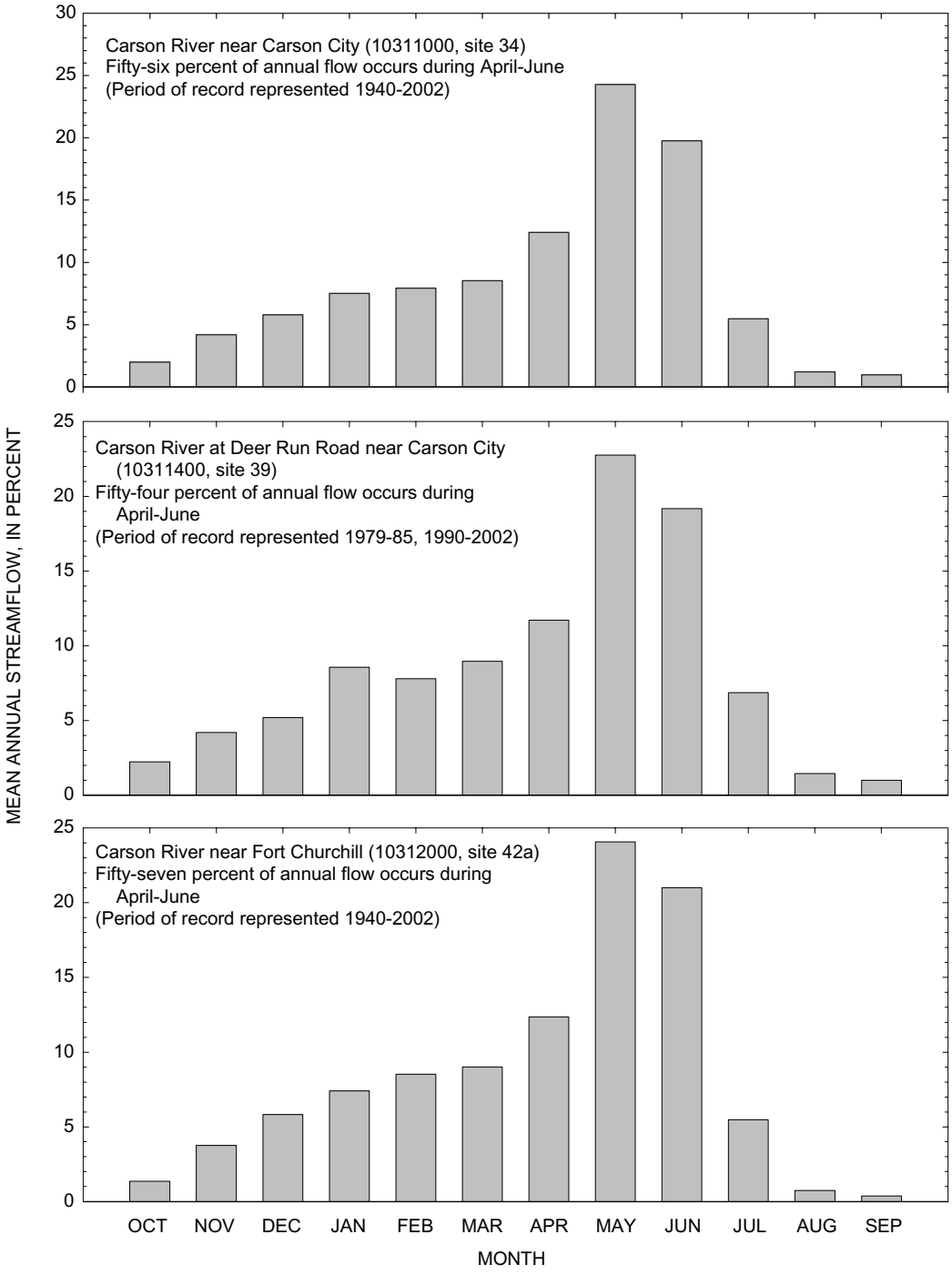


Figure 8. Monthly mean discharge as a percent of mean annual discharge at five sites along the Carson River—Continued.

In Carson Valley, irrigation return flows to the river are principally through an extensive network of ditches, sloughs, and drains. In Eagle, Dayton, and Churchill Valleys, irrigation return flows are principally through the subsurface.

Channel Stability

Following large floods in 1955 and 1963, significant amounts of channelization and construction of levees occurred along the Carson River corridor. Since agricultural use of lands along the river began, permanent and temporary diversion structures have been constructed along the river to divert water from the river into canals. Riparian vegetation along the river has been lost because of grazing and removal of water from the river channel for irrigation (Inter-Fluve, Inc., 1997). Logging, mining, and past and present agricultural activities have resulted in channel instability. The stability of much of the Carson River channel is rated as poor, with miles of eroding streambanks and a degraded riparian corridor (Inter-Fluve, Inc., 1997).

Ground-Water Hydrology

The ground-water flow system in Carson Valley is dominated by the Carson River (Maurer, 1986). The water table is less than 5 ft deep over much of the valley floor, allowing close contact between surface and ground water throughout the valley. Generally, streams and ditches west of U.S. Highway 395 (fig. 4) on the valley floor gain flow, draining the water table. In areas where the water table is deeper, east of U.S. Highway 395 and on the margins of the valley floor west of U.S. Highway 395, streams and ditches lose flow.

Maurer (1986) found, while calibrating a ground-water model of Carson Valley, that during winter months the stream system was gaining as a whole because of discharge from the ground water plus excess precipitation. Prudic and Wood (1995) modeled steady-state ground-water conditions for the Carson Valley and concluded that ground water discharges to the Carson River and ditches at the north end of the Carson Valley.

Water Quality

Surface-water quality is best in the headwater areas and deteriorates in a downstream direction from natural and man-made causes. Discharge of treated effluent to the river ceased in the late 1980's with the completion of the Minden–Gardnerville Sanitation District storage reservoir in 1986 and the Carson City Brunswick Canyon Reservoir in 1987. Concentrations of dissolved solids, orthophosphate, and nitrate for periods before (1966–71) and after (1992–97) discharge of treated effluent to the river ceased are summarized in table 2 and show that a large reduction in orthophosphate and nitrate concentrations occurred, particularly below Carson River at Deer Run Road (site 39; fig. 5) and Carson River near Silver Springs (site 43; fig. 5). The concentration of dissolved solids remained nearly unchanged.

Glancy and Katzer (1975) summarized data collected for the Carson River by NDEP between July 1966 and December 1971 and showed that average orthophosphate values for the West and East Forks upstream from Carson Valley were less than 0.1 mg/L. During this period, the greatest increase in phosphorus concentration occurred across Eagle Valley, principally because large amounts of treated effluent were discharged to the Carson River. For the period 1966–71, the average orthophosphate concentration for the Carson River where it crosses U.S. Highway 395 (Cradlebaugh Bridge, site 31; fig. 5) was 0.43 mg/L (maximum 1.1 mg/L) and for the Carson River downstream from Eagle Valley (site 39; fig. 5) was 1.3 mg/L (maximum 9.2 mg/L).

Water quality in the river may change from one day to the next because of the way the river is regulated. As stated in the Anderson–Bassman Decree, during periods when flow in the West Fork is not sufficient to satisfy all rights (about 180 ft^3/s; Hess and Taylor, 1999), use of West Fork water for irrigation rotates weekly between users in California and users in Nevada. This weekly rotation influences flow in Brockliss Slough (Hess and Taylor, 1999), and may influence water quality as well.

During 1980, numerous samples for suspended-sediment concentrations and particle-size distributions were collected from major sites in the Carson River system (Garcia and Carman, 1986). Suspended-sediment concentrations in the East Fork, West Fork, and mainstem of the Carson River upstream from Lahontan Reservoir ranged from 3 to 1,790 mg/L and loads ranged from 0.11 to 12,500 tons/d. The greatest suspended-sediment concentrations and loads in the entire system occurred during a winter storm. The highest and lowest suspended-sediment concentrations were measured in the East Fork upstream from Carson Valley. The annual suspended-sediment load upstream from most agriculture and urbanization was estimated to be 200,000 tons, and increased by only about 10,000 tons across Carson Valley during 1980. Across Eagle Valley, the load decreased by about 40,000 tons, but across Dayton and Churchill Valleys the load increased by about 60,000 tons.

Numerous ground-water samples were analyzed for orthophosphate between 1987 and 1990 in the Carson River Basin as part of the USGS National Water-Quality Assessment (NAWQA) Program (Whitney, 1994). Orthophosphate concentrations in ground water in the Carson River Basin upstream from Lahontan Valley typically are about 0.05 mg/L or less. In Carson Valley, the median orthophosphate concentration for shallow ground water (<50 ft) was 0.17 mg/L (n = 27) and for the principal aquifer (>50 ft) was 0.03 mg/L (n = 28). For shallow and principal aquifer samples combined, the median orthophosphate concentration in Eagle Valley was 0.06 mg/L (n = 93) and in Dayton and Churchill Valleys it was 0.02 mg/L (n = 35). The maximum observed orthophosphate concentration (0.58 mg/L) was in a sample from a shallow well (12 ft) near the West Fork north of the California–Nevada State line. A

Table 2. Summary of water-quality data for selected sites on the Carson River showing changes in water quality following cessation of treated sewage effluent discharge to the Carson River

[Data from Nevada Division of Environmental Protection. Water-quality data from 1966 to 1971 summarized by Glancy and Katzer (1975). Abbreviations: ft^3/s, cubic feet per second; mg/L, milligrams per liter; P, phosphorus; N, nitrogen; NDEP, Nevada Division of Environmental Protection. Symbol: --, not available]

Site no. (see fig. 16)	NDEP no.[a]	Station name	Mean annual discharge (ft^3/s)		Mean total dissolved-solids concentration (mg/L)		Mean orthophosphate concentration (mg/L as P)		Mean nitrate concentration (mg/L as N)	
			1966–71	1992–97	1966–71	1992–97	1966–71	1992–97	1966–71	1992–97
2	C8	West Fork Carson River at Paynesville[b]	118	126	59	56	0.06	0.01	0.3	0.06
17	C9	East Fork Carson River near Dresslerville[c]	427	435	112	109	0.09	0.02	0.6	0.04
31	C2	Carson River at Cradlebaugh Bridge[d]	486	506	164	163	0.43	0.15	1.2	0.08
39	C1	Carson River at Deer Run Road[e]	--	496	228	225	1.30	0.10	1.5	0.08
43	C10	Carson River near Silver Springs[f]	451	507	237	239	0.45	0.07	1.4	0.07

[a]Identifier for NDEP monitoring stations (Nevada Division of Environmental Protection, 2002a).

[b]Fifty-five samples were collected from July 1966 to December 1971 and 52 from 1992 to 1997. Comparison of discharge is from gaging station 10310000, West Fork Carson River at Woodfords, CA.

[c]Fifty-seven samples were collected from July 1966 to December 1971 and 50 from 1992 to 1997. Comparison of discharge is from gaging station 10309000, East Fork Carson River near Gardnerville, NV.

[d]Fifty-six samples were collected from July 1966 to December 1971 and 53 from 1992 to 1997. Comparison of discharge is from gaging station 10311000, Carson River near Carson City, NV.

[e]Fifty-six samples were collected from July 1966 to December 1971 and 53 from 1992 to 1997.

[f]Fifty-three samples were collected from July 1966 to December 1971 and 51 from 1992 to 1997. Comparison of discharge is from gaging station 10312000, Carson River near Fort Churchill, NV.

NAWQA study looking at ground-water samples within the Carson River Basin found shallow aquifers in urban areas had lower orthophosphate concentrations than agricultural and range areas at a highly significant level ($p < 0.01$; Kilroy and others, 1997).

Land Use

Generalized land use and land cover in the study area is shown in figure 9. Forest and range are by far the largest land covers within the Carson River Basin upstream of Lahontan Reservoir. The upper reaches of the Carson River Basin principally are forested lands in Alpine County, CA. The Dayton and Churchill Valley areas predominately are range land. Barren land primarily is salt flats and sandy areas in the Carson Desert area and exposed bedrock in the upper basin.

The largest agricultural area in the study area is in Carson Valley. Land used for agriculture in Carson Valley covered 45,830 acres in 1990, which includes about 540 acres of land irrigated at the State Prison. Irrigation water principally is supplied from the Carson River and in Carson Valley is supplemented by use of treated effluent. In Eagle, Dayton, and Churchill Valleys agricultural land covers 5,735 acres, mostly along the Carson River. The principal crop grown in the study area is hay and hay-alfalfa.

Parts of the study area are becoming increasingly urban in character (table 3) and some agricultural areas are being converted to residential areas. Many of the agricultural areas being converted to residential areas are along the Carson River corridor. The largest population centers are Carson City (52,457 residents in 2000), Minden–Gardnerville (17,247 residents in 2000), and Dayton (5,907 residents in 2000; University of Nevada, 2001).

Table 3. Irrigated acreage and population trends in Carson River Basin above Lahontan Reservoir

	Acres of irrigated land[a]		Population		
	1992	1997	1990[b]	2000[b]	2010[c]
Alpine County, CA	2,893	2,925	1,113	1,208	1,377
Douglas County, NV	33,082	37,668	27,637	41,259	60,712
Carson City, NV	([d])	1,208	40,443	52,457	63,515
Lyon County, NV	[e]67,365	[e]74,000	20,001	34,501	48,990

[a]Data for irrigated acreage is from the U.S. Department of Agriculture (1997).
[b]Data for 1990 and 2000 population (U.S. Department of Agriculture, 2004a, b).
[c]Projected 2010 population for Nevada (Nevada State Library and Archives, 2000) and for California (California Department of Finance, 2004).
[d]Data withheld by U.S. Department of Agriculture to avoid disclosing data for individual farms.
[e]Very little irrigated land in Lyon County is within the Carson River Basin. Most irrigated land is in the adjacent Walker River Basin.

CYCLING AND TRANSPORT OF PHOSPHORUS

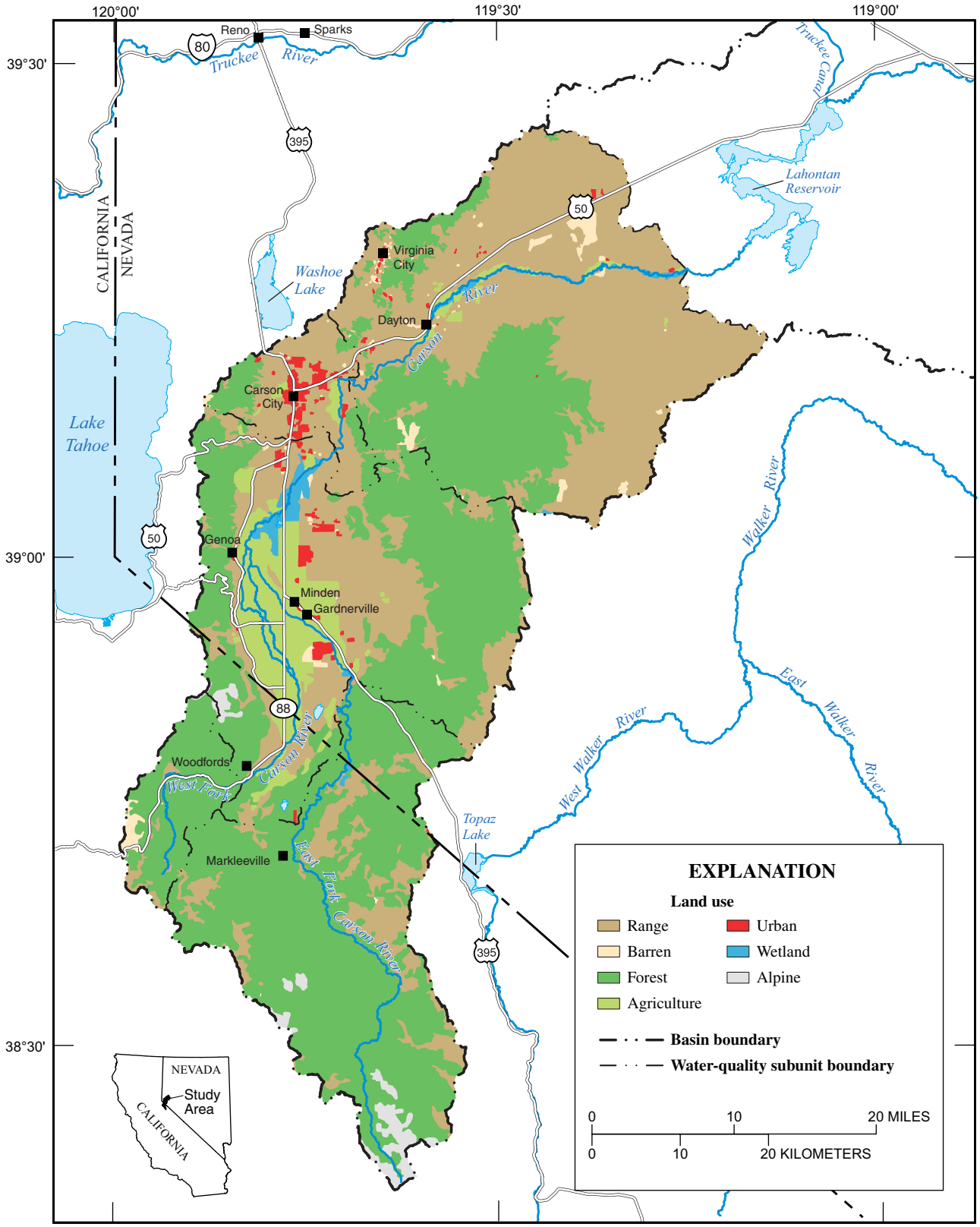
Phosphorus is an essential nutrient for all life on earth. Even though large amounts of phosphorus may be present in soils, phosphorus often is a limiting plant nutrient because of its chemistry. A general understanding of the cycling and transport of phosphorus in the environment is needed to evaluate the importance of phosphorus sources in stimulating nuisance algal growth.

Cycling

The movement of phosphorus involves three cycles, two biological cycles (land and water based) that are superimposed on an inorganic cycle (Vymazal, 1994). In general, the inorganic cycle tracks the movement of phosphorus from sedimentary deposits and igneous rocks into soils by weathering, followed by the riverine transport of phosphorus from the soils to lakes and oceans where sedimentary deposits are formed. Phosphorus moves from the inorganic cycle to the land-based biological cycle following the uptake of soluble soil phosphorus by plant roots. After plant uptake, phosphorus is returned to the soil via litterfall and root turnover to complete the cycle. Phosphorus moves from the inorganic cycle to the water-based biological cycle following the transfer of phosphorus from sediment to the water column and subsequent uptake by phytoplankton and macroalgae. Phosphorus returns to the inorganic cycle following mineralization of organic debris and subsequent incorporation of inorganic phosphorus into soils and sediments.

Orthophosphate ions (primarily $H_2PO_4^{-1}$ and HPO_4^{-2} in natural waters) are the forms of phosphorus most readily available to algae and higher plants (Vymazal, 1994; Schachtman and others, 1998) and, as such, represent a major link between inorganic and biological phosphorus cycling. Plants are efficient at removing orthophosphate from soil and water and incorporating it into their cells. Upon death of the cell, phosphorus is returned to the environment as orthophosphate and organic-particulate phosphorus. In soils, the largest amount of organic phosphorus is associated with the humic and fulvic acid fraction and a much smaller percentage is associated with nucleic acids and other phosphate esters such as phospholipids (Ryden and others, 1973).

Although phosphorus itself does not undergo oxidation-reduction (redox) processes under normal environmental conditions, redox reactions are important in the phosphorus cycle. Under oxic conditions, ferric oxyhydroxide is thermodynamically stable and orthophosphate commonly is adsorbed to it or coprecipitates with it. Under reducing conditions, ferric oxyhydroxide can dissolve, thus releasing any associated phosphorus.



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

Figure 9. Land use in the Carson River Basin upstream from Lahontan Reservoir, 1990.

Under acidic conditions, orthophosphate concentrations in water and soil solutions can be lowered by adsorption onto aluminum and iron oxyhydroxides and oxides and may precipitate as insoluble aluminum and iron phosphates (Vymazal, 1994). At pH values greater than 7, orthophosphate concentrations can be lowered by precipitation of phosphate as calcium phosphate.

Phosphorus bound to particulate matter is not immediately available to support plant growth, though it can provide a long-term source of phosphorus. Organic particulate phosphorus can be converted to orthophosphate as the organic matter is oxidized by physical-chemical processes (for example, photolysis) or as it is metabolized by bacteria and other living organisms. Sources of organic particulate phosphorus include decaying plant matter from leaves falling into streams, the death of aquatic organisms, or erosion from soils. Inorganic particulate phosphorus is converted to orthophosphate through chemical processes. Some forms of inorganic particulate phosphorus, such as the mineral apatite, can dissolve in streams and release orthophosphate to the streamwater. Other forms of inorganic particulate phosphorus, such as phosphorus bound to aluminum and iron oxyhydroxides and oxides, are unlikely to dissolve in streams. These forms dissolve in reducing environments (for example, sediments in lakes and reservoirs) where the orthophosphate then diffuses into the overlying water column. Sources of inorganic particulate phosphorus include eroding surface soil, streambanks, and resuspension of bed sediment.

Transport

Phosphorus can be transported in the riverine environment either as dissolved phosphate ions and complexes, or bound to organic and inorganic particles. Because phosphorus can bind to sediment particles, stream properties and sediment characteristics that result in large amounts of sediment transport affect the amount of phosphorus being transported. Stream properties that affect sediment transport include channel slope, size and character of the material in the bed and banks, flow velocity and volume, vegetation along the banks, and sinuosity of the stream.

Particle size, shape, and charge are important determinants in sediment and phosphorus transport because water discharge is required to move sediment particles and, once in solution, to keep the particles from settling out. Phosphorus binds preferentially to small sediment particles because small particles such as clays have surface charges and large surface area to volume ratios. Up to 50 percent of total phosphorus in soils may be associated with the clay fraction (Ryden and others, 1973). As a result, compared to sands and silts, less discharge is required to remove small, phosphorus-rich clay-sized particles from land surfaces. Once in small channels, fine particles are easily carried in suspension; whereas, coarser particles move in suspension for only short distances. Thus, clay-size phosphorus-rich particles likely are removed from fields, transported in small channels to the Carson River, and remain in suspension during low flow.

Phosphorus does not move easily or quickly through undisturbed soil profiles because, in general, phosphorus is strongly adsorbed by soil particles. This implies that movement of phosphorus to ground water from land-applied surface sources can be slow or unimportant. However, orthophosphate can rapidly move through sandy soils with low phosphorus sorption capabilities or through waterlogged soils where anoxic conditions are present (Sharpley and others, 1995). Mineral sources of phosphorus in the aquifer material can result in high phosphorus concentrations in ground water.

The amount of orthophosphate and organic particulate phosphorus being transported in streams may increase during winter. Leaves falling into streams and the death of algae and subsequent breakdown of the cells following a freeze will release phosphorus to the water, allowing for its movement downstream. Because metabolic activity of algae is lowest during winter, this bioavailable phosphorus may not be taken up by algae as rapidly as during the remainder of the year.

The amount of bioavailable phosphorus changes because of transformations between dissolved phosphorus and particulate phosphorus during transport. The amount of bioavailable phosphorus associated with deposited sediments generally is greater than that of suspended sediment (Sharpley and others, 1995). Once sediment settles to the bottom of a lake or stream, bioavailability will be increased by development of reducing conditions near the sediment-water interface.

POTENTIAL SOURCES OF PHOSPHORUS TO THE CARSON RIVER

Geological Sources and Forested Areas

The ultimate source of most of the naturally occurring phosphorus to the Carson River is the hundreds of thousands of acres of land in the headwaters of the Carson River where granitic and volcanic rocks form the bedrock. Igneous intrusive and volcanic rocks are the most common bedrock in the upper Carson River Basin (fig. 2) and pedogenic weathering of these rocks forms the soils which, in the end, contribute phosphorus to the river. Phosphorus is a common element in igneous rocks (Hem, 1985). The average phosphorus content of basalts and andesites (basic volcanic rocks; fig. 2) is 0.10–0.12 weight percent (as P) and for granodiorites (intrusive igneous rocks; fig. 2) is 0.09 percent (Hyndman, 1972). The average phosphorus content (expressed as P) of silicic igneous rocks is 0.07 percent (Huang, 1962). Although the average phosphorus contents of andesites and granodiorites are nearly the same, Susfalk (2000) observed that extractable phosphorus in granite derived soils from the eastern Sierra Nevada was up to three orders of magnitude greater than from andesite derived soils.

The most common mineral form of phosphorus is apatite (calcium phosphate with varying amounts of hydroxide, chloride, and fluoride ions). Apatite occurs as large crystals in pegmatites and as minute crystals in essentially all types of igneous rocks (Dietrich and Skinner, 1979).

In general, forested watersheds conserve phosphorus because of their low erodibility and, as a result, wooded areas are often used as buffer zones around streams to reduce input from agricultural land (Sharpley, 1995). Runoff from virgin forests carries little sediment and thus most of the transported phosphorus is in the dissolved form (Sharpley, 1995). However, phosphorus release from disturbed forests, such as in logged or burned areas, will be greater than in virgin forests because sediment runoff is greater. Much of the forest in the headwaters in the East and West Forks was logged heavily during the Comstock mining era (1862–80) to provide timber for railroads, mines, and mills (California Department of Water Resources, 1991). Numerous fires, burning hundreds to thousands of acres of forest, have occurred in the area during the last 50 years (Roland Shaw, U.S. Forest Service, oral commun., May 7, 2003).

Soils and Sediment

Sediment in runoff from nonpoint sources is estimated to be the source of 80 percent of total phosphorus in U.S. streams (Fennessey and Jarrett, 1994) and sediment potentially is a large source of phosphorus in the Carson River. In 1987, soil samples were collected at 372 sites within the Carson River Basin by the USGS as part of NAWQA. Field sampling, sample preparation, and analytical methods used for the soil samples are described in Tidball (1989) and Tidball and others (1991). Eighty-two of the 372 sampling sites are in the study area (fig. 10).

Total-phosphorus concentrations from the 82 sites in the study area ranged from 0.03 to 0.19 percent (from 300 to 1,900 mg/kg as P). The median phosphorus concentration was 0.08 percent and the 25th and 75th percentiles were 0.07 and 0.1 percent, respectively. These soil phosphorus concentrations are about the same as, or slightly less than, what is found in the soil-parent rock (see section Geological Sources and Forested Areas). The greatest number of samples with high phosphorus concentration are near the river, perhaps associated with cultivated or pasture land.

The banks and channels of long reaches of the Carson River are unstable and erosion is actively occurring (fig. 11). Low head dams in the river (fig. 7) are destroyed during spring runoff and need to be rebuilt annually using heavy equipment in the river. Bank and channel erosion and operation of heavy equipment in the river have the potential to contribute large amounts of phosphorus to the river. If the assumption is made that the median phosphorus concentration in soil from the basin (0.08 percent) is representative of the concentration in suspended sediment, the State water-quality standard of 0.1 mg/L would be exceeded when the suspended-sediment concentration exceeded 125 mg/L. The State water-quality standard probably will be exceeded at suspended-sediment concentrations even less than 125 mg/L because the phosphorus content of suspended sediment typically is greater than that of the soils from which it is derived (Sharpley and others, 1995). To put the value of 125 mg/L in perspective, the median suspended-sediment concentration in WY 1980 at Carson River near Carson City (site 34; fig. 5) was 234 mg/L and suspended-sediment concentrations in 10 of 16 samples collected that year exceeded 125 mg/L (Garcia and Carman, 1986).

Atmospheric Transfers

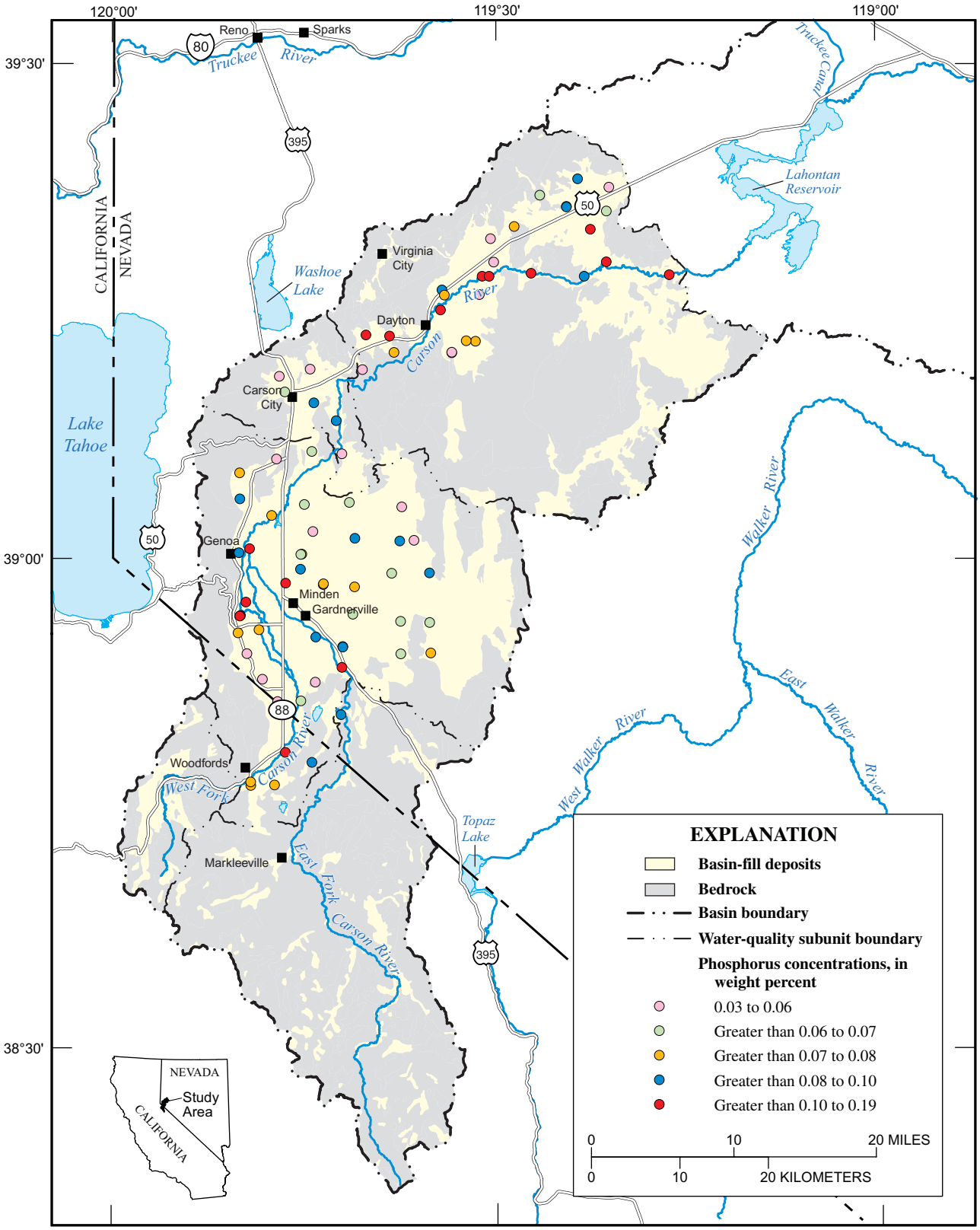
Wet and dry precipitation have the potential to contribute phosphorus directly to surface water. Wind erosion from cultivated land within and outside the basin can be a source of phosphorus to the atmosphere, where it can settle out in the dust or be rained out. In most cases, annual transport of phosphorus to lakes in precipitation is negligible compared with other nonpoint sources (Sharpley and others, 1995). In extremely oligotrophic lakes such as Lake Tahoe, atmospheric deposition may be an important source of phosphorus (Jassby and others, 1994). In the Carson River Basin, however, this is unlikely to be an important source of phosphorus.

Ground Water

Diffuse ground-water inflow to the river also may be a source of phosphorus to the river. Mauer (1986) found that during winter months the stream system in Carson Valley was gaining as a whole because of discharge from the ground water and excess precipitation. Orthophosphate concentrations in shallow ground water in Carson Valley typically are about 0.17 mg/L (see section Water Quality). Phosphorus concentrations were less than 0.1 mg/L for several hot springs near Genoa (Garside and Schilling, 1979). Analyses of phosphorus were not found for water from hot springs in the north part of Carson City and no information about ground-water quality was collected as part of this study.

Animal Grazing

Animal waste from fields near the Carson River and its tributaries may be an important source of phosphorus to surface waters. In Carson City and in Alpine and Douglas Counties in 1997 there were 10,552 beef cows and 807 milk cows (U.S. Department of Agriculture, 1997). Animal waste is rich in phosphorus; the average phosphorus content of manure from beef cattle is 5.6 g/kg and for dairy cattle is 11.7 g/kg (Sharpley, 1995, p. 8). Cattle with an average weight of 1,000 lbs excrete about 17 lbs of phosphorus per year, of which 60–80 percent may be in an inorganic form (Ryden and others, 1973). Given the average phosphorus excretion rate, the 11,359 beef and milk cattle in Carson City, and Douglas and Alpine Counties would



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

Data from Tidball (1989) and Tidball and others (1991)

Figure 10. Phosphorus concentrations in soil samples collected in 1987 from the Carson River Basin upstream from Lahontan Reservoir.

Figure 11. Unstable reach along East Fork Carson River in Carson Valley. Such reaches can contribute large amounts of sediment to the river during high flow.

have excreted about 96.5 tons of phosphorus in 1997. This is a maximum value, however, because most of those cattle are not full time residents of the study area.

Phosphorus loading from large-animal waste to the Carson River depends on the season and the distance these animals are kept from lands where runoff can carry phosphorus into surface water. Movement of phosphorus is particularly great during winter months because of the combination of rainfall and snowmelt on frozen ground (Ryden and others, 1973). Management practices for controlling erosion and phosphorus loading to streams often involve fencing to limit cattle's access to the streams. Although allowing cattle access to streams may have positive effects such as controlling the invasive weed tall whitetop, it also has negative effects such as trampling of streambanks, which causes erosion and increased sediment and phosphorus loading to the streams. Grazing near streams (fig. 12) places waste in or very near the stream and slows development of plant-buffer zones that reduce runoff from fields where cattle graze.

Agriculture

The potential phosphorus loss from agricultural land is largely dependent on the relative importance of surface and subsurface runoff in the watershed (Sharpley and others, 1995). The amount of phosphorus carried in subsurface runoff to streams is lower than the amount carried in surface runoff because phosphorus from infiltrating water adsorbs to sediment particles as it percolates through the soil profile. Artificial drainage shortens soil-contact times and reduces removal of inorganic phosphorus from subsurface runoff.

Few studies exist on losses of phosphorus in runoff from arable land in the Carson River Basin. A study of agricultural-irrigation practices in Carson Valley found concentrations of total phosphorus and orthophosphate consistently greater in surface return flows than in applied irrigation waters (Miller and others, 1977, 1978, and 1984), and that the net loss of orthophosphate from fields through surface return flow ranged from 0.8 to 2.7 lb/acre/yr. One major factor affecting the

Figure 12. Cattle near tributary to Carson River in Carson Valley. Although cattle can control tall white top near streams, they also can contribute to nutrient loading in surface-water bodies.

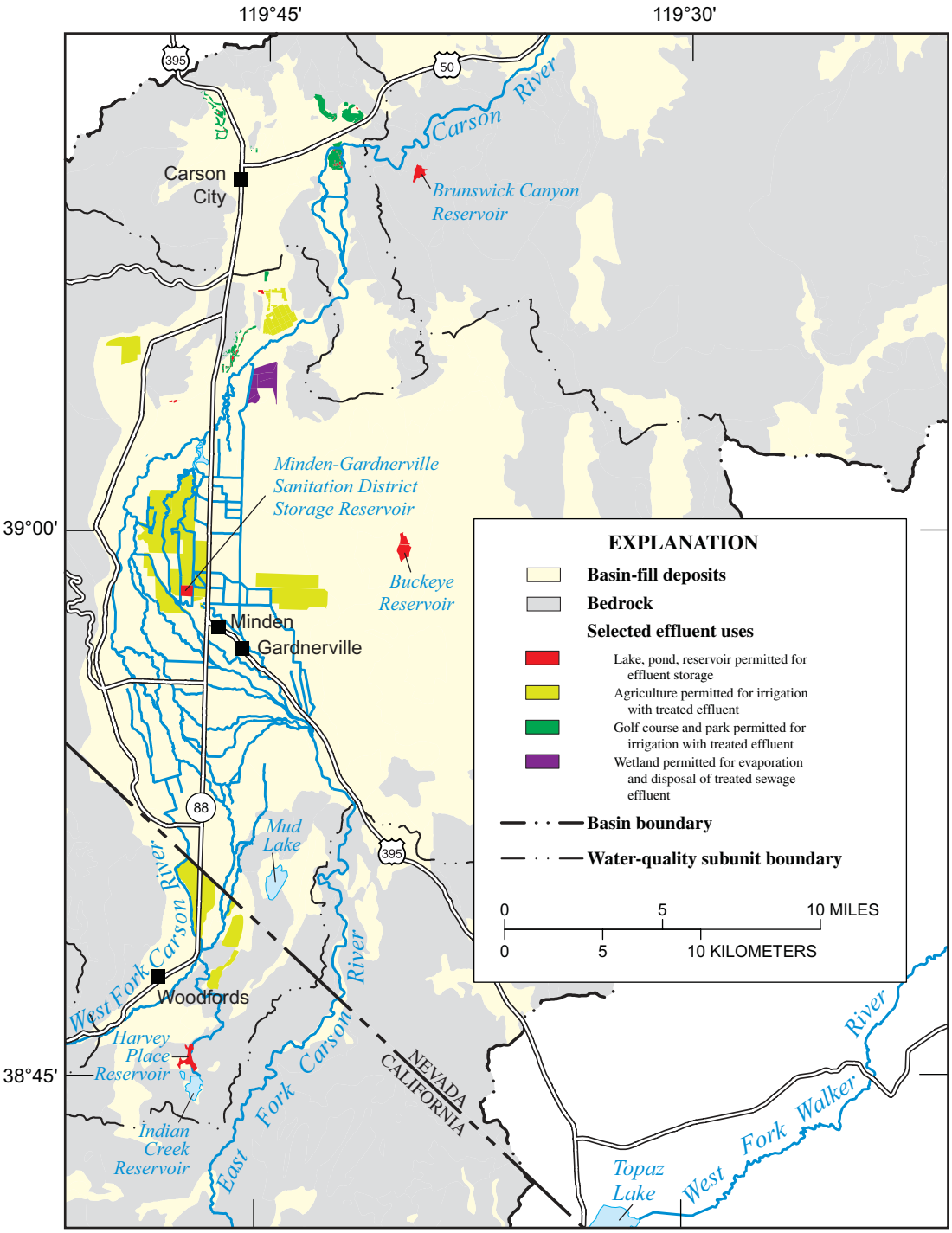
amount of phosphorus in runoff from agricultural land is the time, amount, and intensity of rainfall (Ryden and others, 1973). Runoff from fields during high-intensity storms can mobilize soils and nutrients that would normally remain in place. Once the soils and nutrients have been moved from fields to ditches, they can be carried to the Carson River in less energetic flow regimes.

The amount of fertilizers used is very important in determining the amount of phosphorus in runoff from agricultural land. Compared with much of the United States, very little phosphate fertilizer is used in western Nevada (Alexander and Smith, 1990). In 1985, phosphate-application rates between 0.01 and 0.4 tons/acre were used, whereas rates in the central valley of California and much of the Midwest exceed 2.9 tons/acre (Battaglin and Goolsby, 1995).

Treated Sewage Effluent

Phosphorus concentrations are high in sewage because phosphorus is excreted from the body in waste and because phosphorus is used in household products, principally laundry and dishwashing detergents. The phosphorus content of treated effluent depends on the level of treatment, and unless sewage is specially treated to remove phosphorus, effluent can contain high phosphorus concentrations. Effluent from septic systems, for example, typically contains about 15 mg/L total phosphorus (Cantor and Knox, 1985).

Except for one site, since 1987 treated effluent has been able to reach the Carson River only indirectly. Virginia City discharges its treated effluent to Six-Mile Canyon; however, flow in the creek seldom reaches the Carson River. Carson City stores treated effluent in Brunswick Canyon Reservoir (fig. 13) during winter for use during the rest of the year for irrigation of parks, golf courses, and the Nevada State Prison Farm/Dairy. The reservoir leaks an average of 3,015 acre-ft/yr (Fellos, 2001) and springs have developed downgradient of the reservoir. The phosphorus load to the Carson River from this source is not known. The phosphorus content of springs near the Carson River below the reservoir is reported as <0.1 mg/L total phosphorus (Robert J. Saunders, Carson City Wastewater Reclamation Facility, NEV90008DMR Summary, written commun., Jan. 21, 2003).



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

Figure 13. Areas permitted as of 2001 for storage, irrigation, evaporation, and disposal of treated sewage effluent in Carson and Eagle Valleys.

About 8,900 acres of agricultural fields, golf courses, and parks in the study area are permitted for irrigation using treated effluent (fig. 13). The treated effluent use and storage data are available as geospatial-digital data at URL <http://water.usgs.gov/lookup/getspatial?sir2004-5186_eff_p>.

Use of treated effluent on fields and green areas can be an important way of conserving high quality water for drinking instead of for agricultural purposes. In Nevada, permits issued for applying treated effluent to the land for irrigation prohibit runoff from the fields. In California, permits do not require the prevention of runoff containing treated effluent from reaching surface-water bodies (Paul Pugsley, U.S. Department of Agriculture, oral commun., May 6, 2003).

Fields have been irrigated with treated effluent since the late 1980's and this effluent may be an important source of phosphorus to the Carson River, even though effluent does not directly discharge to surface water. Treated effluent contains much greater phosphorus concentrations than pristine surface water in the Carson River watershed; thus, surficial soils will become phosphorus enriched during the irrigation season. All other things being constant, sediment carried from such fields during spring runoff or summer thunderstorms would carry proportionally more phosphorus to the river than sediment from fields not irrigated with effluent. In addition, drainwater from fields irrigated with effluent may contribute proportionally more phosphorus to streams than fields not irrigated with effluent. Although phosphorus moving through soils typically is removed from solution by adsorption to soil particles, adsorption sites in soils can become saturated with phosphorus if effluent is applied for sufficient time. To prevent salt buildup in irrigated soils, more water must be applied than the plants need. The end result is that drainwater from fields irrigated with effluent may be an important source of phosphorus to the Carson River.

Urban Runoff

Rainfall and snowmelt in urban areas is beneficial in that it cleans the areas, however, it also causes problems by carrying contaminants to local surface-water bodies (fig. 14). U.S. Environmental Protection Agency (1983) characterized contaminant concentrations in urban runoff from numerous sites across the United States in the Nationwide Urban Runoff Program (NURP). The median of the median total-phosphorus concentration at 39 residential areas was 0.345 mg/L; for 20 mixed residential and commercial/industrial areas was 0.321 mg/L; for 14 commercial/industrial areas was 0.202 mg/L; and for 8 urban open and nonurban areas was 0.176 mg/L (U.S. Environmental Protection Agency, 1983).

An important reason that phosphorus concentrations are greater in runoff from residential areas is that homeowners commonly over-fertilize and over-irrigate lawns. This results in fertilizers being washed off the lawns into the gutters where they end up in storm drains and eventually the river. The median total-phosphorus concentration in 28 samples of lawn runoff from two urban residential basins in Wisconsin was 1.1 mg/L (Waschbusch and others, 1999) and the maximum observed concentration was 10.7 mg/L. For comparison, the median total-phosphorus concentration in 50 samples of driveway runoff was 0.26 mg/L and the maximum was 3.1 mg/L.

The rapid urbanization of Carson and Eagle Valleys over the past decade (table 3) has resulted in the development of residential areas and several golf courses along the river corridor (fig. 15). Those golf courses using treated effluent for irrigation in Carson and Eagle Valleys are shown in figure 13. Runoff from storms and snowmelt in these areas is carried in storm drains to the Carson River or its tributaries with only minimal treatment to remove sand and oil from the water.

SAMPLE COLLECTION AND ANALYSIS

Location of Sampling Sites

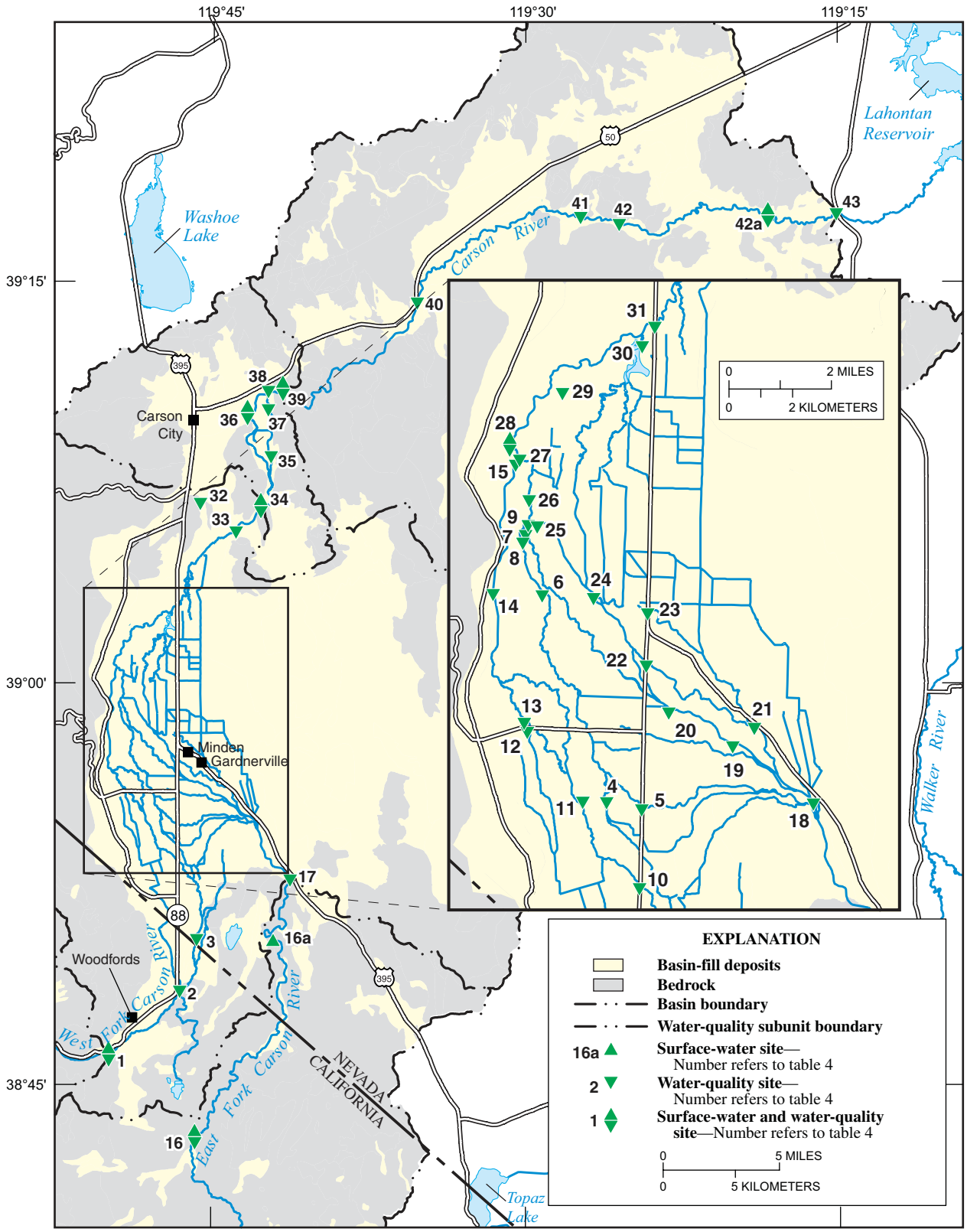
Samples for chemical analysis were collected from 43 sites in the Carson River Basin upstream from Lahontan Reservoir (fig. 16; table 4). Samples were collected from the mainstem of the river, diversions from the river, tributaries to the river, and sloughs and ditches carrying return flow to the river. Locations for sample collection were selected based on whether information obtained would aid in defining changes in water quality across important river reaches or aid in characterizing phosphorus contributions from different lands and land-use categories. The location of sampling sites as related to the overall flow system is shown in figure 5.

Water Samples

Water samples were collected using the equal-width increment method, which is a depth- and width-integration method (Wilde and others, 1998). When streams could be waded, samples for phosphorus analysis were collected using a DH-81 hand-held sampler (Shelton, 1994). When streams could not be waded, samples were collected from bridges or boats using a D-74AL cable–suspended sampler (Edwards and Glysson, 1999). When the river was too shallow to use the DH-81 (<3 in.), samples were collected by dipping a polypropylene bottle in the stream either at the centroid of flow or by dipping the bottle at several equal-width increments across the stream.

Figure 14. Urban runoff in Eagle Valley Creek following a winter rainstorm.

Figure 15. Golf course adjacent to Carson River in Carson Valley. Storm runoff from residential and green areas along the Carson River can carry phosphorus to the river.



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

Figure 16. Location of sampling sites in the Carson River Basin upstream from Lahontan Reservoir.

Table 4. Location of sampling sites and gaging stations, and the types of data collected at each site

[Abbreviations: USGS, U.S. Geological Survey; CR, Carson River; EFCR, East Fork Carson River; WFCR, West Fork Carson River; NDEP, Nevada Division of Environmental Protection; STPUD, South Tahoe Public Utility District]

Site no.[a]	USGS station no.	Latitude[b]	Longitude[b]	Station name	Types of data[c]	Comments on the location/reach[d]
				West Fork Carson River and tributaries		
1	10310000	38.76963	119.83379	West Fork Carson River at Woodfords, CA	P, S, B, N, Q	USGS gaging station. STPUD sampling site SW-01.
2	10310200	38.80879	119.77712	West Fork Carson River at Paynesville, CA	P	NDEP monitoring station C8. STPUD sample site SW-05.
3	10310220	38.84102	119.76379	West Fork Carson River at California–Nevada stateline	P, S, B, N	STPUD sampling site SW-06.
4	10310356	38.91324	119.79212	West Fork Carson River at Centerville Lane near Minden, NV	B	
5	10309082	38.91157	119.77934	Rocky Slough at Highway 88 near Minden, NV	P, S, B, N	The location sampled on Rocky Slough is about 1 mile upstream of its confluence with the WFCR. The Rocky Slough at this location only gives an estimate of water entering the WFCR since there are other return flows that enter Rocky Slough before its confluence with the WFCR. Rocky Slough is adjacent to a golf course and receives urban runoff from the Gardnerville Ranchos.
6	10310358	38.97102	119.81768	West Fork Carson River at Muller Lane near Minden, NV	P, S, B, N	NDEP monitoring station C14.
7	10309114	38.98796	119.82435	Home Slough above confluence West Fork Carson River near Minden, NV	P, S, B, N	
8	103103588	38.98574	119.82518	West Fork Carson River below confluence Home Slough near Genoa, NV	P, B	
9	10310359	38.99074	119.82351	West Fork Carson River above confluence East Fork Carson River near Genoa, NV	P, S, B, N	
				Brockliss Slough and tributaries		
10	10310240	38.88935	119.77934	Brockliss Slough at Highway 88 near Minden, NV	P, S, B, N	
11	10310258	38.91324	119.80073	Brockliss Slough at Centerville Lane near Minden, NV	B	
12	10310255	38.93241	119.82157	Big Ditch at Waterloo Lane near Minden, NV	P, S, B	
13	10310265	38.93491	119.82268	Johnson Slough below confluence Big Ditch near Minden, NV	P, S, B, N	
14	10310403	38.97102	119.83546	West Branch Brockliss Slough at Muller Lane near Minden, NV	P	NDEP monitoring station C5.
15	10310404	39.00769	119.82897	Brockliss Slough above confluence Carson River near Genoa, NV	P, S, B, N	
				East Fork Carson River and tributaries		
16	10308200	38.71463	119.76490	East Fork Carson River below Markleeville Creek near Markleeville, CA	P, S, B, N, Q	USGS gaging station.
16a	10309000	38.84714	119.70378	East Fork Carson River near Gardnerville, NV	Q	USGS gaging station. Streamflow at this gaging station used to calculate loads for site 17.
17	10309010	38.87824	119.68934	East Fork Carson River near Dresslerville, NV	P, S, B, N	NDEP monitoring station C9.
18	10309089	38.91463	119.71740	East Fork Carson River at River View Drive Bridge near Dresslerville, NV	P, B	
19	10309098	38.93018	119.74712	East Fork Carson River at Highway 756 Bridge at Gardnerville, NV	B	
20	10309100	38.93907	119.77073	East Fork Carson River at Minden, NV	B	NDEP monitoring station C16.
21	1030909018	38.93546	119.73962	Cottonwood Slough at Waterloo Lane at Gardnerville	P, S, B	
22	1030909020	38.95213	119.77934	Cottonwood Slough at Highway 88 near Minden, NV	P, S, B, N	Cottonwood Slough receives urban runoff from Minden and Gardnerville and irrigation return flow.
23	1030909042	38.96685	119.77934	Martin Slough at Highway 395 near Minden, NV	B	Martin Slough receives the majority of urban runoff from Minden and Gardnerville.
24	10309120	38.97074	119.79907	East Fork Carson River at Muller Lane near Minden, NV	P, S, B, N	NDEP monitoring station C15.
25	10309130	38.99046	119.82018	East Fork Carson River above confluence West Fork Carson River near Genoa, NV	P, S, B, N	On the EFCR from Muller Lane to the confluence with the WFCR, the streambanks are vertical and unstable.

Main Stem Carson River and tributaries						
26	10310405	38.99769	119.82351	Carson River at Genoa, NV	P, B	NDEP monitoring station C3. From the confluence of the EFCR and WFCR to Genoa Lane, the streambanks are unstable.
27	10310406	39.00907	119.82740	Carson River above confluence Brockliss Slough near Genoa, NV	P, B	
28	10310407	39.01241	119.83101	Carson River near Genoa, NV	P, S, B, N, Q	The golf course is adjacent to the Carson River. USGS gaging station established in October 2002.
29	10310419	39.02824	119.81268	Williams Slough near Genoa, NV	P, S, B, N	
30	10310448	39.04213	119.78435	Ambrosetti Pond Outlet near Genoa, NV	P, S, B, N	USGS gaging station. Ambrosetti Pond receives irrigation tailwater/return water from a significant portion of the Carson Valley. Treated effluent is used to irrigate fields from Muller Lane to Johnson Lane, bounded by the CR and Highway 395 and ditches in this area lead to Ambrosetti Pond. However, the effluent is not allowed to enter Ambrosetti pond based on the NDEP permits.
31	10310450	39.04769	119.77990	Carson River at Cradlebaugh Bridge near Genoa, NV	P, S, B, N	NDEP monitoring station C2. Between Genoa Lane and Cradlebaugh Bridge the streambanks are unstable. Between Cradlebaugh Bridge and the confluence with Clear Creek, the streambanks are vertical and unstable.
32	10310525	39.11269	119.76157	Clear Creek at Center Street near Carson City, NV	P, S, B, N	Urban runoff from the south end of Carson City discharges to Clear Creek.
33	10310550	39.09491	119.73296	Clear Creek above confluence Carson River near Carson City, NV	P, S, B	Urban runoff from the south end of Carson City discharges to Clear Creek. Agricultural input from prison farms.
34	10311000	39.10769	119.71323	Carson River near Carson City, NV	P, S, B, N, Q	USGS gaging station. NDEP monitoring station C13. Located at downstream end of Carson Valley.
35	10311008	39.14185	119.70518	Carson River at Lloyds Bridge near Carson City, NV	P, S	
36	10311300	39.16547	119.72407	Eagle Valley Creek at Carson City, NV	P, S, B	USGS gaging station.
37	10311325	39.17102	119.70740	Eagle Valley Creek above confluence Carson River near Carson City	P, S, B, N	Eagle Valley Creek receives the majority of urban runoff from Carson City.
38	391057-119422301	39.18241	119.70740	Eagle Valley Golf Course drain at Empire, NV	P, S, B	May contain urban runoff from Carson City.
39	10311400	39.18102	119.69546	Carson River at Deer Run Road near Carson City, NV	P, S, B, N, Q	USGS gaging station. NDEP monitoring station C1. Located downstream from golf course adjacent to CR. Located at downstream end of Eagle Valley.
40	10311700	39.23769	119.58823	Carson River at Dayton, NV	P, S, B, N	NDEP monitoring station C11. USGS gaging station re-established in October 2002.
41	10311860	39.29103	119.45739	Carson River at Chaves Ranch near Clifton, NV	P, S, B	
42	10311870	39.28658	119.42656	Carson River below Chaves Ranch near Clifton, NV	P, S, B, N	
42a	10312000	39.29158	119.31211	Carson River near Fort Churchill, NV	Q	USGS gaging station. Streamflow at this gaging station used to calculate loads for site 43. Some USGS water-quality data from this site was used to calculate loads for site 43. Data from water years 1988–95.
43	10312020	39.29297	119.25238	Carson River near Silver Springs, NV	P, S	NDEP monitoring station C10. Located at downstream end of Dayton–Churchill Valleys.

[a]Used in figures 4, 5, and 16.

[b]Horizontal coordinate information is rounded and referenced to the North American Datum of 1983 (NAD 83).

[c]P, total-phosphorus and orthophosphate concentrations for surface water are provided in appendix 1. S; suspended-sediment concentrations are provided in appendix 1. B, phosphorus concentrations in streambed and streambank sediment are presented in appendix 2. N, nitrogen concentrations in surface water are provided in appendix 3. Q, daily mean discharge values for water year 2001 are presented by Garcia and others (2002) and for water year 2002 by Berris and others (2003).

[d]Information about NDEP monitoring stations from Nevada Division of Environmental Protection (2002a).

Samples for phosphorus analysis were composited in an 8-L churn-splitter. Water samples were analyzed for phosphorus by two laboratories, the USGS National Water Quality Laboratory (NWQL) in Lakewood, CO, and the Nevada State Health Laboratory (NSHL) in Reno, NV. Total-phosphorus samples analyzed by NSHL were unfiltered and acidified in the field using a 10 percent (3.75 N) sulfuric acid solution. Orthophosphate samples were filtered at NSHL before analysis. Samples analyzed by NSHL were chilled on ice and delivered to the laboratory on the night of sample collection or the following morning. Total-phosphorus samples analyzed by NWQL were preserved in the field using 4.5 N sulfuric acid. Orthophosphate samples analyzed by NWQL were filtered in the field using 0.45 µm capsule filters. Samples analyzed by NWQL were chilled on ice and delivered using next-day courier to the laboratory. Analytical methods followed by NWQL are described in Fishman and Friedman (1989) and methods followed by NSHL are described in Eaton and others (1995). All phosphorus concentrations are reported as phosphorus.

Data collected as part of this investigation are presented for the convenience of future researchers (apps. 1 and 2). As part of a separate project by Carson Water Subconservancy District (CWSD), some water samples collected during this study also were analyzed by NSHL for nitrogen species (app. 3) following methods described in Eaton and others (1995). The performance of NSHL and the methods they used for nitrogen species have not been evaluated by USGS.

Suspended-Sediment Samples

Samples of suspended sediment were collected using a DH-48 sampler when streams were wadeable and were collected using a D-74 aluminum sampler (Edwards and Glysson, 1999) from bridges or boats when streams were not wadeable. When the river was too shallow (<3 in.) to use the DH-48, samples were collected by dipping a glass bottle in the stream either at the centroid of flow or by dipping the bottle at several equal-width increments across the stream. Samples were sent to the USGS sediment lab in Marina, CA, where they were analyzed for suspended-sediment concentration and percent suspended sediment finer than 0.062 mm (sand), following methods described by Guy (1969).

Samples for total suspended-solids analysis were collected following methods described in the Water Samples section and then composited in an 8-L churn-splitter. A subsample was collected from the churn-splitter and analyzed for total-suspended solids at NSHL following methods described in Eaton and others (1995).

Streambank- and Streambed-Sediment Samples

Collection of streambed-sediment samples consisted of obtaining from 5 to 10 subsamples of the upper 1 cm from depositional areas of the stream followed by compositing the subsamples in a glass bowl (Shelton and Capel, 1994). Streambank samples were collected in a similar manner from the upper 1 cm from areas about 0.3 to 0.6 m below the top of natural banks. Approximately 100 g of composited material was sieved through a 2 mm sieve into widemouth polypropylene bottles and sent to NWQL for analysis. Some samples were stored in the freezer prior to shipping to NWQL. In the laboratory, all forms of phosphorus were converted to orthophosphate by an acid-persulfate digestion, then measured by colorimetric methods (Fishman and Friedman, 1989).

Quality Control

Quality control consisted of collection and analysis of field-split replicate samples for water, streambank- and streambed-sediment samples, and analysis of field equipment blanks and source-water blanks for water samples. All equipment blanks and source-water blanks had total-phosphorus and orthophosphate concentrations less than the laboratory reporting level, indicating that the equipment used for water samples was sufficiently cleaned between each use and that no sample contamination occurred from the equipment or methods used to collect and process samples. Twenty-three field-split replicate water samples indicate good agreement between total-phosphorus concentrations in environmental sample and replicate sample (app. 1) in all but one case. In that sample, the total-phosphorus concentration was 0.30 mg/L in the environmental sample and 0.49 mg/L in the replicate.

The quality of the NSHL data for total phosphorus and orthophosphate was evaluated and approved by the USGS NWQL Branch of Quality Systems. NSHL analyzed standard reference samples provided by the USGS and was rated good to excellent in terms of their performance. NSHL was not evaluated for total-suspended solids (app. 1) or for the nitrogen species listed in appendix 3.

DISCUSSION OF RESULTS

Water-Quality Subunits

For this study, the Carson River Basin upstream from Lahontan Reservoir was divided into five water-quality subunits using topographic divides (fig. 4) that roughly correspond to hydrographic areas defined by Rush (1968). The locations of five sampling sites associated with gaging stations (sites 1, 17, 34, 39, and 43; fig. 4) are used to divide the Carson River into five reaches. Sample collection sites 17 and 43 are slightly downstream of gaging stations at sites 16a and 42a (fig. 16), respectively. Land contributing runoff to each of the five reaches was mapped to create five subunits (Upper West Fork, Upper East Fork, Carson Valley, Eagle Valley, and Dayton–Churchill Valleys). Characteristics of the subunits related to geology, soils, land use, and use of treated effluent for irrigation are listed in table 5.

Table 5. Land characteristics for Carson River water-quality subunits

[Symbol: ≥, greater than or equal to]

Land characteristics	Subunits (acres)				
	Upper West Fork	Upper East Fork	Carson Valley	Eagle Valley	Dayton–Churchill Valleys
GEOLOGY (fig. 2)					
Basin-fill deposits	11,819	26,154	130,666	19,173	84,601
Tertiary sedimentary rocks	0	43	42,297	0	20,084
Metasedimentary and metavolcanic rocks	2,322	8,223	31,493	13,625	18,485
Basic volcanic rocks	9,851	132,928	17,343	2,719	167,820
Silicic volcanic rocks	25	14,044	1,920	1,395	13,102
Intrusive igneous rocks	17,857	58,536	61,783	9,567	21,623
SOIL CLAY CONTENT (fig. 3*A*)					
0 to 12.49 percent	41,874	112,197	75,722	23,887	13,112
12.5 to 19.99 percent	0	22,500	67,852	0	70,730
20 to 24.99 percent	0	2,365	80,308	7,426	84,589
25 to 29.99 percent	0	100,387	45,673	6,181	147,551
≥30 percent	0	2,479	16,032	8,985	9,733
SOIL ERODIBILITY FACTOR (fig. 3*B*)					
0 to 0.20	41,789	132,058	47,874	11,753	102,639
0.21 to 0.25	85	2,707	126,942	11,014	82,540
0.26 to 0.30	0	102,684	94,739	14,748	113,391
0.31 to 0.35	0	2,479	16,032	8,964	13,995
0.36 to 0.42	0	0	0	0	13,150
LAND USE (fig. 9)					
Alpine	334	8,482	1,640	0	0
Barren	2,298	247	1,204	325	5,414
Forest	33,220	171,827	124,371	8,947	84,368
Range	5,942	58,691	100,335	27,935	228,853
Wetland	0	305	5,319	0	2,281
Open water	80	330	465	0	26
Agriculture	0	0	45,830	1,803	3,932
Urban	0	46	6,423	7,469	841
TREATED SEWAGE EFFLUENT PERMITTED FOR IRRIGATION AND STORAGE (fig. 13)					
Agricultural fields	0	0	8,134	0	0
Golf courses	0	0	122	587	0
Parks	0	0	22	40	0
Storage facilities	0	0	441	37	82
Wetlands	0	0	887	0	0

Phosphorus in Water

Phosphorus Concentrations

Total-phosphorus concentrations in surface-water samples collected by the USGS in the study area during WY 2001–02 ranged from <0.01 to 1.78 mg/L and orthophosphate concentrations ranged from <0.01 to 1.81 mg/L (app. 1). One value for total phosphorus was reported as 7.32 mg/L (site 29; app. 1); however, this likely is a laboratory error. The greatest phosphorus concentrations consistently were measured at two sites in Carson Valley, Williams Slough (site 29) and Ambrosetti Pond Outlet (site 30).

In the Carson River system, median total-phosphorus concentrations are low in the headwaters, increase substantially in Carson Valley, and then decrease slightly in a downstream direction. Median concentration at the downstream site for each water quality subunit using data collected from USGS, NDEP, and STPUD for WY 1988–2002 is listed in table 6. At the headwater sites (sites 1 and 17) median total-phosphorus concentrations were 0.02 and 0.04 mg/L, respectively, and the median orthophosphate concentrations were <0.01 and 0.01 mg/L. The median total-phosphorus and orthophosphate concentrations downstream of Carson Valley (site 34) were 0.20 and 0.11 mg/L, respectively. Downstream of Eagle Valley (site 39) the concentrations were 0.17 and 0.08 mg/L, respectively, and downstream of Dayton–Churchill Valleys (site 43) were 0.10 and 0.06 mg/L, respectively.

Phosphorus in the Carson River varies seasonally in total concentration and in the proportional abundance of particulate phosphorus and orthophosphate (figs. 17–18). Concentrations of total phosphorus vary slightly throughout the year at site 1, although the greatest median concentrations for total phosphorus are in April and May (fig. 17*A*). At site 17, the seasonal changes in total-phosphorus concentrations are more pronounced, with the greatest median concentration in May (fig. 17*B*). Rangeland and forested areas in the watershed above site 17 contribute sufficient phosphorus that the Nevada water-quality standard is exceeded in about 18 percent of the samples. The majority of samples exceeding the water-quality standard of 0.1 mg/L occur in March, April, and May during spring runoff. For sites 34 and 39, most of the samples exceed the water-quality standard throughout the year, with the greatest median total-phosphorus concentrations observed during the spring and summer months (figs. 17*C*, *D*). Median total-phosphorus concentrations are lower at site 43 than at sites 34 and 39. For site 43, the median monthly concentrations are lower than the water-quality standard during 5 months of the year (fig. 17*E*).

Only total phosphorus and orthophosphate were measured in water samples, and for this study, particulate phosphorus is estimated as total phosphorus minus orthophosphate. Particulate phosphorus defined this way includes phosphorus bound to clays, minerals, and decaying organic matter; phosphorus incorporated into living tissue (for example, algae/bacteria); and dissolved-nonorthophosphate forms of phosphorus (for example, $CaPO_4$). The ratio of orthophosphate to total-phosphorus concentration is used to determine whether orthophosphate or particulate phosphorus dominates the total-phosphorus concentration. When the ratio is greater than 0.5, orthophosphate dominates the sample and when the ratio is 1 all the phosphorus is orthophosphate. Conversely, when the ratio is less than 0.5, particulate phosphorus dominates the sample. Knowledge about the forms of phosphorus is useful in determining phosphorus sources.

The proportions of orthophosphate and particulate phosphorus in the Carson River change throughout the year (fig. 18). Particulate phosphorus is the dominant form at sites 17, 34, 39, and 43 during the month of May, when streamflow is the highest from spring snowmelt and runoff. At the West Fork Carson River at Woodfords (site 1) several of the samples are less than the detection limit (<0.01 mg/L) for either total phosphorus or orthophosphate, so there are few usable samples for calculating the orthophosphate/total-phosphorus ratio. In the headwater reaches (sites 1 and 17), particulate phosphorus is the dominant form during spring and early summer (figs. 18*A*, *B*). Downstream of Carson Valley at Carson River near Carson City (site 34), a change is observed in the composition of phosphorus. At site 34, orthophosphate concentrations are greater than particulate-phosphorus concentrations during most of the year. Only during spring are particulate-phosphorus concentrations the same as or greater than orthophosphate concentrations (fig. 18*C*). Similar trends are found at Carson River at Deer Run Road (site 39) downstream of Eagle Valley, and Carson River near Silver Springs (site 43) downstream of Dayton–Churchill Valleys.

The composition of the phosphorus changes during summer from particulate phosphorus entering Carson Valley to orthophosphate leaving Carson Valley. This change could indicate that particulate phosphorus entering Carson Valley is settling out, when water is applied to fields for example, and is being replaced by orthophosphate from other sources. Alternatively, the particulate phosphorus could be converted to orthophosphate as it travels across Carson Valley. Data collected during the study are not sufficient to distinguish between the possibilities. The rate at which orthophosphate is released from particulate phosphorus depends on the composition of the particulate phosphorus and the environmental setting. The composition of the particulate phosphorus is not known for Carson Valley, but is important because release of bioavailable phosphorus from organic particulate phosphorus can be relatively rapid compared to release from inorganic particulate phosphorus (Reid and Wood, 1976).

Phosphorus Loads and Yields

The phosphorus load in a stream is the amount of phosphorus transported by the stream in a given amount of time. Instantaneous phosphorus loads (in pounds per day) were calculated by multiplying phosphorus concentrations (in

Table 6. Statistical summary of phosphorus concentrations for water samples collected between 1988 and 2002

[Abbreviation: P, phosphorus. Symbol: <, less than]

Site no. (see fig. 16)	Station name	Number of samples	Phosphorus concentration (milligrams per liter as P)						
			Minimum	Maximum	Percentiles				
					10th	25th	50th	75th	90th
		Total phosphorus							
1	West Fork Carson River at Woodfords, CA[a]	75	<0.01	0.14	<0.01	0.01	0.02	0.02	0.04
17	East Fork Carson River near Dresslerville, NV[b]	152	<0.01	0.44	0.02	0.02	0.04	0.06	0.44
34	Carson River near Carson City, NV[b]	112	0.06	0.56	0.10	0.14	0.20	0.27	0.56
39	Carson River at Deer Run Road, NV[b]	132	0.02	0.64	0.08	0.11	0.17	0.23	0.28
43	Carson River near Silver Springs, NV[c]	159	0.02	3.2	0.06	0.08	0.10	0.16	0.25
		Dissolved orthophosphate							
1	West Fork Carson River at Woodfords, CA[a]	74	<0.01	0.07	<0.01	<0.01	<0.01	<0.01	0.01
17	East Fork Carson River near Dresslerville, NV[b]	152	<0.01	0.21	<0.01	0.01	0.01	0.02	0.03
34	Carson River near Carson City, NV[b]	112	0.03	0.53	0.05	0.06	0.11	0.18	0.28
39	Carson River at Deer Run Road, NV[b]	132	0.01	0.34	0.04	0.06	0.08	0.14	0.18
43	Carson River near Silver Springs, NV[c]	152	0.01	0.15	0.03	0.05	0.06	0.08	0.09

[a]Data from South Tahoe Public Utility District and U.S. Geological Survey.

[b]Data from Nevada Division of Environmental Protection and U.S. Geological Survey.

[c]Data from Nevada Division of Environmental Protection and U.S. Geological Survey. Water-quality data from station 10312000, Carson River near Fort Churchill, NV (site 42a), was included with water-quality data from Carson River near Silver Springs.

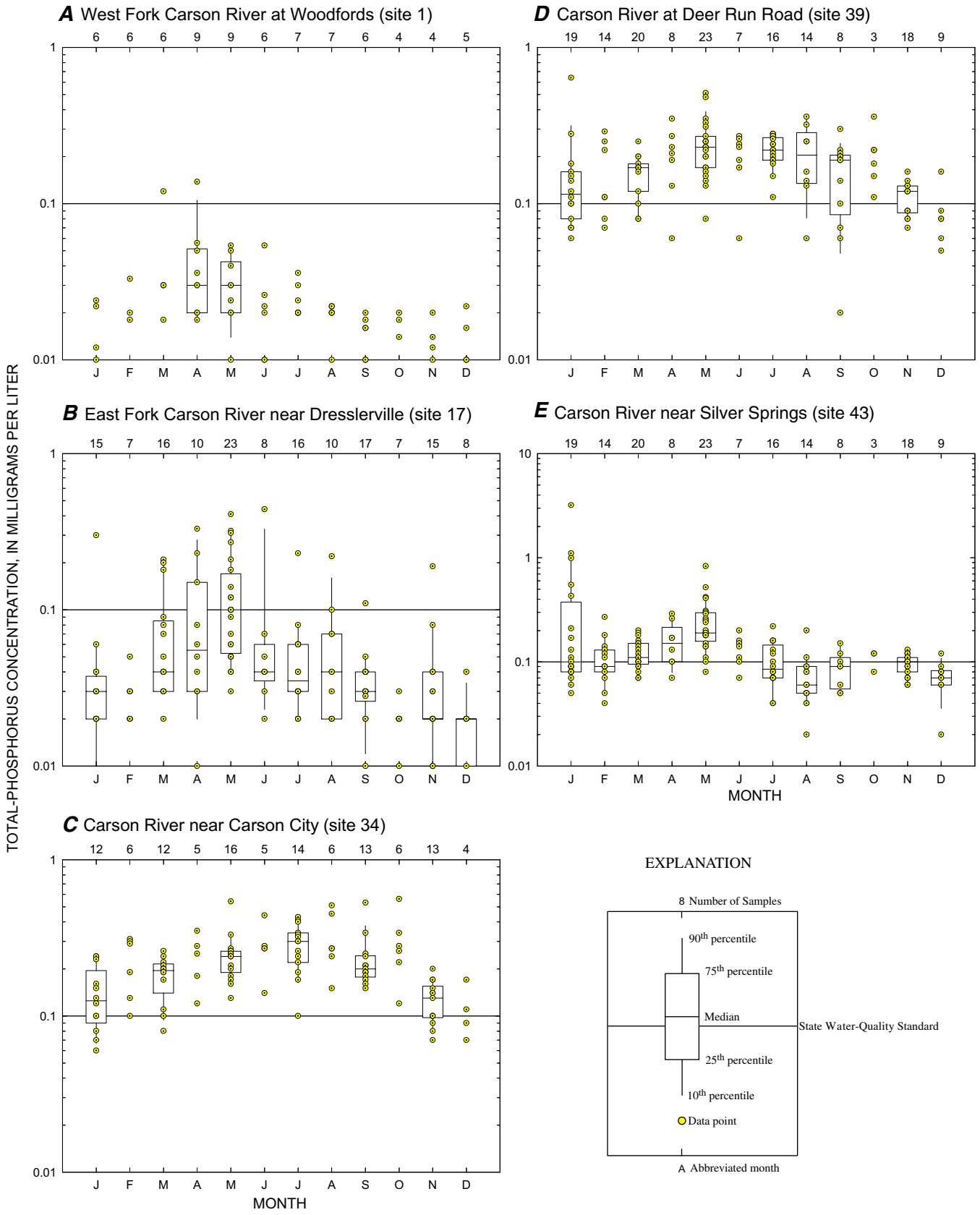


Figure 17. Total-phosphorus concentrations at selected sites in the Carson River Basin, 1988–2002.

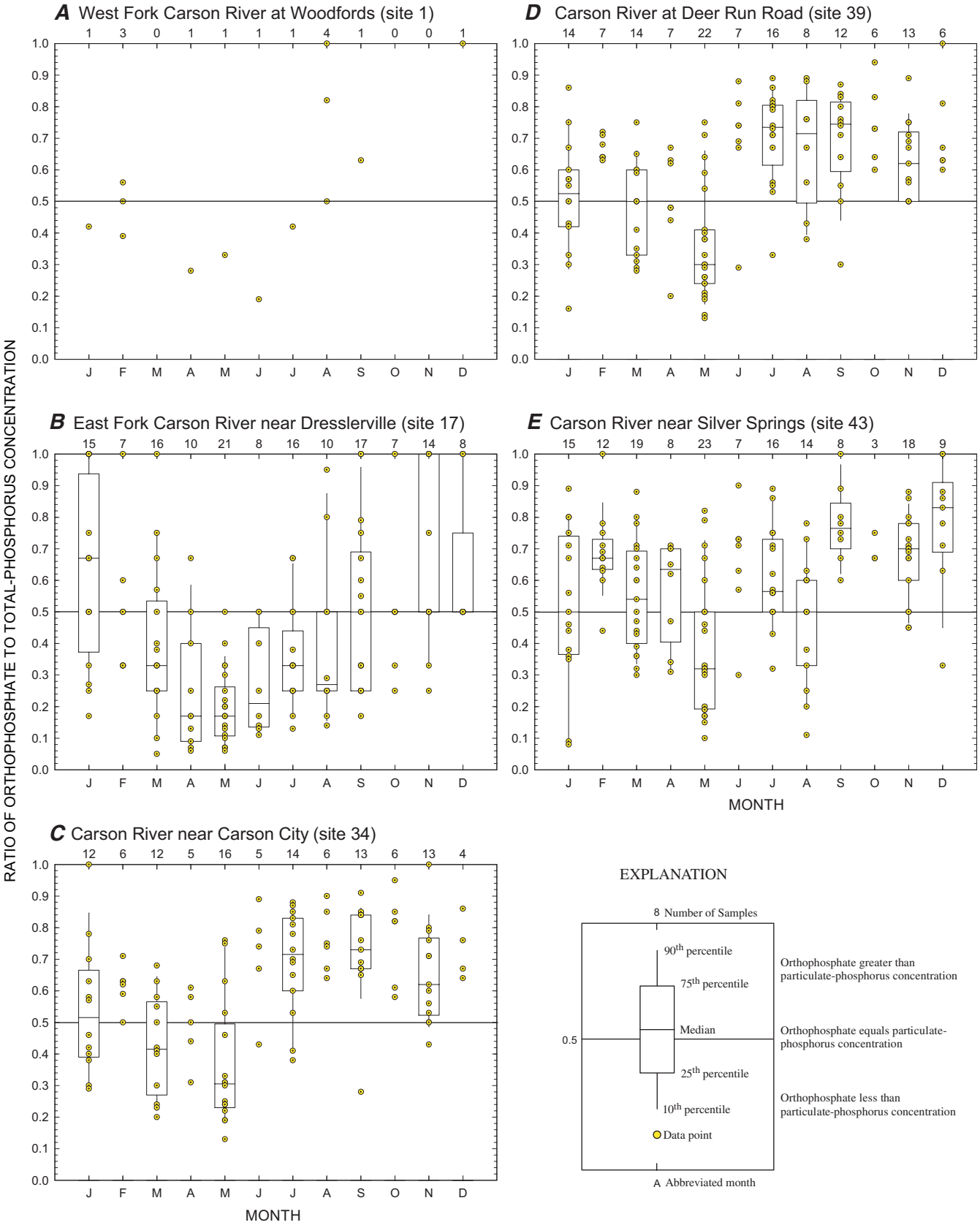


Figure 18. Ratio of orthophosphate to total-phosphorus concentrations at selected sites in the Carson River Basin, 1988–2002.

milligrams per liter) by instantaneous discharge (in cubic feet per second) and by a unit conversion factor (5.39). In cases where the total-phosphorus concentration was less than the detection limit, half the detection limit was used to estimate the load. Instantaneous discharge at the time of sample collection was either measured using a current meter or flume, or determined at a gaging station using the recorded gage height and active rating curve. When discharge was not measured during sample collection at sites 17 and 43, instantaneous phosphorus loads were calculated using recorded gage height and active rating curves for sites 16a and 42a (fig. 16). Gaging stations at sites 16a and 42a are slightly upstream of where samples are collected at sites 17 and 43, respectively. Only samples collected after 1988 were used to develop the regressions because, prior to 1988, discharge from sewage treatment plants was often the dominant source of phosphorus to the river.

Regression equations relating instantaneous total-phosphorus loads (in pounds per day) and instantaneous discharge were developed at the sites associated with active USGS gaging stations (sites 1, 17, 34, 39, and 43). The number of samples used in the regressions ranged from 75 for site 1 to 159 for site 43. Daily total-phosphorus loads for WY 2001–02 at sites 1, 34, and 39 were estimated by applying the regression equations to daily mean discharge for the site. Daily total-phosphorus loads at sites 17 and 43 were estimated applying the regression equations to daily mean discharge for sites 16a and 42a, respectively. Regressions were not developed for orthophosphate loads.

Data collected solely for this study during WY 2001–02 were not sufficient to develop statistically significant regressions that cover the range of discharges observed in the river since 1988. At some sites USGS collected numerous samples between 1993 and 2002 as part of NAWQA and the data from other USGS studies were combined with water-quality data from NDEP at sites 17, 34, 39, and 43 and from STPUD at site 1 and incorporated into the regressions. This substantially increased the number of samples and the range of discharge for which samples were available. For non-USGS data, only data that had a sample-collection time associated with it was used because the time was needed to determine instantaneous discharge.

STPUD has collected samples monthly at site 1 since 1981, however, the time of sample collection is not recorded in computer files for samples collected before December 1997. Therefore, only STPUD data since December 1997 was used for the regression analysis. In a few instances at site 1, usually during the winter when ice affects the gaging station, instantaneous-discharge values were not available. In those cases, the estimated daily mean discharge for the day of sample collection was used instead of an instantaneous discharge to calculate an instantaneous phosphorus load.

NDEP and STPUD use grab-sampling techniques to collect water samples, which may underrepresent total-phosphorus concentrations (Martin and others, 1992). NDEP personnel lower a churn-splitter over the edge of the bridge into the centroid of flow to collect samples during high flow. STPUD personnel collect samples 3–6 in. below the stream surface from the channel edge using a 6-ft long pole with a bottle attached. Bias caused by grab sampling is likely to occur during high discharge when concentrations in the stream may be nonuniform and when high velocity affects movement of fine particles into the sample collection device. The regression curves in figures 19–23 do not indicate a substantial difference between loads determined using USGS, NDEP, and STPUD methods. For this reason, all data available at a given site were combined to generate the regression equations.

As previously discussed, the largest flows and phosphorus concentrations occur during spring runoff (fig. 17). Following NDEP protocol, samples are collected on a fixed schedule every 2 months. The result of this fixed sampling is that the majority of NDEP samples are collected during low flow and that relatively few samples are collected at high flow during spring runoff (figs. 20–23). During this investigation USGS attempted to collect several samples at the gaged sites during spring runoff to better define the upper end of the regression curves (figs. 19–23).

Simple linear regression (SLR) analysis was conducted on natural logarithms of total-phosphorus loads and streamflow using the following model:

$$\ln[load] = \beta_0 + \beta_1 \ln[Q] \qquad (1)$$

where:

- ln[] is the natural logarithm function,
- *load* is total-phosphorus load, in pounds per day,
- β_0 is the intercept coefficient,
- β_1 is the slope coefficient, and
- Q is streamflow, in cubic feet per second.

The regression coefficients and coefficient of determination (R^2) values are listed in table 7 and shown in figures 19–23. The R^2 values range from 0.85 to 0.96; however, R^2 values alone do not guarantee a good model. The residual is the difference between the observed and predicted values and was calculated for each data point. SLR assumes residuals are independent and normally distributed, with zero mean and equal variance (Helsel and Hirsch, 1992). Plots of residuals versus predicted values and residuals versus time for the five regressions show little evidence of structure and that the residuals are near normally distributed, indicating the simple linear-regression models are acceptable.

Daily mean streamflow from the gaged stations was used as the input variable Q in equation 1 along with coefficients listed in table 7 to estimate daily mean total-phosphorus loads. The results from equation 1 were retransformed to estimate total-phosphorus load in original units. The estimated load in the original units was then multiplied by a ‘bias-corrector,’ as described by Helsel and Hirsh (1992, p. 257). The regression equations cannot be used directly because simply transforming estimates into original units provides an estimate of load that is biased low (Helsel and Hirsh, 1992, p. 257). The bias-correctors used to compensate for this bias are listed in table 7.

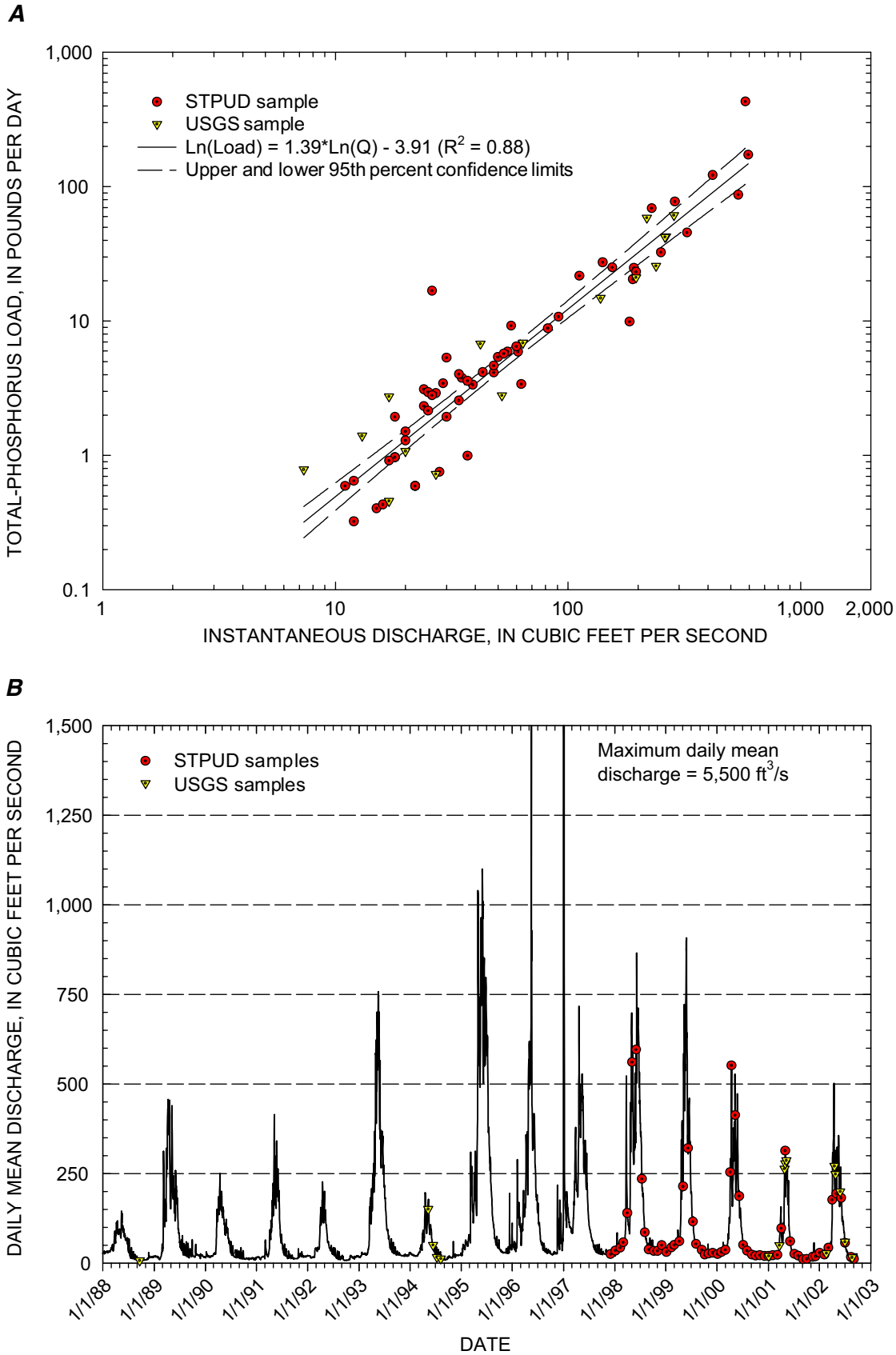


Figure 19. Relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 1, West Fork Carson River at Woodfords (10310000).

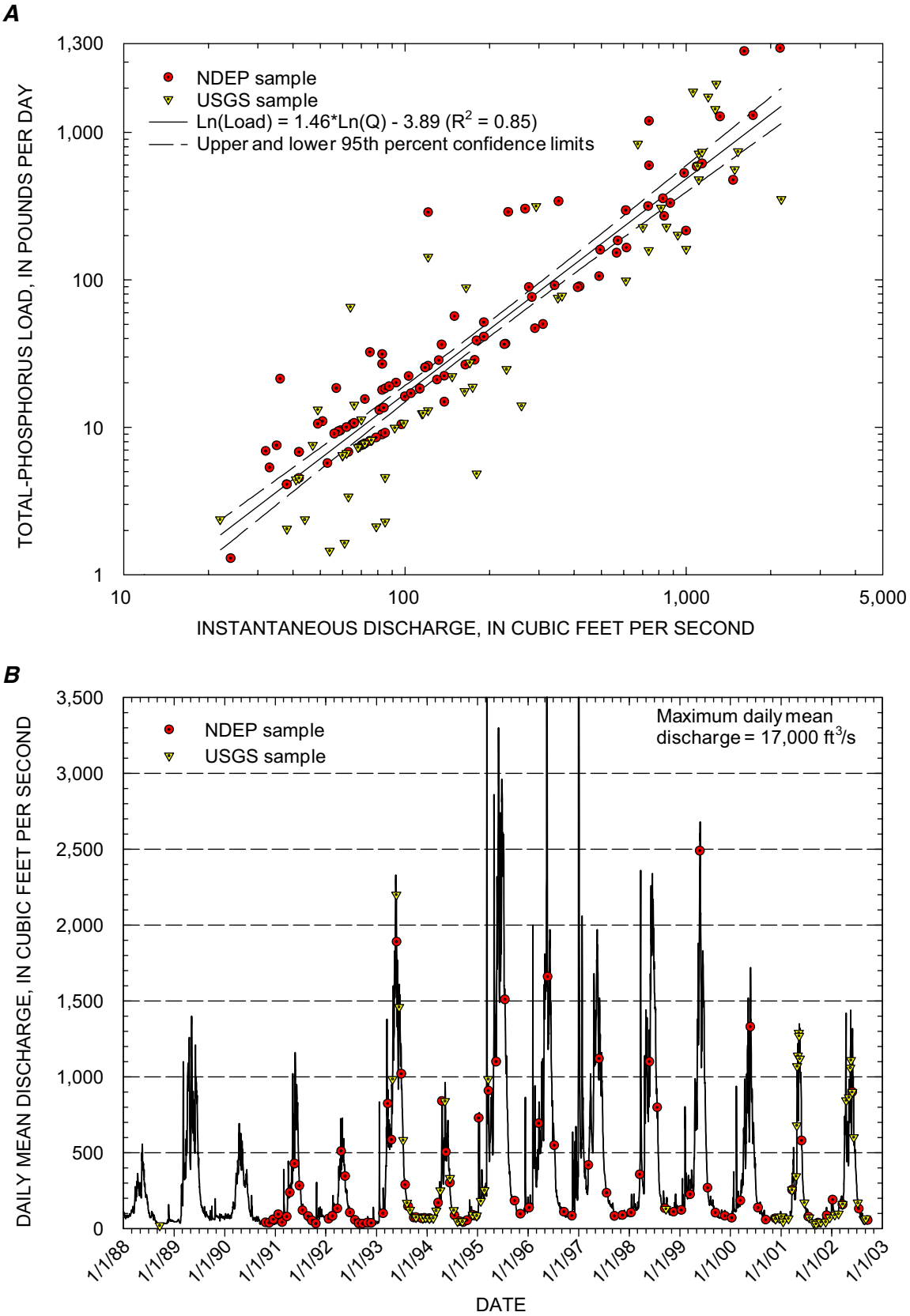


Figure 20. Relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 17, East Fork Carson River near Dresslerville (10309010).

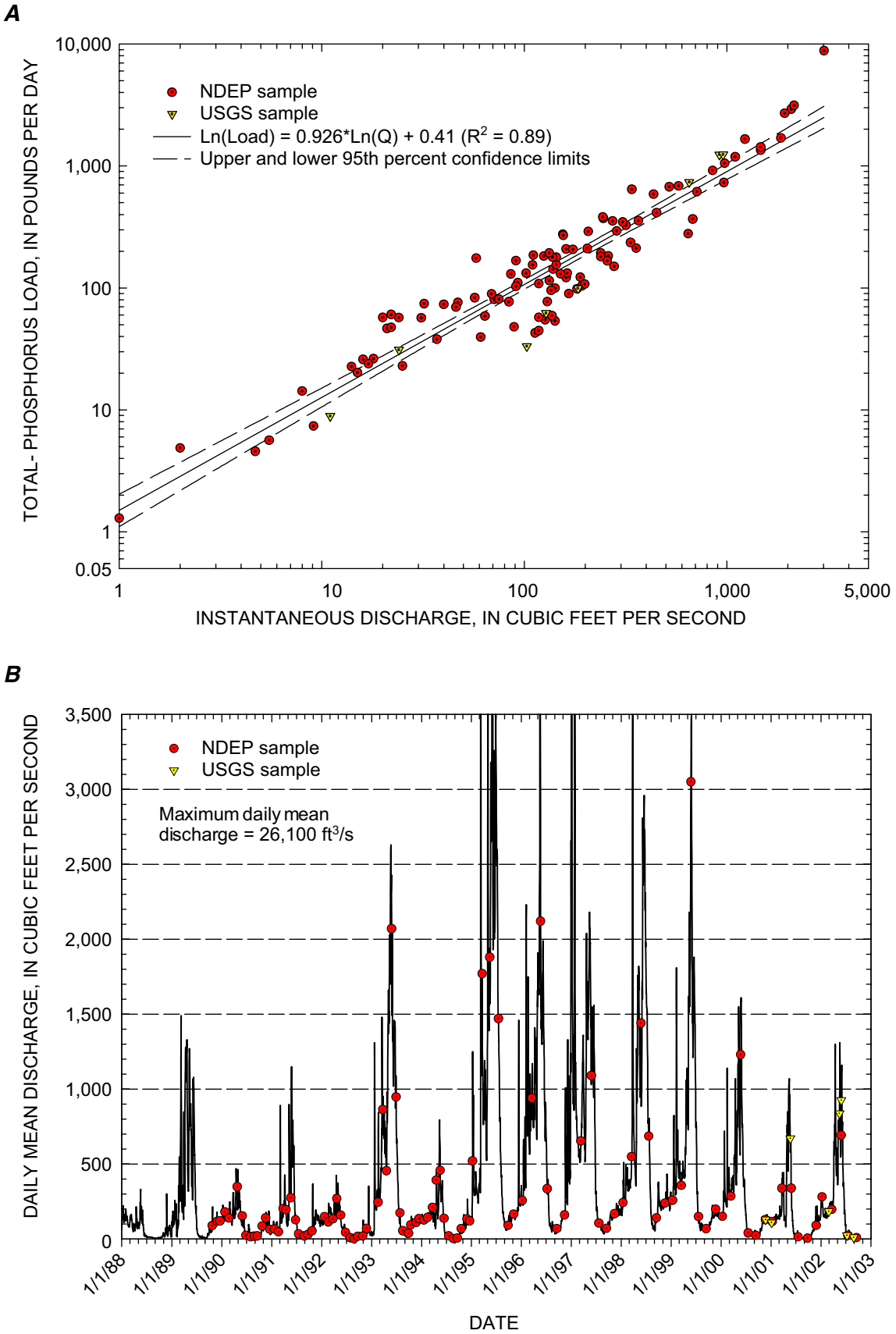


Figure 21. Relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 34, Carson River near Carson City (10311000).

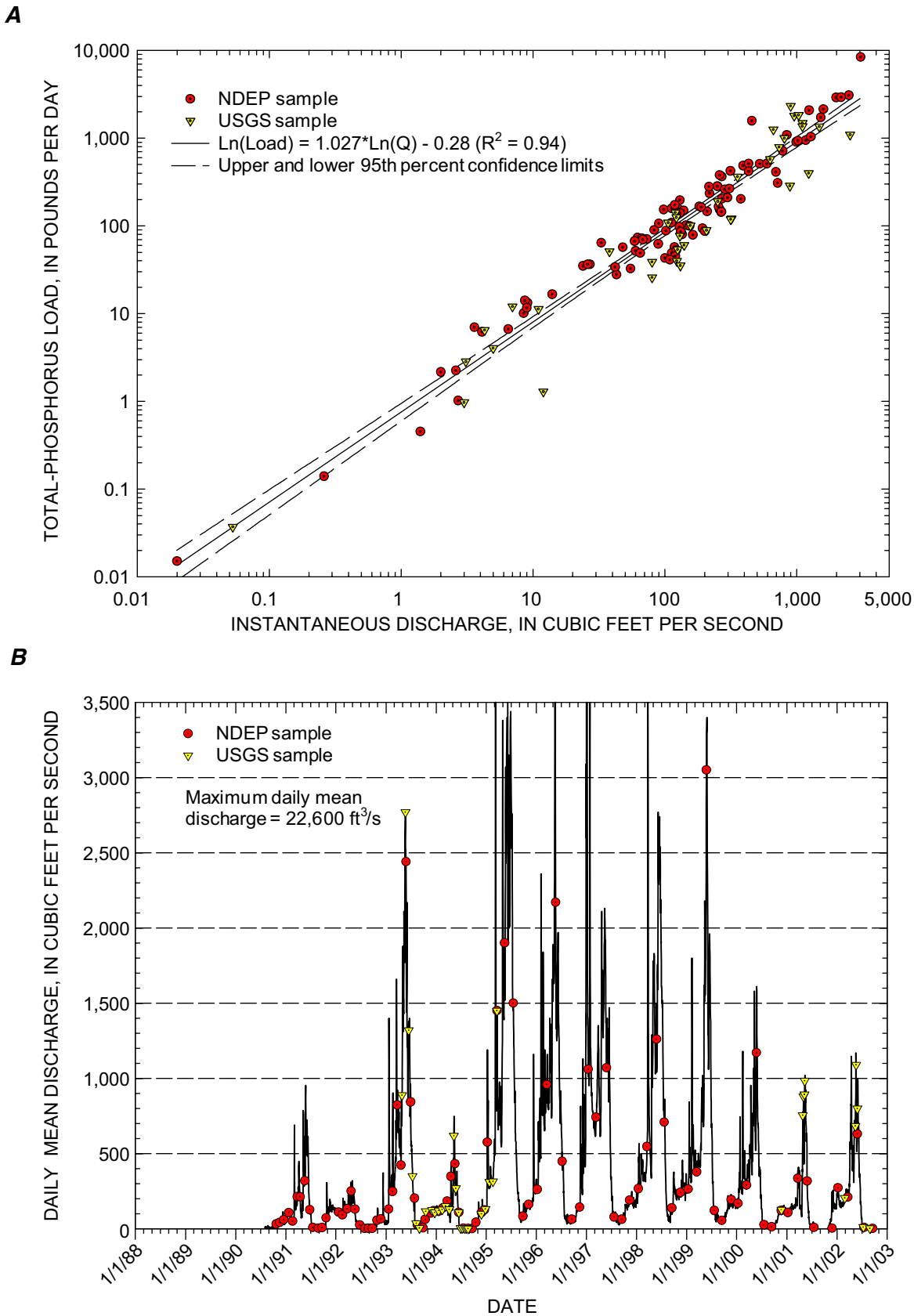


Figure 22. Relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 39, Carson River at Deer Run Road (10311400).

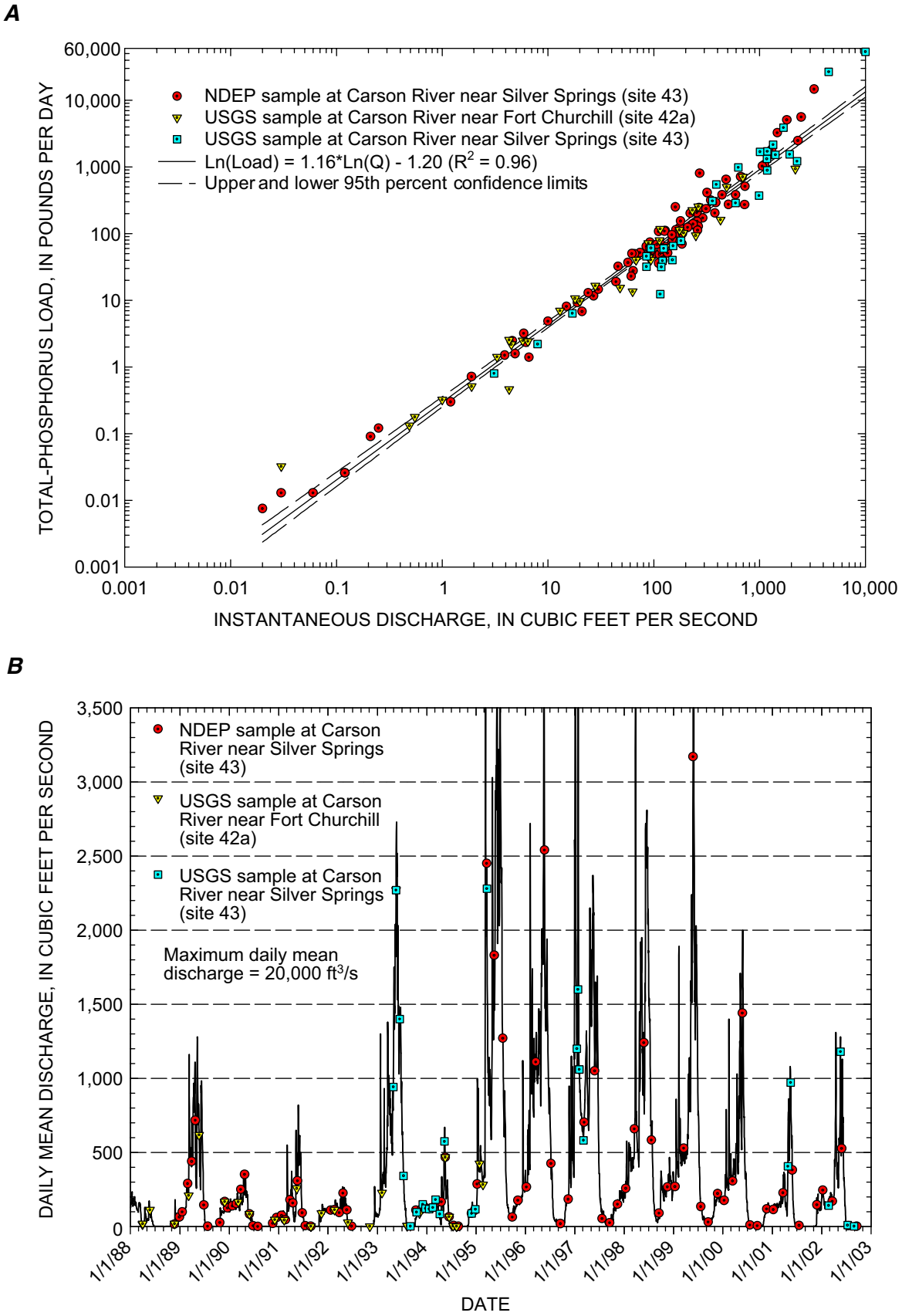


Figure 23. Relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 43, Carson River near Silver Springs (10312020).

Table 7. Coefficients and bias correctors for total-phosphorus load regressions for samples collected between 1988 and 2002

[Symbol: <, less than]

Site no. (see fig. 16)	Number of samples	Coefficient of determination (R^2)	F test (p value)	Slope coefficient (β_1)	Intercept coefficient (β_0)	Bias-corrector
1	75	0.88	$p < 0.0001$	1.39	-3.91	1.20
17	152	0.85	$p < 0.0001$	1.46	-3.89	1.35
34	112	0.89	$p < 0.0001$	0.926	0.41	1.11
39	132	0.94	$p < 0.0001$	1.027	-0.28	1.14
43	159	0.96	$p < 0.0001$	1.16	-1.20	1.21

Seasonal and annual loads of total phosphorus for WY 2001–02 at sampling sites 1, 17, 34, 39, and 43 were calculated by summing the daily loads for each season and for each year (table 8). Annual loads ranged from 1.33 tons at site 1 to 43.41 tons at site 34. Garcia and Carman (1986) estimated seasonal and annual loads of total phosphorus for 1980 at the same sites. Their value for annual load was based on the average of four different methods to estimate loads, using 12–14 measurements made at each site during WY 1980. Although the same general patterns are seen in the 1980 and 2001–02 data, annual loads were much greater in 1980 (table 8). The difference in loads is partly due to differences in streamflow; runoff during WY 1980 was much greater than during WY 2001–02. In addition, mean orthophosphate concentrations have decreased since the early 1970's (table 2; Garcia and Carman, 1986). Decreases in orthophosphate concentrations are most likely due to elimination of direct discharge of treated effluent to the Carson River by 1987. In 2002, estimated annual loads were greater at all sites than in 2001 (table 8), due to increased streamflow.

Estimated seasonal total-phosphorus loads for sampling sites 1, 17, 34, 39, and 43 are greatest during spring runoff, followed by fall and winter, and least during the summer (table 8), which corresponds with the amount of streamflow in the Carson River. Estimated seasonal loads ranged from 0.06 ton (site 1, summer) to 17.10 tons (site 34, spring) in 2001 and from 0.07 ton (site 1, spring and site 43, summer) to 28.20 tons (site 34, spring) in 2002. For each site and year, the greatest seasonal loads were in the spring from April to June.

Estimated daily mean total-phosphorus loads transported in streamflow at sampling sites 1, 17, and 34 were used to estimate the phosphorus load entering and leaving the Carson Valley subunit (fig. 24). Estimated daily mean loads for sites 1 and 17 were combined to estimate the mean load entering the Carson Valley subunit. Site 34 is located where the Carson River leaves the Carson Valley subunit. To show the uncertainty associated with the mean daily total-phosphorus loads estimated by the regression equations, the 95-percent confidence intervals were calculated (Helsel and Hirsh, 1992, p. 240) and shown for load leaving the Carson Valley subunit (site 34) in figure 24. The confidence intervals are not shown for the load entering Carson Valley subunit because the confidence intervals for the load from the East and West Forks cannot be combined.

The average estimated annual phosphorus load entering the Carson Valley (sites 1 and 17) for WY 2001–02 was 21.9 tons; whereas, the average estimated annual phosphorus load leaving the Carson Valley (site 34) was 37.8 tons (table 8), for an average estimated annual gain in load across Carson Valley of 15.9 tons. Thus, about 58 percent of the annual total-phosphorus load leaving Carson Valley could be attributed to headwater reaches upstream from Carson Valley during WY 2001–02. This value, 58 percent, is a maximum and assumes that the phosphorus load entering the valley passes through the valley and is not diverted from the Carson River system.

The contribution from the headwater reaches changes throughout the year. The largest seasonal gain and most of the annual gain in phosphorus load across the Carson Valley occurs during the autumn and winter (October 1–March 31; fig. 24, table 8). During this period, an average of only 17 percent of the phosphorus load leaving Carson Valley could be attributed to headwater reaches upstream of Carson Valley. This means that the majority of load leaving the Carson Valley subunit is generated within the Carson Valley during October through March. During the period April 1–September 30, only a slight increase in load occurs across Carson Valley (table 8). During this period, the streamflow entering Carson Valley is much greater than the streamflow leaving, indicating that there are increases in phosphorus concentration. An average of 85 percent of the phosphorus load leaving Carson Valley could be attributed to headwater reaches during spring and summer. Based on the confidence intervals for phosphorus load shown in figure 24 this value is very uncertain.

During most of the 2-year study period, the estimated total-phosphorus load entering Eagle and Dayton–Churchill Valleys was greater than the amount leaving the valleys (figs. 25–26, table 8). For these valleys, the lower 95 percent confidence limit for the daily estimated phosphorus load entering the valleys exceeded the upper 95-percent confidence limit for the load leaving the Eagle Valley and Dayton–Churchill Valleys 54 and 63 percent of the time, respectively, during WY 2001–02. When the 95 percent confidence limits do not overlap, the estimated phosphorus loads at the upstream and downstream sites

Table 8. Estimated seasonal and annual loads, and average annual yields of total phosphorus at sites on the Carson River, water years 1980, 2001, and 2002

[Abbreviations: A, autumn (October 1–December 31); W, winter (January 1–March 31); Spr, spring (April 1–June 30); S, summer (July 1–September 30); lb/acre, pound per acre]

Site no. (see fig. 16)	Station name	Total-phosphorus load (tons)											2001–02 average annual yield (lb/acre)
		Water year 1980[a]	Water year 2001					Water year 2002					
		Annual	A	W	Spr	S	Annual	A	W	Spr	S	Annual	
1	West Fork Carson River at Woodfords, CA	6.1	0.08	0.16	1.04	0.06	1.33	0.07	0.18	2.13	0.09	2.46	0.091
17	East Fork Carson River near Dresslerville, NV	120	0.58	1.49	14.69	0.56	17.32	0.57	1.77	19.33	1.05	22.72	0.167
34	Carson River near Carson City, NV	230	5.63	8.82	17.10	0.62	32.17	4.26	9.75	28.20	1.19	43.41	0.133
39	Carson River at Deer Run Road, NV	250	4.39	7.41	16.21	0.15	28.16	3.48	8.97	25.54	0.37	38.36	0.108
43	Carson River near Silver Springs, NV	230	2.88	6.27	15.72	0.07	24.93	1.95	6.44	22.70	0.07	31.15	0.060

[a]From Garcia and Carman (1986).

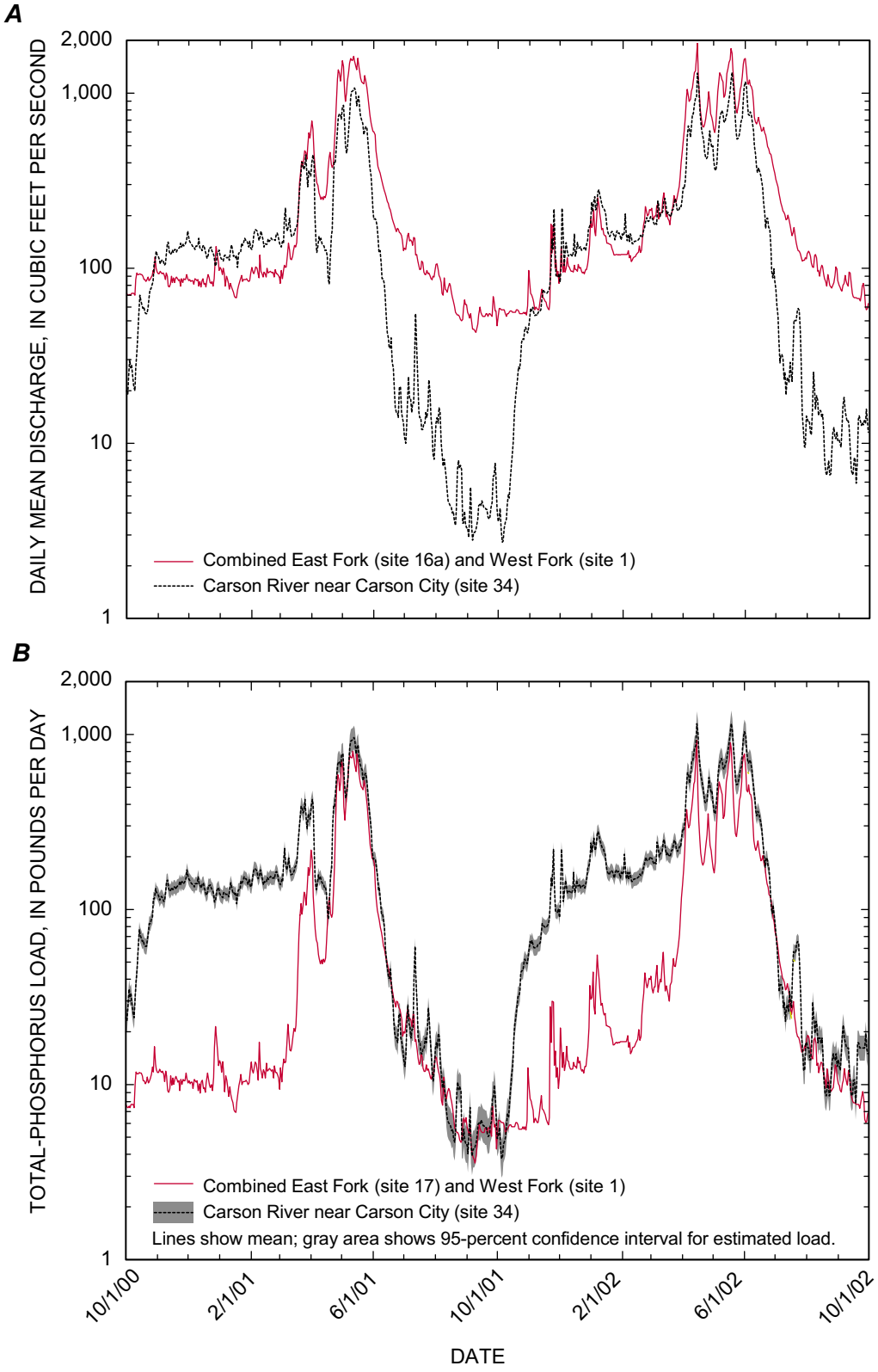


Figure 24. Comparison of (*A*) discharge and (*B*) total-phosphorus loads entering and leaving Carson Valley.

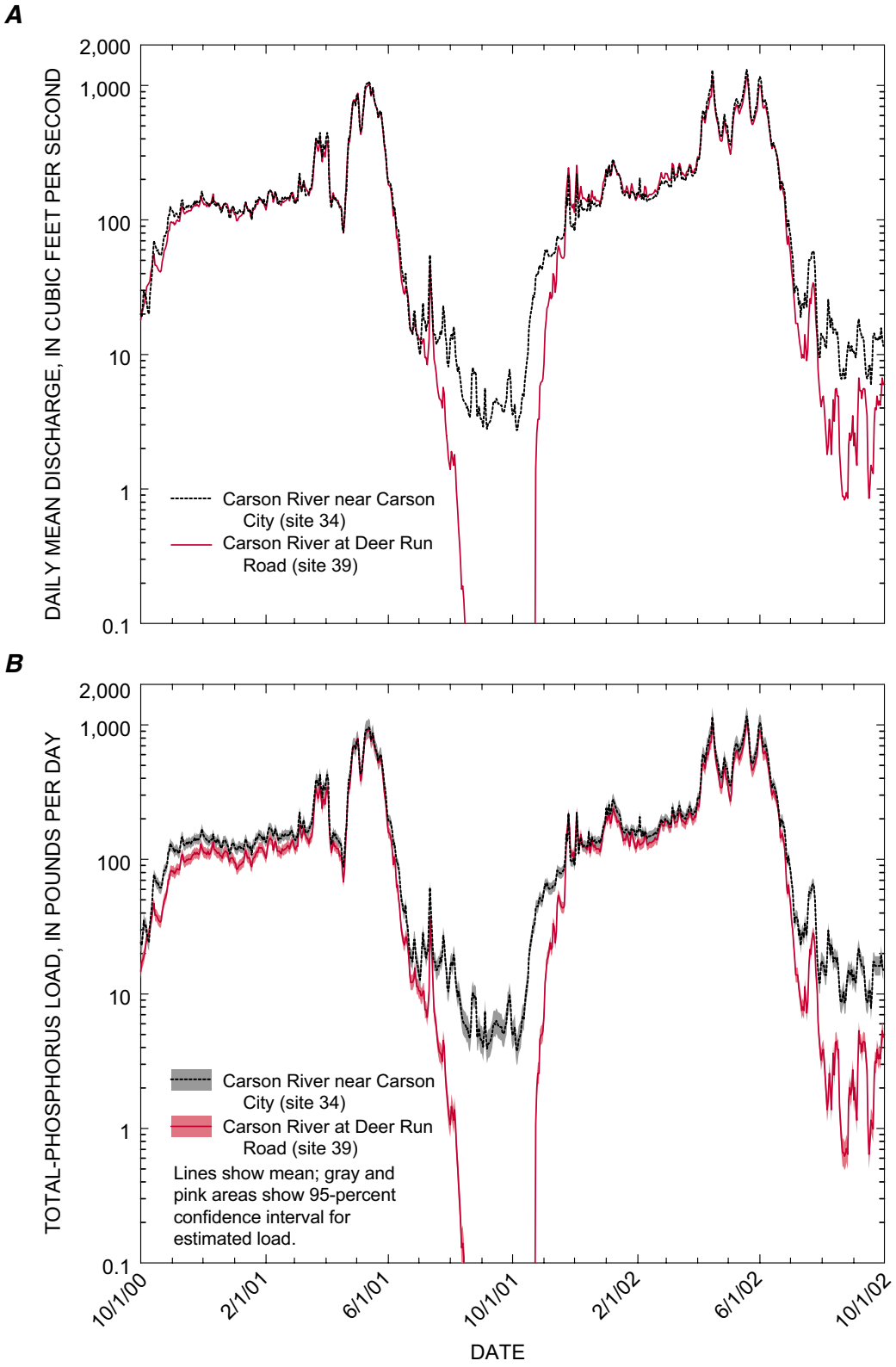


Figure 25. Comparison of (*A*) discharge and (*B*) total-phosphorus loads entering and leaving Eagle Valley.

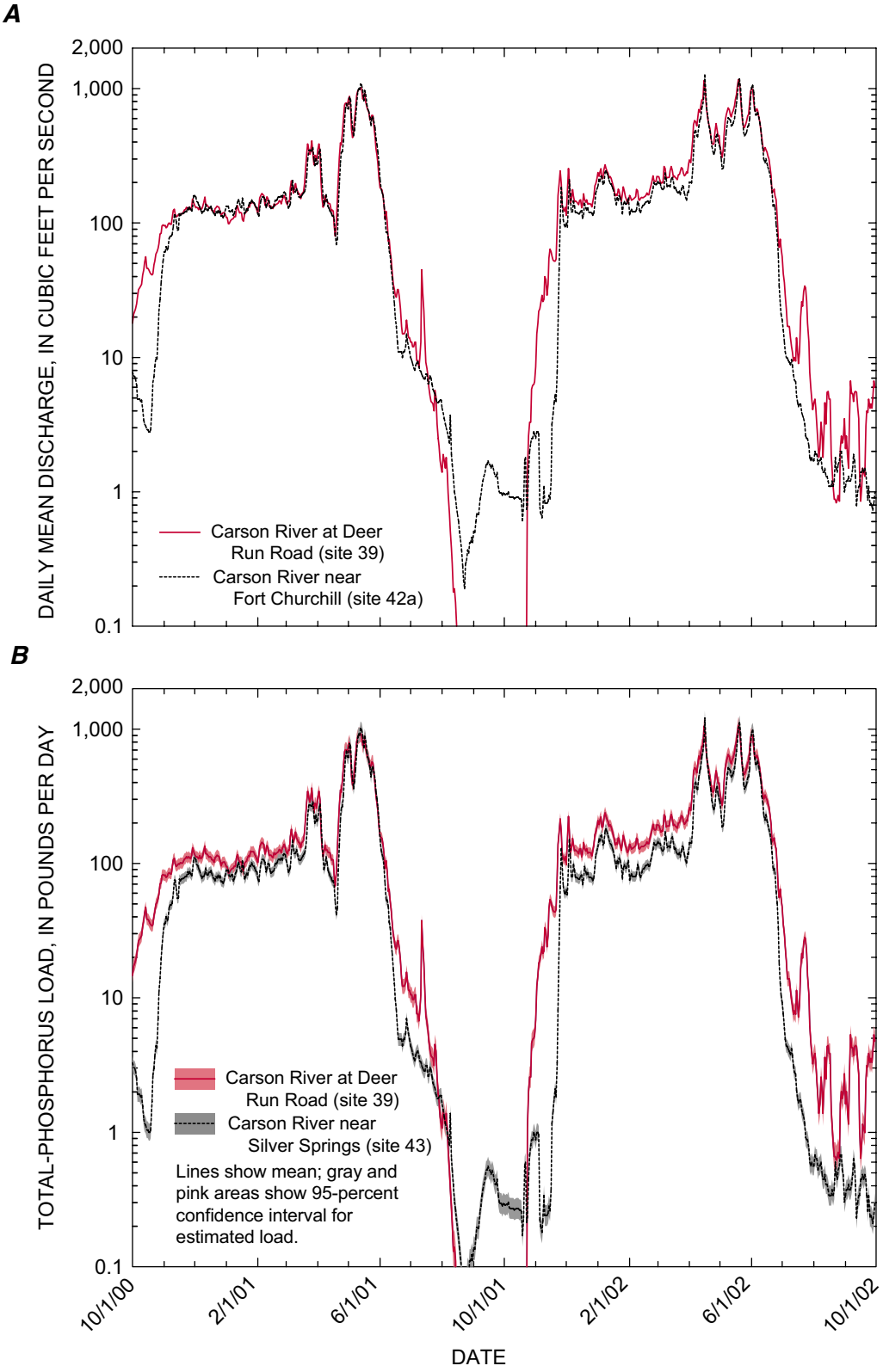


Figure 26. Comparison of (*A*) discharge and (*B*) total-phosphorus loads entering and leaving Dayton–Churchill Valleys.

statistically are different and indicates that the valleys may be acting as sinks, with more phosphorus entering them than is leaving them. On an annual basis (WY 2001–02), about 90 percent and 85 percent of the phosphorus entering Eagle Valley and Dayton–Churchill Valleys, respectively, left them. During flood events, however, the phosphorus may be mobilized and moved downstream.

Generally, sampling sites with the largest drainage areas are assumed to have the largest phosphorus loads (Pope and Milligan, 2000) because streamflow is directly related to drainage area and streamflow is assumed to increase moving downstream. However, for the Carson River system, the amount of annual streamflow generally decreases in a downstream direction (fig. 6). In addition, the total-phosphorus concentrations decrease between site 34 and site 43 (table 6). The combination of decreased flow and concentrations are the reasons the annual and seasonal loads decrease between site 34 and site 43.

The phosphorus yield indicates which sites have the largest annual phosphorus contribution per unit drainage area. Differences in mean annual phosphorus yields among sub-watersheds are related to several factors including water yield, precipitation, soil characteristics, topography, stream gradient, and land-use characteristics (Pope and Milligan, 2000). Site 17 has the largest annual yield with 0.167 lb/acre, followed by site 34 with 0.133 lb/acre (table 8). Yield from the headwaters of the East Fork (site 17) is nearly twice that for the West Fork (site 1). This difference may result from soils in the East Fork being more erodible and having a greater clay content than soils in the headwater reaches of the West Fork (fig. 3, table 5).

Phosphorus in Sediment

Suspended Sediment

The relation between suspended-sediment and phosphorus concentrations in water was evaluated using data collected during this investigation. A relation is expected because phosphorus is a structural component of some minerals in sediments (for example, apatite), and is bound to other minerals in sediment (for example, iron oxyhydroxide). A plot of total-phosphorus against suspended-sediment concentrations (fig. 27*A*) shows that only 28 percent of the variance in total-phosphorus concentration is explained by suspended-sediment concentration.

When total-phosphorus concentrations are corrected for the amount of orthophosphate, the relation between phosphorus and suspended-sediment concentrations improves (fig. 27*B*). The amount of phosphorus bound to particulate matter, particulate phosphorus, is estimated by subtracting orthophosphate from total phosphorus. Particulate phosphorus, as defined here, is an estimate because it includes an unknown amount of dissolved phosphorus that is not orthophosphate. A plot of particulate-phosphorus concentration against suspended-sediment concentration (fig. 27*B*) shows 57 percent of the variance in particulate-phosphorus concentration is explained. These data indicate that phosphorus from particulate phosphorus alone may exceed the water-quality standard for phosphorus when suspended-sediment concentrations exceed about 50 mg/L.

The relation between particulate-phosphorus and suspended-sediment concentrations is improved slightly (R^2 = 0.63) when suspended-sediment concentration is corrected for the contribution from sand-sized particles (fig. 27*C*). These data show that phosphorus from particulate phosphorus alone may exceed the State phosphorus standard when concentrations of clay and silt in suspended sediment exceed about 30 mg/L.

Much of the variance shown in figure 27 is related to the source of the suspended sediment. For example, a water sample from Williams Slough (site 29) had a particulate-phosphorus concentration of 0.29 mg/L and a suspended-sediment concentration of 13 mg/L (app. 1). This sample, which is the largest outlier in figure 27*C*, corresponds to a phosphorus concentration in suspended sediment of 2.2 percent. A water sample from the East Fork Carson River near Dresslerville (site 17), which also had a particulate-phosphorus concentration of 0.29 mg/L, had a suspended-sediment concentration of 195 mg/L (app. 1). In this sample, the phosphorus concentration in suspended sediment was 0.15 percent. Sediment in Williams Slough at site 29 likely originates in fields irrigated with treated effluent (fig. 13) where cattle may have access to the slough. Sediment in the East Fork at site 17 originates in forest and rangeland (fig. 9).

Streambank and Streambed Sediments

Phosphorus concentrations in streambank sediment typically were low (less than 0.07 percent) throughout the study area (fig. 28). The phosphorus concentration in samples of streambank sediment from 19 sites ranged from 220 to 1,200 mg/kg (from 0.02 to 0.12 percent) and the median concentration was 590 mg/kg (0.06 percent; app. 2). The greatest phosphorus concentrations (greater than 0.08 percent) were found in Carson Valley, with the greatest at site 33 on Clear Creek.

The phosphorus concentration in samples of streambed sediment from 39 sites ranged from 220 to 1,600 mg/kg (from 0.02 to 0.16 percent) and the median concentration was 810 mg/kg (0.08 percent; app. 2). Phosphorus concentrations greater than 0.08 percent were commonly found in samples from Carson Valley (fig. 29), but also were found in tributaries to the Carson River in Eagle Valley (sites 37 and 38) and in the Carson River in Dayton Valley. Phosphorus concentrations exceeding 0.1 percent were restricted to Carson Valley.

Relation Between Suspended-Sediment Concentration and Total-Suspended Solids

Although suspended-sediment concentration (SSC) and total-suspended solids (TSS) are used to measure the amount of suspended matter being carried by rivers and streams, analytical

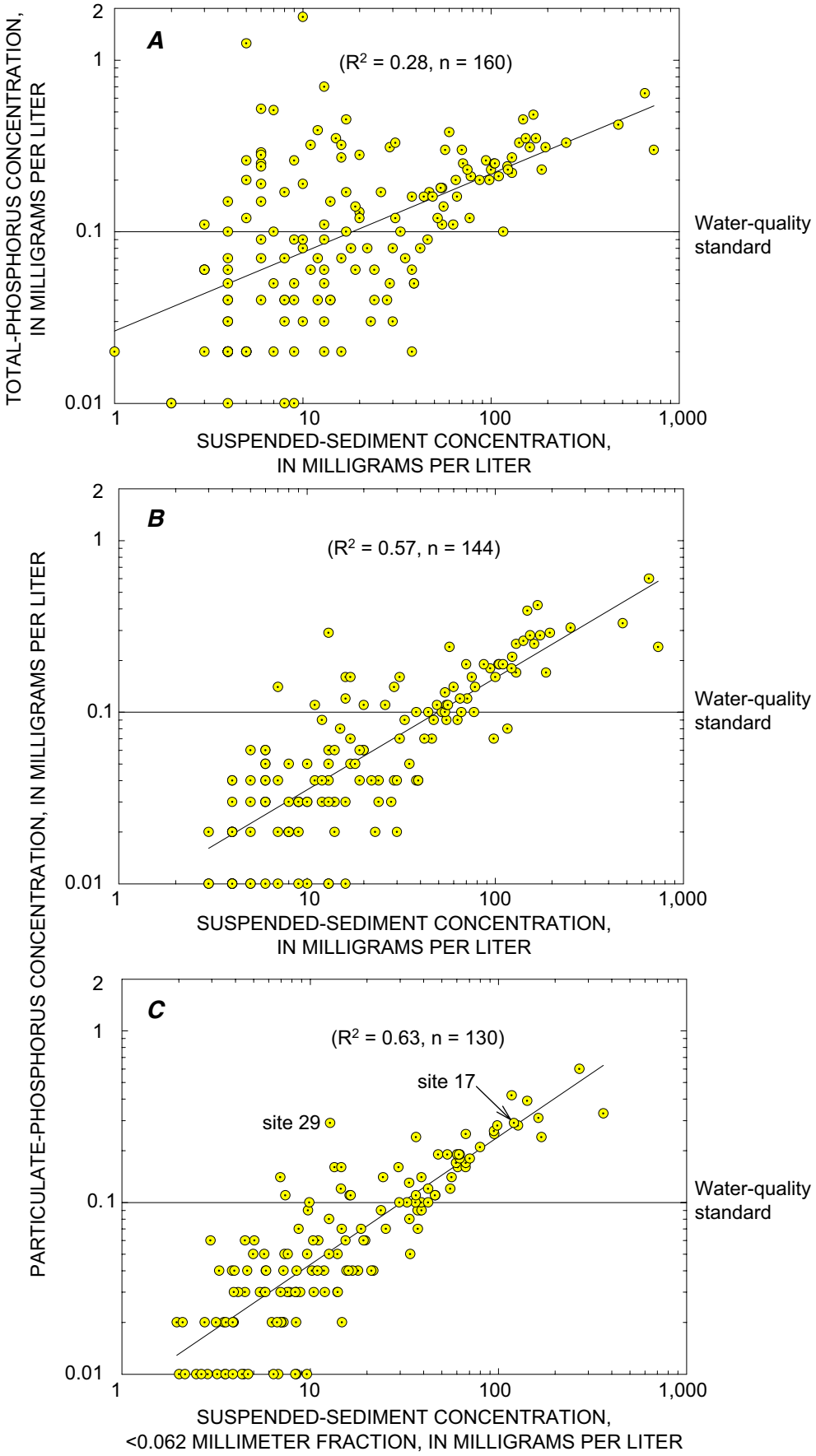
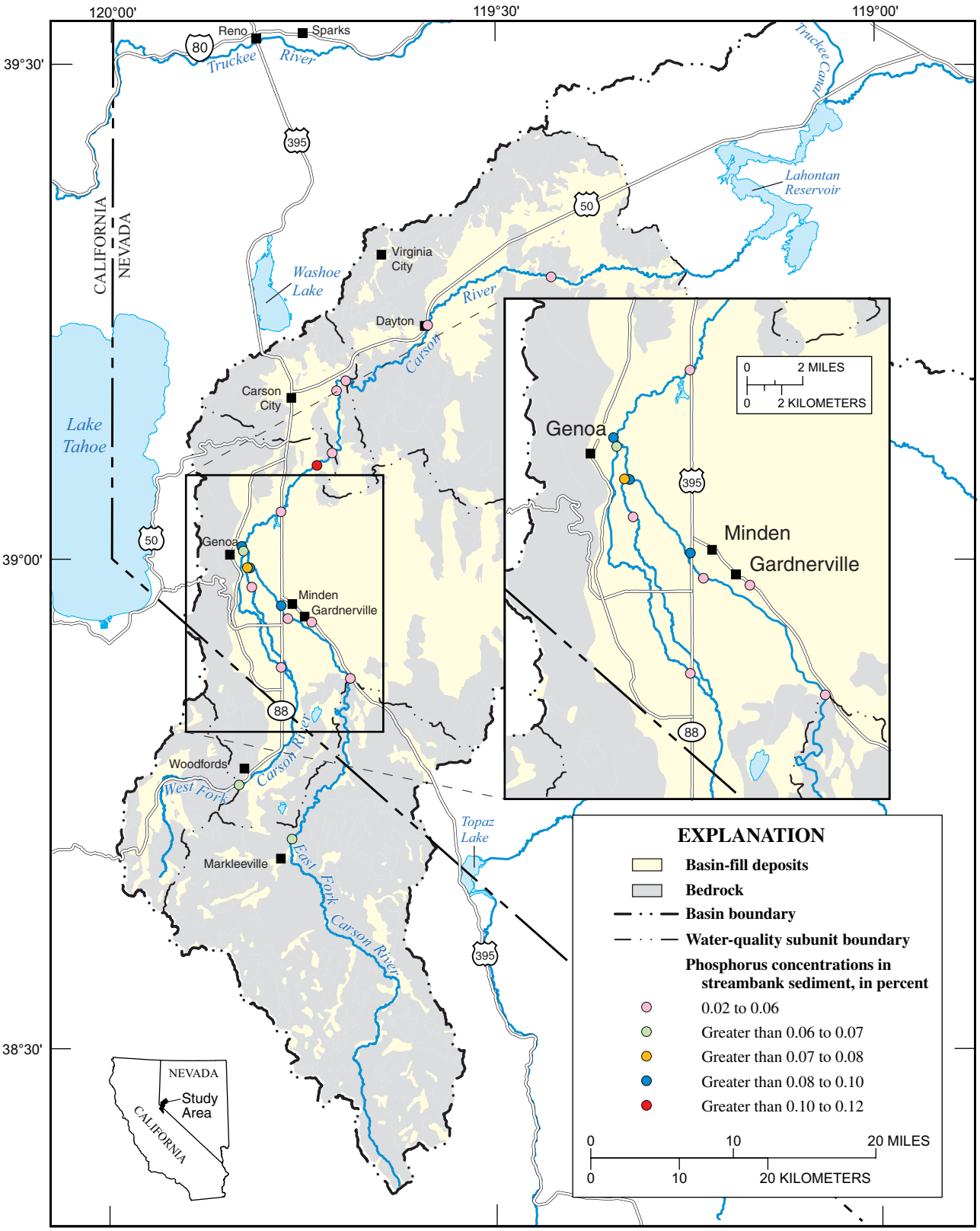
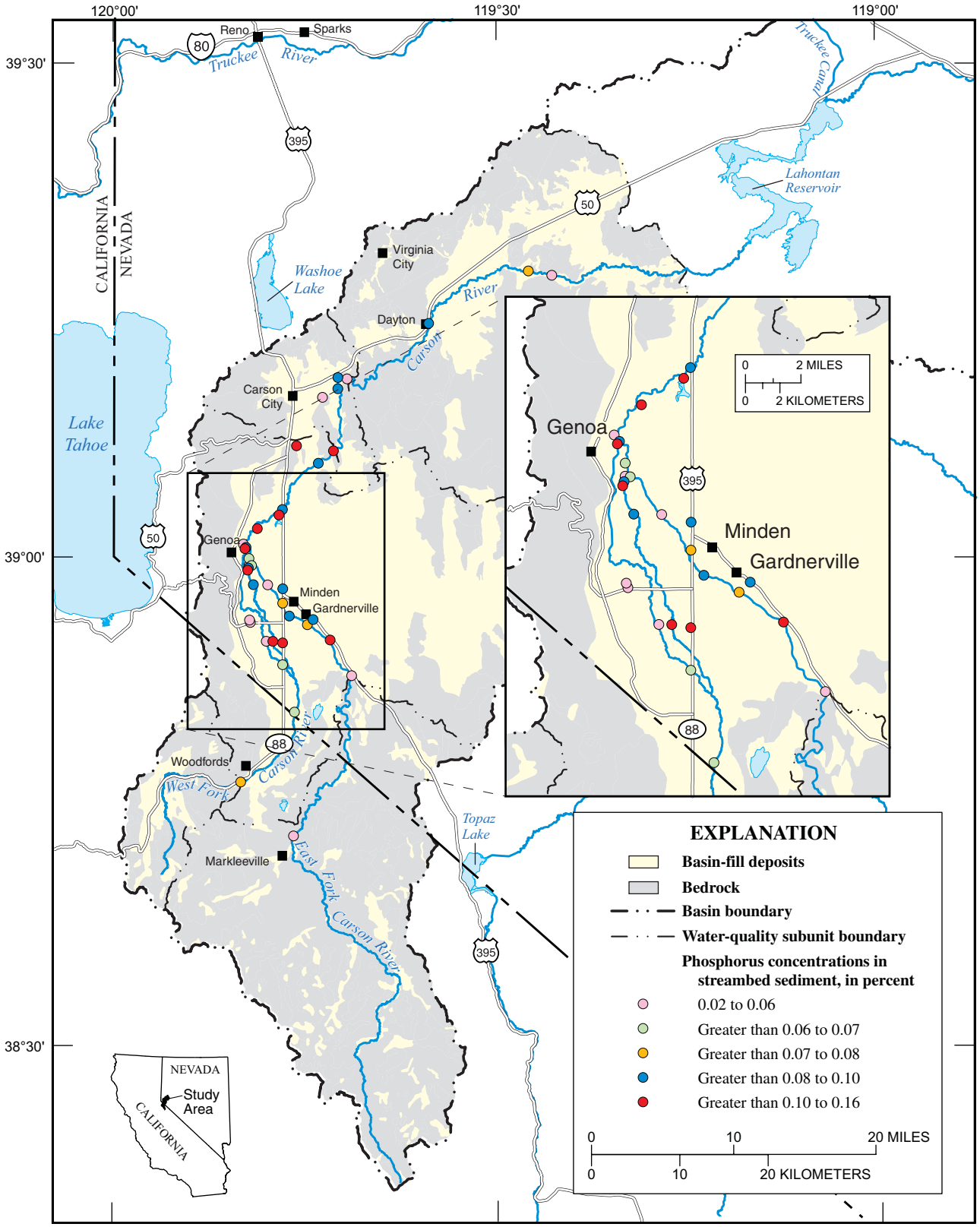


Figure 27. Relation between phosphorus and suspended-sediment concentrations in samples from the Carson River Basin upstream from Lahontan Reservoir, 2000–02.



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

Figure 28. Phosphorus concentrations in streambank-sediment samples in the Carson River Basin upstream from Lahontan Reservoir, 2001–02.



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

Figure 29. Phosphorus concentrations in streambed-sediment samples in the Carson River Basin upstream from Lahontan Reservoir, 2001–02.

methods for determining the two differ. The SSC method is a measure of all of the sediment and all of the water in a sample to determine concentration; whereas, the TSS method is a measure of a subsample of the original sample (Gray and others, 2000). NDEP uses the TSS method and water-quality standards for Nevada rivers and streams are based on the TSS.

A statistically significant relation between SSC and TSS ($R^2 = 0.79$; $p < 0.001$) exists for TSS concentrations greater than 10 mg/L. Although TSS concentrations less than 10 mg/L are reported in appendix 1, they are less than the laboratory reporting limit and are considered estimates. For concurrently collected samples in the Carson River Basin, TSS almost always underestimates SSC (fig. 30) for two possible reasons. First, the difference could result from how samples were composited; SSC samples were composited instream; whereas, TSS samples were composited in a churn-splitter. Second, the process by which TSS samples are subsampled in the laboratory may result in subsamples that are different from the original sample.

Studies indicate that, for particle sizes less than 250 µm and SSC values less than 1,000 mg/L, SSC does not differ for instream and churn-splitter compositing of samples (Wilde and others, 1998). Hence, the difference in SSC and TSS values probably is the result of subsampling during TSS analysis. Figure 31 shows that the difference between SSC and TSS decreases as the amount of clay and silt in the sample increases. A national study (Gray and others, 2000) reported that SSC was more reliable at representing the true concentration of suspended material in the stream than TSS, particularly when the amount of sand in a sample exceed about a quarter of the dry sediment mass.

Some of the TSS samples from the Carson River may accurately reflect the mass of suspended matter in the river; however, such samples cannot be identified reliably nor is there a reliable procedure to correct TSS biased data (Gray and others, 2000). None of the TSS samples collected by NDEP from the Carson River were analyzed for the amount of sand. These results indicate that historical TSS data collected by NDEP could be used to calculate estimates for fluvial-sediment loads because there is a statistically significant relation between SSC and TSS. Use of uncorrected TSS values would be biased low compared to the actual concentration of suspended material in the stream. The bias likely would be greatest during periods of high discharge.

Changes Across Specific Reaches

Data were collected in five synoptic surveys during winter, spring, and summer of 2002. Along the Carson River, about 25 sites were sampled during four synoptic surveys and 12 sites were sampled during an abbreviated spring synoptic survey. Previous results from this study showed changes in phosphorus concentration, composition, and loads across Carson, Eagle, and Dayton–Churchill Valleys. The purpose of the synoptic surveys was to identify specific reaches where changes in water quality occur and to identify the possible causes for those changes. Results of the synoptic surveys for discharge, phosphorus concentration, phosphorus load, and suspended-sediment concentrations are shown in figures 32–36.

For the purposes of data interpretation, the Carson River was broken into four reaches (figs. 5 and 16):

1. West Fork/Brockliss Slough: West Fork Carson River at Woodfords (site 1) to Brockliss Slough above confluence Carson River near Genoa (site 15).
2. West Fork Ditch: West Fork Carson River from the split with Brockliss Slough to the West Fork Carson River above confluence East Fork Carson River near Genoa (site 9).
3. East Fork: East Fork Carson River below Markleeville Creek (site 16) to East Fork Carson River above confluence West Fork Carson River near Genoa (site 25).
4. Mainstem: Carson River near Genoa (site 28) to Carson River near Silver Springs (site 43).

Sampling locations within those reaches were chosen on how useful the data obtained from them would be in characterizing phosphorus contributions from different lands and land-use categories.

The synoptic surveys in 2002 took from 4 days to 3 weeks to complete:

1. Winter: February 19–28
2. Spring 1: April 24–May 15
3. Spring 2: May 28–31
4. Summer 1: July 1–12
5. Summer 2: August 21–29.

Sampling within specific reaches was done in as short a time as possible to minimize changes in discharge and upstream water quality. Spring 2 was completed in 4 days because a reduced number of sites were sampled.

West Fork/Brockliss Slough

During all of the synoptic surveys, total-phosphorus concentrations increased substantially between West Fork Carson River at Woodfords (site 1) and Brockliss Slough above confluence Carson River (site 15). At site 15, total-phosphorus concentrations were always greater than the water-quality standard, ranging from 0.12 mg/L during winter to 0.38 mg/L during summer. During all the synoptic surveys, the largest increases in total-phosphorus concentration and load occurred in the nearly 12 mi reach between Brockliss Slough at Highway 88 (site 10) and Brockliss Slough above confluence Carson River (site 15). During the winter and summer surveys, about two-thirds of the increase in total-phosphorus concentration between sites 10 and 15 is due to increases in orthophosphate. During the winter survey, almost 31 percent of the total-phosphorus load measured at Carson River near Genoa (site 28) originated in this reach. During summer surveys, 10–22 percent of the total-phosphorus load measured at the Carson River near

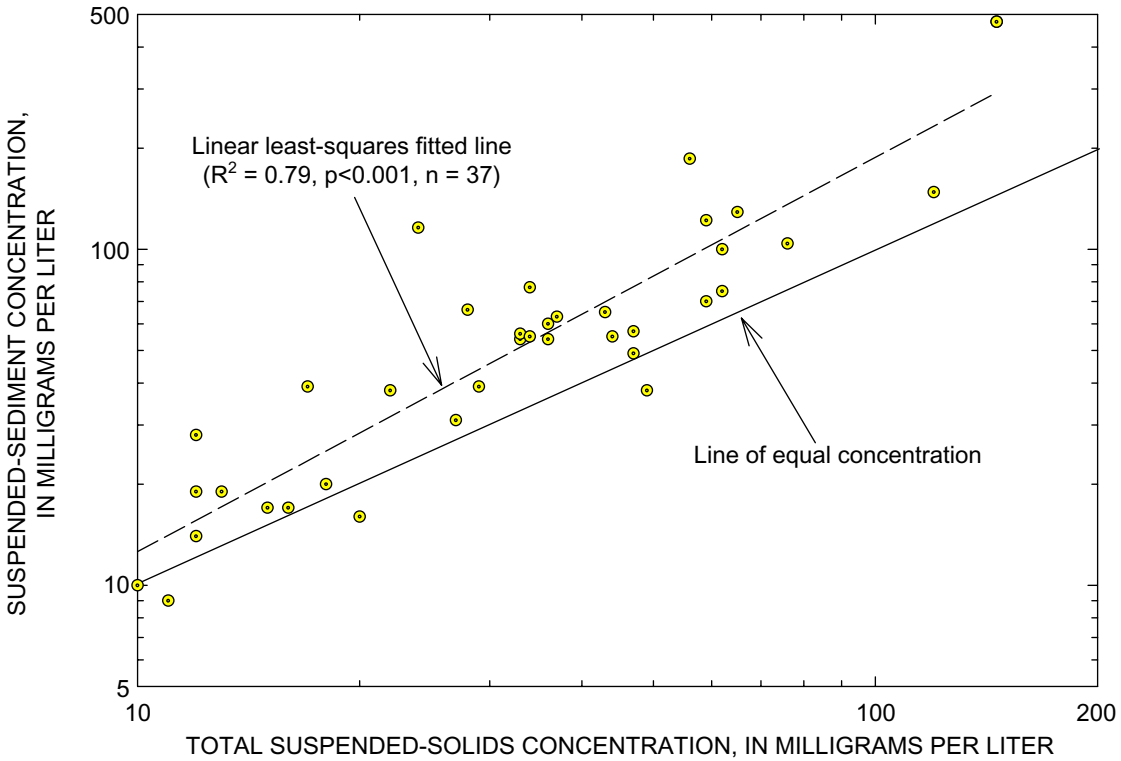


Figure 30. Relation between suspended-sediment concentration and total-suspended solids in samples from the Carson River Basin upstream from Lahontan Reservoir, 2002.

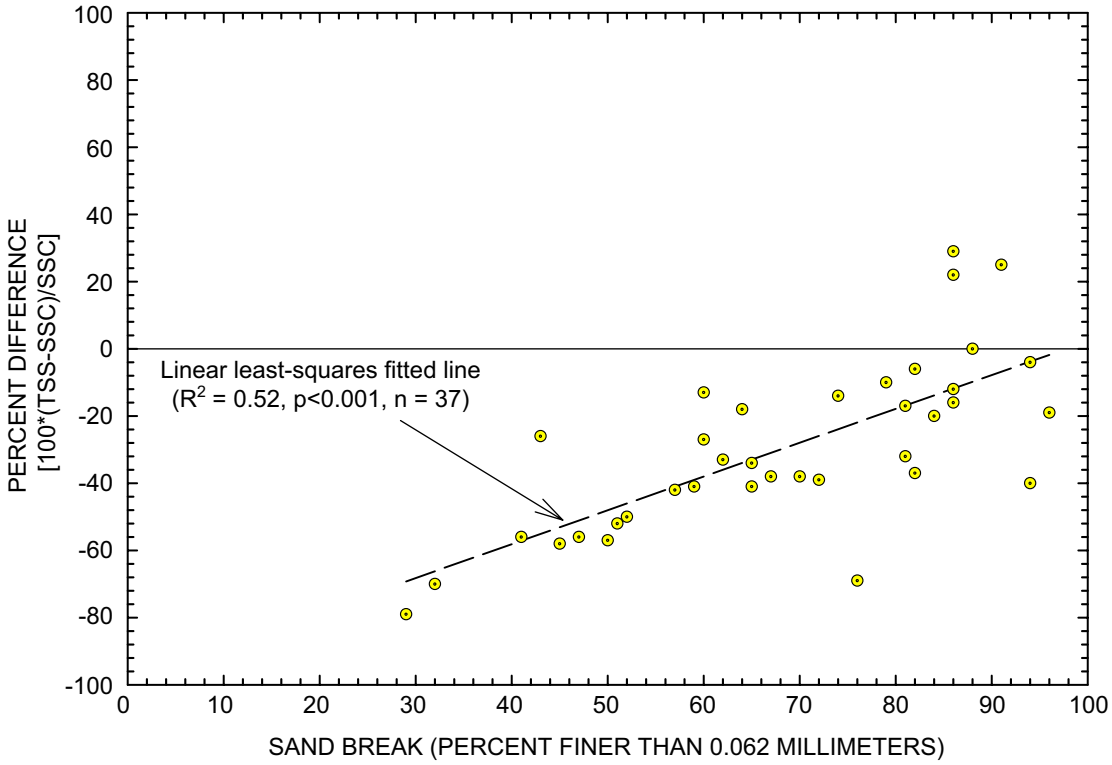


Figure 31. Relation between sand break and percent difference between suspended-sediment concentration and total-suspended solids in samples from the Carson River Basin upstream from Lahontan Reservoir, 2002.

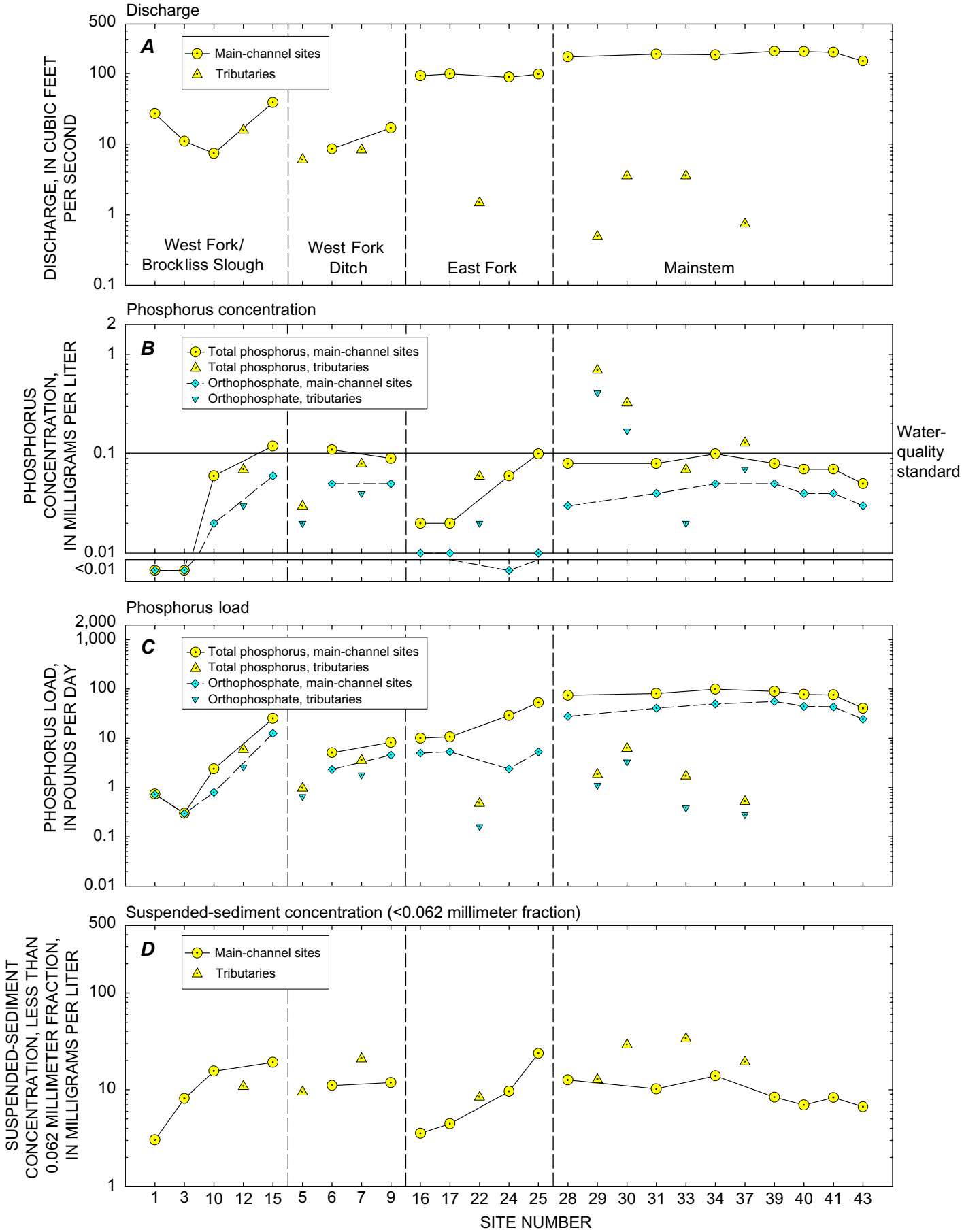


Figure 32. Discharge, phosphorus concentrations and loads, and suspended sediment (<0.062 millimeter fraction) at sites sampled during Winter synoptic survey (February 19–28, 2002).

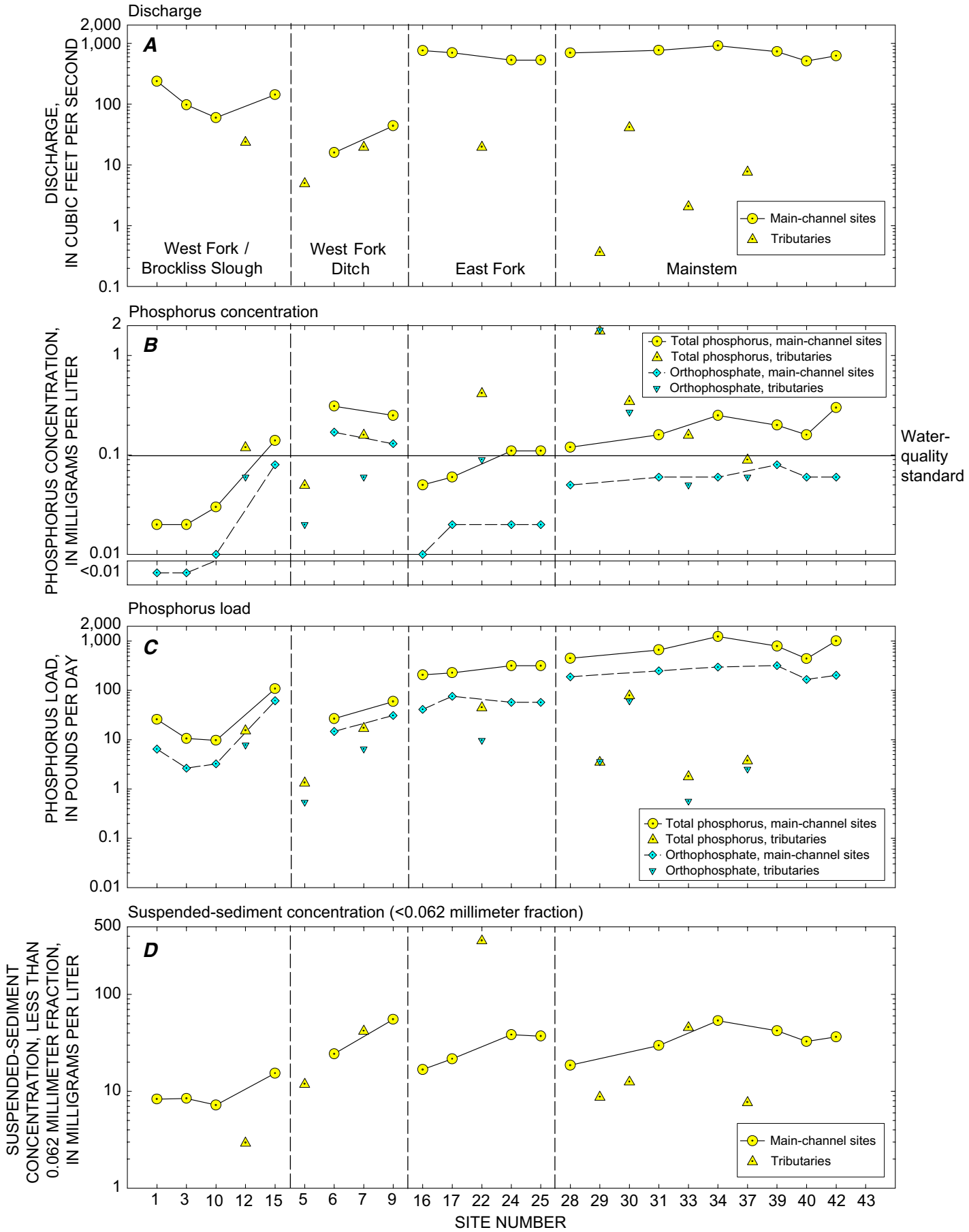


Figure 33. Discharge, phosphorus concentrations and loads, and suspended sediment (<0.062 millimeter fraction) at sites sampled during Spring 1 synoptic survey (April 24–May 15, 2002).

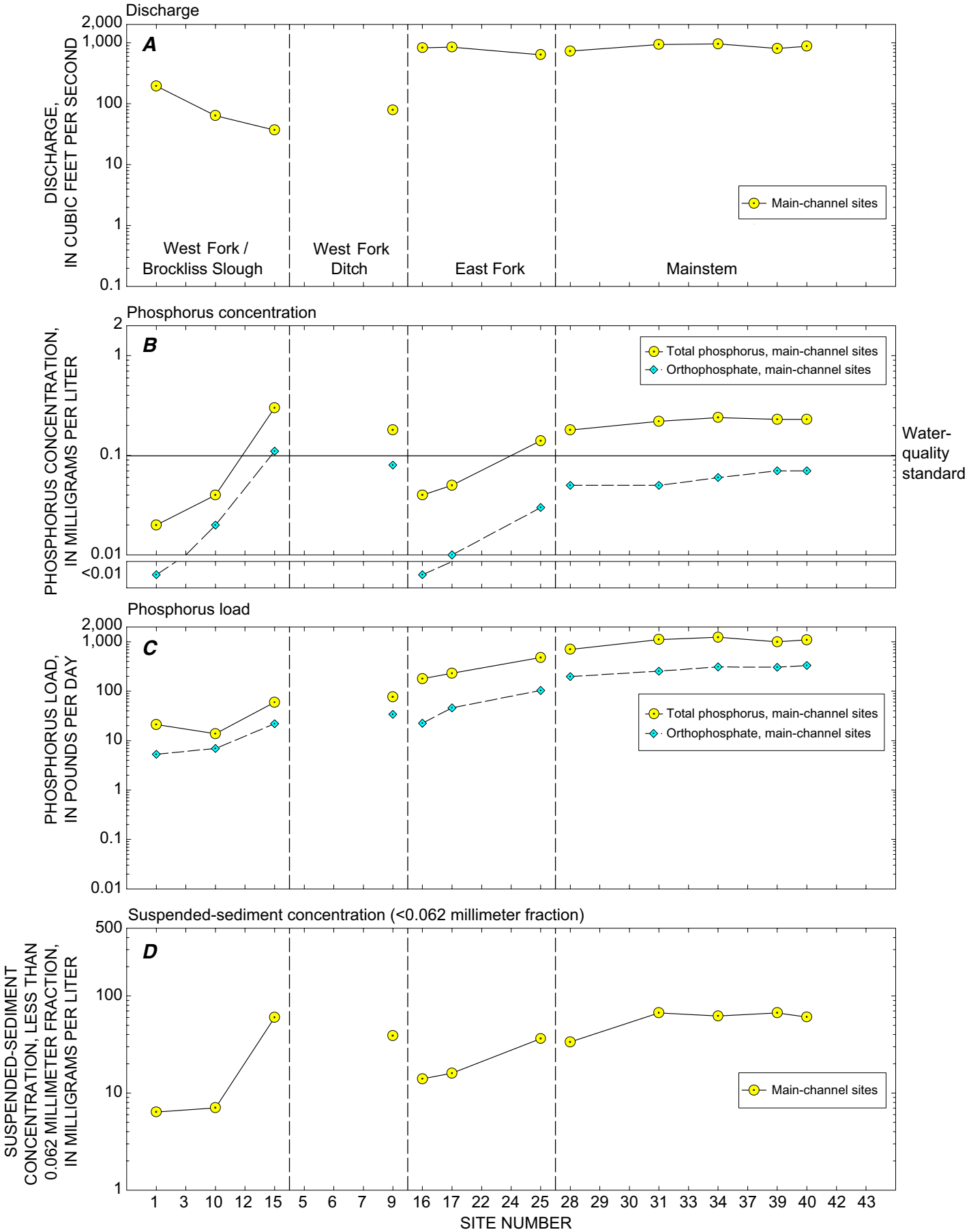


Figure 34. Discharge, phosphorus concentrations and loads, and suspended sediment (<0.062 millimeter fraction) at sites sampled during Spring 2 synoptic survey (May 28–31, 2002).

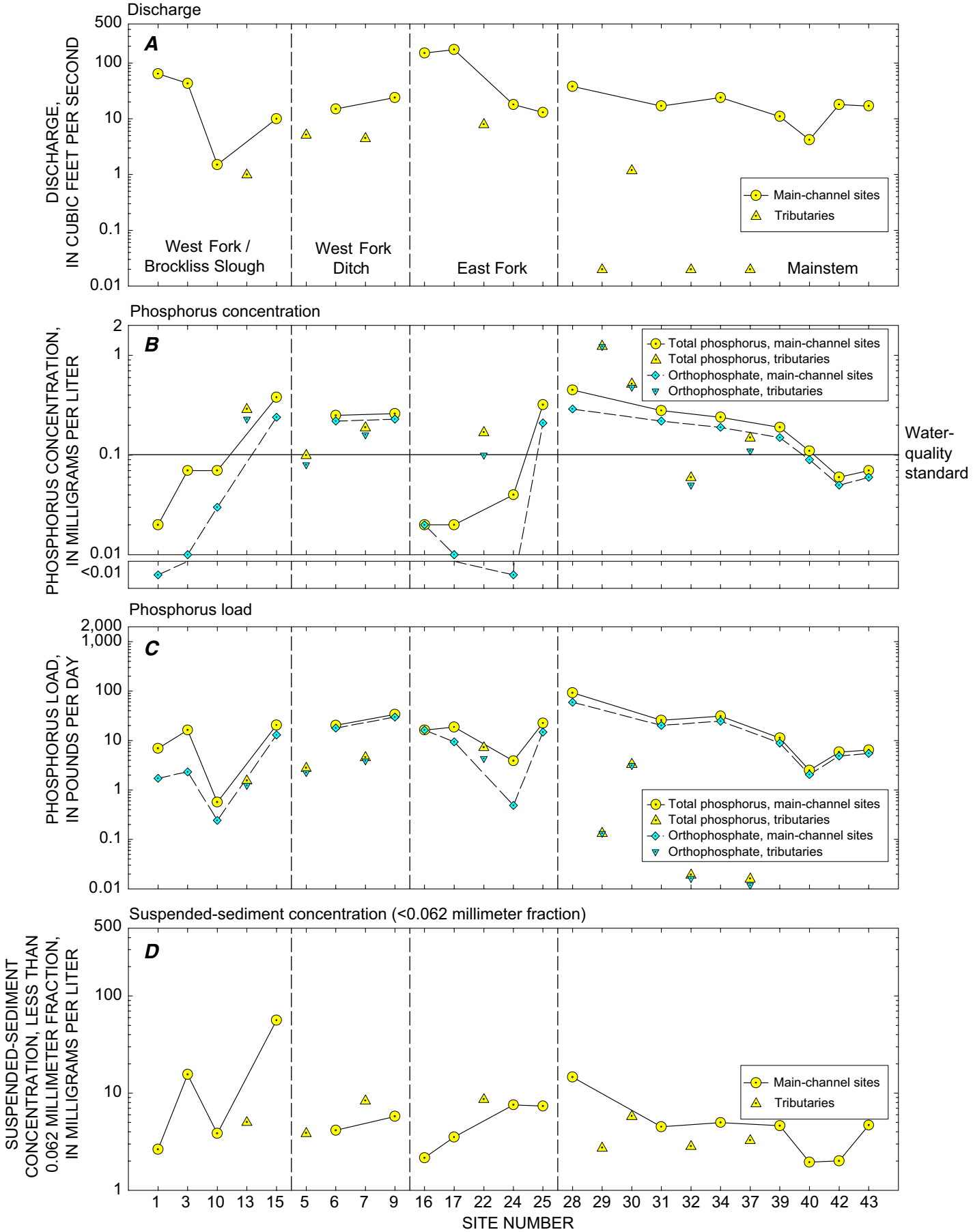


Figure 35. Discharge, phosphorus concentrations and loads, and suspended sediment (<0.062 millimeter fraction) at sites sampled during Summer 1 synoptic survey (July 1–12, 2002).

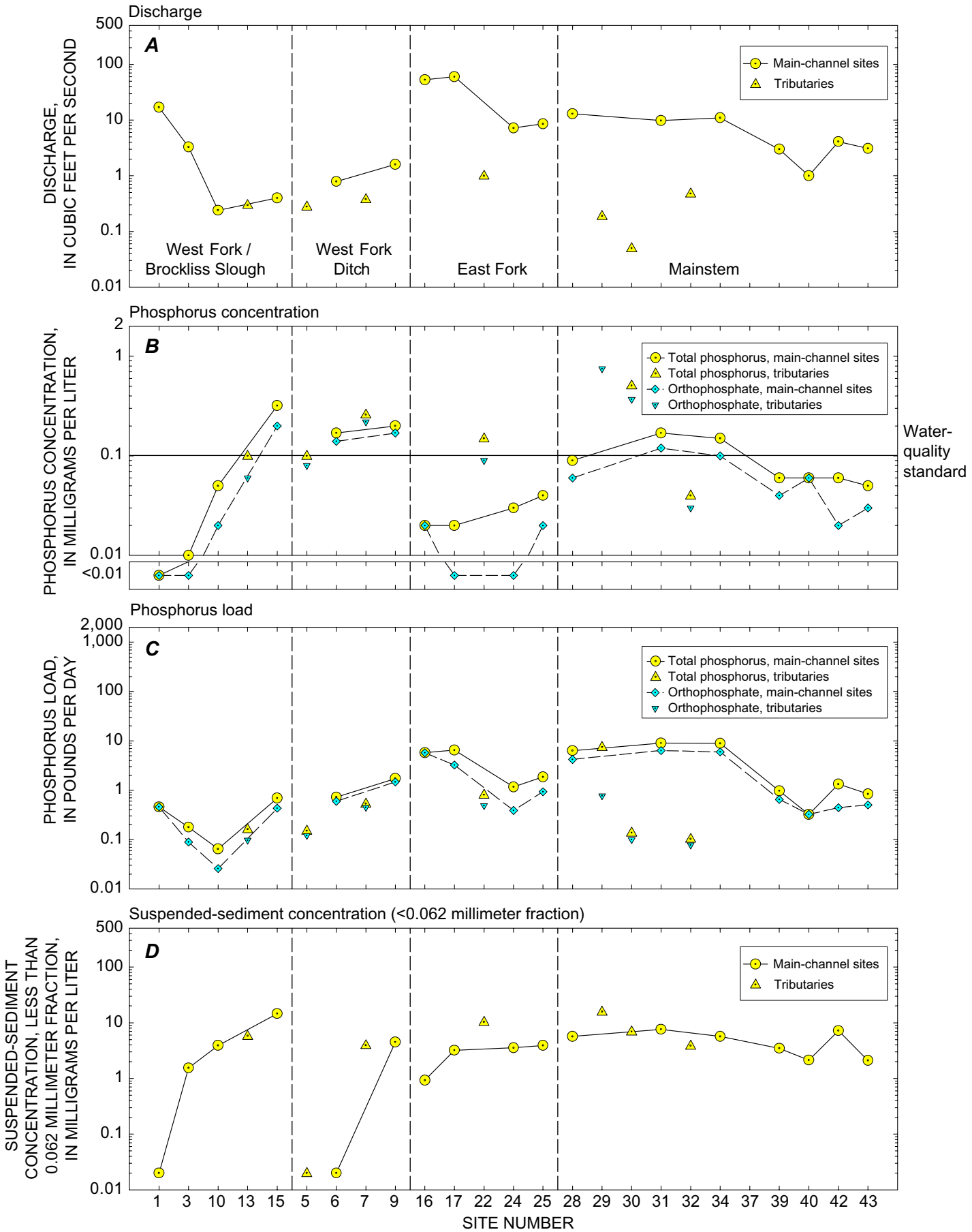


Figure 36. Discharge, phosphorus concentrations and loads, and suspended sediment (<0.062 millimeter fraction) at sites sampled during Summer 2 synoptic survey (August 21–29, 2002).

Genoa (site 28) originated in this reach. During spring surveys, 6–22 percent of the total-phosphorus load measured at Carson River near Genoa (site 28) originated in this reach.

Big Ditch at Waterloo Lane (site 12) and Johnson Slough below confluence Big Ditch (site 13) carry return flows from fields irrigated with treated effluent in Alpine County and, except during winter, total-phosphorus concentrations at these sites always exceeded the water-quality standard. Although the total-phosphorus concentrations at the two sites are high, the data collected during this study show that Big Ditch/Johnson Slough was a minor contributor to the observed increase of loads across the reach between sites 10 and 15. This may indicate that the source of phosphorus is along the channel itself, or that unsampled tributaries are the source. Surface-water inflows to this reach include Wally's Hot Springs, streams from the east side of the Carson Range, and a complex of sloughs along the west side of the valley.

West Fork Ditch

Concentrations of total phosphorus at West Fork Carson River at Muller Lane (site 6) and West Fork Carson River above confluence East Fork Carson River (site 9) were similar and almost always exceeded the water-quality standards. Although total-phosphorus concentrations were similar, phosphorus loads increased over the reach because of increases in streamflow.

During the winter survey, about 11 percent of the total-phosphorus load measured at Carson River near Genoa (site 28) originated in the West Fork Ditch section of the river; whereas, during summer surveys, 27–36 percent of the load originated in the West Fork Ditch and its tributaries. West Fork Ditch was dry at Highway 88 during the summer, therefore, in summer all of the phosphorus load in the West Fork Ditch originates in the 8.7 mi reach downstream of Highway 88 and its tributaries. During the spring surveys, 11–13 percent of the load measured at site 28 was from the West Fork Ditch system.

Two principal tributaries, Rocky and Home Sloughs, contributed substantial amounts of phosphorus to West Fork Ditch. Total-phosphorus concentrations and loads were substantially higher in Home Slough above confluence West Fork Carson River (site 7) than in Rocky Slough at Highway 88 (site 5). Rocky Slough connects the East and West Forks and, ultimately, agricultural returns from the Rocky Slough diversions reach the West Fork. Home Slough also is influenced by agriculture and runs along the edge of a field irrigated with treated effluent. Phosphorus from Home Slough (site 7) accounted for between 14 and 44 percent of the load at West Fork Carson River above confluence East Fork Carson River (site 9).

During winter and spring surveys, the orthophosphate concentration is about half of the total-phosphorus concentration in the West Fork Ditch system. However, during the summer surveys, almost all of the phosphorus is comprised of orthophosphate.

East Fork

Little change in suspended-sediment and phosphorus concentrations and loads exists between East Fork Carson River below Markleeville Creek (site 16) and East Fork Carson River near Dresslerville (site 17) during all the synoptic surveys. This implies that phosphorus and sediment entering Carson Valley in the East Fork originated upstream from site 16. The source of the phosphorus may be the intrusive granitic rocks found high in the headwater areas (fig. 2). Susfalk (2000) observed that extractable phosphorus in granite derived soils was much greater than from andesite derived soils.

During the synoptic surveys, total-phosphorus concentrations increased between East Fork Carson River near Dresslerville (site 17) and the East Fork Carson River above confluence West Fork Carson River (site 25). Total-phosphorus concentrations typically increased from below the water-quality standard to at or above the standard. During winter and spring surveys, the increase was almost entirely due to increases in particulate phosphorus, which is consistent with increases in the suspended-sediment concentration (figs. 32–34). The increase in particulate phosphorus likely is due to unstable streambanks in this reach (fig. 11), and urban or agricultural runoff. During the Summer 1 survey, the increase was principally due to orthophosphate although particulate phosphorus also increased substantially during this period (fig. 35). During the Summer 2 survey, total-phosphorus concentration slightly increased (fig. 36).

In the East Fork section of the river, the reach that contributed the largest phosphorus load to the Carson River during the summer and winter surveys was the 1.5 mi reach between the East Fork Carson River at Muller Lane (site 24) and the East Fork Carson River above confluence West Fork Carson River (site 25). During the winter survey, 32 percent of the total-phosphorus load at Carson River near Genoa (site 28) could be accounted for from within this short reach and, during the summer surveys, 11–20 percent of the load at site 28 could be accounted for from within the reach. The likely source of the phosphorus in this reach is agricultural land where treated effluent is used for irrigation (fig.13). During the Spring 1 survey, total-phosphorus load did not increase within this reach (fig. 33). During the spring surveys, the reach from site 17 to site 25 accounted for 19–36 percent of the load at site 28.

The principal inflow to the East Fork downstream of site 17 is Cottonwood Slough, which contributes a much larger portion of the streamflow in the East Fork Carson River at Muller Lane (site 24) during summer (14–44 percent) than during winter and spring surveys (2–4 percent). Cottonwood Slough flows through agricultural land and also receives urban runoff from the Minden–Gardnerville area. Total-phosphorus concentrations in Cottonwood Slough at Highway 88 (site 22) generally were high and, except in winter, exceeded the water-quality standard. During spring and summer surveys, Cottonwood Slough accounted for between 8 and 13 percent of the phosphorus load at Carson River near Genoa (site 28), but less than 1 percent during the winter survey. Other surface

water inflows to this reach include Indian Creek, and possibly a few storm drains and ditches. These tributaries may be important sources of phosphorus, but no samples were collected. No water-quality data were collected for Indian Creek during this study, even though Indian Creek is listed for total-phosphorus on Nevada's 303(d) list of impaired waters.

Mainstem

The maximum total-phosphorus load measured in the mainstem of the Carson River was 4,588 lb/d on April 15, 2002, at Carson River at Cradlebaugh Bridge (site 31). During the synoptic surveys, the largest total-phosphorus load measured was 1,240 lb/d during the Spring 2 survey at Carson River near Carson City (site 34). Total-phosphorus loads increased substantially in the reach between Carson River near Genoa (site 28) and Carson River near Carson City (site 34) during the spring synoptic surveys and either decreased or increased slightly during the winter and summer surveys. The large increase in total-phosphorus concentration and load between the Carson River at Cradlebaugh Bridge (site 31) and Carson River near Carson City (site 34) during the Spring 1 survey was due to large increases in particulate-phosphorus and suspended-sediment concentrations.

Of the three tributaries that were measured between site 28 and site 34, only Ambrosetti Pond Outlet (site 30) was observed to contribute substantial amounts of phosphorus. Although Williams Slough (site 29) has very high concentrations of total phosphorus, it contributes small amounts of phosphorus to the river due to its low streamflow. The combined loads from Ambrosetti Pond Outlet and Williams Slough contributed between 6.7 and 11 percent of the load at Carson River near Carson City (site 34) during the winter, spring, and Summer 1 synoptic surveys. Clear Creek (sites 32 and 33) accounted for less than 2 percent of the load at Carson River near Carson City (site 34) during the synoptic surveys.

Estimated total-phosphorus loads computed using statistical regressions indicated that a large increase in load occurred across the Carson Valley during the winter months (see section Phosphorus Loads). This was observed during the winter synoptic survey when only 12 percent of the instantaneous total-phosphorus load leaving Carson Valley (site 34) could be attributed to headwater reaches upstream from Carson Valley (sites 1 and 17). The regression results indicated that during spring and summer much of the total-phosphorus load leaving Carson Valley could be attributed to headwater reaches. During the summer surveys, instantaneous total-phosphorus load in the headwater reaches (sites 1 and 17) were from 78 to 83 percent of the instantaneous load at Carson River near Carson City (site 34); however, during the spring surveys only about 20 percent was observed. Rapid changes in streamflow during the spring may cause large variations in load, which add uncertainty in estimating change in load across Carson Valley.

Estimated total-phosphorus loads computed using statistical regressions indicated that decreases in phosphorus load occurred across Eagle and Dayton–Churchill Valleys, which is supported by data from the synoptic surveys. Total-phosphorus loads decreased in the reach between Carson River near Carson City (site 34) and Carson River at Deer Run Road (site 39) in all synoptic surveys. The decrease can be attributed to decreases in discharge and total-phosphorus concentrations as the Carson River crossed Eagle Valley. Even though the total-phosphorus concentrations were relatively high in Eagle Valley Creek above confluence Carson River (site 37), less than 1 percent of the load at site 39 could be attributed to Eagle Valley Creek (site 37). The creek was dry and no flow entered the Carson River from it during the summer.

Total-phosphorus loads decreased between the Carson River at Deer Run Road (site 39) and Carson River at Dayton (site 40) during all the synoptic surveys. For the three synoptic surveys where Carson River near Silver Springs (site 43) was sampled, there was an overall decrease in total-phosphorus load and concentration between sites 39 and 43 (fig. 4).

Storm Runoff

Compared with average years, little summer precipitation occurred during the study period and, as a result, few data were collected that could be used to evaluate the effects of storm runoff from urban areas and no data were collected to evaluate the effects of storm runoff from agricultural fields. The best set of data to evaluate the effects of summer storms from an urban area was collected in July 2002 at Clear Creek at Center Street near Carson City (site 32). On July 10, the total-phosphorus concentration was 0.06 mg/L and the discharge was about 0.02 ft^3/s at site 32 (app. 1). During a rainstorm on July 18, the total-phosphorus concentration was 0.45 mg/L and the discharge was 2.4 ft^3/s. Almost the entire increase in phosphorus concentration was due to particulate phosphorus which, together with a great increase in suspended-sediment concentration, indicates erosion is the source of the phosphorus. During the study period, substantial amounts of construction and earthmoving occurred in areas adjacent to Clear Creek upstream of the site. Similar results have been found for other urban streams in the West (Anderson and Rounds, 2003, p. 36).

Phosphorus Sources

A two-step process was used to assess sources of phosphorus to the Carson River. First, reaches where significant changes in phosphorus loading and concentration occur were identified. Second, once tributaries or reaches of river were identified as being associated with significant increases in phosphorus, types of land use, transport processes, and biochemical and physical processes that could have caused the increases were investigated.

During the winter and spring surveys, the East Fork was the largest contributor to the phosphorus load measured at Carson River near Genoa (site 28), and the West Fork Ditch was a relatively minor contributor. During the summer surveys, the contribution of phosphorus load from the West Fork Ditch increased almost threefold more than during the winter and spring surveys, and the West Fork Ditch was the largest contributor of phosphorus load to the mainstem during the Summer 1 survey.

An important finding was that, on an annual basis, the estimated total-phosphorus load contributed from headwater reaches of the East and West Forks was about the same as that contributed by Carson Valley. The data indicate that particulate phosphorus is the principal component of phosphorus entering Carson Valley during at least half of the year, and that the East Fork upstream from East Fork Carson River below Markleeville Creek (site 16) is the primary source of that phosphorus. This indicates that erosion of soils in the reach upstream from site 16 is an important contributor to phosphorus loading in the Carson River. The principal land uses in that reach are forest and rangeland (fig. 9), which typically do not contribute large loads of phosphorus. The watershed upstream from East Fork Carson River near Dresslerville (site 17) has soils that are much greater in clay content and erodibility than headwater reaches in the West Fork (fig. 3). This difference likely explains why phosphorus yield from the East Fork was nearly twice that from the West Fork (table 8); however, it does not explain the similarity between sites 16 and 17 on the East Fork. Soil erodibility and clay content are slightly greater in the reach between the two sites than in the reach upstream from site 16. Historic logging during the Comstock era and forest fires within the last few decades may be the reason that forest and rangeland are contributing phosphorus; however, additional research is required.

Even though the estimated annual total-phosphorus loading upstream from and within Carson Valley are about the same, analyses indicate during summer the composition of the phosphorus changes from particulate phosphorus entering Carson Valley to orthophosphate leaving Carson Valley. This finding indicates that particulate phosphorus entering Carson Valley could be settling out and being replaced by orthophosphate from another source. Consumption of water for irrigation and changes in river velocity caused by diversion structures allow sediment to drop out during the irrigation season. Diversions also result in phosphorus and sediment being removed from the river and applied to irrigated fields where sediment and particulate phosphorus can drop out. The sediment and phosphorus may be resuspended and moved downstream during the following spring runoff. Alternatively, the particulate phosphorus could be converted to orthophosphate as it travels across Carson Valley, however, data collected during the study are not sufficient to distinguish between the possibilities.

During summer, large increases in total-phosphorus loads occur in the East Fork, West Fork/Brockliss Slough, and West Fork Ditch systems and the increase in load is caused principally by increases in orthophosphate. The principal source of orthophosphate in these reaches likely is agricultural return flows. In the West Fork/Brockliss Slough and West Fork Ditch reaches where the greatest increases occur, land use is almost exclusively agricultural. Land use principally is agricultural in the East Fork reaches. Nevertheless, decaying organic matter, urban runoff, and ground water contaminated by septic-system effluent are potential phosphorus sources that were not evaluated in detail as part of this investigation.

During winter, releases from Ambrosetti Pond may be the source of substantial amounts of the phosphorus load in the Carson River. In samples from Ambrosetti Pond Outlet (site 30), the median total-phosphorus concentration was 0.34 mg/L (app. 1) and discharge accounted for 11 percent of the streamflow at Carson River near Carson City (site 34) during November 1999–February 2000 (Garcia and others, 2002). On November 20, 2000, the total-phosphorus concentration was 0.17 mg/L when the instantaneous discharge was 27 ft^3/s (site 30; app. 1), which corresponds to a phosphorus load of about 25 lb/d. Also, on this day, NDEP sampled at site 34 and the total-phosphorus concentration was 0.08 mg/L when the instantaneous discharge was 137 ft^3/s, which corresponds to a phosphorus load of about 59 lb/d (app. 1). Thus, on November 20, Ambrosetti Pond accounted for about 42 percent of the phosphorus load leaving Carson Valley.

Because treated effluent contains elevated phosphorus concentrations, drainwater from fields irrigated with effluent is an obvious and potentially large source of phosphorus. During the Summer 1 survey, a more than 20-fold increase in orthophosphate concentration occurred in the 1.5 mi reach between sites 24 and 25 on the East Fork. Land use in that reach is predominantly agricultural land irrigated with effluent, which potentially could contribute large amounts of phosphorus. Data from Williams Slough (site 29) and Ambrosetti Pond Outlet (site 30) also support this conclusion. Orthophosphate concentration in Williams Slough, which drains fields irrigated with effluent, during the Summer 1 survey was 1.23 mg/L (app. 1); however, the load to the river was small because the discharge was small. Ambrosetti Pond, which stores water from fields irrigated with effluent, contributed almost 11 percent of the phosphorus load measured at Carson River near Carson City (site 34) during the Summer 1 survey even though Ambrosetti Pond Outlet was only discharging 1.2 ft^3/s at the time.

The potential phosphorus contribution to the Carson River from treated effluent used for irrigation was estimated using a mass-balance approach. Such an approach requires information about the amount of effluent used for irrigation and its phosphorus content. In 1999, the average total-phosphorus content of raw influent to the STPUD wastewater treatment plant was 4.63 mg/L and was 2.65 mg/L in the treated effluent (Terry Powers, South Tahoe Public Utility District, oral commun., April 16, 2003). The median total-phosphorus concentration in 117 samples of treated effluent collected by STPUD from Harvey Place Reservoir (fig. 5) between February 1989 and July 2000 was 2.45 mg/L and the maximum observed concentration was 5.1 mg/L. The average total-phosphorus

concentration in effluent from Incline Village General Improvement District in 2001 was 4 mg/L, however, beginning in 2003 a change in treatment process greatly lowered concentrations to approximately 0.5 mg/L (Ed Pollock, Incline Village General Improvement District, written commun., April 2003). A sample of the effluent from the Douglas County Sewer Improvement District No. 1 in February 2001 contained 2.6 mg/L total phosphorus (John Homenick, Douglas County Sewer Improvement District, written commun., April 2003). Between 1999 and 2001, nine samples of effluent were collected from the Carson City Wastewater Reclamation Plant and the average for total phosphorus was 4 mg/L (Kelvin Ikehara, Carson City Wastewater Reclamation Plant, written commun., April 10, 2003).

An estimated 55 tons of phosphorus from treated effluent are applied annually to fields in the study area and more than 30 tons to fields in Carson Valley (table 9). For comparison, the estimated total gain in phosphorus across Carson Valley was about 14 tons in 2001 and 18 tons in 2002 (table 8). Although the potential load from effluent is greater than the observed gain in load across Carson Valley, the actual amount of the observed gain in load that can be attributed to effluent reuse is not known and cannot be determined with data collected during this investigation.

SUMMARY

The Carson River watershed extends from its headwaters in the eastern Sierra Nevada of California to its terminus in the Carson Desert of Nevada. Discharge of treated effluent to the river ceased in 1987, resulting in a substantial decrease in phosphorus concentrations in the Carson River. However, concentrations of total phosphorus and suspended sediment still commonly exceed beneficial-use criteria established for the Carson River. 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 streamsides, drainage from fields irrigated with streamwater and treated effluent, ground-water seepage, and urban runoff including inputs from golf courses.

Table 9. Mass-balance calculations for the study area showing potential phosphorus loads from treated sewage effluent used for irrigation, 2000–02

[Abbreviation: mg/L, milligram per liter. Symbol: --, data not available]

Source of water	Effluent provided for irrigation (acre-feet)	Total-phosphorus concentration (mg/L)	Potential phosphorus load (tons per year)
South Tahoe Public Utility District	[a]4,910	2.5	16.7
Incline Village General Improvement District	[b]205	[c]4.0	1.1
Douglas County Sewer Improvement District #1	[d]2,200	2.6	7.8
Douglas County North Valley	[e]0	--	0
Indian Hills General Improvement District	[f]323	--	[g]1.1
Minden-Gardnerville Sanitation District	[h]1,800	--	[g]6.0
Carson City Wastewater Reclamation Plant	[i]4,500	4.0	24.5

[a]Reported as an average of 1.6 billion gallons annually (Ross Johnson, South Tahoe Public Utility District, oral commun., July 11, 2003).

[b]Reported as 66.822 million gallons for 2000 (Harvey Johnson, Incline Village General Improvement District, oral commun., July 17, 2003). The majority of effluent (445.185 million gallons in 2000) is delivered to their wetlands and not used for irrigation.

[c]A new treatment process starting in 2003 has reduced total-phosphorus concentrations in treated effluent to 0.3–0.5 mg/L.

[d]Reported as 721.92 million gallons for 2001 (John Hastie, Douglas County Sewer Improvement District, oral commun., July 17, 2003).

[e]In 2000, 33.591 million gallons of effluent were delivered to Incline Village General Improvement District wetlands but were not used for irrigation (Carl Ruschmeyer, Douglas County Community Development, written commun., July 25, 2003).

[f]The amount of effluent produced is not measured. Reported value is for 105.154 million gallons of influent to treatment facility in 2002 (Noel Huber, Indian Hills General Improvement District, written commun., July 16, 2003).

[g]Value based on estimated phosphorus concentration of 2.5 mg/L.

[h]The amount of effluent produced is not measured. Reported value is for influent to treatment facility in 2002 (David LaBarbara, Minden–Gardnerville Sanitation District, oral commun., July 15, 2003).

[i]Records of effluent used for irrigation are for 2001 (Kelvin Ikehara, Carson City Wastewater Reclamation Facility, written commun., July 15, 2003).

The USGS, in cooperation with CWSD, began an investigation in 2000 of the watershed with two specific goals: (1) 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) identify the most important sources of phosphorus within the reaches of the Carson River where the greatest increases in concentration and loading occur.

Agriculture is by far the largest use of Carson River water, with almost all of the water diverted from the East and West Forks during summer for irrigation. Water supply for irrigation in Carson Valley comes from direct diversions of surface water through an extensive system of ditches, stored water in mountain reservoirs, treated effluent from sewage treatment plants within the Carson River Basin, and imported treated effluent from the Lake Tahoe Basin. About 47,000 acres are irrigated in Carson Valley and much smaller areas are irrigated in Eagle and Dayton–Churchill Valleys. About 8,900 acres of agricultural fields, golf courses, and parks in the study area are permitted for irrigation using treated effluent.

In late summer, diversions for irrigation and consumption of water by evapotranspiration results in periods of low flow in the main channel of the river downstream of Carson Valley. Peak flows along the Carson River occur during periods of snowmelt runoff in spring, and during winter floods caused by rain on snow.

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

The composition of phosphorus in the Carson River changes in a downstream direction. During spring runoff and at least half of the year, particulate phosphorus is the dominant form of phosphorus in water entering Carson Valley from headwater reaches in the East Fork. Downstream from Carson Valley, particulate phosphorus is the predominant form only during spring runoff; during the remainder of the year orthophosphate is the predominant form.

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

Data collected by USGS, NDEP, and STPUD during WY 1988–2002 were used to develop regressions between discharge and total-phosphorus loads at five gaged sites along the West Fork, East Fork, and mainstem of the Carson River. Total-phosphorus loads for WY 2001–02 were estimated using the regression equations and daily mean discharge for the five gaged sites. Estimated annual loads were greater at all sites during 2002 than 2001 due to increased streamflow. Annual 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. Loads were the greatest during spring runoff, followed by fall and winter, and least during summer, largely due to similar patterns in the amount of streamflow in the Carson River.

During WY 2001–02, about 58 percent of the total-phosphorus load leaving Carson Valley on an annual basis could be attributed to headwater reaches upstream of Carson Valley. The relative contribution from the headwaters reaches changes over the year. During the period April 1–September 30 for the 2 years, about 85 percent of the total-phosphorus load leaving Carson Valley could be attributed to headwater reaches upstream of Carson Valley, whereas, during the period October 1–March 31 only about 17 percent could be attributed to headwater reaches.

Eagle Valley and Dayton–Churchill Valleys may act as sinks for phosphorus in the Carson River. On an annual basis (WY 2001–02), only about 90 percent and 85 percent of the phosphorus entering Eagle Valley and Dayton–Churchill Valleys, respectively, remained in the river. During flood events, however, the phosphorus may be mobilized and moved downstream.

Five synoptic surveys were conducted during winter, spring, and summer to identify specific reaches where changes in water quality occur and to identify the possible causes for those changes. During all of the synoptic surveys, total-phosphorus concentrations increased substantially between West Fork Carson River at Woodfords and Brockliss Slough above confluence Carson River. In this section of the river, the largest increases in total-phosphorus concentration and load were observed in the reach between Brockliss Slough at Highway 88 and Brockliss Slough above confluence Carson River. In this reach, most of the increase in phosphorus concentration during winter and summer surveys was due to increases in orthophosphate. During the summer surveys, 10–22 percent of the total-phosphorus load measured at Carson River near Genoa originated in this reach and its tributaries. Surface water inflows to the West Fork/Brockliss Slough include Wally's Hot Springs, streams from the east side of the Carson Range, and a complex of sloughs along the west side of the valley.

During the summer synoptic surveys, 27–36 percent of the total-phosphorus load measured at Carson River near Genoa originated in the West Fork Ditch part of the river. Because the ditch was dry at Highway 88 during the summer, all load in West Fork Ditch originated in the 8.7 mi reach downstream of Highway 88 and its tributaries.

Little change in water quality occurred between the East Fork below Markleeville Creek and Dresslerville during all the synoptic surveys. This indicates that phosphorus and sediment entering Carson Valley in the East Fork originates upstream

from the Markleeville site. The source of the phosphorus may be soils derived from granitic rocks high in the headwaters. In addition, the headwaters of the East Fork have soils that are more erodible and have a greater clay content than the headwaters of the West Fork, which may explain why the phosphorus yield from the East Fork (0.167 lb/acre) is greater than that from the West Fork (0.091 lb/acre).

The reach of the East Fork that contributes the largest phosphorus load to the Carson River during the winter and summer surveys is the 1.5 mi reach between the East Fork Carson River at Muller Lane and the East Fork Carson River above confluence West Fork Carson River. During the summer synoptic surveys, 11–20 percent of the total-phosphorus load at Carson River near Genoa may be attributed to this short reach. The likely source of the phosphorus in this reach is erosion or agricultural return flows from land where treated effluent is used for irrigation. Data are not available to determine whether surface-water runoff to the river occurs in this reach or whether phosphorus is migrating through ground water.

During the winter and spring surveys, the East Fork is the major contributor to the phosphorus load measured at Carson River near Genoa, and the West Fork Ditch is a relatively minor contributor. During the summer surveys, the contribution of phosphorus load from the West Fork Ditch increases almost threefold more than winter and spring, and was the largest contributor of phosphorus load to the mainstem during the Summer 1 survey.

The maximum total-phosphorus load measured on the mainstem of the Carson River during the synoptic surveys was 1,240 lb/d during spring 2002 at Carson River near Carson City. The largest total-phosphorus load measured was 4,588 lb/d on April 15, 2002, at Carson River at Cradlebaugh Bridge. During all of the synoptic surveys, total-phosphorus load and concentration decreased as the Carson River crossed Eagle Valley and tended to decrease as the Carson River crossed Dayton–Churchill Valley.

Ambrosetti Pond can contribute substantial amounts of phosphorus to the mainstem of the river, particularly during winter when flow in the mainstem is low. About 42 percent of the phosphorus load on November 20, 2000, at Carson River near Carson City came from Ambrosetti Pond. Although Williams Slough has very high concentrations of total phosphorus, it contributes small loads due to its low streamflow. Clear Creek above confluence Carson River accounted for less than 2 percent of the load at Carson River near Carson City during the synoptic surveys.

Data collected during this study are insufficient to determine specific phosphorus sources within a given reach; nevertheless, some general conclusions can be reached about the types of land use associated with phosphorus contributing areas. An important finding was that, on an annual basis, the total-phosphorus load contributed from headwater reaches of the East and West Forks was about the same as that contributed by sources within Carson Valley. Particulate phosphorus is the principal form of phosphorus entering Carson Valley during spring and summer, and upstream from East Fork Carson River below Markleeville Creek is the source of that phosphorus. Erosion of soils in the reach upstream from the Markleeville site is an important contributor to phosphorus loading in the Carson River.

During summer, large increases in phosphorus loads occur in the East Fork, West Fork/Brockliss Slough, and West Fork Ditch systems and the increase in load is caused principally by increases in orthophosphate. The principal source of orthophosphate in these reaches is most likely associated with agriculture, either return flows from irrigated lands or animal grazing. In the West Fork/ Brockliss Slough, and West Fork Ditch reaches where the greatest increases occur, land use is almost exclusively agricultural. Land use principally is agricultural in the East Fork reaches. Because treated effluent contains elevated phosphorus concentrations, drainwater from fields irrigated with effluent is a potentially large source of phosphorus. In 2002, during the Summer 1 survey, a more than 20-fold increase in orthophosphate concentration occurred in the 1.5 mi reach between East Fork Carson River at Muller Lane and East Fork Carson River above confluence West Fork Carson River. In that reach, agricultural lands are irrigated almost exclusively with effluent, indicating a potentially large contribution of phosphorus.

Phosphorus contributions from urban runoff and cattle grazing near the river were not evaluated in detail as part of this investigation. Ground-water samples were not collected to evaluate natural or anthropogenic sources of phosphorus to the river.

The importance of measures to control streambank and channel erosion is demonstrated by the observation that concentrations of particulate phosphorus alone can exceed the State water-quality standard for phosphorus when suspended-sediment concentrations exceed about 50 mg/L.

FUTURE DIRECTIONS

The principal goal of this project has been to define sources and source areas of phosphorus so that measures can be taken by resource-management agencies to attain water-quality standards for the Carson River. Of the various forms of phosphorus, orthophosphate is immediately bioavailable. As a result, it may contribute to nuisance algal growth in stream or river settings. Particulate phosphorus in suspension, however, tends not to be immediately bioavailable though it can become available later through desorption, decomposition, or other processes. Particulate phosphorus may ultimately contribute to eutrophication in Lahontan Reservoir or lakes in the Carson Desert. This study has shown that particulate phosphorus and orthophosphate have different sources, different seasonality, and may have different effects on the watershed.

The Carson River has been placed on Nevada's 303(d) list because total-phosphorus concentrations commonly exceed the State water-quality standard of 0.1 mg/L. As Gburek and others (2000) noted, 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. To effectively use the data collected during this investigation to solve actual problems and focus future research, it will be necessary to determine exactly what types of water-quality problems are being caused by these elevated phosphorus concentrations and where they are occurring.

Two major findings of this study show the need for additional research to provide State and Federal managers with the information needed to solve present and future problems. The first major finding is that headwater reaches of the river contribute up to 58 percent of the phosphorus leaving Carson Valley on an annual basis. Rangeland and forested areas in the watershed above the East Fork Carson River near Dresslerville site contributed sufficient phosphorus that the Nevada water-quality standard was exceeded in about 18 percent of the samples. Information is needed to identify why phosphorus yields from these headwaters reaches are much greater than expected for rangeland and forest. Specific headwater reaches where large increases in phosphorus loading occur need to be identified so the economics and feasibility of remediation can be evaluated.

The second major finding is that reaches of the river in Carson Valley where the largest increases in phosphorus loading occur are associated with agriculture, and in particular, fields permitted for use of treated effluent. Information gained from detailed investigations within these reaches is required to identify the importance of the source of water on phosphorus yield from irrigated fields. As the study area and surrounding areas become increasingly urban, the rapidly growing population will generate additional treated effluent, and areas which are now on septic systems may need to be connected to municipal wastewater treatment plants to protect ground-water resources. Managers will be faced with an increase in the amount of wastewater generated and a reduced capacity to reuse it as the number and area of fields where effluent can be safely used decreases because of population growth.

Several pieces of information are needed to effectively evaluate the contribution of phosphorus loads to the Carson River from reuse of treated effluent. Basic information needs include monitoring of phosphorus concentrations in treated effluent prior to land application, the amount of effluent applied to the land, and the time of year that effluent is used. Maps showing the area of effluent use, how the water is routed, and the associated drainage system to collect runoff and percolated effluent would help determine whether downstream water quality could be affected by the effluent use. Because Ambrosetti Pond receives drainage from fields irrigated with effluent, these data also are required to evaluate the importance of the pond as a phosphorus source. Additional data about phosphorus concentrations in water discharged from Ambrosetti Pond are required so that annual phosphorus loads from the pond to the river can be estimated.

It will be important to test the degree to which phosphorus binds to soils in areas where treated effluent is used to assess the potential for transport of phosphorus offsite or percolation to ground water. If phosphorus binding sites in the soil have become saturated, phosphorus may move through the soil profile. On the other hand, if phosphorus in effluent is effectively bound by soils, phosphorus concentrations in surficial soils might become elevated, leading to increases in phosphorus concentrations in runoff, particularly during high intensity rainstorms. Phosphorus loads in runoff during storms from fields irrigated with effluent should be compared with that from fields irrigated with stream water.

The composition of phosphorus changes during the summer from mostly particulate phosphorus entering Carson Valley to orthophosphate leaving it. More information is needed to understand what is happening to particulate phosphorus entering Carson Valley. If particulate phosphorus entering Carson Valley is deposited in fields during irrigation and remains there, then the actual phosphorus loading from Carson Valley may be greater than what was estimated in this study. Detailed analyses on the composition of particulate phosphorus are needed to determine how fast and under what environmental conditions the particulate phosphorus will release orthophosphate.

This study did not evaluate the effects of urban runoff, primarily because the locations of such discharges to the Carson River system are poorly known. Estimates of the amount of runoff and measurements of phosphorus concentrations in the runoff are needed to estimate the potential phosphorus load to the river from commercial and residential areas.

Additional research is needed to determine the areas of and conditions when ground water discharges to the Carson River system. Sampling of ground water known to discharge to the Carson River system is needed to quantify any phosphorus loading from ground water. For example, ground-water inflows to the Carson River account for increases in flow across the Carson Valley during the winter, but the extent to which that ground water influences the observed increase in phosphorus load is unknown. This investigation was a first step towards quantifying phosphorus sources and loads to the Carson River, but additional research is still needed to fill in the remaining gaps.

REFERENCES CITED

Alexander, R.B., and Smith, R.A., 1990, County-level estimates of nitrogen and phosphorus fertilizer use in the United States, 1945–85: U.S. Geological Survey Open-File Report 90-130, 12 p.

Anderson, C.W., and Rounds, S.A., 2003, Phosphorus and *E. coli* and their relation to selected constituents during storm runoff conditions in Fanno Creek, Oregon, 1998–99: U.S. Geological Survey Water-Resources Investigations Report 02-4232, 45 p.

Battaglin, W.A., and Goolsby, D.A., 1995, Spatial data in Geographic Information System format on agricultural chemical use, land use, and cropping practices in the

United States: U.S. Geological Survey Water-Resources Investigations Report 94-4176, 87 p.

Berris, S.N., Crompton, E.J., Joyner, J.D., and Ryan, Roslyn, 2003, Water resources data Nevada water year 2002: U.S. Geological Survey Water-Data Report NV-02-1, 600 p.

Bonham, H.F., 1969, Geology and mineral deposits of Washoe and Storey Counties, Nevada, *with a section on* Industrial rock and mineral deposits, by K.G. Papke: Nevada Bureau of Mines and Geology, Bulletin 70, 140 p.

California Department of Finance, 2004, Population projections by race/ethnicity for California and its counties 2000–2050 report 03 P-1: California Department of Finance, Demographic Research Unit, accessed July 27, 2004, at URL <http://www.dof.ca.gov/HTML/DEMOGRAP/DRU_Publications/Projections/P-1_Tables.xls>.

California Department of Water Resources, 1991, Carson River Atlas: State of California Department of Water Resources, 132 p.

Cantor, L.W., and Knox, R.C., 1985, Ground Water Pollution Control: Chelsea, MI, Lewis Publishers, 526 p.

Dietrich, R.V., and Skinner, B.J., 1979, Rocks and Rock Minerals: New York, John Wiley and Sons, 319 p.

Eaton, A.D., Clesceri, L.S., and Greenberg, A.E., eds., 1995, Standard methods for the examination of water and wastewater, 19th edition: Washington D.C., American Public Health Association, various pagination.

Edwards, T.K., and Glysson, G.D., 1999, Field methods for measurement of fluvial sediment: Techniques of Water-Resources Investigations of the U.S. Geological Survey, book 3, chap. C2, 89 p.

Fellos, J., 2001, Brunswick Reservoir water balance, City of Carson City Wastewater Treatment Plant, reuse master plan update, April 2001: Technical Memorandum 3.0, HDR Engineering Inc., 7 p.

Fennessey, L.A.J., and Jarrett, A.R., 1994, The dirt in a hole: A review of sedimentation basins for urban areas and construction sites: Journal of Soil and Water Conservation, v. 49, no. 4, p. 317–323.

Fishman, M.J., and Friedman, L.C., eds., 1989, Methods for determination of inorganic substances in water and fluvial sediments: 3rd edition, Techniques of Water-Resources Investigations of the U.S. Geological Survey, book 5, chap. A1, 545 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., Munson, R.H., Spaulding, R.J., and Vasquez, S.L., 2002, Water resources data Nevada water year 2001: U.S. Geological Survey Water-Data Report NV-01-1, 527 p.

Garside, L.J., and Schilling, J.H., 1979, Thermal waters of Nevada: Nevada Bureau of Mines and Geology Bulletin 91, 163 p.

Gburek, W.J., Sharpley, A.N., Heathwaite, A.L., and Folmar, G.J., 2000, Phosphorus management at the watershed scale—A modification of the phosphorus index: Journal of Environmental Quality, v. 29, p. 130–144.

Glancy, P.A., and Katzer, T.L., 1975 [1976], Water-resources appraisal of the Carson River Basin, western Nevada: Nevada Division of Water Resources, Reconnaissance Report 59, p. 126.

Gray, J.R., Glysson, G.D., Turcios, L.M., and Schwarz, G.E., 2000, Comparability of suspended-sediment concentration and total suspended solids data: U.S. Geological Survey Water-Resources Investigations Report 00-4191, 14 p.

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: Techniques of Water-Resources Investigations of the U.S. Geological Survey, book 5, chap. C1, 58 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: Amsterdam, Netherlands, Elsevier Science Publishers, 529 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 264 p.

Hess, G.W., 1996, Progress report on daily flow-routing simulation for the Carson River, California and Nevada: U.S. Geological Survey Open-File Report 96-211, 41 p.

Hess, G.W., and Taylor, R.L., 1999, River-operations model for Upper Carson River Basin, California and Nevada: U.S. Geological Survey Water-Resources Investigations Report 98-4240, 40 p.

Huang, W.T., 1962, Petrology: New York, McGraw-Hill Book Co., 480 p.

Hyndman, D.W., 1972, Petrology of Igneous and Metamorphic Rocks: New York, McGraw-Hill Book Co., 533 p.

Inter-Fluve, Inc., 1997, Fluvial geomorphic assessment of the Carson River: Implications for management of a changing river, final report: Bozeman, MT, June 6, 1997, various pagination and six appendixes.

Jassby, A.D., Reuter, J., Axler, R., Goldman, C., and Hackley, S., 1994, Atmospheric deposition of nitrogen and phosphorus in the annual nutrient load of Lake Tahoe (California–Nevada): Water Resources Research, v. 30, no. 7, p. 2207–2216.

Johnson, M.G., 1977, Geology and mineral deposits of Pershing County, Nevada: Nevada Bureau of Mines and Geology Bulletin 89, 115 p.

Kilroy, K.C., Lawrence, S.J., Lico, M.S., Bevans, H.E., and Watkins, S.A., 1997, Water-quality assessment of the Las Vegas area and the Carson and Truckee River Basins, Nevada and California—Nutrients, pesticides, and suspended sediment, October 1969–April 1990: U.S. Geological Survey Water-Resources Investigations Report 97-4106, 144 p.

Martin, G.R., Smoot, J.L., and White, K.D., 1992, A comparison of surface-grab and cross sectionally integrated stream-water quality sampling methods: Water Environment Research, v. 64, no. 7, p. 866–876.

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.

Miller, W.W., Guitjens, J.C., and Mahannah, C.N., 1977, Quality of irrigation water and surface return flows from selected agricultural lands in Nevada during the 1974 irrigation season: Journal of Environmental Quality, v. 6, no. 2, p. 193–200.

Miller, W.W., Guitjens, J.C., and Mahannah, C.N., 1984, Water quality of irrigation and surface return flows from flood-irrigated pasture and alfalfa hay: Journal of Environmental Quality, v. 13, no. 4, p. 543–548.

Miller, W.W., Guitjens, J.C., Mahannah, C.N., and Joung, H.M., 1978, Pollutant contributions from irrigation surface return flows: Journal of Environmental Quality, v. 7, no. 1, p. 35–40.

Moore, J.G., 1969, Geology and mineral deposits of Lyon, Douglas, and Ormsby Counties, Nevada: Nevada Bureau of Mines and Geology Bulletin 75, 45 p.

National Climatic Data Center, 2002, Monthly station normals of temperature, precipitation, and heating and cooling days, 1971–2001: Asheville, NC, National Oceanic and Atmospheric Administration, Climatography of the United States, no. 81, (Nevada).

Nevada Division of Environmental Protection, 2002a, Carson River Basin: Nevada Division of Environmental Protection, accessed July 26, 2004, at URL <http://ndep.nv.gov/bwqp/CarsonMap.html>.

Nevada Division of Environmental Protection, 2002b, Nevada's 2002 303(d) impaired waters list: Nevada Division of Environmental Protection, accessed May 11, 2004, at URL <http://ndep.nv.gov/bwqp/303list.pdf>.

Nevada State Library and Archives, 2000, Population projections for Nevada counties: 2000 to 2010: Nevada State Library and Archives, Department of Cultural Affairs, accessed July 26, 2004, at URL <http://dmla.clan.lib.nv.us/docs/nsla/sdc/stats/stat3.htm>.

Pope, L.M., and Milligan, C.R., 2000, Preliminary assessment of phosphorus transport in the Cheney Reservoir watershed, south-central Kansas, 1997–98: U.S. Geological Survey Water-Resources Investigations Report 00-4023, 29 p.

Prudic, D.E., and Wood, J.L., 1995, Results of hypothetical ground-water pumping in Carson Valley, a river-dominated basin in Douglas County, Nevada, and Alpine County, California: U.S. Geological Survey Water-Resources Investigations Report 95-4174, 29 p.

Reid, G.K., and Wood, R.D., 1976, Ecology of inland waters and estuaries, 2nd edition: New York, D. Van Nostrand Co., 485 p.

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

Ryden, J.C., Syers, J.K., and Harris, R.F., 1973, Phosphorus in runoff and streams: Advances in Agronomy, v. 25, p. 1–45.

Schachtman, D.P., Reid, R.J., and Ayling, S.M., 1998, Phosphorus uptake by plants – from soil to cell: Plant Physiology, v. 116, p. 447–453.

Schwarz, G.E., and Alexander, R.B., 1995, State Soil Geographic (STATSGO) database for the Conterminous United States: U.S. Geological Survey Open-File Report 95-449, Arc 7.0 coverage.

Sharpley, A.N., 1995, RCA III fate and transport of nutrients: Phosphorus, Working Paper No. 8: U.S. Department of Agriculture, Agricultural Research Service, accessed June 2004 at URL <http://www.nrcs.usda.gov/technical/land/pubs/wp08text.html>.

Sharpley, A.N., Hedley, M.J., Sibbesen, Erik, Hillbricht-Ilkowska, Anna, House, W.A., and Ryszkowski, Lech, 1995, Phosphorus transfers from terrestrial to aquatic ecosystems, *in* Tiessen, Holm, Phosphorus in the global environment: Chichester, NY, John Wiley and Sons, p. 171–199.

Shelton, L.R., 1994, Field guide for collecting and processing stream-water samples for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-455, 42 p.

Shelton, L.R., and Capel, P.D., 1994, Guidelines for collecting and processing samples of stream bed sediment for analysis of trace elements and organic contaminants for the National Water-Quality Assessment Program: U.S. Geological Survey Open-File Report 94-458, 20 p.

Stewart, J.H., 1980, Geology of Nevada—A discussion to accompany the geologic map of Nevada: Nevada Bureau of Mines and Geology, Special Publication 4, 135 p.

Stewart, J.H., 1983, Geology map of Walker Lake 1 degree quadrangle, Nevada and California: U.S. Geological Survey Miscellaneous Field Studies Map, MAP MF-1382-A.

Susfalk, R.B., 2000, Relationships of soil-extractable and plant-extractable phosphorus in forest soils of the eastern Sierra Nevada: Ph.D. dissertation, University of Nevada Reno, 228 p.

Tidball, R.R., 1989, Geochemistry of soils in the Carson River Valley, Nevada, *in* Schindler, K.S., ed., USGS research on mineral resources—1989 Program and Abstracts: U.S. Geological Survey Circular 1035, p. 74–75.

Tidball, R.R., Briggs, P.H., Stewart, K.C., Vaughn, R.B., and Welsch, E.P., 1991, Analytical data for soil and well core samples from the Carson River Basin, Lyon and Churchill Counties, Nevada: U.S. Geological Survey Open-File Report 91-584-A, 140 p.

University of Nevada, 2001, 2000 Nevada population & race: Bureau of Business and Economic Development, University of Nevada, Reno, accessed April 16, 2003, at URL <http://www.nsbdc.org/demographer/census2000/images/countys_and_places.pdf>.

U.S. Department of Agriculture, 1997, 1997 Census of agriculture highlights: National Agricultural Statistics Service, accessed on July 31, 2003, at URL <http://www.nass.usda.gov/census/census97/highlights/ag-state.htm>.

U.S. Department of Agriculture, 2004a, County-level population data for California: Economic Research Service, accessed on July 27, 2004, at URL <http://www.ers.usda.gov/Data/Population/PopList.asp?ST=CA&LongName=California>.

U.S. Department of Agriculture, 2004b, County-level population data for Nevada: Economic Research Service, accessed on July 27, 2004, at URL <http://www.ers.usda.gov/Data/Population/PopList.asp?ST=NV&LongName=Nevada>.

U.S. Environmental Protection Agency, 1983, Results of the Nationwide Urban Runoff Program, volume 1—Final report: Water Planning Division, Washington D.C., NTIS PB#84-185552, 200 p.

U.S. Environmental Protection Agency, 1999, Protocol for developing nutrient TMDLs: Washington, D.C., Office of Water, U.S. Environmental Protection Agency Report EPA 841-B-99-007, 135 p.

Vymazal, Jan, 1994, Algae and element cycling in wetlands: Boca Raton, FL, Lewis Publishers, 689 p.

Waschbusch, R.J., Selbig, W.R., and Bannerman, R.T., 1999, Sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin, 1994–95: U.S. Geological Survey Water-Resources Investigations Report 99-4021, 47 p.

Whitney, Rita, 1994, Data of ground-water quality in the Carson River Basin, western Nevada and eastern California, 1987–90: U.S. Geological Survey Open-File Report 94-39, 139 p.

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., eds., 1998, National field manual for the collection of water-quality data: Techniques of Water-Resources Investigations of the U.S. Geological Survey, book 9, chaps. A4 and A5 (Handbooks for Water-Resources Investigations), various pagination.

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.

APPENDIXES

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements: Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)	Analysis type	Phosphorus: Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	Suspended sediment: SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
West Fork Carson River and tributaries																	
1	10310000	01/03/01	0930	S	16	77	7.3	0.7	--	0.37	E	S	<0.01	<0.01	--	--	0.42
		01/04/01	1310	U	20	76	--	--	--	--	E	H	0.01	<0.01	--	--	--
											R	H	0.04	<0.01	--	--	--
		02/01/01	0825	S	e22	78	6.9	0.3	9.1	0.48	E	S	<0.01	<0.01	--	--	0.64
		03/06/01	0908	S	22	77	7.4	2.2	9.4	0.35	E	S	<0.01	0.04	--	--	0.91
		03/20/01	0925	U	42	74	--	3.5	--	--	E	H	0.03	<0.01	--	--	--
		04/03/01	0915	S	82	56	7.5	2.8	11.4	2.8	E	S	0.02	<0.01	--	--	6.4
		04/26/01	1230	U	218	45	--	6.0	--	--	E	H	0.05	<0.01	29	62	--
											R	H	0.04	<0.01	--	--	--
		05/01/01	0919	S	288	41	7.0	4.6	10.5	7.9	E	S	0.05	<0.01	--	--	24
		05/02/01	1135	U	264	41	--	3.0	--	--	E	H	0.03	<0.01	30	28	--
		05/09/01	0815	U	285	37	--	4.5	--	--	E	H	0.04	<0.01	24	58	--
		06/05/01	0923	S	63	58	7.4	10.2	9.0	1.5	E	S	0.01	<0.01	--	--	3.8
		07/05/01	0830	S	26	66	7.2	15.5	8.0	1.0	E	S	0.02	<0.01	--	--	4.7
		08/01/01	0830	S	18	81	7.2	11.9	8.7	0.72	E	S	0.02	0.07	--	--	1.1
		09/05/01	0835	S	11	84	7.0	13.1	8.6	0.50	E	S	0.01	<0.01	--	--	0.40
		10/02/01	0820	S	12	89	6.9	9.4	9.2	0.33	E	S	<0.01	<0.01	--	--	0.70
		11/14/01	0840	S	18	79	6.6	4.2	9.9	0.56	E	S	0.01	<0.01	--	--	0.84
		12/04/01	0900	S	18	81	7.0	0.9	11.5	0.62	E	S	0.01	<0.01	--	--	2.2
		01/02/02	0930	S	28	80	7.5	2.4	10.3	0.90	E	S	<0.01	<0.01	--	--	1.1
		02/05/02	0923	S	22	84	7.5	1.0	--	0.50	E	S	<0.01	<0.01	--	--	0.46
		02/19/02	0910	U	27	78	6.6	2.0	11.4	0.94	E	H	<0.01	<0.01	4	76	<10
		03/05/02	0906	S	37	81	7.0	1.4	11.8	0.90	E	S	<0.01	<0.01	--	--	1.2
		04/02/02	0907	S	155	56	6.9	1.9	11.4	6.4	E	S	0.03	<0.01	--	--	12

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements: Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)	Analysis type	Phosphorus: Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	Suspended sediment: SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
		04/17/02	1245	U	261	45	7.4	2.0	12.1	6.1	E	H	0.03	<0.01	23	64	--
		04/24/02	1025	U	239	46	7.3	4.3	11.5	3.2	E	H	0.02	<0.01	16	52	--
		05/01/02	0827	S	184	54	7.5	2.4	11.1	1.5	E	S	0.01	<0.01	--	--	2.4
		05/28/02	1030	U	196	42	7.3	7.5	9.3	2.9	E	H	0.02	<0.01	9	71	4
		06/04/02	0755	S	190	42	6.9	8.9	9.5	2.8	E	S	0.02	<0.01	--	--	5.7
		07/01/02	1000	U	64	56	7.0	14.5	9.4	1.6	E	H	0.02	<0.01	4	66	<10
		07/02/02	0816	S	60	58	7.5	14.1	8.0	1.4	E	S	0.02	<0.01	--	--	3.9
		08/13/02	0900	S	17	78	7.5	12.0	8.6	0.10	E	S	0.01	0.01	--	--	0.46
		08/21/02	0906	U	17	74	7.4	10.0	--	0.22	E	H	<0.01	<0.01	<1	--	3
		09/03/02	1005	S	12	78	7.8	13.1	8.9	0.13	E	S	0.01	<0.01	--	--	0.70
2	10310200	11/20/00	1015	U	9.7	91	--	3.0	--	--	E	H	0.08	0.06	--	--	--
		03/20/01	1045	N	37	--	--	--	--	--	E	H	0.04	[c]<0.01	--	--	--
3	10310220	08/08/01	1410	U	0.93	--	--	24.0	--	--	E	H	0.06	<0.01	--	--	--
		02/19/02	1200	U	11	96	7.6	2.5	12.2	0.89	E	H	<0.01	<0.01	9	90	--
											R	H	<0.01	<0.01	--	--	--
		04/17/02	1625	U	157	54	7.8	6.1	11.0	4.9	E	H	0.04	<0.01	14	63	--
		04/24/02	1300	U	98	54	7.7	8.8	10.2	2.8	E	H	0.02	<0.01	13	64	--
		07/01/02	1225	U	43	69	7.2	19.5	7.8	7.5	E	H	0.07	0.01	19	82	12
		08/21/02	1345	U	3.3	104	8.5	18.0	9.4	0.91	E	H	0.01	<0.01	2	77	1.5
5	10309082	08/10/01	1135	U	0.81	--	--	21.0	--	--	E	H	0.09	0.06	--	--	--
		02/20/02	0910	U	6.1	209	7.7	6.0	11.0	4.5	E	H	0.03	0.02	10	96	--
		04/25/02	0920	U	5.0	104	7.5	10.5	10.8	7.3	E	H	0.05	0.02	13	92	--
		07/02/02	0815	U	5.2	188	6.8	16.0	8.3	2.6	E	H	0.10	0.08	4	97	4.0
		08/21/02	1550	U	0.28	292	7.4	16.5	8.6	0.58	E	H	0.10	0.08	1	--	0.5
6	10310358	03/20/01	1330	N	0.22	284	8.3	15.0	10.0	6.9	E	H	0.16	0.09	--	--	7.0
		02/20/02	1130	U	8.6	253	7.7	9.0	10.8	8.0	E	H	0.11	0.05	13	85	--

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements: Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)	Analysis type	Phosphorus: Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	Suspended sediment: SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
		04/25/02	1155	U	16	197	8.5	17.5	12.4	16	E	H	0.31	0.17	29	84	--
											R	H	0.31	0.18	--	--	--
		07/02/02	1150	U	15	199	7.6	23.5	12.4	1.8	E	H	0.25	0.22	6	69	4
		08/22/02	1015	U	0.79	324	7.7	16.0	6.4	1.2	E	H	0.17	0.14	1	--	1
7	10309114	08/06/01	1015	U	0.43	--	--	19.0	--	--	E	H	0.32	0.20	--	--	--
		02/20/02	1440	U	8.4	232	7.9	12.2	10.5	12	E	H	0.08	0.04	22	96	--
		04/25/02	1430	U	20	148	8.4	16.6	9.7	22	E	H	0.16	0.06	44	96	--
		07/02/02	1500	U	4.5	248	8.1	25.0	11.4	3.0	E	H	0.19	0.16	10	84	4
		08/22/02	1250	U	0.38	357	9.1	21.0	19.0	1.2	E	H	0.26	0.22	5	79	0.5
8	103103588	08/06/01	1130	U	1.6	--	--	27.0	--	--	E	H	0.31	0.23	--	--	--
9	10310359	02/21/02	0950	U	17	237	7.7	7.5	11.0	6.6	E	H	0.09	0.05	13	91	--
		04/25/02	1630	U	44	167	8.9	19.8	11.2	24	E	H	0.25	0.13	71	78	--
		05/28/02	1430	U	79	130	8.6	19.5	12.5	16	E	H	0.18	0.08	54	72	33
		07/03/02	0800	U	24	213	7.3	19.0	5.7	3.0	E	H	0.26	0.23	9	64	6
											R	H	0.26	0.23	--	--	2
		08/22/02	1435	U	1.6	337	9.2	27.0	14.0	2.2	E	H	0.20	0.17	5	90	2.5
Brockless Slough and tributaries																	
10	10310240	02/20/02	1410	U	7.4	138	7.8	11.0	10.1	9.0	E	H	0.06	0.02	19	82	--
		05/02/02	0940	U	60	80	7.6	7.8	10.7	6.1	E	H	0.03	0.01	8	90	7
		05/28/02	1222	U	64	74	7.6	14.3	8.8	3.3	E	H	0.04	0.02	8	88	3
		07/01/02	1540	U	1.5	206	7.1	24.0	7.0	2.2	E	H	0.07	0.03	4	96	2
		08/21/02	1135	U	0.24	220	7.3	14.5	6.6	2.4	E	H	0.05	0.02	4	98	6.5
12	10310255	02/21/02	1445	U	16	153	8.0	10.9	8.6	5.5	E	H	0.07	0.03	12	91	--
		05/02/02	1150	U	24	218	7.9	12.1	13.2	4.1	E	H	0.12	0.06	5	59	2
13	10310265	07/12/02	0852	U	<1	240	7.2	21.5	3.5	2.9	E	H	0.29	0.23	6	84	7
		08/23/02	1100	U	e0.3	213	8.4	14.0	5.0	3.0	E	H	0.10	0.06	7	83	3
14	10310403	03/20/01	1340	N	51	146	8.0	8.8	11.8	21	E	H	0.12	0.04	--	--	42

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements: Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)	Analysis type	Phosphorus: Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	Suspended sediment: SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
15	10310404	08/07/01	1120	U	0.64	--	--	25.0	--	--	E	H	0.36	0.16	--	--	--
		02/22/02	0950	U	39	213	7.8	7.3	11.7	12	E	H	0.12	0.06	20	96	--
		05/09/02	1000	U	143	142	7.7	12.2	8.8	7.9	E	H	0.14	0.08	19	81	13
		05/29/02	1100	U	37	246	7.3	18.0	5.9	29	E	H	0.30	0.11	70	86	59
		07/03/02	1051	U	10	330	7.6	22.0	6.6	22	E	H	0.38	0.24	60	94	36
		08/23/02	0820	U	e0.4	399	7.6	16.5	6.1	13	E	H	0.32	0.20	16	91	20
											R	H	0.32	0.19	--	--	14
East Fork Carson River and tributaries																	
16	10308200	10/16/01	1210	U	29	168	--	10.0	--	0.6	E	U	<0.06	--	1	--	--
		01/16/02	1315	U	89	161	7.9	1.0	11.4	1.3	E	U	<0.06	--	2	--	--
		02/19/02	1110	U	93	161	--	4.0	--	0.76	E	H	0.02	0.01	5	71	--
		04/23/02	1245	U	434	76	8.0	6.5	10.1	5.7	E	U	<0.06	--	20	--	--
		05/06/02	1030	U	762	57	7.7	5.8	10.4	9.0	E	H	0.05	0.01	39	43	29
		05/28/02	1135	U	832	49	7.7	10.0	14.7	6.8	E	H	0.04	<0.01	28	50	12
		07/08/02	0940	U	151	85	7.2	14.0	9.0	1.4	E	H	0.02	0.02	3	72	3
		07/10/02	0925	U	138	88	8.0	14.5	9.5	3.1	E	U	<0.06	--	3	--	--
		08/26/02	1050	U	53	119	7.9	13.5	9.2	0.83	E	H	0.02	0.02	1	--	<10
		09/10/02	1115	U	52	125	8.3	11.3	--	1.9	E	U	0.02	--	4	--	--
17	10309010	11/20/00	0900	U	e64	224	--	0.0	--	--	E	H	0.19	0.18	--	--	--
		11/20/00	1005	N	e71	227	8.2	0.2	16.0	3.4	E	H	0.02	0.01	--	--	2
		11/21/00	1025	U	e60	224	7.8	0.8	12.1	--	E	U	0.02	e0.02	4	77	--
		12/20/00	1010	U	76	225	7.9	1.2	11.9	--	E	U	0.02	e0.01	4	54	--
		01/04/01	1055	U	e116	233	--	--	--	--	E	H	0.02	0.02	--	--	--
											R	U	0.02	e0.01	--	--	--
											R	H	0.02	0.02	--	--	--

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements: Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)	Analysis type	Phosphorus: Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	Suspended sediment: SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
		01/09/01	1015	N	e62	223	8.2	1.5	8.6	1.2	E	H	0.03	0.02	--	--	0
		01/16/01	1100	U	60	220	7.9	0.1	12.0	--	E	U	0.02	e0.01	4	62	--
		02/23/01	1100	U	72	232	8.0	0.5	12.0	--	E	U	0.02	<0.02	4	89	--
		03/20/01	1010	N	e268	172	7.5	7.7	10.3	55	E	H	0.21	0.02	--	--	111
		03/20/01	1120	U	293	171	8.0	8.2	10.5	--	E	U	0.20	e0.01	87	55	--
		04/19/01	1045	U	362	106	7.7	6.7	10.5	--	E	U	0.04	<0.02	14	50	--
		04/25/01	1310	U	e674	97	--	11.0	--	--	E	H	0.23	0.02	123	65	--
		04/27/01	1130	U	e1,060	72	--	7.5	--	--	E	H	0.33	0.02	251	65	--
		05/02/01	0910	U	e1,200	58	--	5.0	--	--	E	H	0.27	0.02	129	52	--
											R	H	0.25	0.02	--	--	--
		05/09/01	1010	U	e1,280	50	--	7.0	--	--	E	H	0.31	0.02	195	62	--
		05/11/01	0945	U	e1,270	50	--	8.0	--	--	E	H	0.21	0.02	110	56	--
		05/15/01	1155	U	1,110	55	7.4	9.6	10.3	--	E	H	0.12	0.02	52	19	--
											R	U	0.17	e0.01	--	--	--
		05/29/01	1050	N	e614	70	6.3	12.5	9.5	7.2	E	H	0.05	0.01	--	--	13
		06/18/01	1015	U	163	114	7.9	14.8	9.3	--	E	U	0.02	e0.01	7	62	--
		07/17/01	1035	N	e79	171	8.4	14.2	8.8	1.4	E	H	0.02	[c]<0.01	--	--	3
		07/24/01	1040	U	70	172	8.0	17.7	9.2	--	E	H	0.03	0.01	4	79	--
											R	U	0.02	<0.02	--	--	--
		08/22/01	1045	U	41	247	8.4	16.4	9.9	--	E	U	0.02	<0.02	4	63	--
		09/10/01	1018	U	38	270	8.2	14.5	9.2	--	E	U	0.01	<0.02	8	71	--
		09/25/01	1030	N	e36	290	9.1	14.0	9.5	5.5	E	H	0.11	0.06	--	--	10
		10/15/01	1000	U	e44	270	8.2	8.9	10.4	--	E	U	0.01	<0.02	2	91	--
		11/19/01	1000	U	e42	242	8.2	3.5	11.6	--	E	U	0.02	<0.02	5	73	--
		11/27/01	1930	N	e75	240	8.4	--	--	4.3	E	H	0.08	0.06	--	--	12

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements: Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)	Analysis type	Phosphorus: Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	Suspended sediment: SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
		12/18/01	1030	U	e68	207	8.1	0.2	11.8	--	E	U	0.02	<0.02	4	82	--
		01/08/02	1050	N	e191	180	8.4	3.5	12.3	7	E	H	0.04	0.02	--	--	11
		01/24/02	1025	U	e92	212	7.4	0.0	12.7	--	E	U	0.02	0.03	38	39	--
		02/19/02	1030	U	e99	197	7.9	5.0	11.1	1.7	E	H	0.02	0.01	5	89	<10
											R	U	0.02	<0.02	--	--	--
		03/20/02	1015	N	e164	190	8.4	5.5	10.6	2.6	E	H	0.03	0.01	--	--	8
		03/21/02	0950	U	e170	175	7.3	6.2	11.2	--	E	U	0.03	<0.02	13	52	--
		04/16/02	1110	U	1,110	72	6.9	3.8	11.8	--	E	U	0.08	e0.01	42	60	--
		05/06/02	1530	U	703	65	7.8	12.0	9.3	12	E	H	0.06	0.02	38	57	22
		05/15/02	1220	U	1,530	60	7.2	10.5	9.8	--	E	H	0.09	0.02	46	81	--
											R	U	0.07	<0.02	--	--	--
		05/20/02	1000	U	e1,140	52	7.5	7.5	11.3	22	E	H	0.12	0.02	77	47	34
		05/20/02	1230	U	e1,100	52	7.4	7.5	--	19	E	H	0.10	0.02	116	29	24
		05/28/02	1540	U	e851	59	7.4	14.0	12.4	9.8	E	H	0.05	0.01	39	41	17
		05/28/02	1600	N	e837	61	7.7	14.0	9.6	12	E	H	0.06	0.01	--	--	30
		06/10/02	1200	U	737	61	7.6	9.4	9.9	--	E	U	0.04	e0.01	12	87	--
		07/09/02	1030	U	e174	110	8.0	18.9	8.1	1.2	E	H	0.02	0.01	4	88	3
											R	U	0.03	e0.01	--	--	--
		07/16/02	1110	N	e130	140	8.6	20.7	8.3	2.3	E	H	0.03	0.01	--	--	8
		08/20/02	0950	U	e62	180	7.8	15.0	9.6	--	E	U	0.02	<0.02	5	72	--
		08/26/02	1330	U	e60	186	8.8	20.5	8.6	1.8	E	H	0.02	<0.01	4	80	0.5
		09/05/02	1015	U	e66	202	7.7	15.8	9.4	--	E	U	0.04	e0.01	6	90	--
		09/17/02	1000	N	e56	220	8.4	13.7	8.4	6	E	H	0.03	[c]<0.01	--	--	2
18	10309089	08/08/01	0915	U	25	--	--	20.0	--	--	E	H	0.04	0.02	--	--	--
21	1030909018	05/31/01	0905	U	4.8	--	--	15.0	--	--	E	H	0.04	0.02	8	78	--
		08/08/01	1015	U	5.0	--	--	22.0	--	--	E	H	0.04	0.02	--	--	--

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements					Analysis type	Phosphorus			Suspended sediment		
						Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)		Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
22	1030909020	05/31/01	1038	U	4.4	--	--	15.0	--	--	E	H	0.09	0.04	10	72	--
		08/08/01	1205	U	2.7	--	--	24.0	--	--	E	H	0.14	0.07	--	--	--
		02/19/02	1540	U	1.5	202	--	12.0	--	6.1	E	H	0.06	0.02	11	77	--
		05/07/02	0930	U	20	123	7.5	12.5	9.0	70	E	H	0.42	0.09	475	76	146
		07/08/02	1310	U	8.0	180	7.2	25.0	7.8	4.9	E	H	0.17	0.10	17	51	8
		08/27/02	0830	U	1.0	255	7.4	12.0	7.2	4.6	E	H	0.15	0.09	14	74	12
24	10309120	03/20/01	1250	N	232	--	--	--	--	--	E	H	0.22	0.02	--	--	--
		02/20/02	1130	U	89	213	8.7	9.5	13.4	5.6	E	H	0.06	<0.01	13	74	--
		05/07/02	1205	U	531	70	7.8	11.0	10.4	22	E	H	0.11	0.02	55	70	34
		07/08/02	1525	U	18	233	8.9	27.0	17.5	1.8	E	H	0.04	<0.01	9	84	4
		08/28/02	0850	U	7.2	311	8.0	14.2	11.1	1.0	E	H	0.03	<0.01	4	89	8
											R	H	0.03	0.01	--	--	4
25	10309130	08/06/01	1330	U	3.3	--	--	27.0	--	--	E	H	0.17	0.09	--	--	--
		02/21/02	1155	U	98	214	8.2	8.5	11.9	11	E	H	0.10	0.01	33	72	--
		05/08/02	1100	U	531	71	7.8	9.4	10.4	20	E	H	0.11	0.02	63	59	37
		05/29/02	1225	U	639	70	7.3	15.0	10.3	18	E	H	0.14	0.03	56	65	33
											R	H	0.12	0.03	--	--	37
		07/08/02	1750	U	13	441	7.9	27.5	9.2	3.4	E	H	0.32	0.21	11	67	9
		08/28/02	1040	U	8.6	346	8.3	19.6	8.8	1.5	E	H	0.04	0.02	4	98	7
Mainstem Carson River and tributaries																	
26	10310405	03/21/01	1315	N	298	--	--	--	--	--	E	H	0.39	0.03	--	--	--
		08/06/01	1500	U	4.3	--	--	29.5	--	--	E	H	0.28	0.18	--	--	--
27	10310406	08/07/01	1300	U	5.0	--	--	30.0	--	--	E	H	0.17	0.13	--	--	--
28	10310407	02/25/02	0940	U	172	199	7.9	4.0	--	7.0	E	H	0.08	0.03	18	70	--
		05/09/02	1325	U	697	100	7.5	13.1	9.8	14	E	H	0.12	0.05	31	60	27
		05/29/02	1400	U	730	90	7.5	17.7	9.1	19	E	H	0.18	0.05	54	62	36
											R	H	0.14	0.05	--	--	34

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements					Analysis type	Phosphorus			Suspended sediment		
						Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)		Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
		07/09/02	1048	U	38	351	7.4	23.0	6.6	9.5	E	H	0.45	0.29	17	86	15
		08/28/02	1220	U	13	352	8.3	23.3	9.3	2.7	E	H	0.09	0.06	6	95	4
29	10310419	02/28/02	1530	U	e0.5	605	8.9	14.8	--	15	E	H	0.70	0.41	13	98	--
		05/10/02	0840	U	e0.37	440	8.0	9.5	5.9	9.5	E	H	1.78	1.81	10	88	10
		07/09/02	1230	U	e0.02	379	7.0	21.5	5.8	1.6	E	H	1.25	1.23	5	55	4
											R	H	1.25	1.23	--	--	4
		08/27/02	1035	U	0.19	462	7.6	15.5	6.2	17	E	H	7.32	0.75	20	79	18
30	10310448	11/20/00	1445	U	27	428	--	4.5	--	--	E	H	0.17	0.07	--	--	--
		01/04/01	0930	U	9.5	483	--	--	--	--	E	H	0.12	0.10	--	--	--
		03/21/01	1447	U	7.6	483	--	16.0	--	--	E	H	0.25	0.11	--	--	--
		05/31/01	1208	U	9.5	--	--	22.0	--	--	E	H	0.39	0.30	12	81	--
		02/25/02	1300	U	3.6	468	8.7	7.7	14.0	29	E	H	0.33	0.17	31	95	--
		05/10/02	1045	U	42	332	8.0	14.0	7.8	8.5	E	H	0.35	0.27	15	84	8
		07/09/02	1500	U	1.2	423	8.3	20.0	6.9	3.3	E	H	0.52	0.48	6	97	7
		08/27/02	1245	U	e<0.05	530	8.3	19.0	8.3	4.8	E	H	0.51	0.37	7	99	6
31	10310450	11/20/00	1255	U	103	277	--	5.0	--	--	E	H	0.09	0.04	--	--	--
		03/21/01	1200	N	346	186	7.8	11.5	12.8	45	E	H	0.20	0.04	--	--	102
		08/07/01	0830	U	5.4	--	--	16.0	--	--	E	H	0.29	0.25	--	--	--
		02/25/02	1520	U	188	218	7.9	8.0	12.0	6.6	E	H	0.08	0.04	30	34	9
		04/15/02	1530	U	1,330	82	6.9	8.5	--	--	E	H	0.64	0.04	656	41	--
		05/13/02	1140	U	770	119	7.5	12.0	8.7	14	E	H	0.16	0.06	66	45	28
		05/30/02	0920	U	939	94	6.7	16.5	7.7	32	E	H	0.22	0.05	129	52	65
		07/10/02	0955	U	17	387	7.4	23.5	6.8	3.4	E	H	0.28	0.22	6	75	6
		08/27/02	1400	U	9.8	384	8.4	25.0	10.8	4.5	E	H	0.17	0.12	8	95	8
32	10310525	08/10/01	0810	U	0.29	--	--	14.0	--	--	E	H	0.06	0.04	--	--	--
		07/10/02	1255	U	e0.02	177	7.4	29.5	6.3	3.6	E	H	0.06	0.05	3	95	4
		07/18/02	1435	U	2.4	162	7.5	16.2	7.4	--	E	H	0.45	0.06	148	96	120

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements					Analysis type	Phosphorus			Suspended sediment		
						Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)		Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
		08/27/02	1550	U	0.48	168	8.4	19.0	8.1	3.3	E	H	0.04	0.03	4	97	4
33	10310550	03/05/01	1055	U	5.8	203	--	--	--	--	E	H	0.04	0.01	--	--	--
											R	H	0.04	0.01	--	--	--
		07/11/01	1120	U	0.92	--	--	26.0	--	--	E	H	0.17	0.06	26	63	--
		08/10/01	0927	U	0	--	--	--	--	--	--	--	--	--	--	--	--
		02/26/02	0930	U	4.6	183	8.0	3.5	12.1	17	E	H	0.07	0.02	35	97	--
		05/13/02	1400	U	2.1	176	8.2	24.7	7.9	36	E	H	0.16	0.05	49	94	47
											R	H	0.16	0.05	--	--	<10
		07/10/02	1255	U	0	--	--	--	--	--	--	--	--	--	--	--	--
		08/27/02	1550	U	0	--	--	--	--	--	--	--	--	--	--	--	--
34	10311000	11/20/00	1320	N	137	305	8.3	5.0	11.3	10	E	H	0.08	0.04	--	--	10
		11/21/00	0915	U	128	320	--	1.0	--	--	E	H	0.09	0.05	--	--	--
		01/04/01	1430	U	103	323	--	--	--	--	E	H	0.06	0.06	--	--	--
		01/09/01	0855	N	118	311	9.0	2.7	8.0	6.2	E	H	0.07	0.04	--	--	9
		03/21/01	1135	N	306	212	8.0	12.1	12.2	40	E	H	0.21	0.05	--	--	84
		05/21/01	1045	U	652	--	--	16.0	--	--	E	H	[d]e0.21	0.07	78	50	--
		05/29/01	1400	N	335	155	7.9	20.5	7.8	14	E	H	0.13	0.06	--	--	35
		07/17/01	1455	N	14	568	8.4	26.1	6.2	10	E	H	0.30	0.21	--	--	24
		09/25/01	1355	N	4.7	780	8.9	24.0	7.7	8.9	E	H	0.18	0.05	--	--	16
		11/27/01	1310	N	89	300	8.2	--	--	9	E	H	0.10	0.11	--	--	13
		01/08/02	1410	N	278	240	--	6.2	11.5	15	E	H	0.10	0.03	--	--	27
		02/26/02	1355	U	184	248	8.1	9.5	10.8	8.9	E	H	0.10	0.05	17	82	16
		03/20/02	1300	N	182	260	8.0	13.0	8.3	11	E	H	0.10	0.04	--	--	21
		05/15/02	1445	U	919	104	7.8	16.5	--	25	E	H	0.25	0.06	105	51	--
		05/28/02	1220	N	712	120	8.1	16.0	7.9	25	E	H	0.16	0.05	--	--	65

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements					Analysis type	Phosphorus			Suspended sediment		
						Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)		Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
		05/30/02	1100	U	959	108	7.8	17.5	9.0	28	E	H	0.24	0.06	122	51	59
		07/10/02	1500	U	24	469	8.0	32.0	9.3	4.0	E	H	0.24	0.19	6	83	6
		07/17/02	1105	N	22	510	8.5	23.2	8.3	11	E	H	0.40	0.31	--	--	27
		08/28/02	1410	U	11	500	8.5	27.7	8.4	4.6	E	H	0.15	0.10	6	95	6.5
		09/17/02	1335	N	9.1	510	8.4	22.9	10.9	6	E	H	0.15	0.11	--	--	10
35	10311008	05/15/02	0830	U	779	114	7.6	13.8	8.3	21	E	H	0.18	0.07	55	84	44
36	10311300	03/05/01	1200	U	3.8	836	--	--	--	--	E	H	0.27	0.05	--	--	--
		04/23/01	1330	U	1.2	1,259	--	19.5	--	--	E	H	0.28	0.17	20	81	--
37	10311325	04/23/01	1520	U	11	442	--	19.5	--	--	E	H	0.19	0.10	--	--	--
		07/11/01	1410	U	[e]1.4	--	--	28.0	--	--	E	H	0.27	0.11	16	84	--
		08/09/01	1400	U	0	--	--	--	--	--	--	--	--	--	--	--	--
		02/27/02	0905	U	e0.75	1,120	8.7	5.5	9.4	16	E	H	0.13	0.07	20	98	--
		05/14/02	1100	U	7.8	201	8.4	19.5	9.4	8.4	E	H	0.09	0.06	9	86	11
		07/11/02	0750	U	[e]e0.02	446	7.6	19.5	6.3	2.2	E	H	0.15	0.11	4	82	8
		08/29/02	0830	U	0	--	--	--	--	--	--	--	--	--	--	--	--
38	391057-119422301	03/05/01	1300	U	0.13	1,829	--	--	--	--	E	H	0.14	0.06	--	--	--
		04/23/01	1410	U	e0.1	1,929	--	--	17.0	--	E	H	0.20	0.13	98	15	--
39	10311400	11/20/00	1340	N	120	345	8.3	4.5	11.2	8.4	E	H	0.07	0.04	--	--	6
		11/21/00	1105	U	125	326	--	3.5	--	--	E	H	0.08	0.04	--	--	--
		01/08/01	1130	N	109	366	8.0	3.1	7.7	7.2	E	H	0.07	0.04	--	--	8
		03/21/01	1105	N	308	239	8.0	11.9	13.1	27	E	H	0.16	0.05	--	--	54
		04/27/01	0910	U	664	155	--	13.0	--	--	E	H	0.35	0.07	153	83	--
		05/02/01	1405	U	898	123	--	12.0	--	--	E	H	0.48	0.06	168	70	--
		05/09/01	1225	U	955	121	--	15.5	--	--	E	H	0.35	0.07	173	57	--
		05/11/01	1255	U	1,030	117	--	15.5	--	--	E	H	0.33	0.07	141	67	--

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements: Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)	Analysis type	Phosphorus: Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	Suspended sediment: SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
		05/29/01	1430	N	299	148	8.0	20	8.5	14	E	H	0.13	0.07	--	--	29
		07/17/01	1530	N	8.5	528	8.6	26	7.2	2.7	E	H	0.22	0.18	--	--	4
		11/27/01	1330	N	132	300	8.2	--	--	15	E	H	0.12	0.06	--	--	24
		01/08/02	1450	N	268	250	8.8	5.3	12.8	16	E	H	0.10	0.03	--	--	39
		02/27/02	1200	U	207	264	8.1	7.0	11.1	6.2	E	H	0.08	0.05	10	84	7
		03/20/02	1330	N	201	280	8.2	10.0	10.2	8	E	H	0.08	0.04	--	--	14
		05/14/02	1430	U	735	138	7.8	16.3	8.7	19	E	H	0.20	0.08	65	65	43
		05/20/02	1550	U	1,100	96	7.8	12.7	8.5	37	E	H	0.25	0.06	104	60	76
		05/20/02	1700	U	1,100	94	7.7	12.7	--	35	E	H	0.23	0.06	186	32	56
		05/28/02	1120	N	593	120	8.1	16.0	8.3	22	E	H	0.16	0.06	--	--	45
		05/30/02	1230	U	806	119	7.4	19.1	7.0	29	E	H	0.23	0.07	100	67	62
		07/11/02	0900	U	11	516	7.7	22.5	6.1	3.7	E	H	0.19	0.15	6	77	5
											R	H	0.19	0.15	--	--	5
		07/17/02	1130	N	e9.0	550	8.3	25.2	7.5	11	E	H	0.24	0.16	--	--	39
		08/29/02	0955	U	3.0	624	8.0	21.0	8.8	2.0	E	H	0.06	0.04	4	87	1.5
											R	H	0.06	0.04	--	--	3
		09/17/02	1415	N	1.4	570	8.2	20.0	--	2.0	E	H	0.06	0.05	--	--	4
40	10311700	11/21/00	1210	U	110	354	--	4.5	--	--	E	H	0.06	0.03	--	--	--
		03/21/01	0945	N	284	--	--	--	--	--	E	H	0.14	0.05	--	--	--
		05/21/01	1300	U	613	--	--	17.5	--	--	E	H	[d]e0.17	0.08	47	83	--
		08/09/01	0845	U	1.6	--	--	20.0	--	--	E	H	0.07	0.05	--	--	--
		02/27/02	1500	U	205	280	8.0	9.5	10.2	4.8	E	H	0.07	0.04	8	87	--
											R	H	0.07	0.04	--	--	--
		05/15/02	0930	U	513	118	7.9	14.5	9.1	20	E	H	0.16	0.06	38	86	49
		05/31/02	0945	U	883	102	7.8	18.5	8.2	37	E	H	0.23	0.07	75	81	62
		07/11/02	1130	U	4.2	530	7.5	25.0	7.7	1.4	E	H	0.11	0.09	3	65	4

Appendix 1. Field measurements and chemical and suspended-sediment analyses for surface-water samples collected from the study area, water years 2001–02—Continued

[Abbreviations and symbols: e, estimated; E, environmental; U, USGS; NTU, nephelometer turbidity units; R, replicate sample; H, Nevada State Health Laboratory; N, Nevada Division of Environmental Protection; S, South Tahoe Public Utility District; P, phosphorus; SSC, suspended-sediment concentration; TSS, total-suspended solids; ft^3/s, cubic feet per second; °C, degrees Celsius; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius;%, percent; <, less than; --, data not collected or analyzes]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Collecting agency	Discharge (ft^3/s)	Field measurements					Analysis type	Phosphorus			Suspended sediment		
						Specific conductance (µS/cm)	pH	Water temperature (°C)	Dissolved oxygen (mg/L)	Turbidity (NTU)		Lab	Total (mg/L as P)	Orthophosphate (mg/L as P)	SSC (mg/L)	Sand break[a] (%)	TSS[b] (mg/L)
		08/29/02	1140	U	1.0	586	7.6	23.0	7.7	0.71	E	H	0.06	0.06	3	71	0.5
41	10311860	08/09/01	1110	U	4.8	--	--	26.0	--	--	E	H	0.05	0.03	--	--	--
		02/28/02	1135	U	200	309	8.1	7.5	11.1	4.4	E	H	0.07	0.04	16	52	--
42	10311870	05/15/02	1315	U	626	148	7.4	18.0	8.1	23	E	H	0.30	0.06	57	64	47
											R	H	0.49	0.06	--	--	46
		07/11/02	1430	U	18	610	7.8	32.5	7.7	1.5	E	H	0.06	0.05	3	67	1
		08/29/02	1355	U	4.1	667	8.4	29.0	10.4	4.7	E	H	0.06	0.02	24	30	7.5
43	10312020	11/20/00	1530	N	122	427	8.4	6.0	11.6	3.4	E	H	0.06	0.04	--	--	2
		01/08/01	1020	N	111	418	8.0	1.5	8.0	4.9	E	H	0.06	0.04	--	--	7
		03/21/01	0945	N	209	358	7.7	12.3	11.3	12	E	H	0.11	0.04	--	--	28
		04/26/01	1220	U	390	301	8.1	18.0	8.0	--	E	H	0.26	0.08	94	75	--
		05/17/01	1330	U	1,010	124	7.6	18.5	7.8	--	E	H	[d]e0.31	0.06	161	59	--
		05/29/01	1535	N	386	209	8.0	23.4	7.0	16	E	H	0.14	0.07	--	--	40
		07/18/01	1005	N	6.6	576	8.2	20.0	9.6	0.8	E	H	0.04	0.03	--	--	0
		11/27/01	1435	N	148	340	8.1	--	--	15	E	H	0.12	0.06	--	--	23
		01/09/02	1040	N	260	310	8.7	3.9	13.0	11	E	H	0.08	0.03	--	--	19
		02/21/02	1150	U	150	388	8.1	10.5	9.7	3.3	E	H	0.05	0.03	9	74	--
		03/20/02	1440	N	185	340	8.2	9.8	12.0	4.5	E	H	0.07	0.03	--	--	9
		05/20/02	1320	U	1,340	110	7.6	12.5	8.7	89	E	H	0.30	0.06	735	23	--
		05/28/02	1030	N	661	180	8.1	17.8	8.3	32	E	H	0.20	0.06	--	--	72
		07/11/02	1000	U	17	539	7.7	23.5	7.2	2.1	E	H	0.07	0.06	6	78	2
		07/17/02	1240	N	3.9	530	8.1	26.6	7.6	1.8	E	H	0.07	0.05	--	--	5
		08/29/02	1030	U	3.1	522	7.9	20.5	8.0	0.99	E	H	0.05	0.03	7	30	1
		09/17/02	1530	N	1.2	540	8.4	21.2	8.7	1.8	E	H	0.05	0.04	--	--	1

[a]The sand break indicates the percent of material in the sample, by weight, that is finer than 0.062 millimeter (sand). Sand break is not reported when suspended-sediment concentration is less than or equal to 1 mg/L.
[b]The detection limit for total suspended-solids values from Nevada State Health Lab is 10 mg/L; values less than the detection limit are estimates.
[c]Nevada Division of Environmental Protection reports value as zero. Detection limit confirmed with Nevada State Health Lab.
[d] Sample sat in laboratory beyond recommended holding time before analysis. Value is considered an estimate.
[e]Discharge at site was zero at time of sample collection; data and sample were collected about 300 feet upstream of regular site above a retention basin.

Appendix 2. Chemical analyses for streambed- and streambank-sediment samples collected from the study area, water years 2001–02

[Abbreviations: P, phosphorus; E, environmental; R, replicate; mg/kg, milligrams per kilogram. Symbol: --, data not collected or analyzed]

Site no. (see fig. 16)	USGS station no.	Date sampled	Time	Sample type	Total phosphorus (mg/kg as P)	
					Streambed sediment	Streambank sediment
West Fork Carson River and tributaries						
1	10310000	07/12/01	1245	E	730	630
3	10310220	08/08/01	1410	E	690	--
4	10310356	09/05/01	1210	E	1,600	--
		09/05/01	1210	R	1,400	--
5	10309082	08/10/01	1135	E	1,200	--
6	10310358	09/04/02	1430	E	900	590
		09/04/02	1430	R	1,000	--
7	10309114	08/06/01	1015	E	910	--
8	103103588	08/06/01	1130	E	1,100	--
9	10310359	09/04/02	1530	E	290	720
Brockliss Slough and tributaries						
10	10310240	09/05/01	1115	E	660	--
		09/04/02	0945	E	--	460
11	10310258	09/05/01	1155	E	480	--
12	10310255	09/04/02	1100	E	300	--
		09/04/02	1100	R	320	--
13	10310265	09/04/02	1135	E	400	--
15	10310404	08/07/01	1120	E	1,100	670
East Fork Carson River and tributaries						
16	10308200	09/05/02	1010	E	360	650
		09/05/02	1010	R	--	740
17	10309010	07/12/01	1115	E	340	480
18	10309089	08/08/01	0915	E	1,400	--
19	10309098	09/05/01	1035	E	800	--
20	10309100	09/05/01	1300	E	820	350
21	1030909018	07/12/01	1010	E	870	580
22	1030909020	07/12/01	0910	E	760	830
23	1030909042	09/05/01	1000	E	1,000	--
24	10309120	09/04/02	1330	E	450	--
25	10309130	08/06/01	1330	E	670	850
Carson River and tributaries						
26	10310405	08/06/01	1500	E	630	--
27	10310406	08/07/01	1300	E	880	--
28	10310407	09/05/02	1240	E	220	940
29	10310419	09/05/02	1410	E	1,500	--
30	10310448	08/10/01	1415	E	1,100	--
31	10310450	08/07/01	0830	E	890	590
32	10310525	08/10/01	0810	E	1,200	--
33	10310550	07/11/01	1120	E	810	1,200
34	10311000	08/28/01	1230	E	1,100	550
		08/28/01	1230	R	630	660
36	10311300	08/28/01	1100	E	490	--
37	10311325	07/11/01	1330	E	940	220
38	391057119422301	08/28/01	0930	E	850	--
39	10311400	08/28/01	0815	E	510	430
40	10311700	08/09/01	0845	E	980	470
41	10311860	08/09/01	1110	E	750	--
42	10311870	09/04/02	1920	E	500	330

Appendix 3. Chemical analyses for nitrogen species in surface-water samples collected from the study area, water year 2002

[Abbreviations: E, environmental; R, replicate; mg/L, milligrams per liter. Symbol: <, less than]

Site no. (see fig. 16)	USGS station no.	Date	Time	Sample type	Nitrogen concentration (mg/L as N)			
					Nitrite plus nitrate[a]	Nitrite[b]	Ammonia[a]	Kjeldahl[a]
1	10310000	07/01/02	1000	E	0.1	<0.01	<0.1	0.21
		08/21/02	0906	E	<0.1	<0.01	<0.1	0.17
3	10310220	07/01/02	1225	E	0.1	<0.01	<0.1	0.44
		08/21/02	1345	E	<0.1	<0.01	<0.1	0.19
5	10309082	07/02/02	0815	E	1.1	0.02	<0.1	0.55
		08/21/02	1550	E	0.3	<0.01	<0.1	0.36
6	10310358	07/02/02	1150	E	0.1	0.01	<0.1	0.82
		08/22/02	1015	E	<0.1	<0.01	<0.1	0.34
7	10309114	07/02/03	1500	E	<0.1	<0.01	<0.1	0.39
		08/22/02	1250	E	<0.1	<0.01	<0.1	0.49
9	10310359	07/03/02	0800	E	0.1	<0.01	<0.1	0.45
				R	0.1	<0.01	<0.1	0.52
		08/22/02	1435	E	<0.1	<0.01	<0.1	0.46
10	10310240	07/01/02	1540	E	<0.1	<0.01	<0.1	0.49
		08/21/02	1135	E	<0.1	<0.01	<0.1	0.37
13	10310265	07/12/02	0852	E	<0.1	<0.01	<0.1	0.87
		08/23/02	1100	E	<0.1	<0.01	<0.1	0.90
15	10310404	07/03/02	1051	E	0.1	<0.01	0.12	1.13
		08/23/02	0820	E	<0.1	<0.01	<0.1	0.56
				R	<0.1	<0.01	<0.1	0.60
16	10308200	07/08/02	0940	E	0.1	<0.01	<0.1	0.14
		08/26/02	1050	E	0.1	<0.01	<0.1	0.13
17	10309010	07/09/02	1030	E	<0.1	<0.01	<0.1	0.22
		08/26/02	1330	E	<0.1	<0.01	<0.1	0.16
22	1030909020	07/08/02	1310	E	0.1	<0.01	<0.1	0.91
		08/27/02	0830	E	0.1	<0.01	0.1	0.40
24	10309120	07/08/02	1525	E	0.2	0.01	0.1	0.64
		08/28/02	0850	E	0.5	0.01	<0.1	0.40
				R	0.5	0.01	<0.1	0.33
25	10309130	07/08/02	1750	E	<0.1	<0.01	<0.1	1.08
		08/28/02	1040	E	<0.1	<0.01	<0.1	0.35
28	10310407	07/09/02	1048	E	<0.1	<0.01	<0.1	1.34
		08/28/02	1220	E	<0.1	<0.01	<0.1	0.39
29	10310419	07/09/02	1230	E	<0.1	<0.01	<0.1	1.13
				R	<0.1	<0.01	<0.1	1.03
		08/27/02	1035	E	<0.1	<0.01	0.17	1.02
30	10310448	07/09/02	1500	E	0.1	<0.01	<0.1	1.29
		08/27/02	1245	E	<0.1	0.01	0.18	0.81
31	10310450	07/10/02	0955	E	<0.1	<0.01	<0.1	0.74
		08/27/02	1400	E	0.1	<0.01	<0.1	0.46
32	10310525	07/10/02	1255	E	0.1	<0.01	<0.1	0.23
		07/18/02	1435	E	0.4	0.02	0.15	1.05
		08/27/02	1550	E	<0.1	<0.01	<0.1	0.14
34	10311000	07/10/02	1500	E	<0.1	<0.01	<0.1	0.69
		08/28/02	1410	E	<0.1	<0.01	<0.1	0.39
37	10311325	07/11/02	0750	E	0.1	<0.01	<0.1	0.55
39	10311400	07/11/02	0900	E	<0.1	<0.01	<0.1	0.55
				R	0.1	<0.01	<0.1	0.54
		08/29/02	0955	E	<0.1	<0.01	<0.1	0.41
				R	<0.1	<0.01	<0.1	0.44
40	10311700	07/11/02	1130	E	0.1	<0.01	<0.1	0.42
		08/29/02	1140	E	<0.1	<0.01	<0.1	0.32
42	10311870	07/11/02	1430	E	<0.1	<0.01	<0.1	0.29
		08/29/02	1355	E	0.1	<0.01	<0.1	0.34

[a]Concentrations are for unfiltered samples.

[b]Concentrations are for filtered samples.