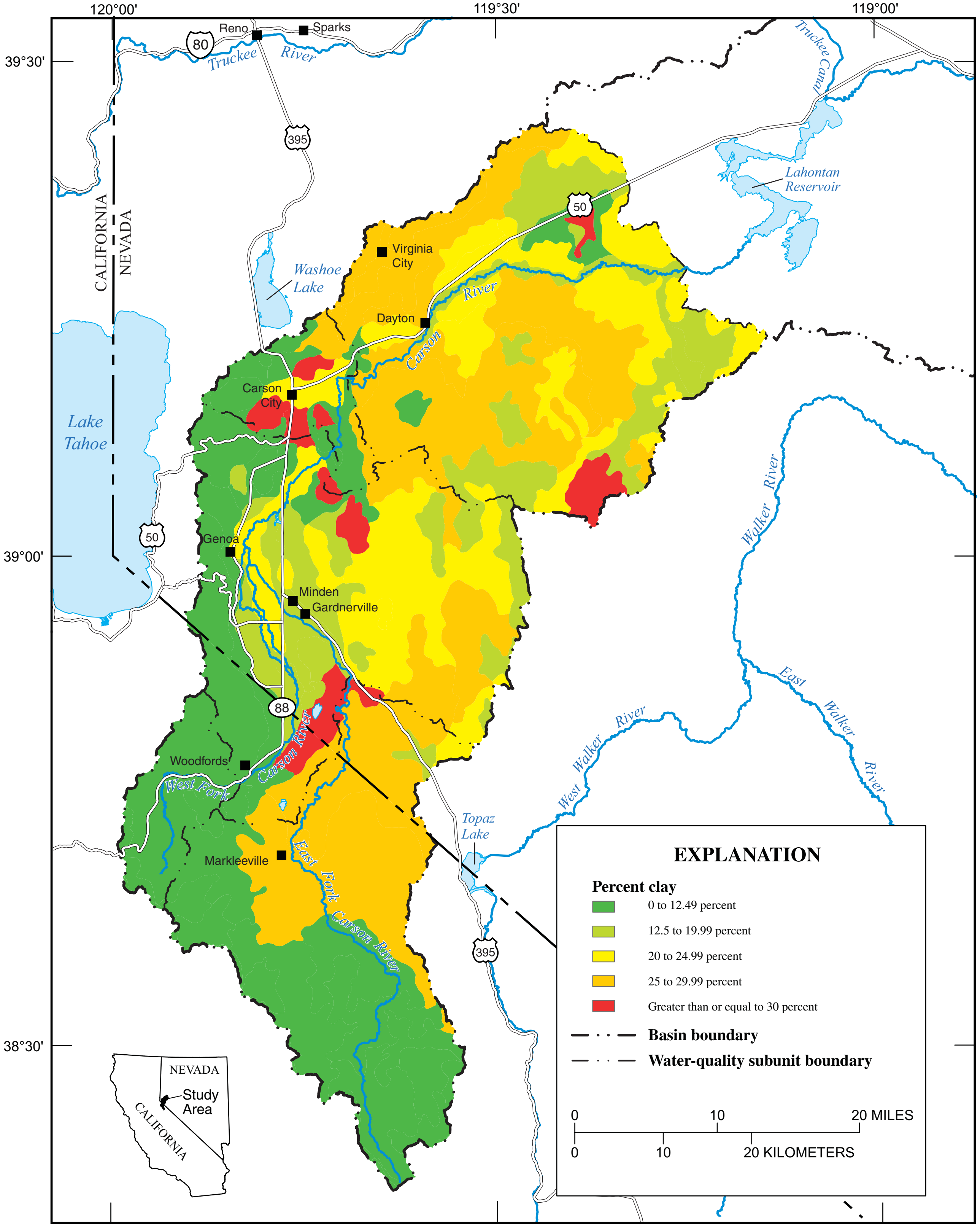
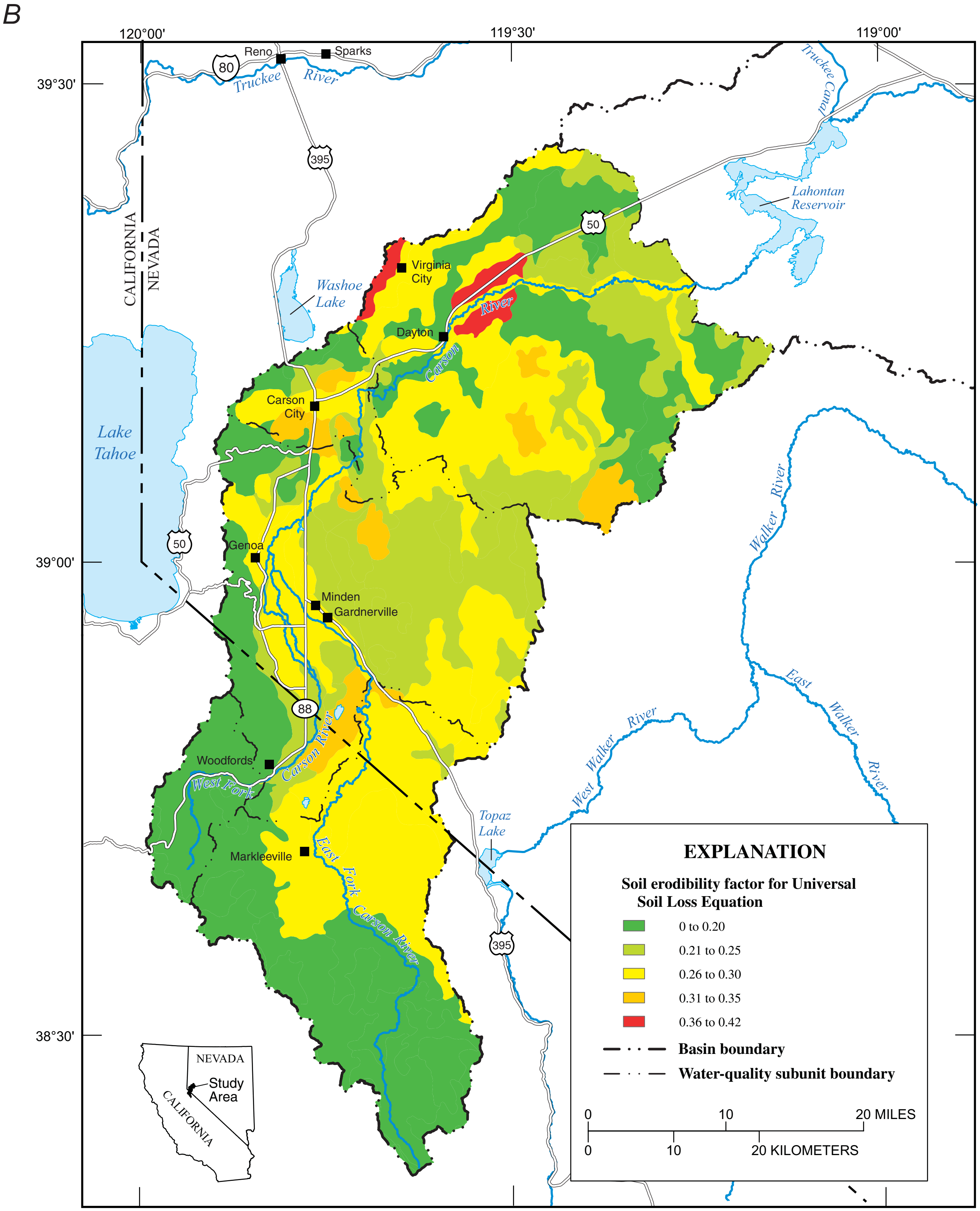
A



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)

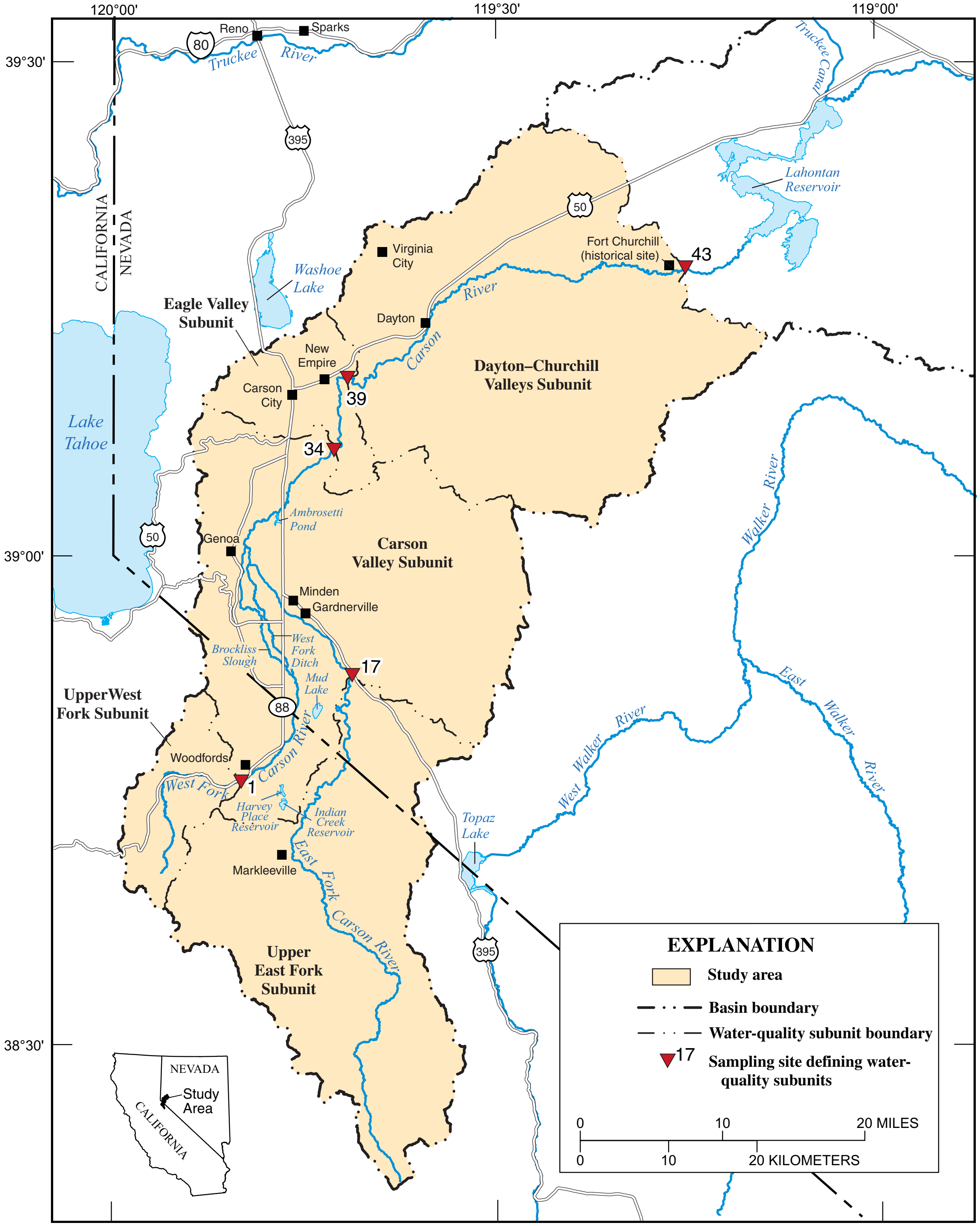
Figure 3. Soils of the Carson River Basin upstream from Lahontan Reservoir (*A*) clay content and (*B*) erodibility.



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.

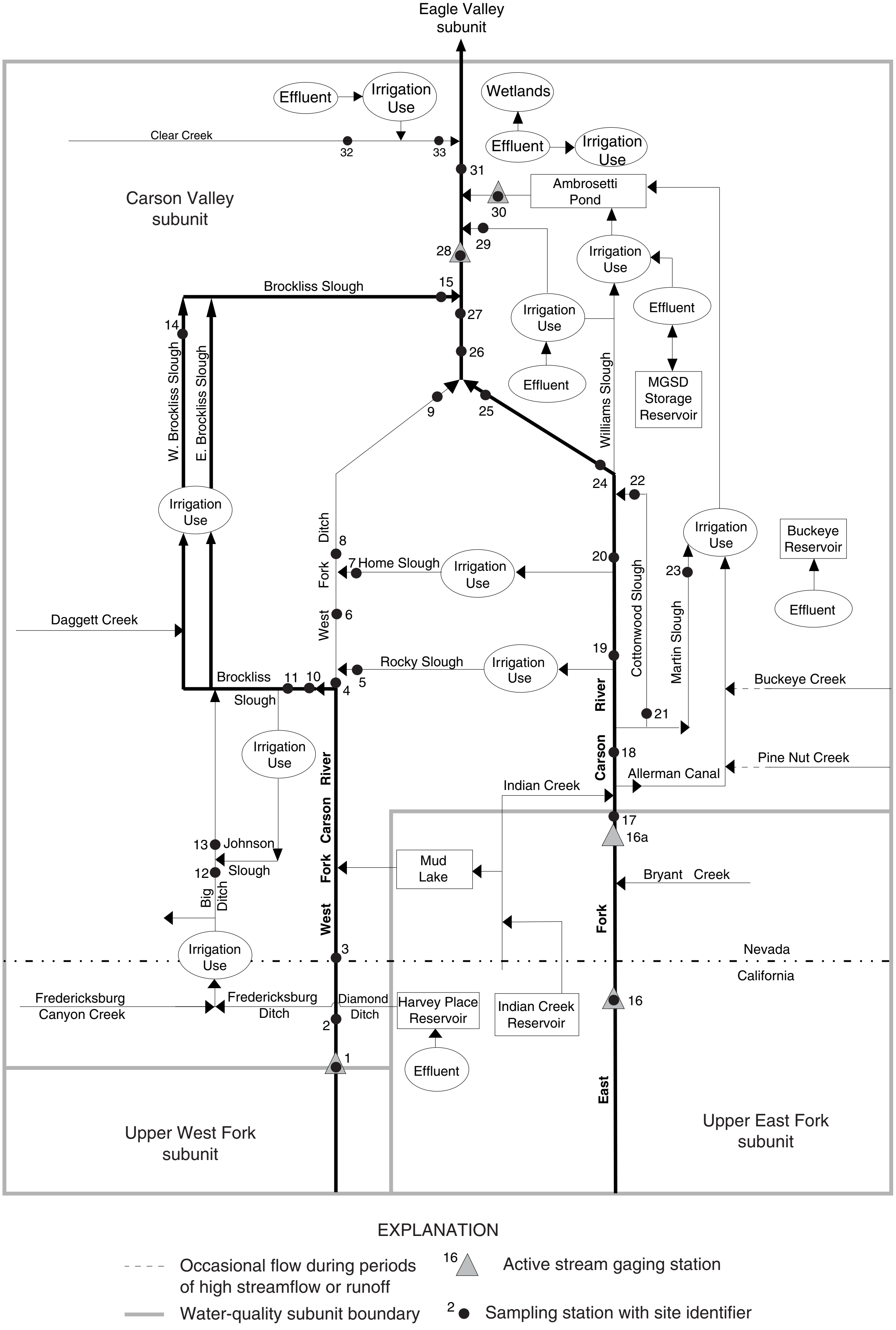


Figure 5. Schematic diagram of flow in the Carson River system upstream from Lahontan Reservoir.

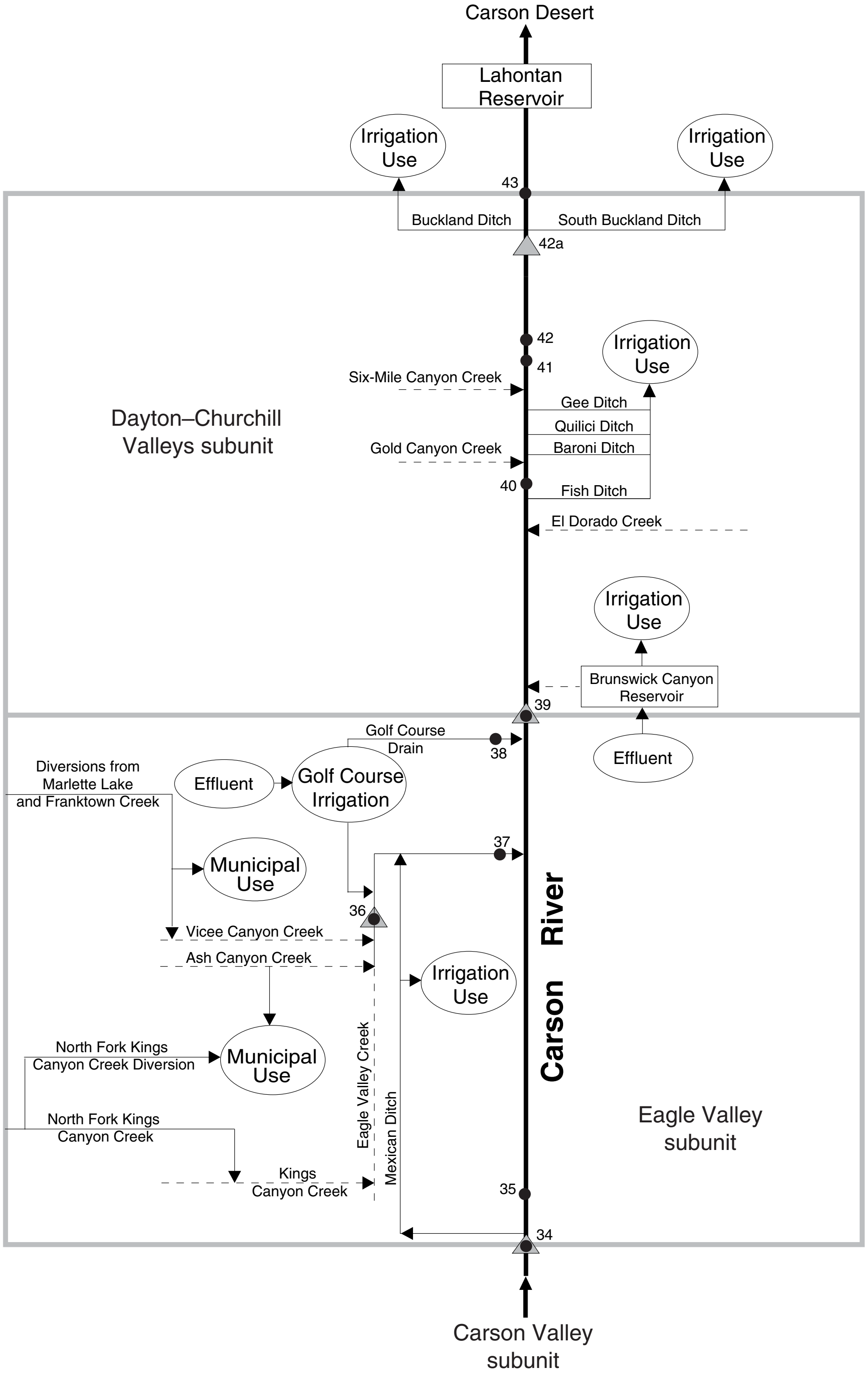


Figure 5. Schematic diagram of flow in the Carson River system upstream from Lahontan Reservoir—Continued.

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.

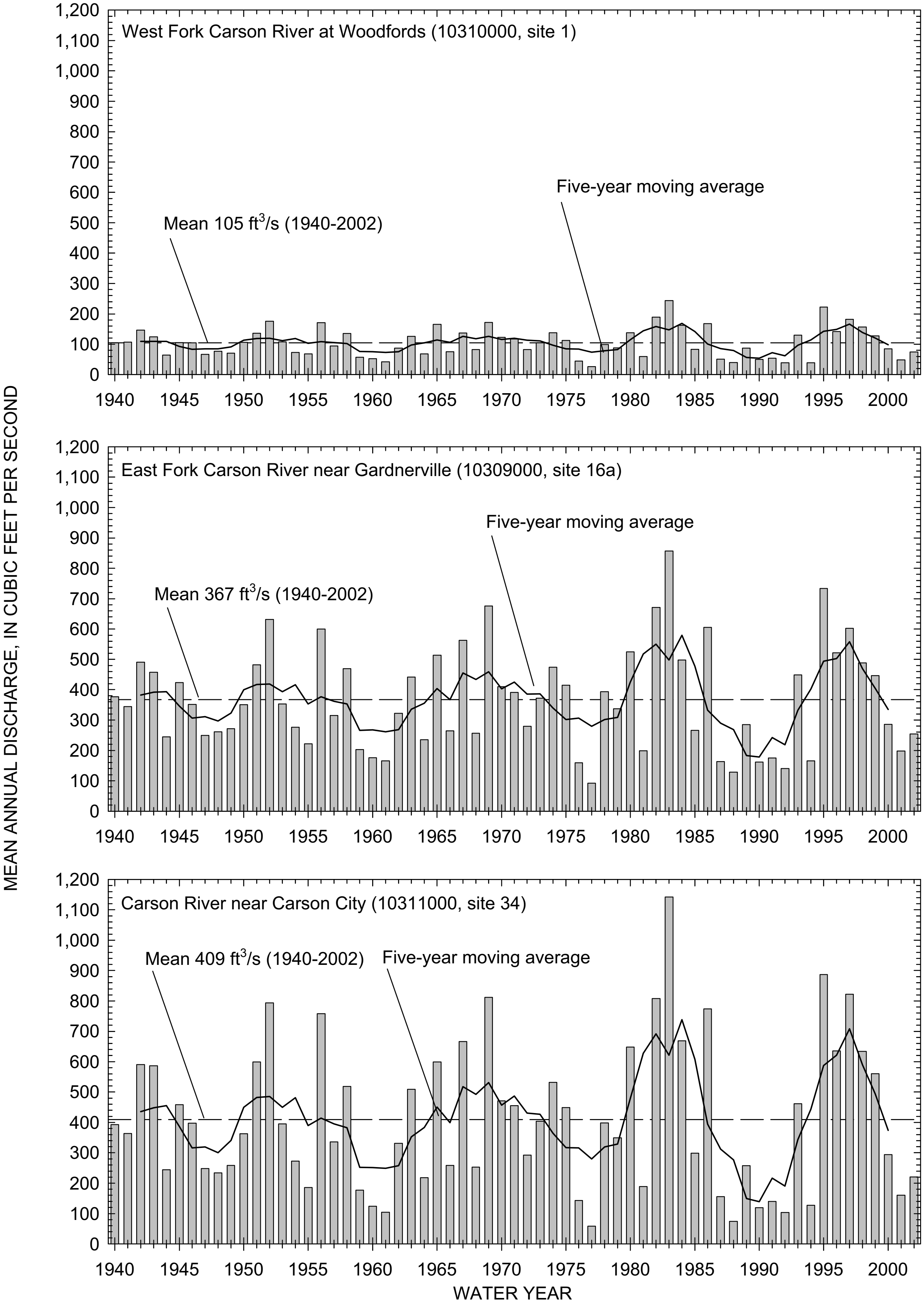


Figure 6. Mean annual discharge at sites along the Carson River.

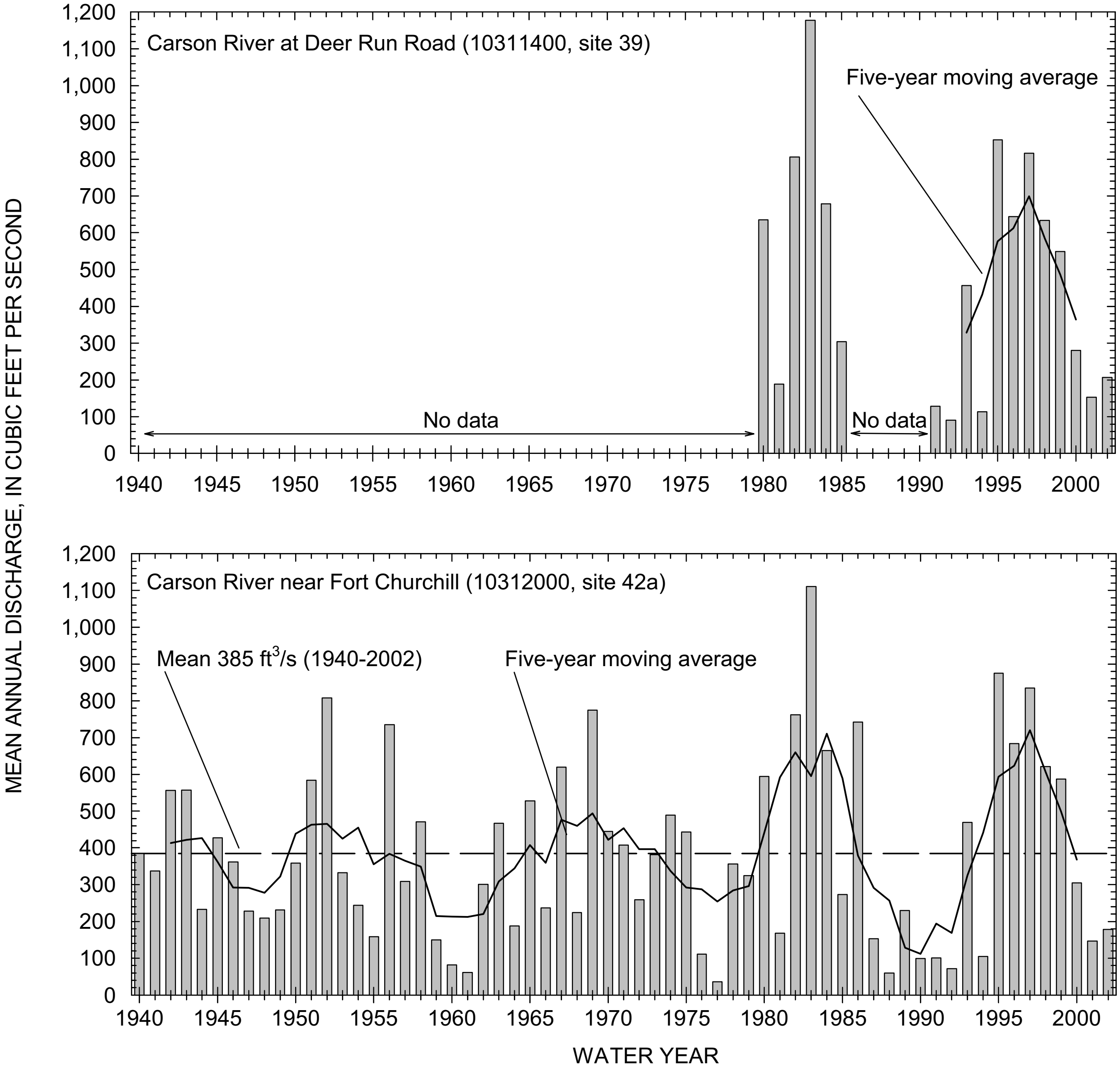


Figure 6. Mean annual discharge at sites along the Carson River—Continued.

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

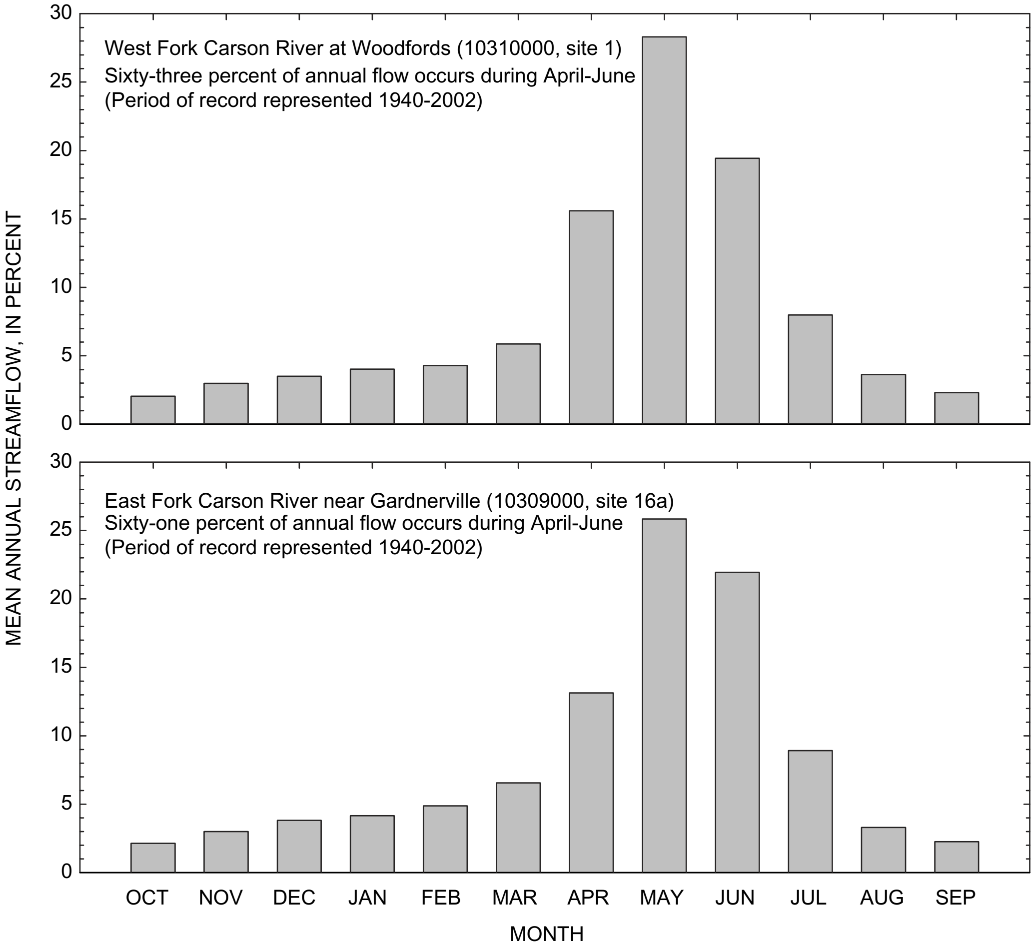


Figure 8. Monthly mean discharge as a percent of mean annual discharge at five sites along the Carson River.

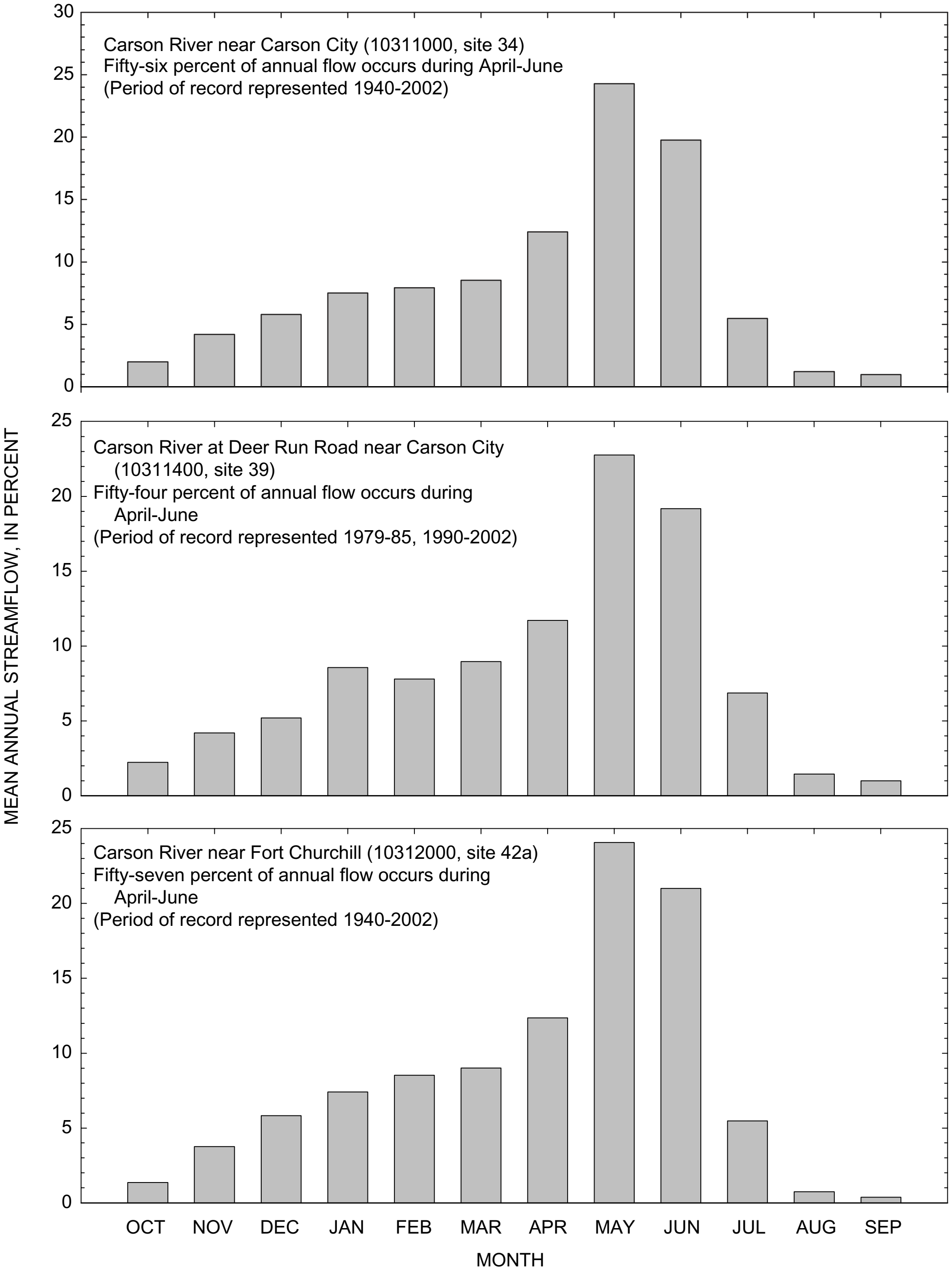


Figure 8. Monthly mean discharge as a percent of mean annual discharge at five sites along the Carson River—Continued.

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.