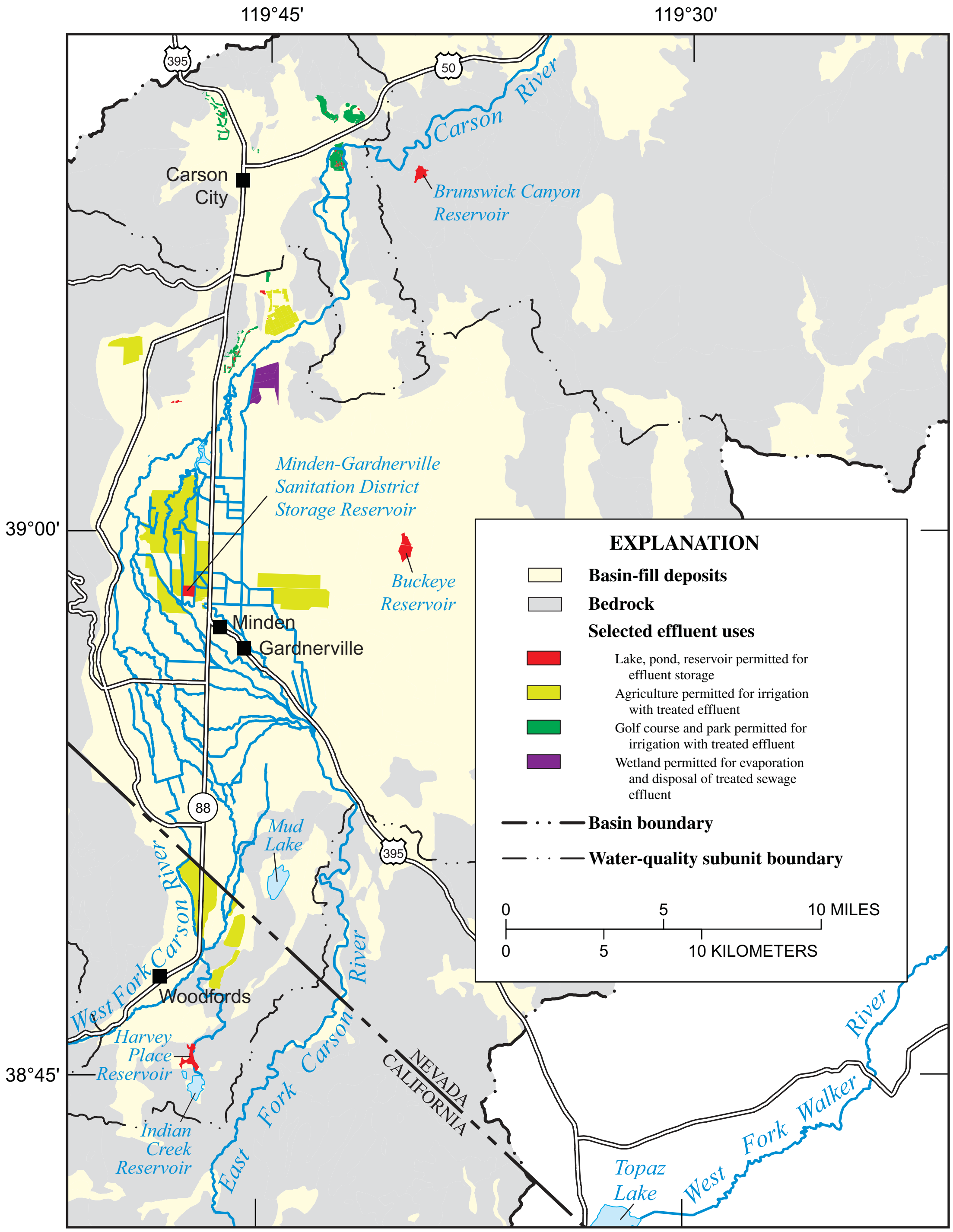


Base from U.S. Geological Survey digital data, 1:100,000- and 1:24,000-scale, 1979-82
Universal Transverse Mercator projection, zone 11
North American Datum 1927

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

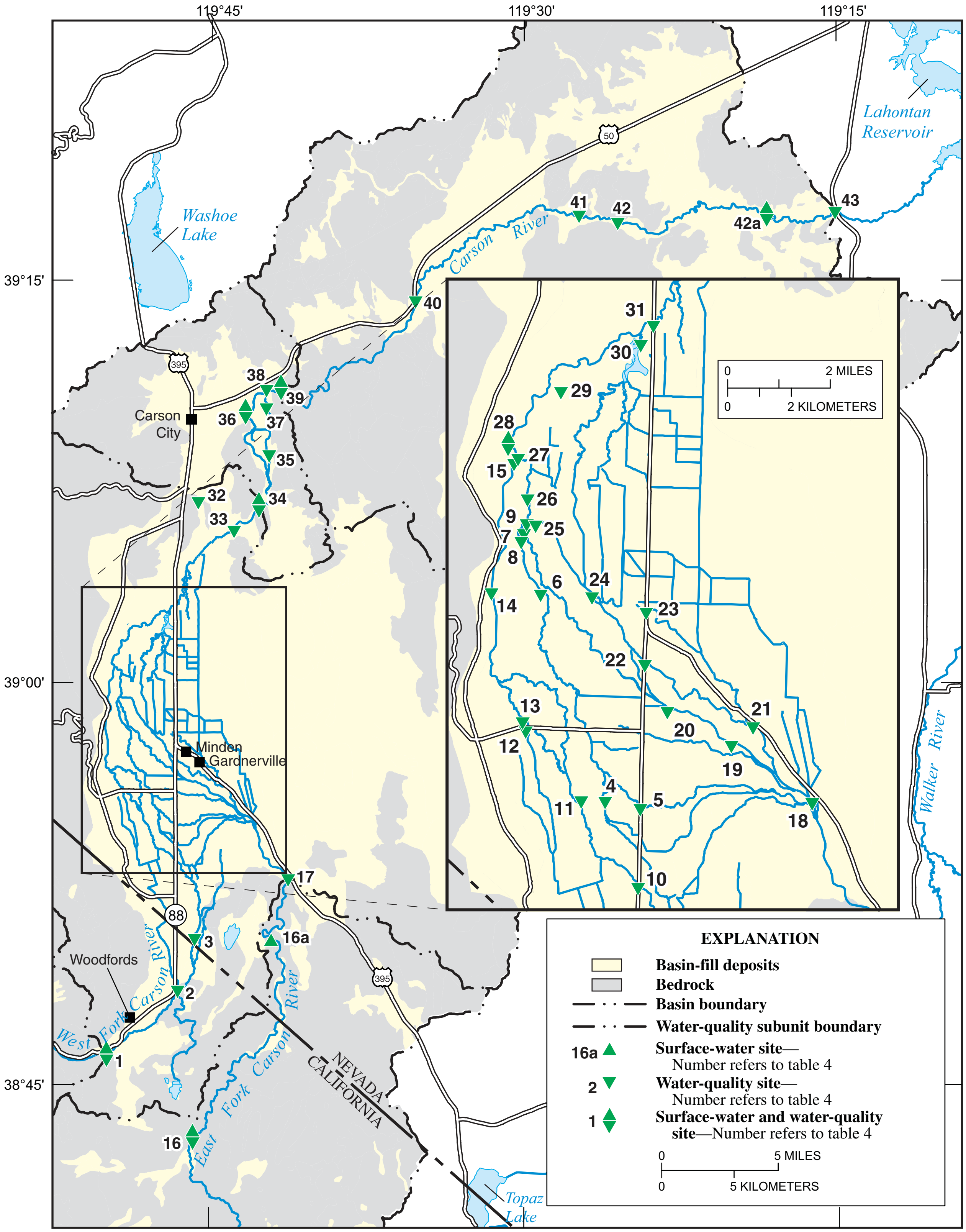
Samples for chemical analysis were collected from 43 sites in the Carson River Basin upstream from Lahontan Reservoir (fig. 16; table 4). Samples were collected from the mainstem of the river, diversions from the river, tributaries to the river, and sloughs and ditches carrying return flow to the river. 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.

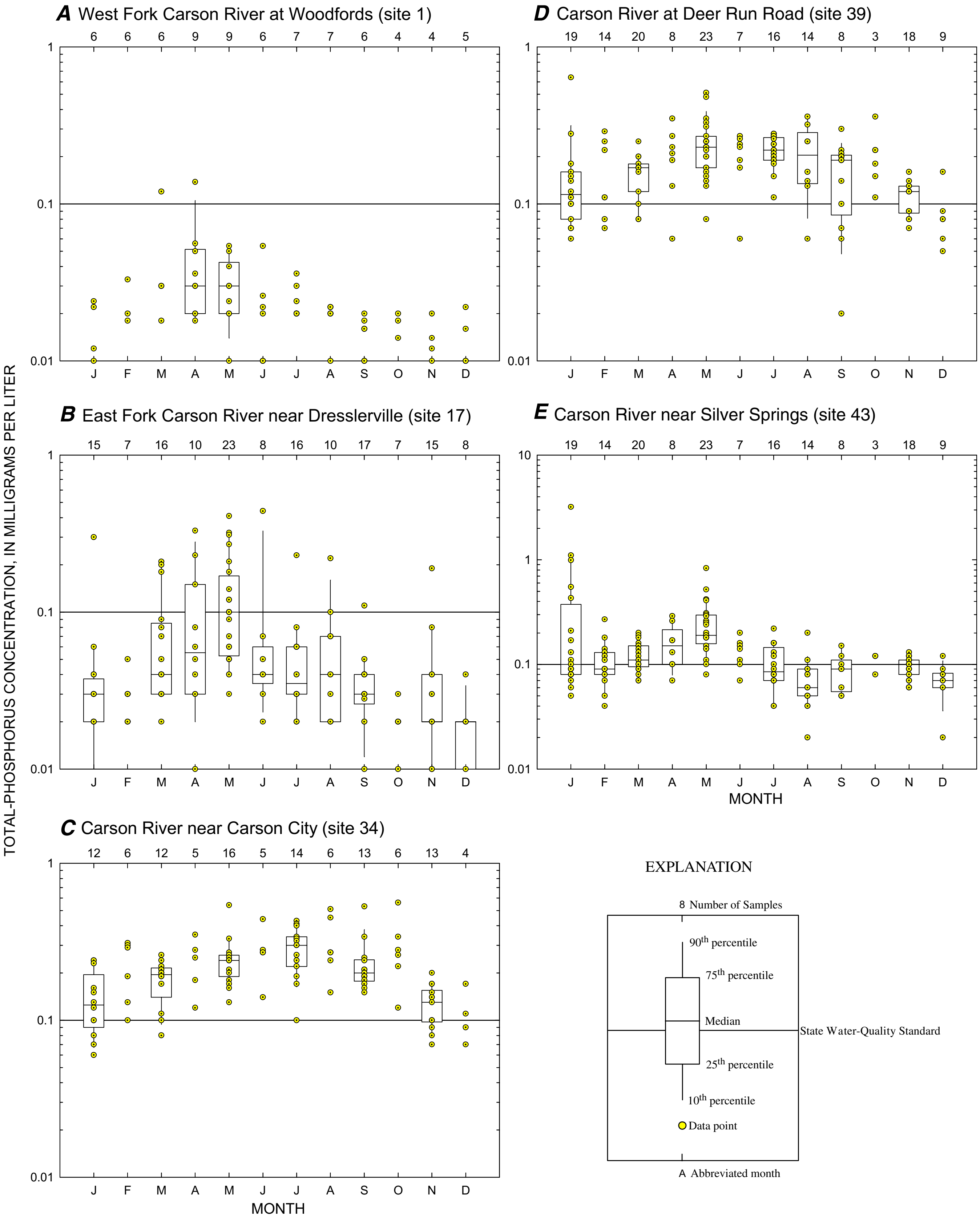


Figure 17. Total-phosphorus concentrations at selected sites in the Carson River Basin, 1988–2002.

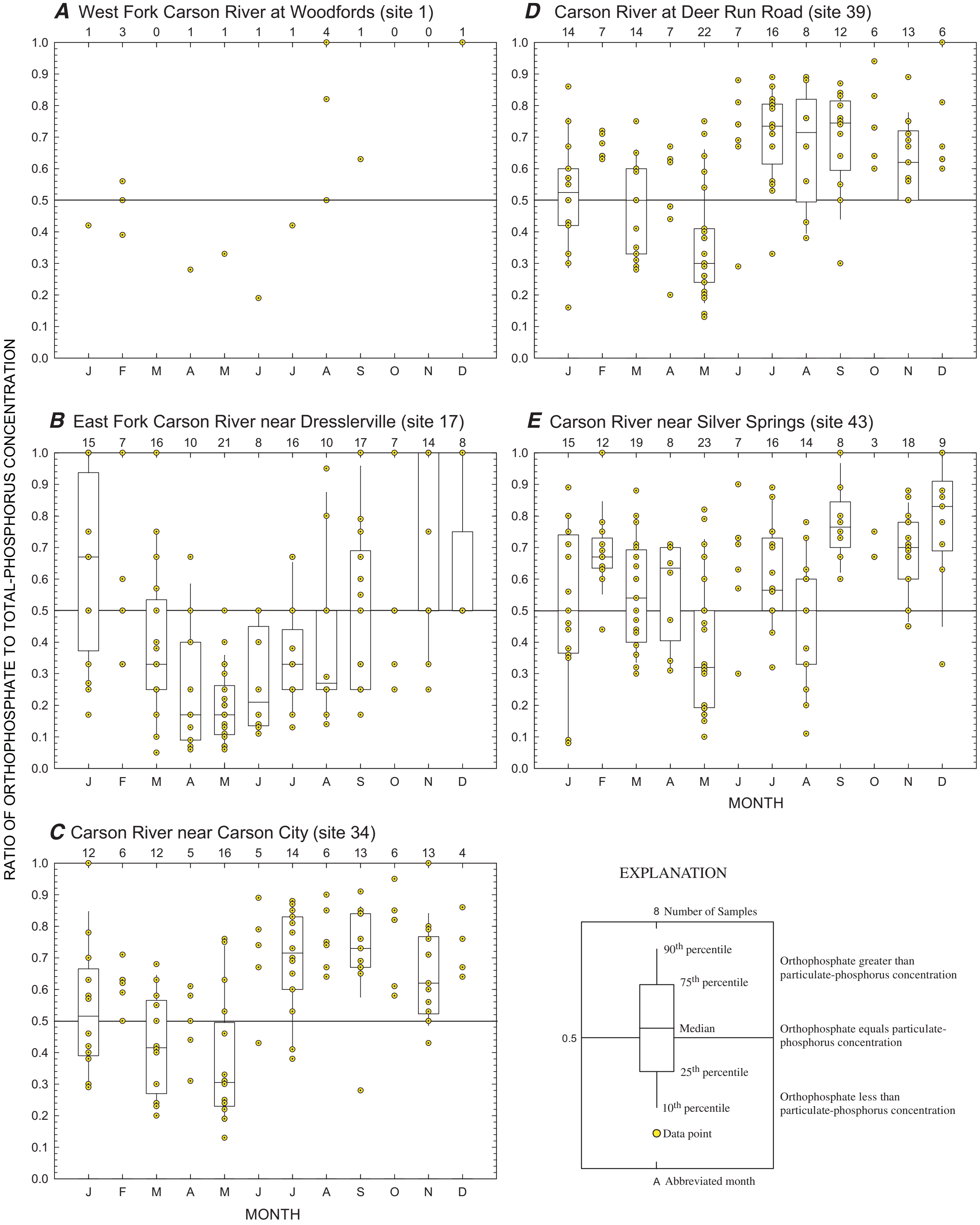


Figure 18. Ratio of orthophosphate to total-phosphorus concentrations at selected sites in the Carson River Basin, 1988–2002.

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:

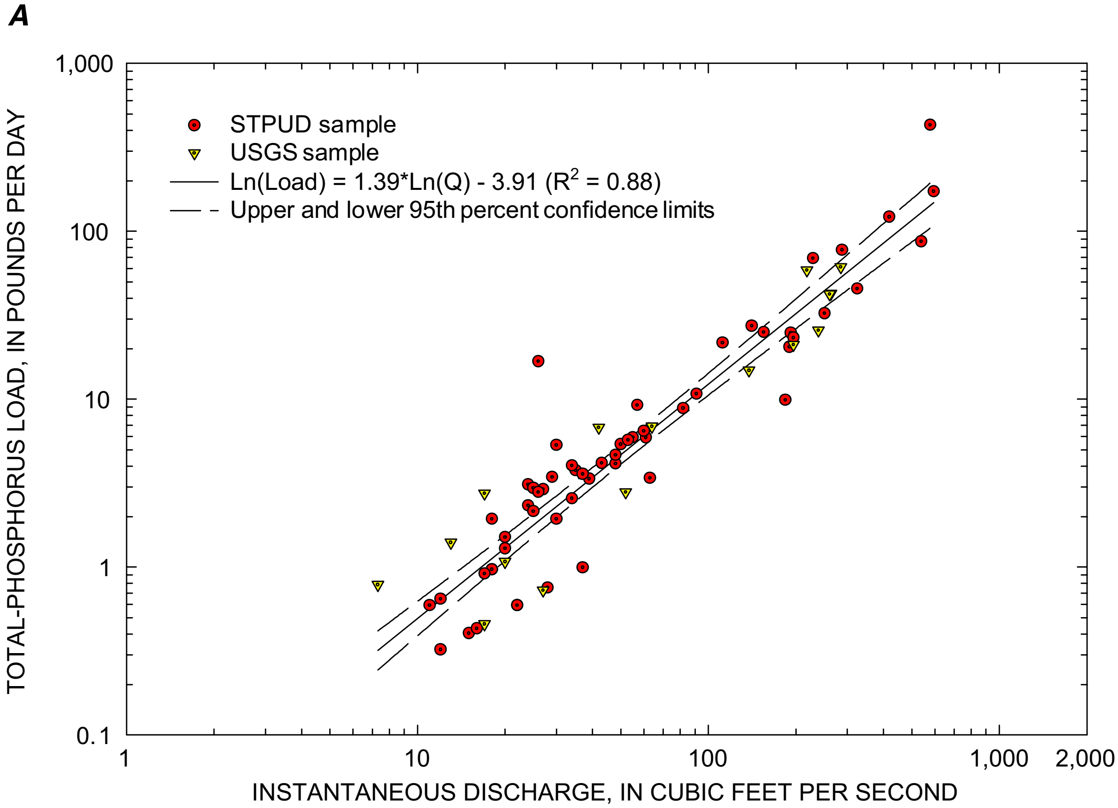
$$\ln[load] = \beta_0 + \beta_1 \ln[Q] \tag{1}$$

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.



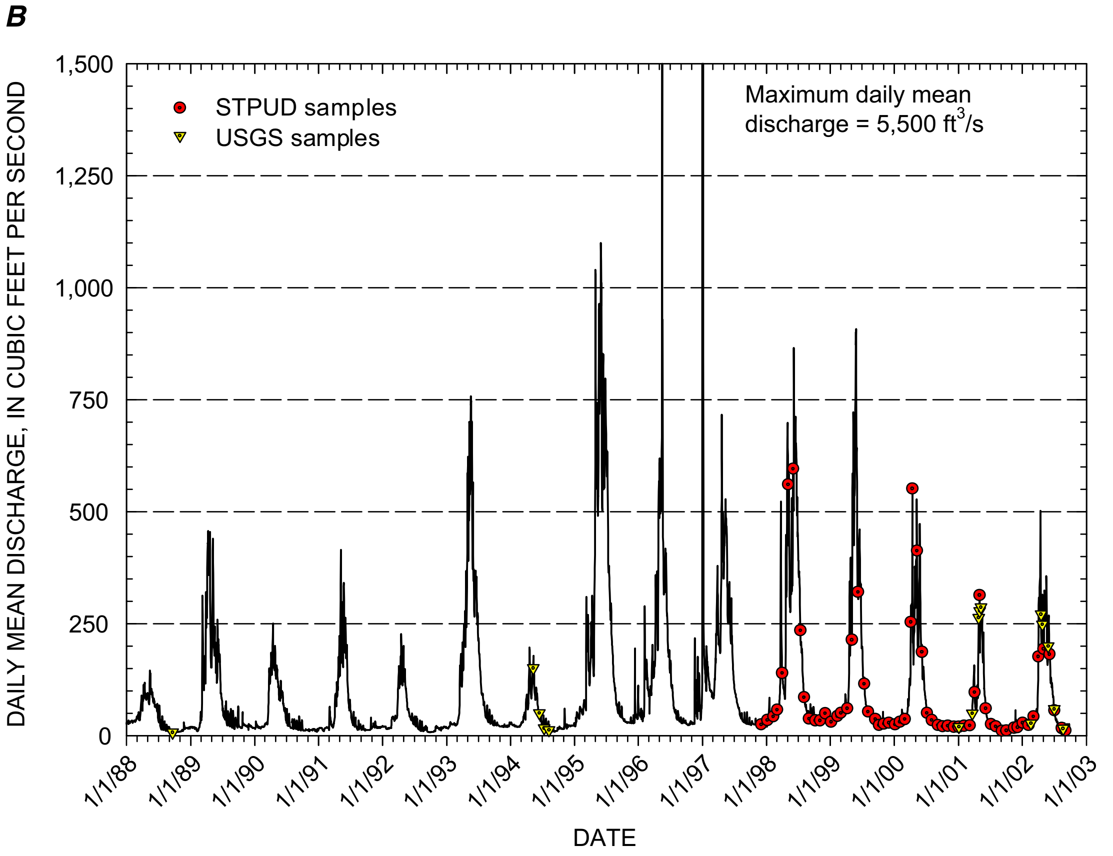


Figure 19. Relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 1, West Fork Carson River at Woodfords (10310000).

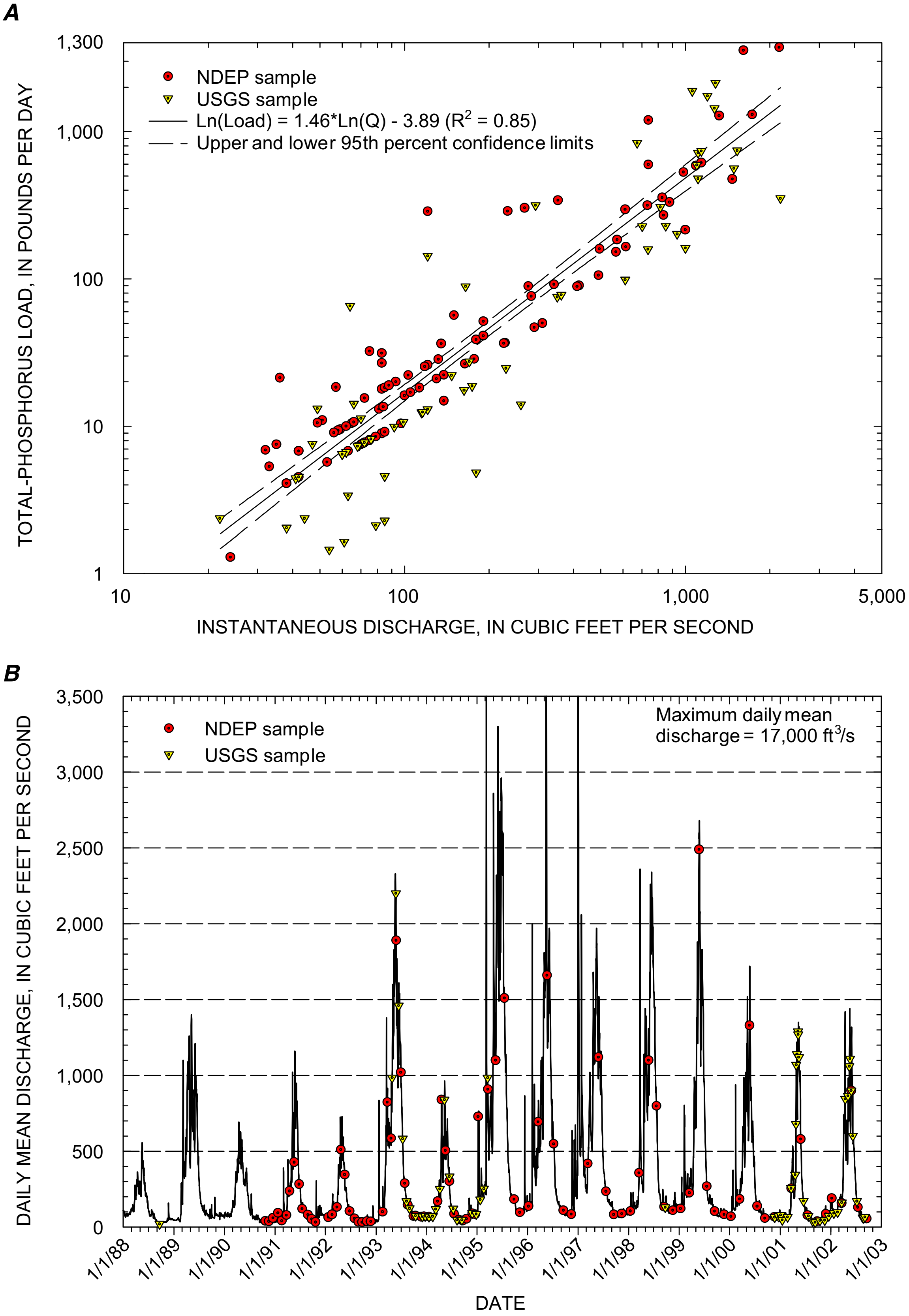


Figure 20. Relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 17, East Fork Carson River near Dresslerville (10309010).

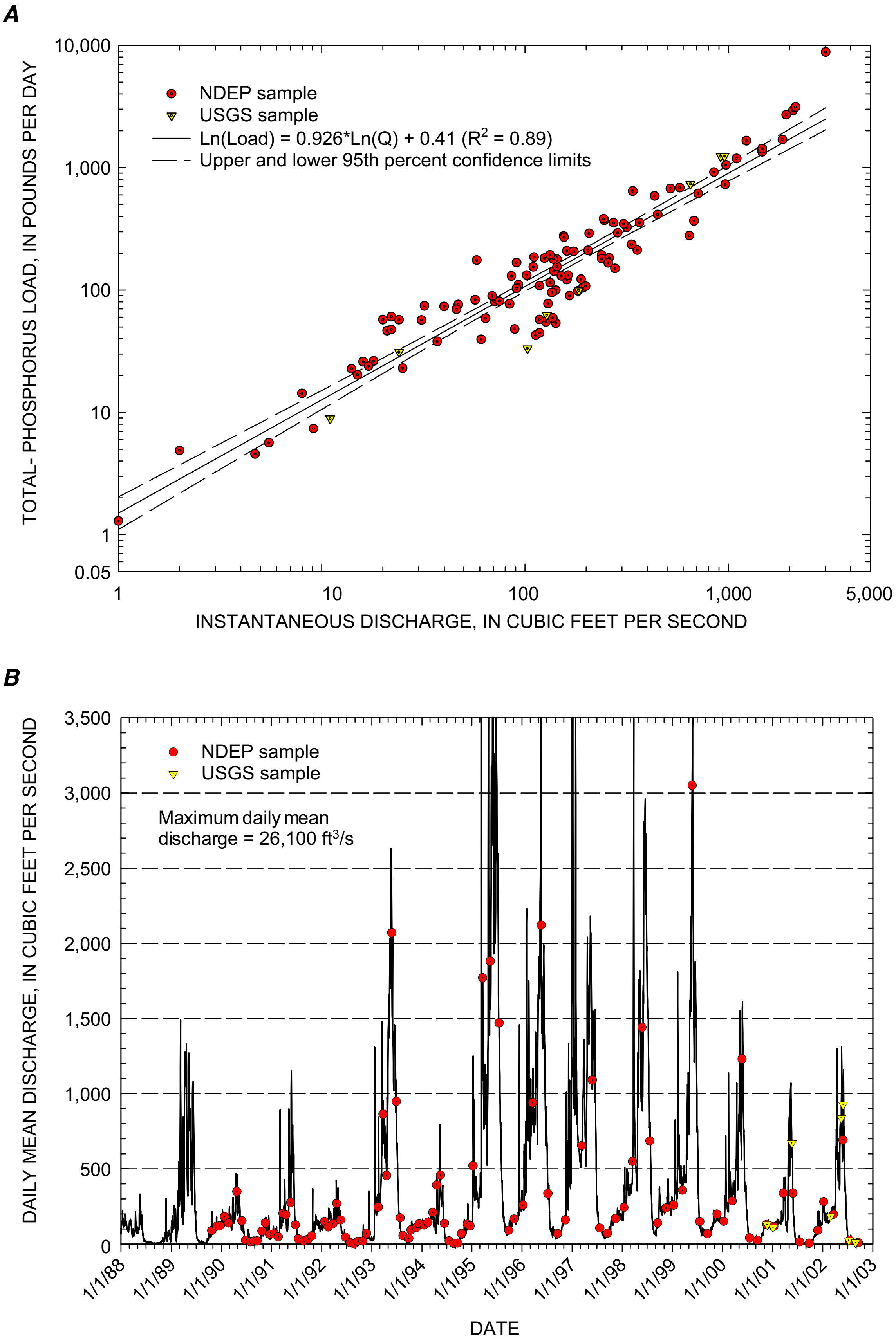


Figure 21. Relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 34, Carson River near Carson City (10311000).

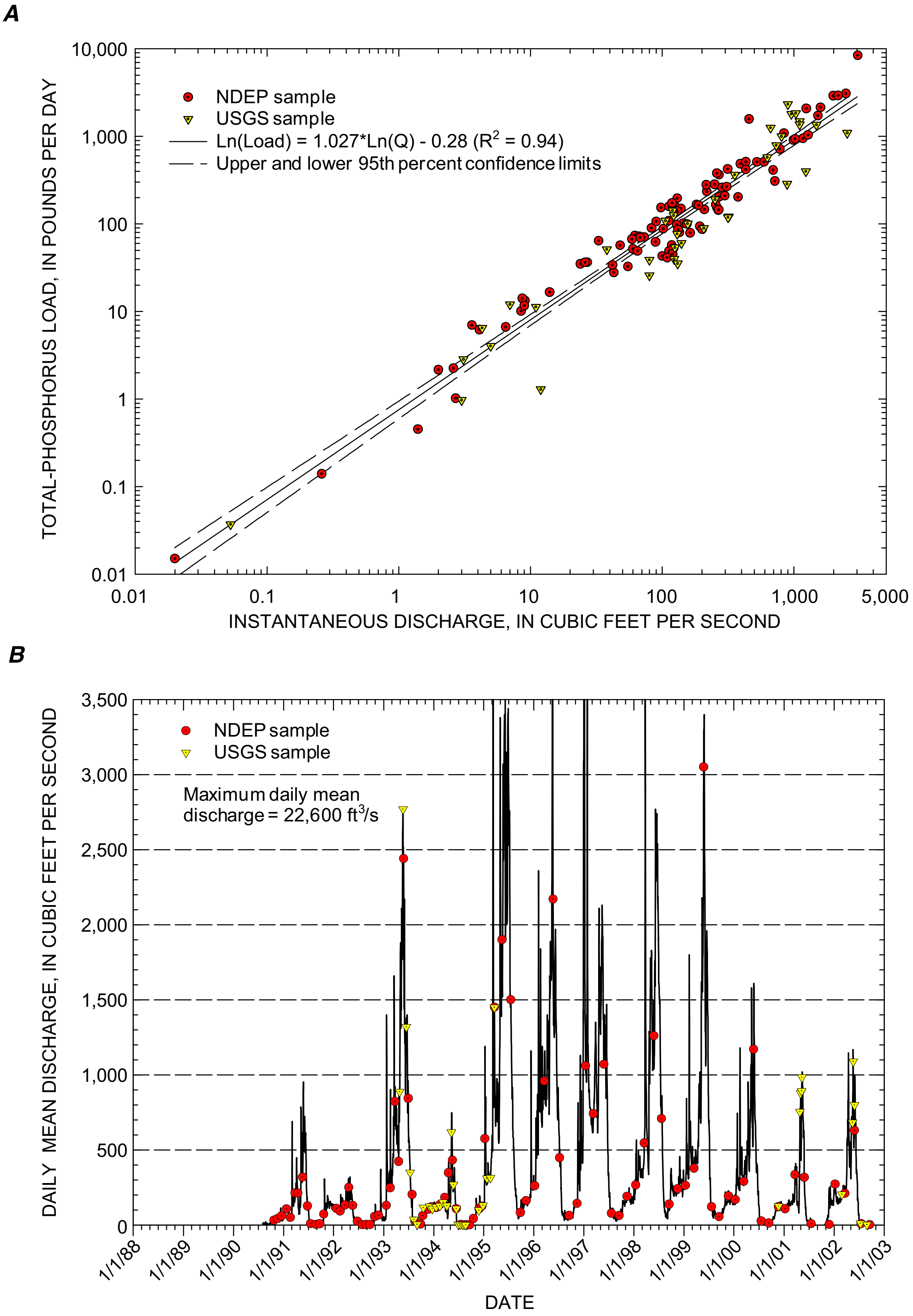
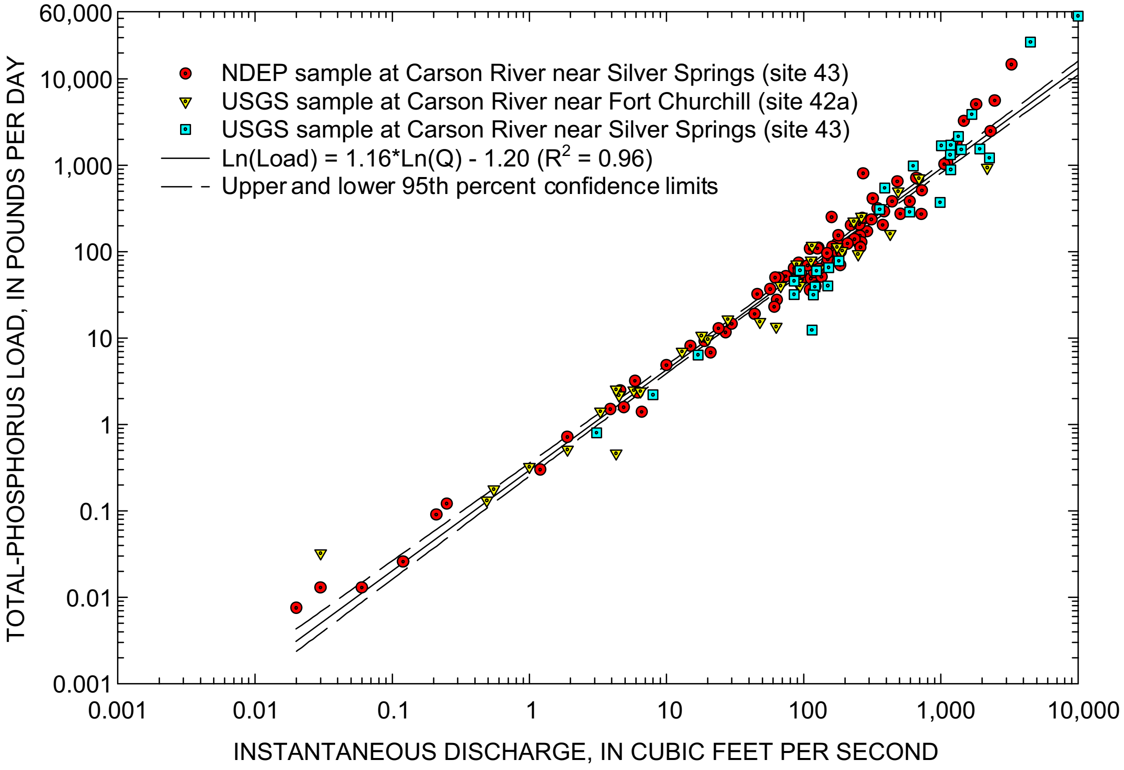


Figure 22. Relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 39, Carson River at Deer Run Road (10311400).

A



B

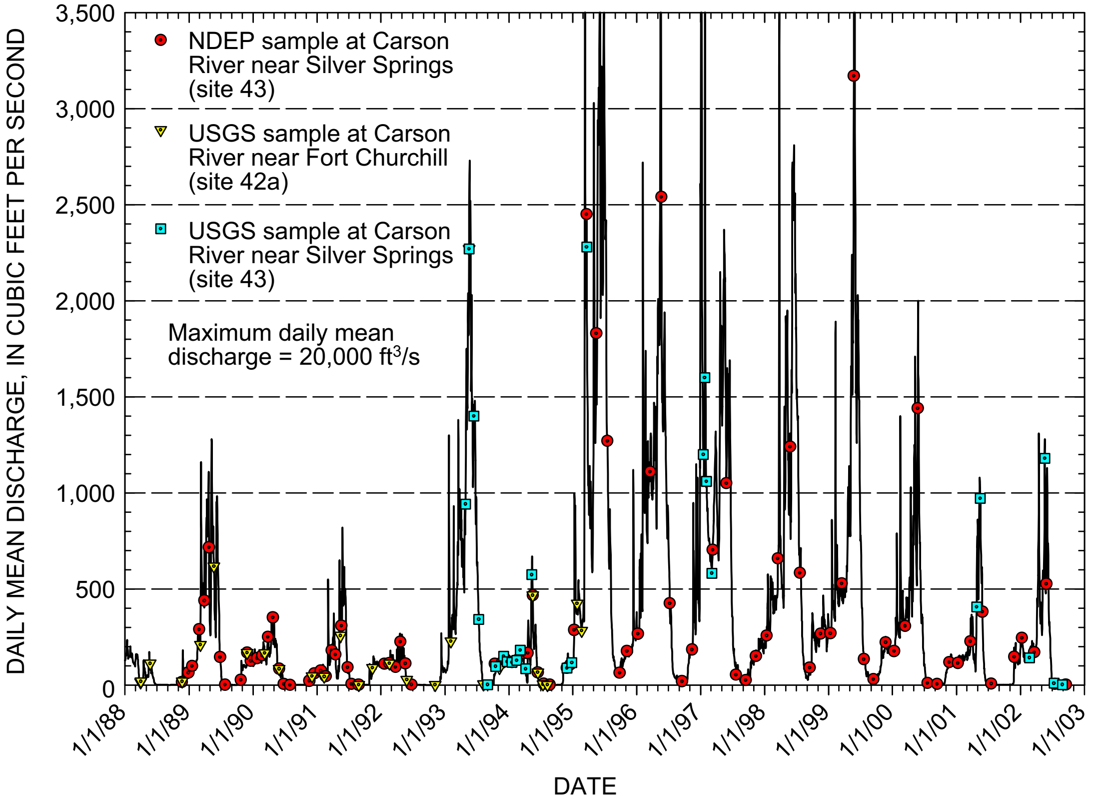


Figure 23. Relation between (*A*) instantaneous discharge and total-phosphorus load and (*B*) daily mean discharge and time of sample collection for site 43, Carson River near Silver Springs (10312020).