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Selenium and Sediment Loads in Storm Runoff in Panoche Creek, California, February 1998

Water-Resources Investigations Report 02-4286

Prepared in cooperation with the

U.S. BUREAU OF RECLAMATION

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

Front cover: Panoche Creek looking upstream from the Interstate-5 bridge. The photograph was taken at 10:30 a.m. on February 3, 1998 at a streamflow of 9,530 cubic feet per second. The peak streamflow of record for Panoche Creek (9,940 cubic feet per second) occurred two hours earlier. The suspended sediment sample collected at the time of this photograph had a concentration of 177,000 milligrams per liter for an instantaneous sediment loading rate of over 4.5 million tons per day. The instantaneous total selenium loading rate at the time of this photograph was over seven tons per day. Note the trees and branches, standing waves, and the old gage house in the photograph. The current U.S. Geological Survey gage house is just downstream of the bridge. *(Photograph by Willie B. Kinsey, U.S. Geological Survey)*

Selenium and Sediment Loads in Storm Runoff in Panoche Creek, California, February 1998

By Charles R. Kratzer[1], Dina K. Saleh[2], and Celia Zamora[1]

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CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch (in.)	2.54	centimeter
pound (lb)	0.4536	kilogram
pound per day (lb/d)	0.4536	kilogram per day
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
ton, short (2,000 lb)	0.9072	megagram

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8.

VERTICAL DATUM

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum *derived* from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Water Quality Units

Concentrations of constituents in water samples are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is equivalent to "parts per million" and micrograms per liter is equivalent to "parts per billion."

Water Year

In U.S. Geological Survey papers dealing with surface water supply, the 12-month period October 1 to September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. For example, the year ending September 30, 1999, is called the "1999 water year." In this paper, unless otherwise defined, "years" refer to water years.

ABBREVIATIONS

I-5, Interstate 5

log, logarithm

MDL, method detection limit

NWQL, National Water Quality Laboratory

RPD, relative percent difference

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ABSTRACT

Five to nine samples were collected per storm throughout the hydrograph of four storms in February 1998 from Panoche Creek at Interstate 5, California. The rainfall total of 10.40 inches for the month was greater than any other month during 1957 to 2000, and peak streamflows on February 3 and 7 exceeded the previous peak streamflow of record. Concentrations of suspended sediment, which were highly variable during the storms, ranged from 32,900 to 251,000 mg/L (milligram per liter) with a median of 126,000 mg/L. Dissolved selenium concentrations in the storm samples ranged from 16 to 60 μg/L (microgram per liter), with a median of 30 μg/L. These concentrations were considerably higher during the first storm than during subsequent storms. Total selenium concentrations in the storm samples ranged from 57 to 320 μg/L, with a median of 115 μg/L. Total selenium in four replicate and four rerun samples was highly variable (relative percent differences ranged from 0 to 57 percent), probably due to the extremely high concentrations of suspended sediment in the samples and possible interferences from other compounds. The calculated concentration of selenium attached to suspended sediment was less variable than suspended sediment or total selenium concentrations during storm runoff; concentrations ranged from 0.50 to 2.1 μg/g (microgram per gram) with a median of 0.89 μg/g.

The logarithms of suspended sediment and total selenium concentrations were closely correlated to the logarithm of streamflow (R^2 = 0.82, R^2 = 0.71, respectively for all storm data). These relations for the first storm were significantly different from the later three storms. Because of these correlations, the logarithm of suspended sediment loading rate and the logarithm of total selenium loading rate were closely correlated to the logarithm of streamflow (R^2 = 0.982 for both for all storm data). Loads of suspended sediment and total selenium were calculated for each of the four storms in three ways, including simple linear regression with streamflow for all storms, simple linear regressions for the first storm and the combined later three storms, and integration under the instantaneous load curves. The resulting suspended sediment loads for all four storms ranged from 1,793,000 to 2,555,000 tons; total selenium ranged from 4,909 to 5,830 lb (pound).

Dissolved selenium concentrations correlated significantly with both the logarithm of streamflow and specific conductance. Simple linear regression with the logarithm of streamflow had an R^2 of 0.45, and a multiple linear regression with the logarithm of streamflow and specific conductance had an adjusted R^2 of 0.48 for all storm data. The relation between streamflow and specific conductance for the first storm and for the later three storms were significantly different. As for suspended sediment and total selenium, dissolved selenium loads were calculated three ways. The resulting loads for all four storms ranged from 773 to 1,007 lb.

No significant storm occurred during the remainder of the study period (water years 1998 to 2000), and thus, no additional storm sampling took place. Assuming that future sediment and selenium transport is similar to that of 1998, a

reasonable estimate of loading rates can be calculated from the streamflow record at the Interstate 5 gage. Additional storm sampling would improve the estimates and possibly allow for separate equations for the rising and falling limbs of storm hydrographs.

INTRODUCTION

The Panoche Creek Basin, which is a major source of selenium owing to extensive surficial exposures of selenium-rich shale formations (Presser and others, 1990), is located on the margin between the San Joaquin Valley and the Coast Ranges (fig. 1). Mean annual rainfall in the basin ranges from about 20 in. (inch) at the western boundary (ridge of the Coast Ranges) to about 7.5 in. at the Interstate 5 (I-5) bridge. The drainage area for the U.S. Geological Survey (USGS) gaging station at the I-5 bridge is 305 mi^2 (square mile).

Several studies have focused on shallow ground water and surficial deposits in the Panoche Creek Basin owing to selenium-induced problems at Kesterson National Wildlife Refuge, which indicate the basin is a major source area (San Joaquin Valley Drainage Program, 1990). The work by Presser and others (1990) provided a preliminary look at surface water quality in the basin. Samples of storm runoff during water year 1988 had dissolved selenium concentrations of 44 and 57 μg/L in Panoche Creek at I-5 and of 55 μg/L in Silver Creek at Panoche Road (Presser and others, 1990). Because the 57 and 55 μg/L (microgram per liter) samples were collected on January 17, 1988 (during runoff from the same storm), this suggests that the selenium concentrations in the Silver Creek portion of the Panoche Creek Basin may be very similar to selenium concentrations in the rest of the basin.

The purpose of this study was to sample storm events during water years 1998 to 2000 at the I-5 gage and calculate the loads of dissolved and total selenium and suspended sediment. This work was funded by the U.S. Bureau of Reclamation primarily to help evaluate potential selenium loads from Panoche Creek to canals that can contribute to the San Luis Drain in the Mendota area during extremely high streamflow events (fig. 1).

METHODS

Sampling Design

The advance warning of possible storm runoff in Panoche Creek was based on information available from the California Data Exchange Center for two real-time rainfall gages in the basin (stations PCH and IDR on figure 1). The USGS streamflow gage at I-5, which is operated annually from December through June, was installed in December 1997. Gage height data are transmitted in 4-hour blocks to the USGS's Automated Data Processing System (and subsequently to the USGS's public website—http://ca.water.usgs.gov/).

Sample Collection

All storm samples were collected from the I-5 bridge using a rope-suspended grab sampler, which consists of a 3-L Teflon bottle strapped into a metal cage. Samples were collected at three equally spaced points across the channel and composited in a churn splitter. The sample-collection bottle and the churn splitter were cleaned between samples using the following protocol: after collecting a sample, the collection bottle and splitter were rinsed with deionized water, then with 5-percent hydrochloric acid solution, and then thoroughly rinsed again with deionized water. Before sample collection, the collection bottle was rinsed three times with native water (U.S. Geological Survey, 1997 to present).

The grab sampler probably integrated the top 3 to 4 ft (foot) of streamflow at the three points in the cross-section. Standard USGS width- and depth-integrated samples were not collected because of safety concerns related to bridge traffic, stream velocities, and debris; further, in many cases, stream velocities exceeded the operational range of such integrating samplers (U.S. Geological Survey, 1997 to present). Because of the high velocities, the streamflow appeared to be well mixed.

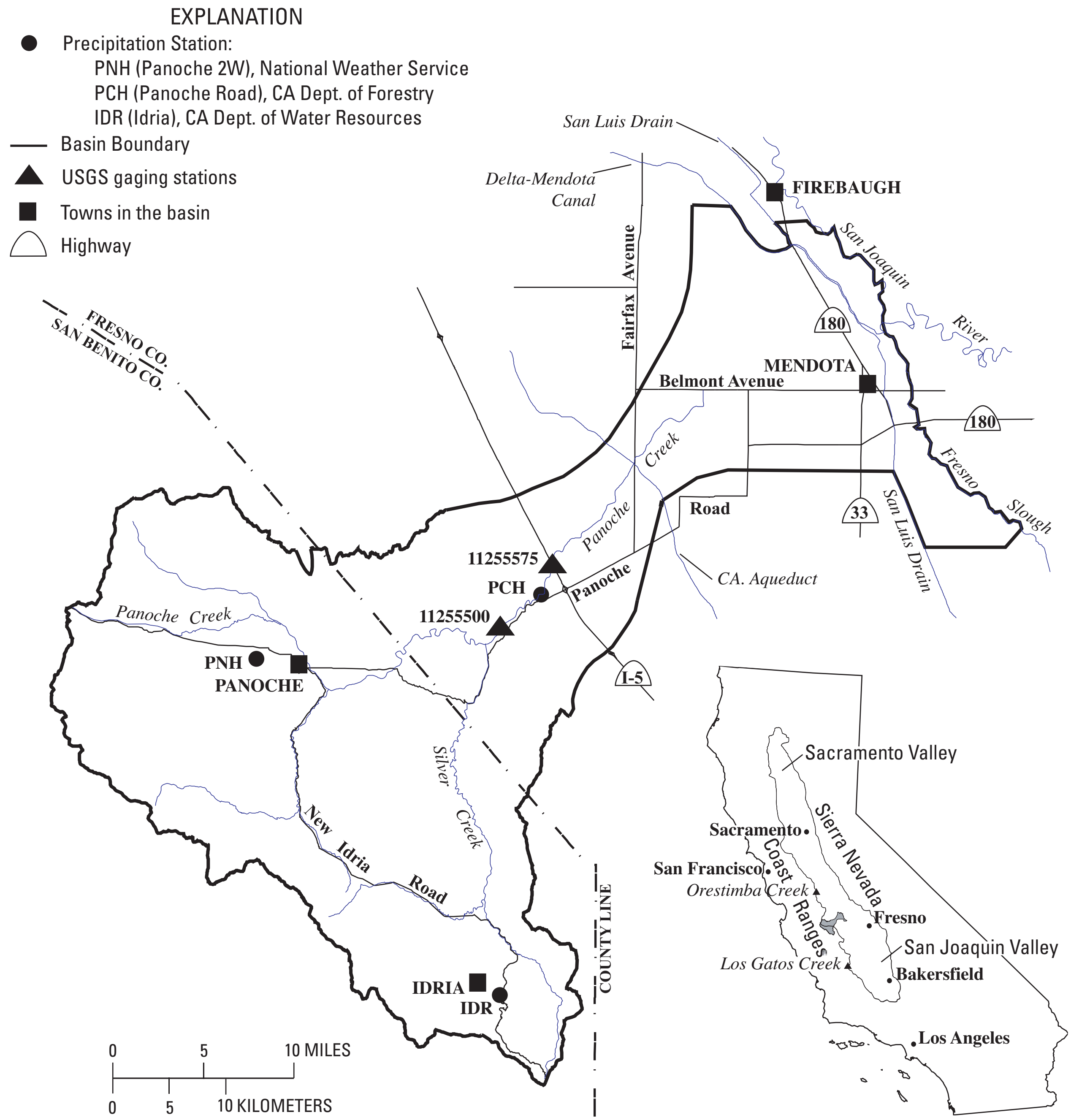


Figure 1. Location of Panoche Creek Basin, California.

Sample Processing and Laboratory Methods

Samples collected for dissolved selenium analyses were filtered through 0.45-µm (micrometer) glass-fiber filters. Both dissolved and total selenium samples were preserved using nitric acid. All selenium samples were sent to the USGS's National Water Quality Laboratory (NWQL) in Denver, Colorado, for analysis using the atomic absorption spectrometric, hydride generation method (Fishman and Friedman, 1989). The method detection level (MDL) is 1 µg/L. Suspended sediment samples were sent to the USGS's California District Sediment Laboratory in Salinas. Two additional parameters were calculated for discussion in this report: suspended selenium concentration and selenium attached to suspended sediment. Suspended selenium concentration was calculated as the difference between total selenium and dissolved selenium concentrations. Selenium attached to suspended sediment was calculated as the suspended selenium concentration divided by the suspended sediment concentration.

Quality Control Samples

In addition to 32 environmental samples collected during February 1998, eight quality control samples were collected during the storms: four field blanks to evaluate possible contamination during sample collection and four replicates to evaluate the variability in selenium concentrations (table 1). The relative percent differences (RPD) for dissolved selenium replicates ranged from 0.0 to 18.2 percent. The RPDs for total selenium replicates ranged from 0.0 to 50.0 percent. The dissolved and total selenium concentrations in the field blanks were all below the MDL of 1 µg/L. Thus, variability of dissolved selenium was acceptable, and contamination was not a problem. However, the variability in total selenium concentrations was a significant concern. This was also a problem in four samples that were rerun for total selenium (table 1). The RPDs for the reruns ranged from 8.0 to 57.1 percent.

The variability in total selenium concentrations increased with suspended sediment concentrations; suspended sediment may interfere by reacting with the reagents used to change the oxidation state of selenium prior to hydride formation (Glenda Brown, USGS-NWQL, written commun., 1998). Also, the amount of suspended sediment is probably different each time the sample is run because the analyst shakes the bottle and pipettes a subsample; the amount of settling probably varies each time, especially for samples containing high suspended sediment. In addition, relatively high specific conductance and sulfate concentrations in the samples could interfere with selenium analyses and reduce the recovery of selenium (Jones and Garbarino, 1999). Seven samples collected during the third storm had a median sulfate concentration of 1,350 mg/L as SO_4 analyzed at a USGS laboratory in Menlo Park, California (Theresa Presser, U.S. Geological Survey, written commun., 1999).

Regression Methods

Simple linear regressions were performed on several pairs of constituents. In some cases, one or both axes were transformed by taking the base 10 logarithm (log) to improve the linearity of the data. The goodness of fit is determined by the R^2 value, and the significance of the slope of the fit is determined from the *p*-value. In some regressions one or more outliers were removed based on two criteria. An outlier in the *x*-direction was determined by a leverage point criteria (Helsel and Hirsch, 1992). The leverage value, h_i, is calculated as:

$$h_i = 1/n + (x_i - \bar{x})^2 / SS_x$$

where

h_i = leverage value

n = number of observations

x_i = x value for i^{th} observation

$\bar{x}$ = mean of all x values

SS_x = sum of squares in x-direction

An observation was discarded as a high leverage point if:

$$h_i > 3p/n$$

where

p = number of coefficients in regression model ($p = 2$ for simple linear regression, b_0 and b_1).

Table 1. Quality control samples for Panoche Creek at I-5, California, February 1998

[Numbers in parentheses are parameter codes from NWIS database. Relative percent difference is the absolute value of env. (environmental sample) minus repl. (replicate sample) divided by the average of env. and repl., multiplied by 100. —, not applicable; Se, selenium. ft^3/s, cubic foot per second; mg/L, milligram per liter; mm, millimeter; µg/L, microgram per liter; µS/cm, microsiemen per centimeter; <, less than; %, percent]

Date, time	Streamflow, instantaneous (ft^3/s) (00061)	Specific conductance (µS/cm) (00095)	Suspended sediment (mg/L) (80154)	Suspended sediment (sieve diameter % finer than 0.062 mm) (70331)	Dissolved selenium (µg/L as Se) (01145)	Dissolved selenium; relative percent difference (%)	Total selenium (µg/L as Se) (01147)	Total selenium; relative percent difference (%)
A. Blanks								
2/3/98, 1405	3,920	2,610	229,251	48	<1	—	<1	—
2/7/98, 0935	182	2,180	48,721	65	<1	—	<1	—
2/21/98, 2345	924	2,890	135,448	56	<1	—	<1	—
2/24/98, 0635	164	2,330	52,682	43	<1	—	<1	—
B. Replicates								
2/3/98, 1600 (env.)	2,420	2,480	176,800	53	45	—	230	—
2/3/98, 1601 (repl.)	—	—	—	—	54	18.2	170	30.0
2/6/98, 1530	1,620	2,280	135,800	52	32	—	120	—
2/6/98, 1531	—	—	—	—	28	13.3	200	50.0
2/22/98, 0240	472	2,200	86,900	63	29	—	100	—
2/22/98, 0241	—	—	—	—	26	10.9	100	0.0
2/24/98, 0630	164	2,330	52,700	43	21	—	73	—
2/24/98, 0631	—	—	—	—	21	0.0	76	4.0
C. Reruns								
2/3/98, 1400	3,920	2,610	229,300	48	60	—	450	—
Rerun	—	—	—	—	—	—	250	57.1
2/6/98, 1140	1,570	3,680	251,500	47	38	—	340	—
Rerun	—	—	—	—	—	—	260	26.7
2/6/98, 1240	2,420	2,850	156,700	58	37	—	120	—
Rerun	—	—	—	—	—	—	130	8.0
2/6/98, 1340	2,190	2,670	163,300	60	32	—	260	—
Rerun	—	—	—	—	—	—	200	26.1

An outlier in the *y*-direction was determined by using the standardized residual test (Helsel and Hirsch, 1992). The standardized residual, e_{si}, is calculated as:

$$e_{si} = e_i / s(1 - h_i)^{0.5}$$

where

e_{si} = standardized residual

$e_i = y_i - \hat{y}_i$ (= prediction residual in *y*-direction for i^{th} observation)

y_i = *y* value for i^{th} observation

$\hat{y}_i$ = predicted *y* value for i^{th} observation

s = standard error of regression

An observation was discarded as an outlier in the *y*-direction if:

$$|e_{si}| > 3$$

This is considered an extreme outlier and should occur only an average of three times out of 1,000 observations if the residuals are normally distributed.

The uncertainty in loads calculated from regression equations is expressed in this report as a 95-percent confidence interval for predictions. This interval was calculated using the following equation (Helsel and Hirsch, 1992):

$$(\hat{y} - t_{\alpha/2, n-2}s;\ \hat{y} + t_{\alpha/2, n-2}s)$$

where

$\hat{y}$ = predicted value of *y* for a given *x* from regression equation

$t_{\alpha/2,n-2}$ = *t* statistic for significance level α and *n* samples

s = standard error of regression

For the load calculation regressions using 29 data points, this interval can be simplified to:

$$(\hat{y} - 2.05s;\ \hat{y} + 2.05s)$$

For log-transformed regressions, this interval applies to the transformed *x* and *y* (e.g., $x = \log_{10}$ streamflow, $y = \log_{10}$ suspended sediment load). The predicted load must be untransformed (10^y) to calculate the confidence interval for the desired load.

The determination of significant differences between simple linear regressions was based on the Student’s *t* test between slopes. The method is analogous to the testing of differences between two population means (Zar, 1974). The *t* statistic is calculated from the following equation (Zar, 1974):

$$t = (b_1 - b_2) / (S_{b_1 - b_2})$$

where

b_1, b_2 = slopes for regressions 1 and 2

$S_{b_1 - b_2}$ = pooled sample standard deviation

If this *t* value exceeds $t_{\alpha/2, n_1 + n_2 - 4}$, then the slopes are significantly different at the α significance level for sample sizes n_1 and n_2 for regressions 1 and 2.

Multiple linear regression was performed to predict dissolved selenium concentrations as a function of both log streamflow and specific conductance. As with simple linear regression, the goodness of fit is determined by the adjusted R^2 value, and the significance of the slope of the fit is determined by the *p*-value. The adjusted R^2 value accounts for the degrees of freedom in the regression (Helsel and Hirsch, 1992).

STORM HYDROLOGY

Historical Hydrology

Average annual precipitation (1911–60) in the Panoche Creek Basin ranges from about 20 in. in the upper part of the basin in the Coast Ranges to about 7.5 in. in the lower part of the basin in the San Joaquin Valley (Kratzer and Shelton, 1998). The overall area-weighted average annual rainfall for the basin is about 12 in. Historical averages (1911–60) for the three rainfall gages shown in figure 1 are about 14 in. at Idria (station IDR), 9 in. at Panoche 2W (station PNH), and 7.5 in. at Panoche Road (station PCH). The average annual rainfall at the PNH rainfall gage for 1957–2000 was about 8 in., with over 80 percent of the annual rainfall taking place during November through March (Gronberg and others, 1998).

The streamflow record for Panoche Creek is not as extensive as the rainfall record. The old USGS gaging station (station no. 11255500) recorded streamflows for 1950–53 and 1959–70. This site (fig. 1) is 4.8 river mile upstream of the present gaging station at I-5 (station no. 11255575) and has a drainage area of 293 mi^2 compared to 305 mi^2 for the present site. The peak streamflow of record at the old site was 5,400 ft^3/s (cubic foot per second) on February 24, 1969. Precipitation and streamflow records for Panoche Creek for 1959–70 are shown in figure 2. Overall, the Panoche Creek basin has a much lower frequency of high streamflows compared with other smaller Coast Range basins. For the 16 years of streamflow records, Panoche Creek (293 mi^2) had daily mean streamflows of over 100 ft^3/s for only 24 days; whereas, Los Gatos Creek (96 mi^2) had 243 days in 54 years (water years 1946 to 1999) and Orestimba Creek (134 mi^2) had 851 days in 64 years (water years 1936 to 1999) (see figure 1 and inset for locations).

Hydrology for Study Period (Water Years 1998 to 2000)

Average daily precipitation (at PNH gage) and streamflow at the new USGS gaging station (at I-5; station no. 11255575) for the study period are shown in figure 3. Rainfall during water year 1998 at the PNH gage was 26.36 in., well above the long-term average of 8 to 9 in. Rainfall during water years 1999 and 2000 were about average, 9.16 and 8.51 in., respectively. The rainfall total of 10.40 in. during February 1998 at the PNH gage was greater than any other month during

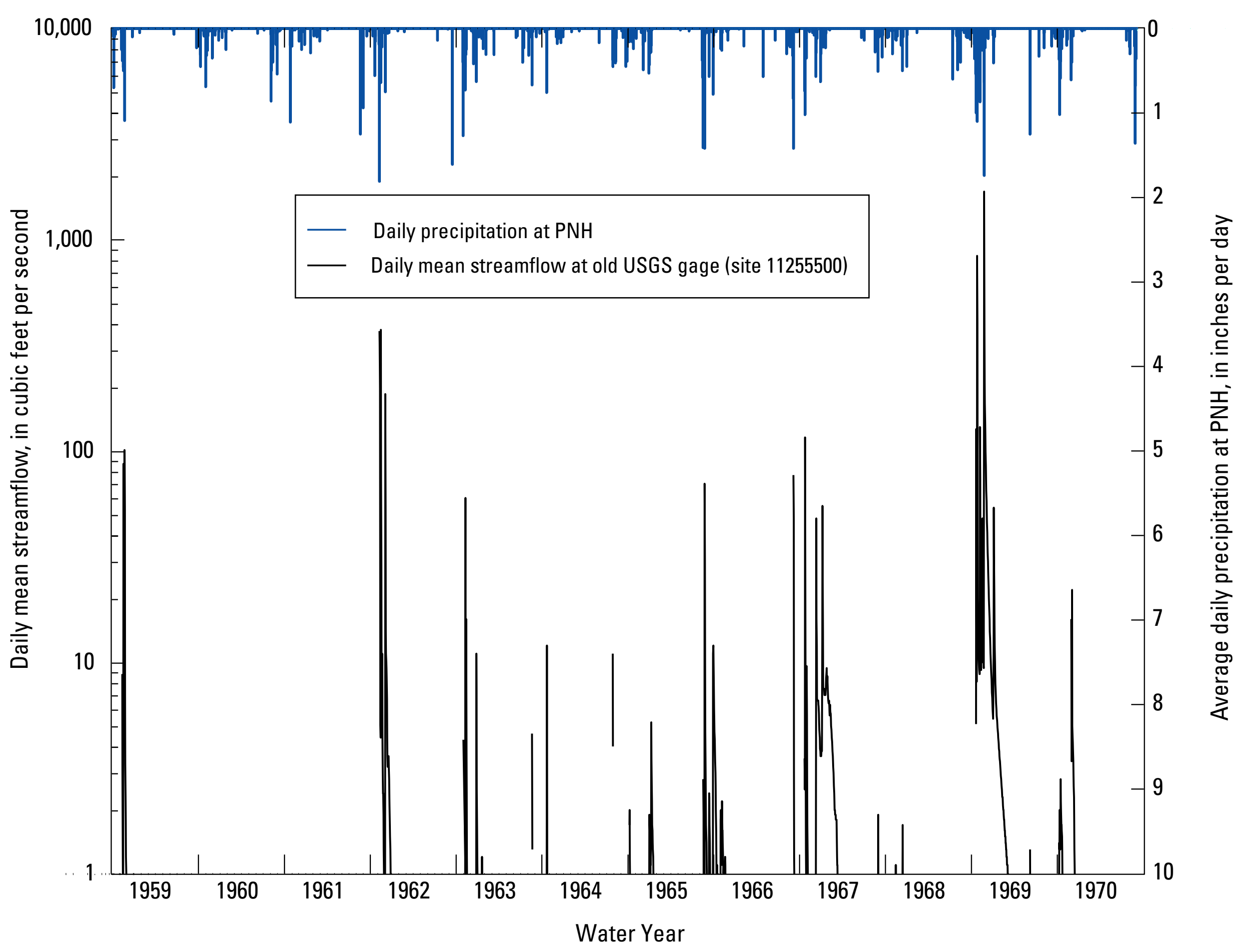


Figure 2. Daily precipitation and streamflow in Panoche Creek, California, for water years 1959 to 1970.

PNH, Panoche 2W (National Weather Service) precipitation station.

1957 to 2000. The 1998 streamflows also were unusually high compared with the 1950–53 and 1959–70 periods. Peak streamflows on February 3, 1998 (9,940 ft^3/s) and on February 7, 1998 (8,550 ft^3/s) both exceeded the peak streamflow of record at the old gage (fig. 4). The peak streamflow during water years 1999 and 2000 was only 188 ft^3/s on February 23, 2000.

The relation between hourly precipitation in the basin and streamflow at the I-5 gage for February 1998 is shown in figure 4. Since the PNH rainfall gage only records daily totals, we used the average of the PCH and IDR gages for the hourly rainfall. Although these two sites represent two extremes of rainfall in the basin, their average is close to the overall basin average. For February 1998, the average of PCH and IDR was 8.60 in. compared with 10.40 in. at PNH. Streamflow at the I-5 gage occurred about 6 to 12 hours after significant rainfall in the basin for the February 1998 storms. The delay period is affected by antecedent moisture in the basin, rainfall intensity, and the initial water level in the pond at the gravel pit less than a mile upstream of the I-5 gage.

WATER QUALITY

Time Series Data During Storms

A total of 32 environmental samples were collected during February 1998 (fig. 4). The first two samples were collected on February 2, before the first sampled storm. The other 30 environmental samples were collected throughout the hydrograph following four storms; five to nine samples were collected per storm runoff event (table 2). Seven of the 30 environmental samples were collected on the rising

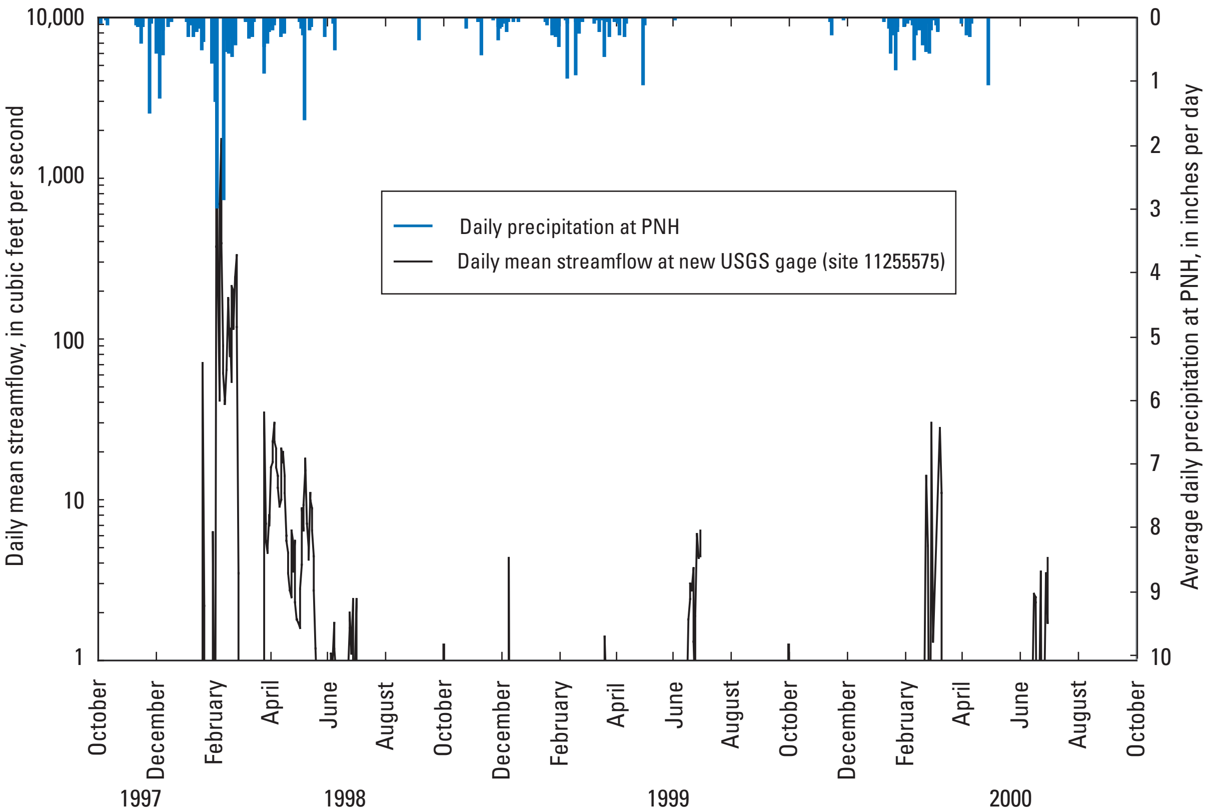


Figure 3. Daily precipitation and streamflow in Panoche Creek, California, for water years 1998 to 2000.

PNH, Panoche 2W (National Weather Service) precipitation station.

limb of the storm hydrographs, four samples were collected within 4.1 percent of the peak streamflow, and 19 samples were collected on the falling limb. For five of the seven rising limb samples, falling limb samples were collected during the same storm at streamflows within 7.1 percent RPD (table 2 [see samples paired by color]).

Specific conductance peaked on the rising limb of the storm hydrographs for the last three storms and on the falling limb of the first storm (fig. 5). In all four storms, the specific conductance increased towards the end of the storm hydrograph. This could be a function of bank storage of high conductivity water being released or a second source of high conductivity water reaching the site from upstream in the watershed.

The suspended sediment concentrations generally followed the form of the storm hydrographs (fig. 6). As with specific conductance, suspended sediment concentrations peaked on the rising limb for the last three storms and on the falling limb for the first storm. The percentage of suspended material that is silt and clay (<0.062 mm [millimeter] diameter) varied from 43 to 71 percent during the storms, except for one sample on February 21 at the beginning of a storm that had only 31 percent fine material. The pre-storm samples on February 2 had 87 and 82 percent fine material. The percentage of fine material was usually lower near the peak streamflow than it was farther out on the falling limb of the storm hydrograph.

The concentration pattern of dissolved selenium was very similar to specific conductance (fig. 7). The concentration patterns of total and suspended selenium (calculated) were very similar to suspended sediment (figs. 7 and 8). One exception to this was near the peak streamflow of the first storm (figs. 7A and 8A). Suspended (calculated) and total selenium concentrations peaked on the rising limb while suspended sediment peaked on the falling limb of the storm hydrograph. The concentration of selenium attached to the suspended sediment (calculated in

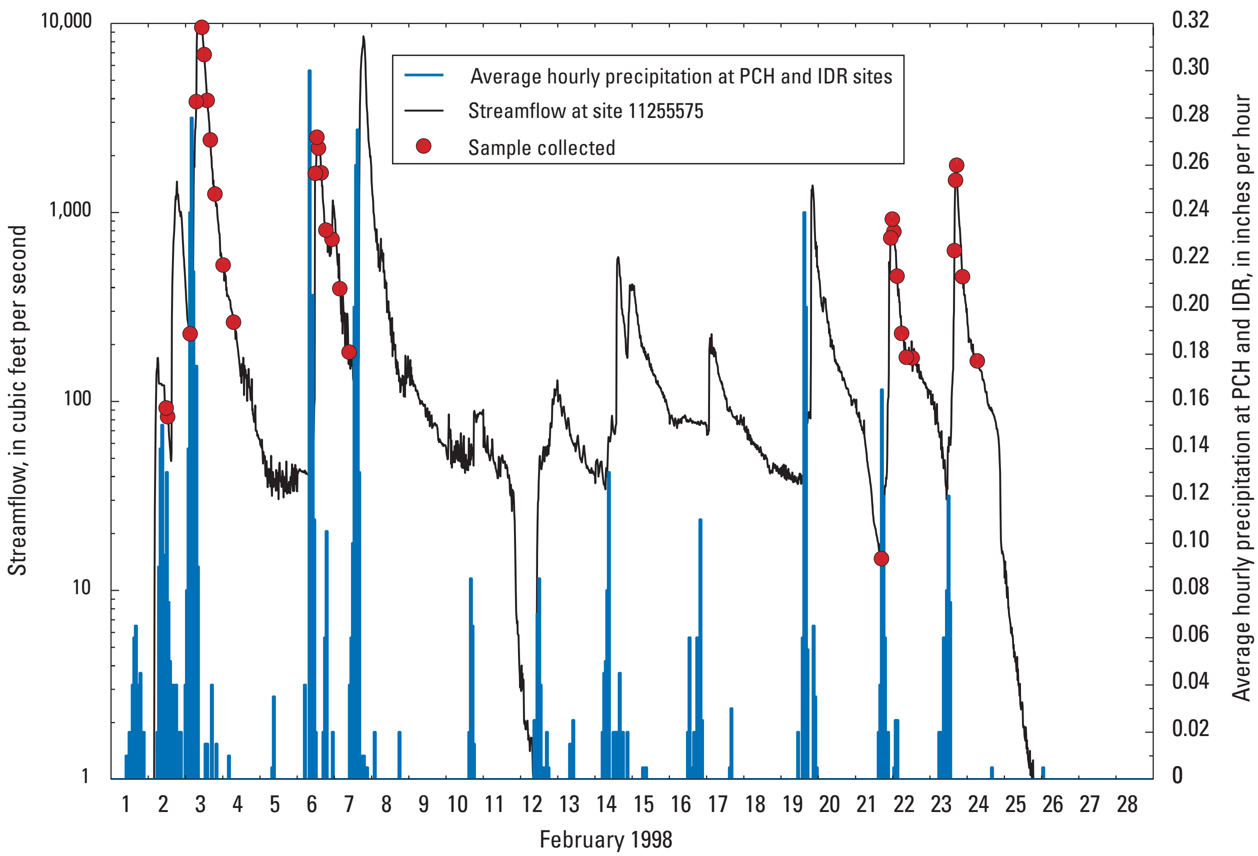


Figure 4. Hourly precipitation, 15-minute streamflow, and sample collection times in Panoche Creek, California, February 1998.

PCH, Panoche Road (California Department of Forestry) precipitation station; IDR, Idria (California Department of Water Resources) precipitation station.

Table 2. Water quality data for storm sampling in Panoche Creek at I-5, California, February 1998

[Numbers in parentheses denote parameter codes in NWIS database. Each color indicates a paired sample (rising limb; falling limb) at similar streamflow during the same storm. Storm hydrograph: R, rising; F, falling; P, peak. Se, selenium; T/D, tons per day; ft^3/s, cubic foot per second; lb/d, pound per day; mg/L, milligram per liter; mm, millimeter; µg/g, microgram per gram; µg/L, microgram per liter; µS/cm, microsiemen per centimeter; —, not applicable; %, percent]

Date, time	Streamflow, instantaneous (ft^3/s) (00061)	Storm hydrograph	Specific conductance (µS/cm) (00095)	Suspended sediment (mg/L) (80154)	Suspended sediment (sieve diameter % finer than 0.062 mm) (70331)	Dissolved selenium (µg/L as Se) (01145)	Suspended selenium (calculated) (µg/L as Se)[4]	Total selenium (µg/L as Se) (01147)	Suspended sediment loading rate, instantaneous (T/D)[5]	Dissolved selenium loading rate, instantaneous (lb/d)[6]	Suspended selenium loading rate, instantaneous (lb/d)[7]	Total selenium loading rate, instantaneous (lb/d)[8]	Suspended selenium/suspended sediment (µg/g)[9]
2/2/98, 09:30	122	—	[1]1,420	[1]24,000	[1]87	[1]7	13	[1]20	7,888	4.6	8.5	13	0.54
2/2/98, 12:30	83	—	[2]1,390	[2]18,100	[2]82	[2]5	12	[2]17	4,047	2.2	5.4	7.6	0.66
Storm 1:													
2/3/98, 03:00	228	R	1,500	54,400	70	16	71	87	33,412	20	87	107	1.3
2/3/98, 07:00	3,860	R	1,670	140,000	71	26	294	320	1,455,747	541	6,114	6,655	2.1
2/3/98, 10:30	9,530	P	2,420	177,000	60	30	260	290	4,543,984	1,540	13,350	14,890	1.5
2/3/98, 12:00	6,840	F	2,540	230,000	48	56	204	260	4,237,937	2,064	7,518	9,581	0.89
2/3/98, 14:00	3,920	F	2,610	229,000	48	60	190	250	2,418,200	1,267	4,013	5,280	0.83
2/3/98, 16:00	2,420	F	2,480	177,000	53	[3]50	150	[3]200	1,153,876	652	1,956	2,608	0.85
2/3/98, 19:00	1,250	F	2,130	131,000	58	46	114	160	441,115	310	768	1,078	0.87
2/4/98, 00:00	517	F	2,250	86,400	60	25	85	110	120,330	70	237	306	0.98
2/4/98, 07:00	263	F	2,270	63,900	70	24	86	110	45,272	34	122	156	1.3
Storm 2:													
2/6/98, 11:40	1,570	R	3,680	251,000	47	38	222	260	1,061,559	321	1,878	2,199	0.89
2/6/98, 12:40	2,420	P	2,850	157,000	58	37	93	130	1,023,495	482	1,213	1,695	0.59
2/6/98, 13:40	2,190	F	2,670	163,000	60	32	168	200	961,617	378	1,982	2,360	1.0
2/6/98, 15:30	1,620	F	2,280	136,000	52	[3]30	130	[3]160	593,505	262	1,135	1,397	0.96
2/6/98, 18:30	806	F	2,250	129,000	52	30	65	95	280,089	130	282	413	0.50
2/6/98, 22:30	722	F	2,390	122,000	47	30	80	110	237,284	117	311	428	0.66
2/7/98, 03:30	395	F	2,100	90,300	60	22	65	87	96,085	47	138	185	0.72
2/7/98, 09:30	182	F	2,180	48,700	65	25	48	73	23,877	25	47	72	0.99

Table 2. Water quality data for storm sampling in Panoche Creek at I-5, California, February 1998—*Continued*

Date, time	Streamflow, instanta-neous (ft^3/s) (00061)	Storm hydro-graph	Specific conduct-ance (µS/cm) (00095)	Suspended sediment (mg/L) (80154)	Suspended sediment (sieve diameter % finer than 0.062 mm) (70331)	Dissolved selenium (µg/L as Se) (01145)	Suspended selenium (calculated) (µg/L as Se)[4]	Total selenium (µg/L as Se) (01147)	Suspended sediment loading rate, instanta-neous (T/D)[5]	Dissolved selenium loading rate, instanta-neous (lb/d)[6]	Suspended selenium loading rate, instanta-neous (lb/d)[7]	Total selenium loading rate, instanta-neous (lb/d)[8]	Suspended selenium/ suspended sediment (µg/g)[9]
Storm 3:													
2/21/98, 16:40	15	R	3,190	3,900	31	30	27	57	1,329	2.4	2.2	4.6	0.82
2/21/98, 22:40	735	R	3,140	150,000	56	44	146	190	296,995	174	578	752	0.97
2/21/98, 23:40	924	P	2,890	135,000	56	32	108	140	336,029	159	538	697	0.80
2/22/98, 00:40	824	F	2,430	116,000	57	25	75	100	257,487	111	333	444	0.65
2/22/98, 02:40	472	F	2,200	86,900	63	[3]28	72	[3]100	110,492	71	183	254	0.83
2/22/98, 05:40	235	F	2,130	54,500	71	20	62	82	34,501	25	79	104	1.1
2/22/98, 08:40	176	F	2,250	51,500	61	20	62	82	24,417	19	59	78	1.2
2/22/98, 12:30	170	F	2,410	42,000	65	24	62	86	19,234	22	57	79	1.5
Storm 4:													
2/23/98, 15:40	518	R	3,200	94,500	52	30	80	110	131,866	84	223	307	0.85
2/23/98, 16:30	1,480	R	2,750	150,000	52	31	89	120	598,031	247	710	957	0.59
2/23/98, 17:10	1,780	P	2,570	152,000	52	26	94	120	728,843	249	902	1,151	0.62
2/23/98, 21:00	458	F	2,060	106,000	59	21	99	120	130,780	52	244	296	0.93
2/24/98, 06:30	164	F	2,330	52,700	43	[3]21	54	[3]75	23,282	19	48	66	1.0

[1]Average of samples collected at 0920, 0930, and 1010.

[2]Average of samples collected at 1230 and 1240.

[3]Average of replicates for dissolved selenium (01145) and total selenium (01147).

[4]Calculated by difference: total selenium (01147) minus dissolved selenium (01145).

[5]Calculated: 0.002694 × suspended sediment concentration (mg/L) × streamflow (ft^3/s).

[6]Calculated: 0.00538 × dissolved selenium concentration (µg/L) × streamflow (ft^3/s).

[7]Calculated: 0.00538 × suspended selenium concentration (µg/L) × streamflow (ft^3/s).

[8]Calculated: 0.00538 × total selenium concentration (µg/L) × streamflow (ft^3/s).

[9]Calculated: suspended selenium concentration (µg/L)/(suspended sediment concentration [mg/L] × g/1000mg).

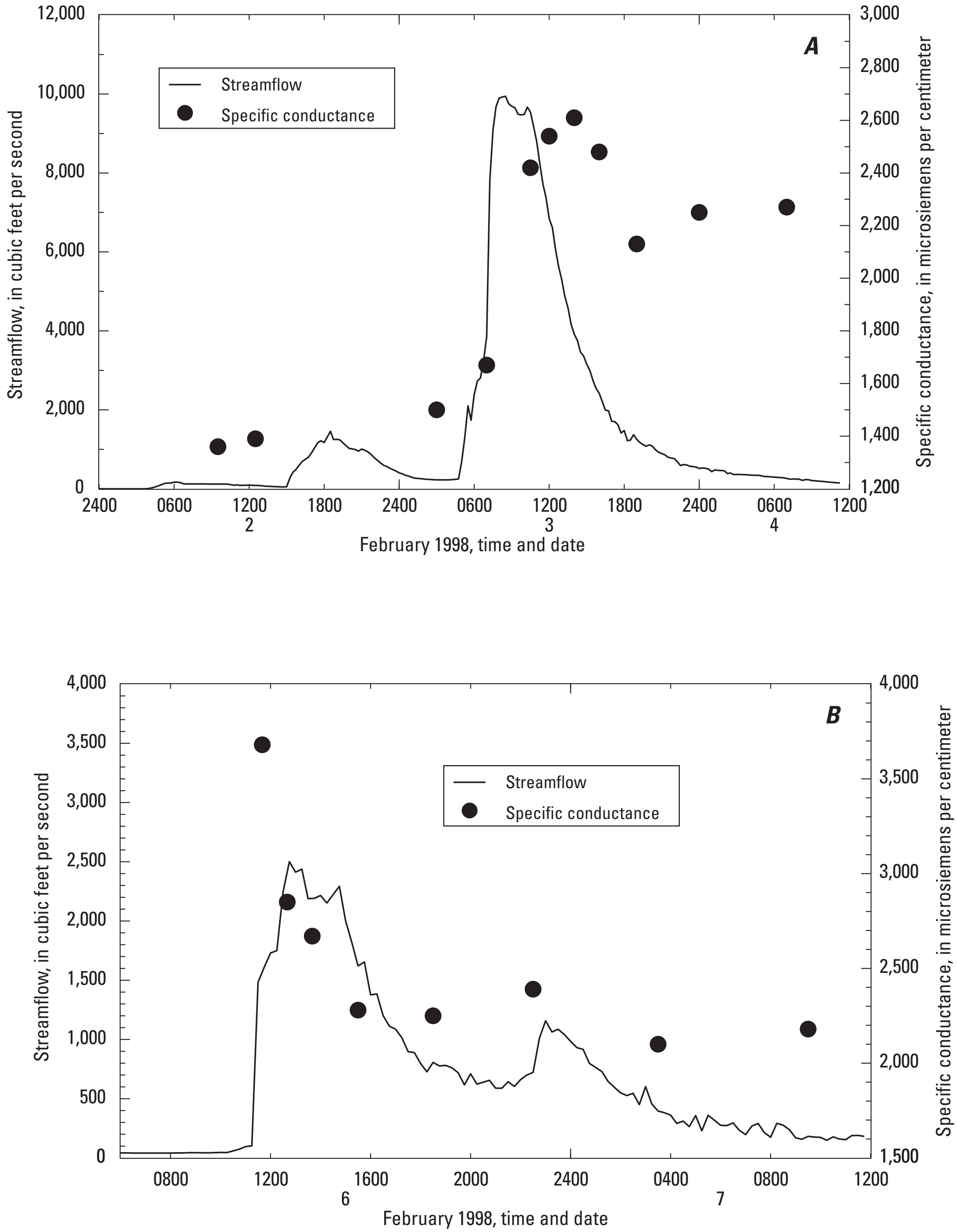
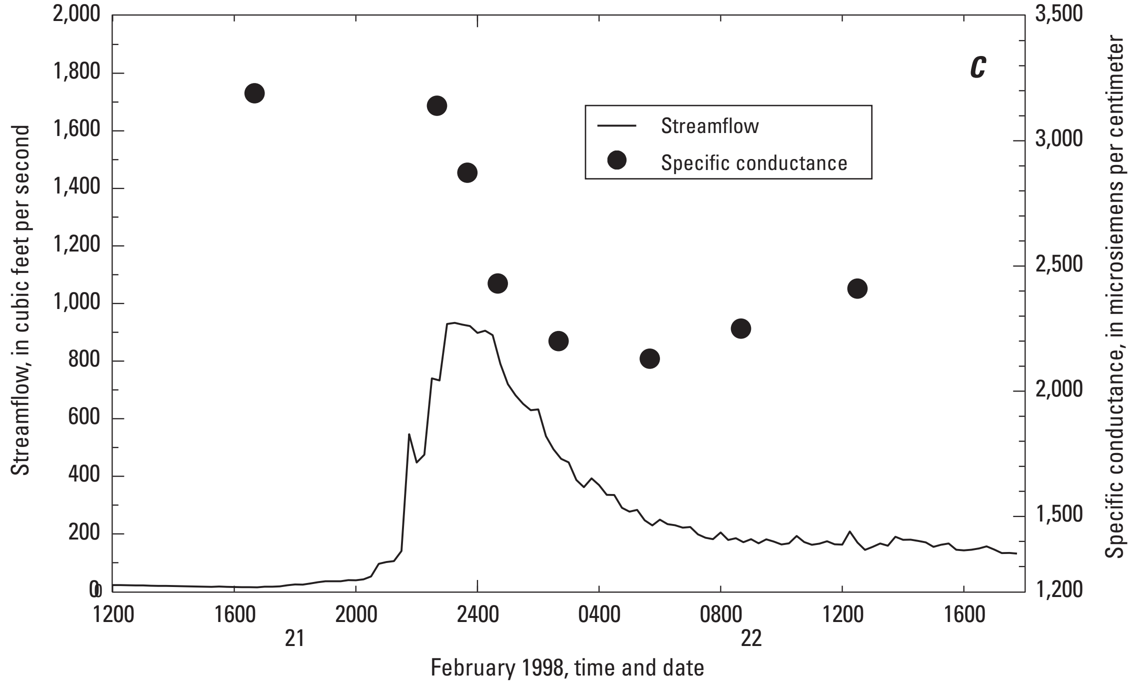


Figure 5. Streamflow and specific conductance in Panoche Creek, California, for February 1998 storms.

A. February 2–4.
B. February 6 and 7.
C. February 21 and 22.
D. February 23 and 24.



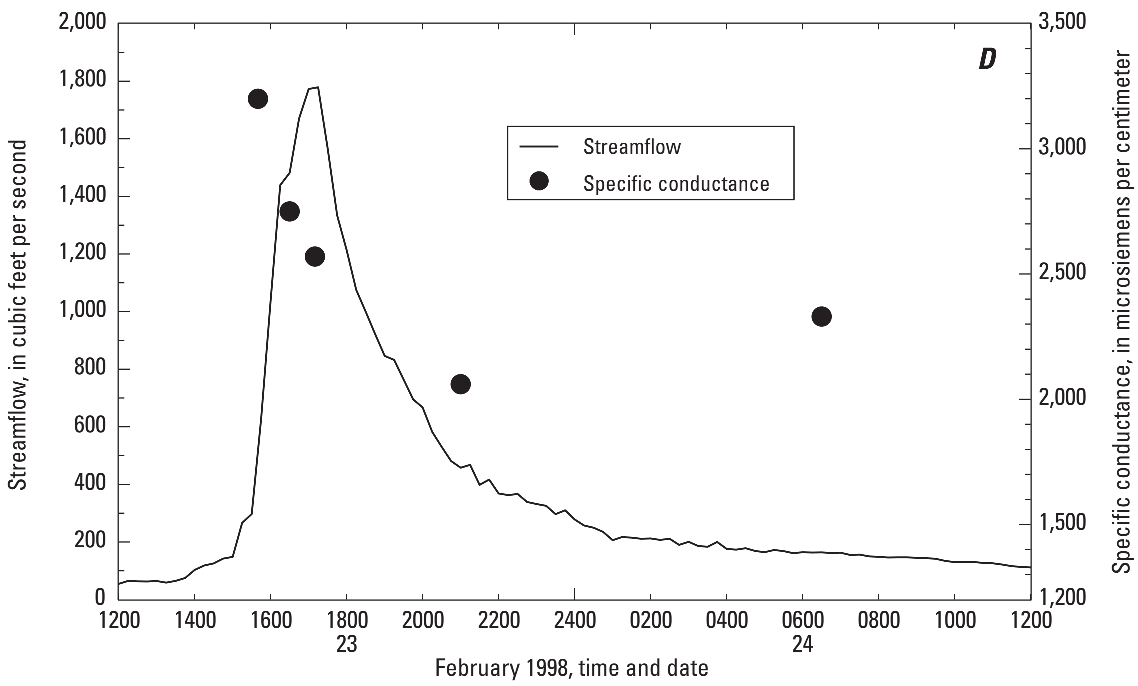
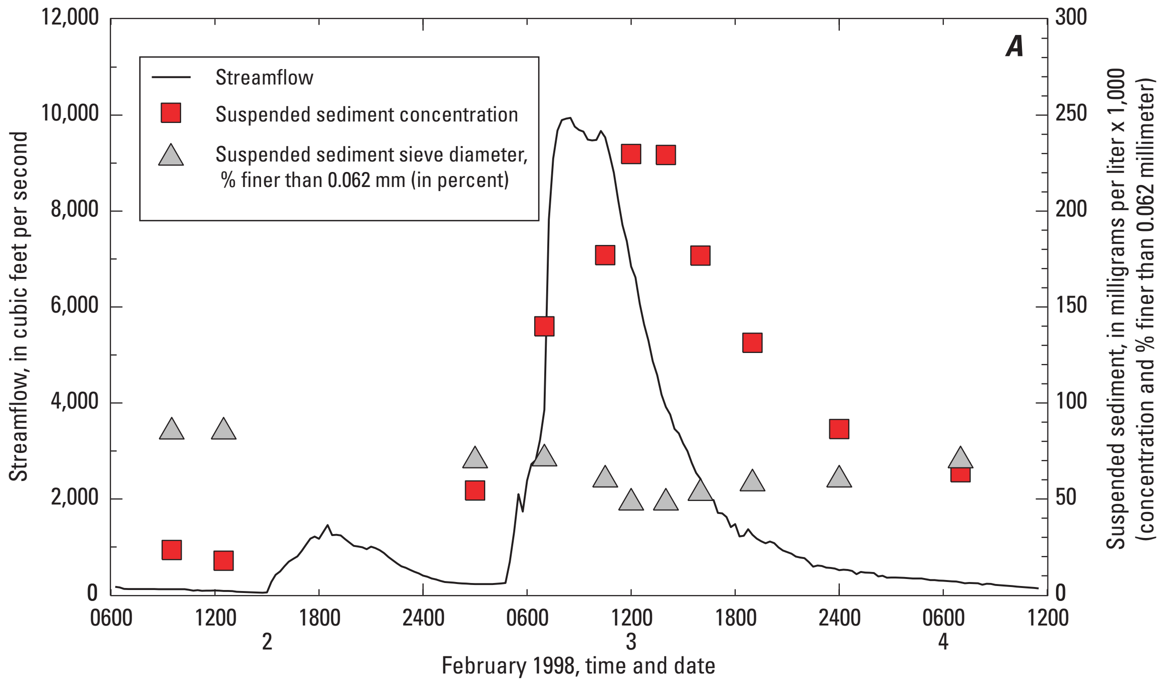


Figure 5. *Continued.*



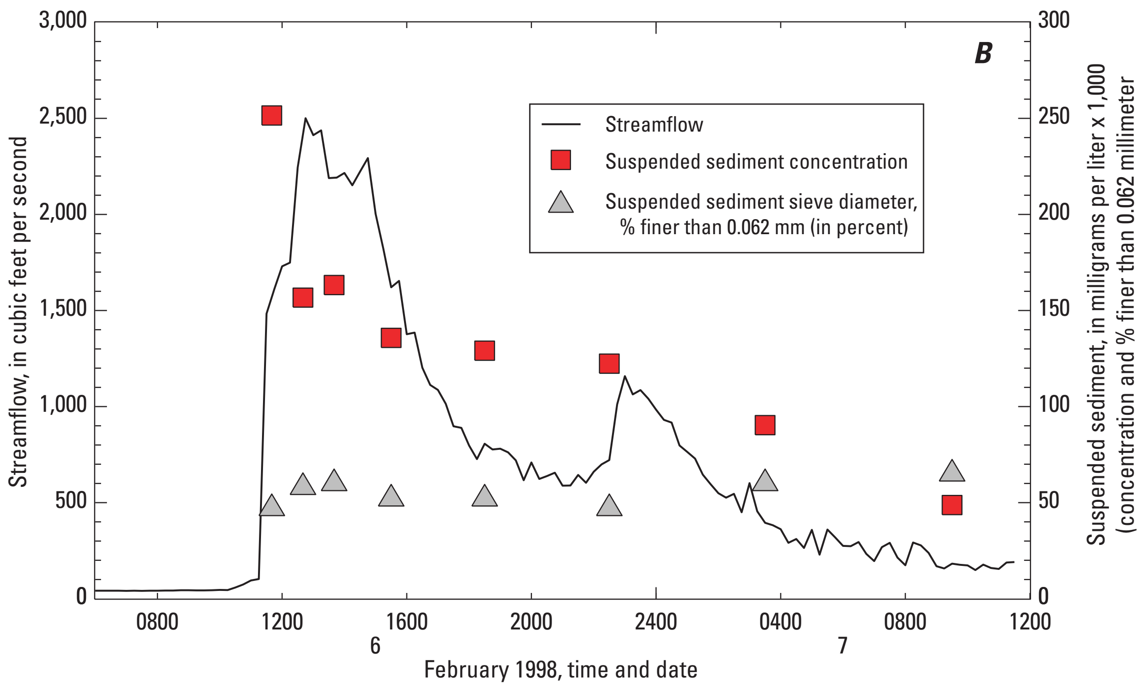
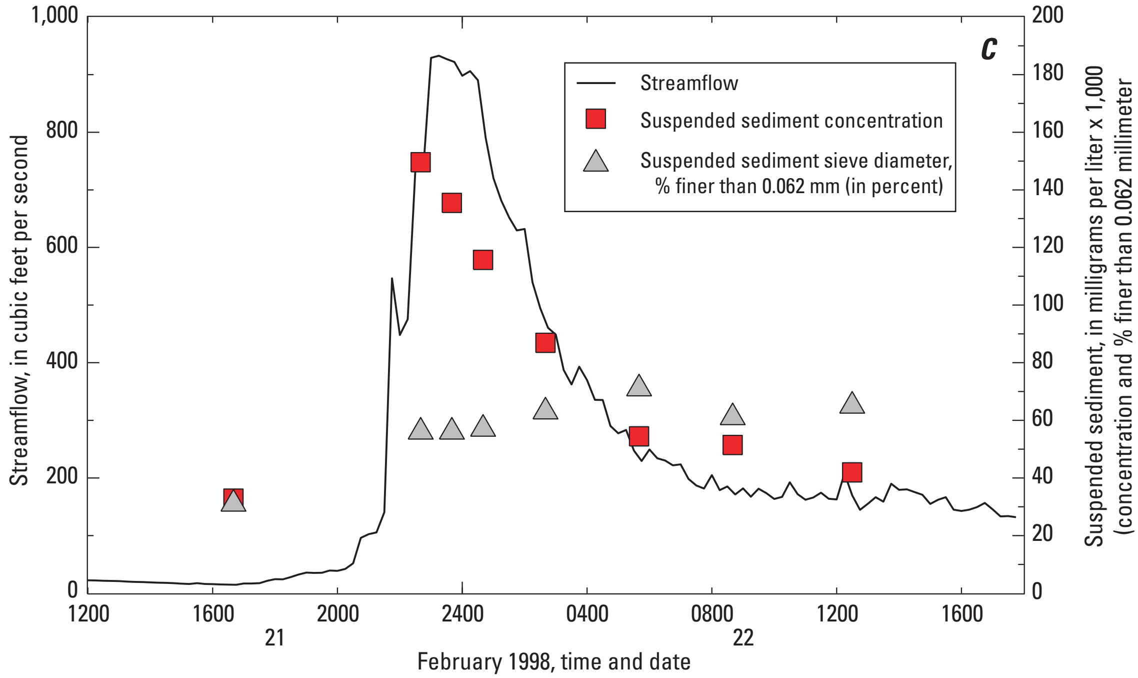


Figure 6. Streamflow and suspended sediment in Panoche Creek, California, for February 1998 storms.

[%, percent; mm, millimeter]

A. February 2–4.
B. February 6 and 7.
C. February 21 and 22.
D. February 23 and 24.



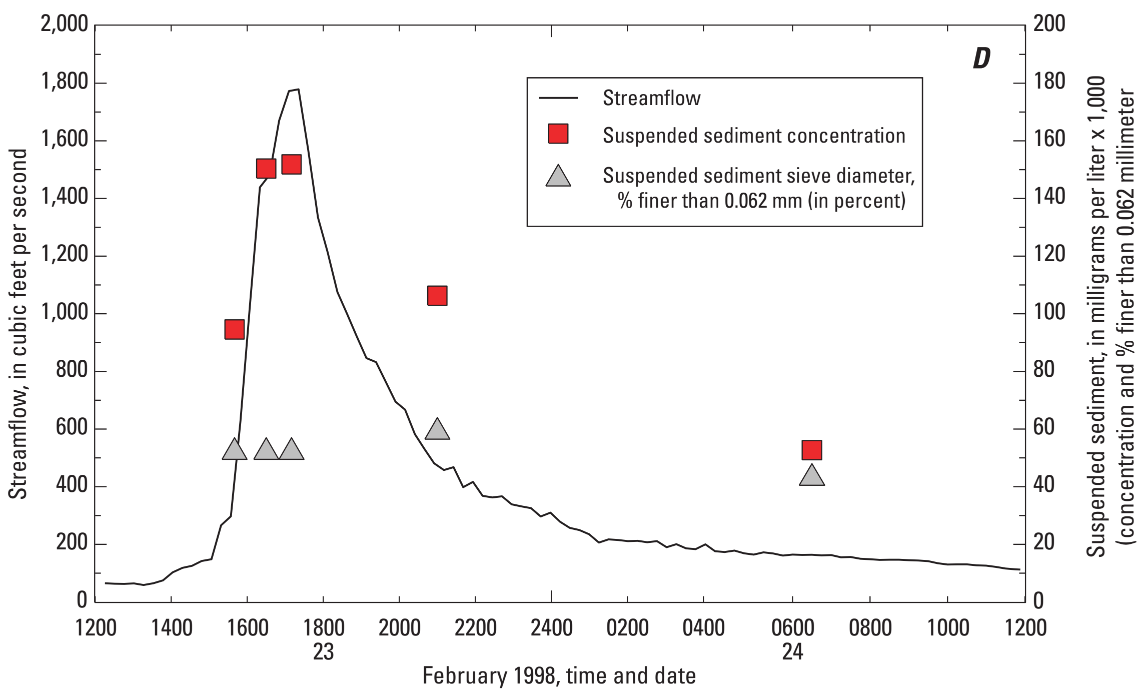


Figure 6. *Continued.*

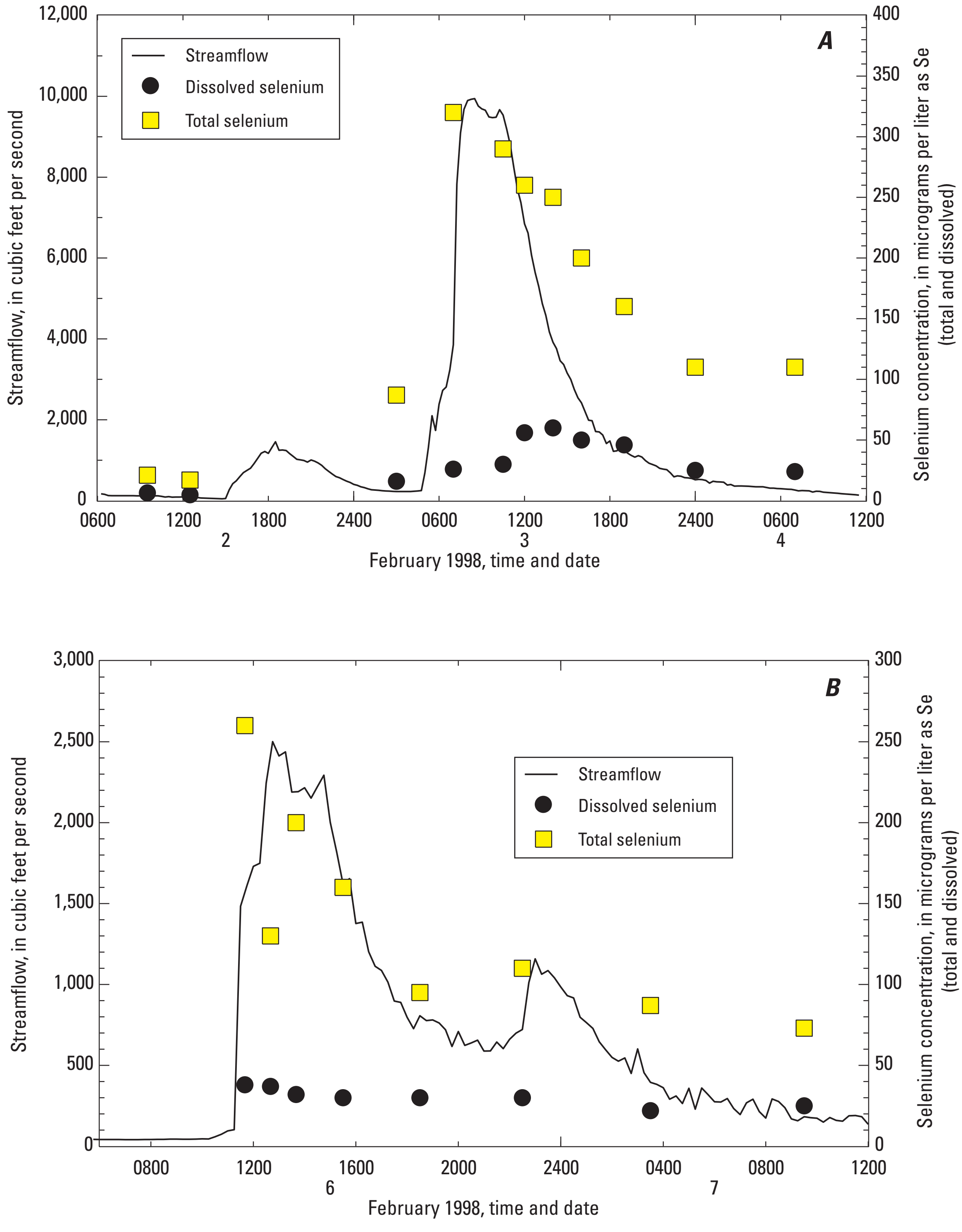


Figure 7. Streamflow and dissolved and total selenium in Panoche Creek, California, for February 1998 storms.

A. February 2–4.
B. February 6 and 7.
C. February 21 and 22.
D. February 23 and 24.

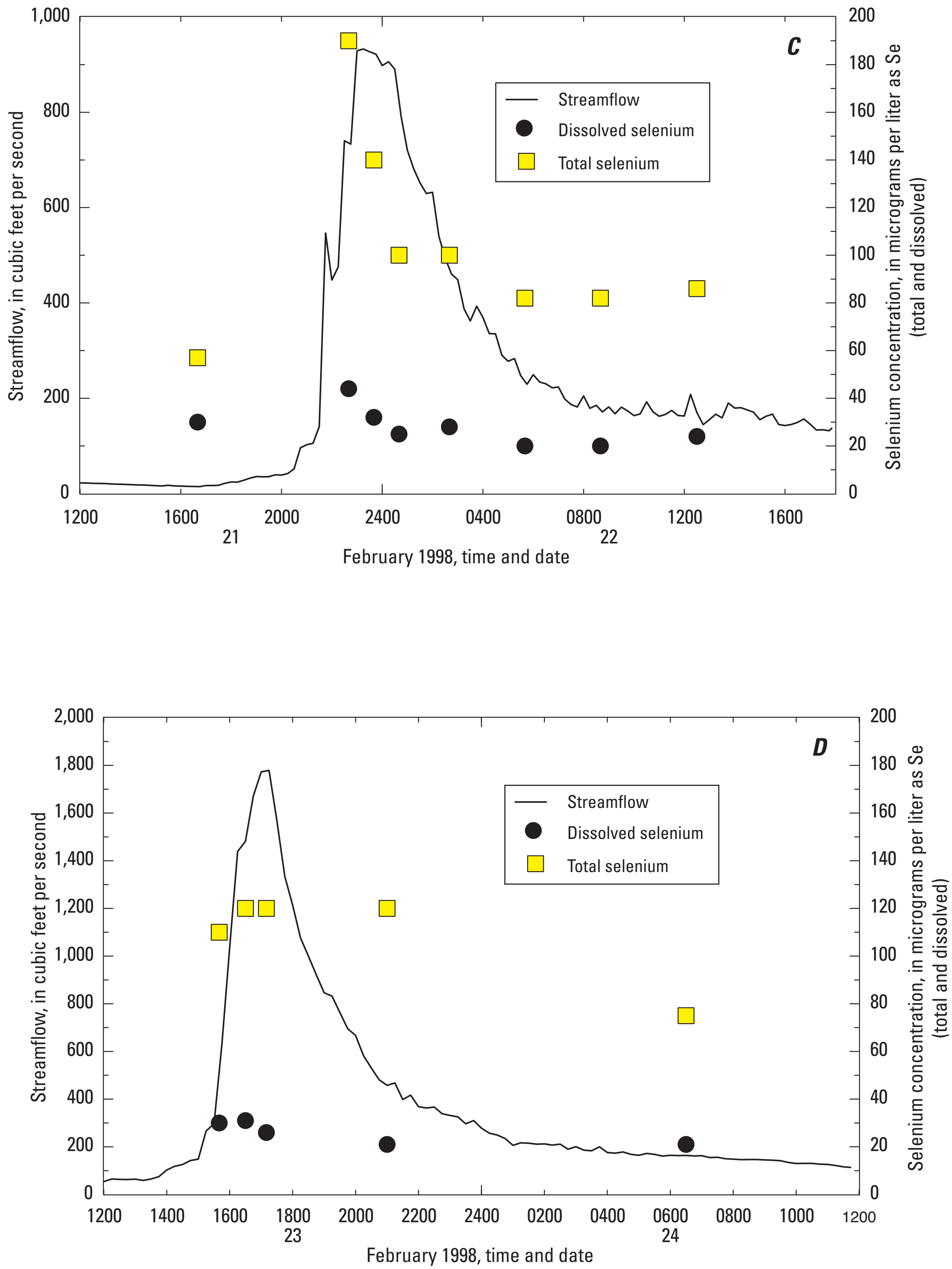


Figure 7. *Continued.*

microgram per gram) generally increased on the rising limb, decreased near the peak flow, and increased again on the falling limb of the storm hydrographs (fig. 8).

Although concentrations at a given streamflow were usually greater on the rising limb of the storm hydrographs, there were many exceptions (table 2 [see samples paired by color], figures 5–8). The instances during which concentrations at a given streamflow were greater on the falling limb than the rising limb are as follows:

- Specific conductance in the first storm
- Suspended sediment in the first and fourth storms
- Total selenium in the first and fourth storms
- Dissolved selenium in the first storm
- Suspended selenium (calculated) in the first and fourth storms
- Some concentrations of selenium attached to the suspended sediment (calculated) in the second and fourth storms.

Relations Between Constituents

Several correlations between constituents were evaluated for the February 1998 storm data (figs. 9*A*–9*K*). Most of the discussion focuses on regressions that had slopes significant at the 95-percent confidence level (p-value < 0.05). Because the water-quality time-series data for the first storm are different from storms 2–4 for several constituents (table 2, figs. 5–8), separate regressions were done for these two populations in addition to the combined regression. The linear regression slopes for storm 1 and storms 2–4 are significantly different (at the 95-percent confidence level) for specific conductance versus log streamflow, dissolved selenium versus specific conductance, dissolved selenium versus log streamflow, total selenium versus log streamflow, selenium attached to suspended sediment (calculated) versus log streamflow, and log suspended sediment versus log streamflow (figs. 9*A*, *B*, *D*, and *F*–*H*, respectively).

For the regressions that are based on all storm data, no significant correlations (p-value of slope > 0.05) were found between the following constituents: specific conductance and log streamflow (fig. 9*A*); total selenium and specific conductance (fig. 9*C*); selenium attached to suspended sediment (calculated) and log streamflow (fig. 9*G*); and suspended sediment size and log streamflow (fig. 9*K*). Moderate correlations (p-value of slope < 0.05 and $R^2 < 0.5$) occurred between dissolved selenium and specific conductance (fig. 9*B*) and between dissolved selenium and log streamflow (fig. 9*D*). Relatively strong correlations (p-value of slope < 0.05 and $R^2 > 0.5$) occurred between log suspended selenium (calculated) and log streamflow (fig. 9*E*), total selenium and log streamflow (fig. 9*F*), log suspended sediment and log streamflow (fig. 9*H*), suspended selenium (calculated) and suspended sediment (fig. 9*I*), and total selenium and suspended sediment (fig. 9*J*). These relations suggest that an acceptable estimate of suspended sediment and total selenium could be made from the continuous streamflow record at the I-5 gage. A summary of regressions between water quality constituents is shown in table 3.

Separating data for the first storm from all storm data improved some regressions and made some worse. The regression for dissolved selenium versus specific conductance (fig. 9*B*) was substantially improved. The goodness of fit (R^2) improved from 0.18 to 0.54 while the significance (p) of the correlation remained unchanged. No previously nonsignificant correlations became significant by separating storm 1 data from the other storm data. Significant correlations ($p < 0.05$) had substantially improved goodness of fit (R^2) for log suspended selenium (calculated) versus log streamflow (fig. 9*E*) and total selenium versus log streamflow (fig. 9*F*). The regressions for dissolved selenium versus log streamflow (fig. 9*D*), suspended selenium (calculated) versus suspended sediment (fig. 9*I*), and total selenium versus suspended sediment (fig. 9*J*) were substantially worse. Significant correlations ($p < 0.05$) became nonsignificant ($p > 0.05$) for dissolved selenium versus log streamflow (fig. 9*D*) and suspended selenium (calculated) versus suspended sediment (fig. 9*I*). Although still significant, the goodness of fit (R^2) was substantially worse than for the regression using all storm data for total selenium versus suspended sediment (fig. 9*J*).

Similarly, separating data for storms 2–4 improved some regressions and made some worse. The regressions for specific conductance versus log streamflow (fig. 9*A*), dissolved selenium versus specific conductance (fig. 9*B*), and selenium attached to suspended sediment (calculated) versus specific

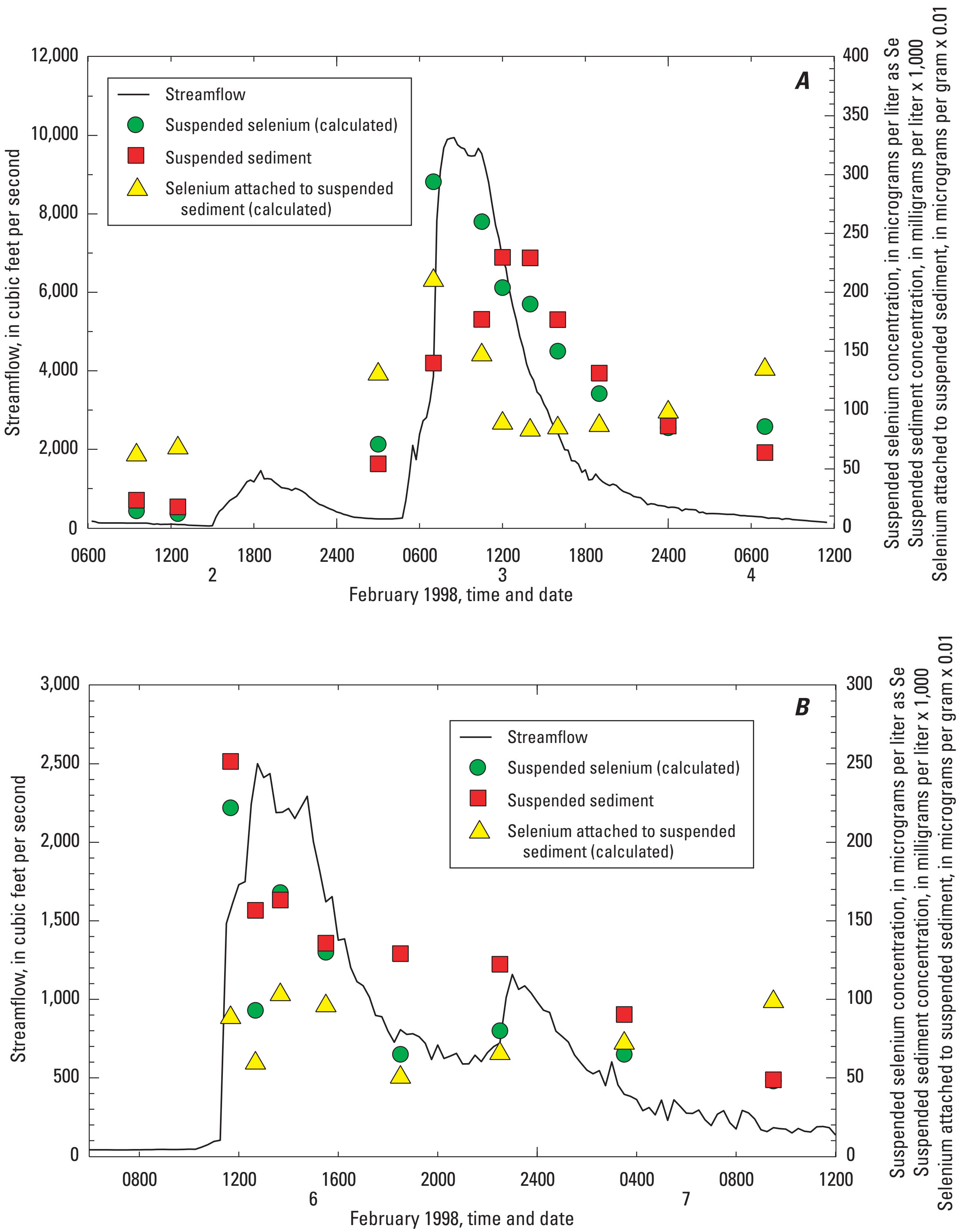
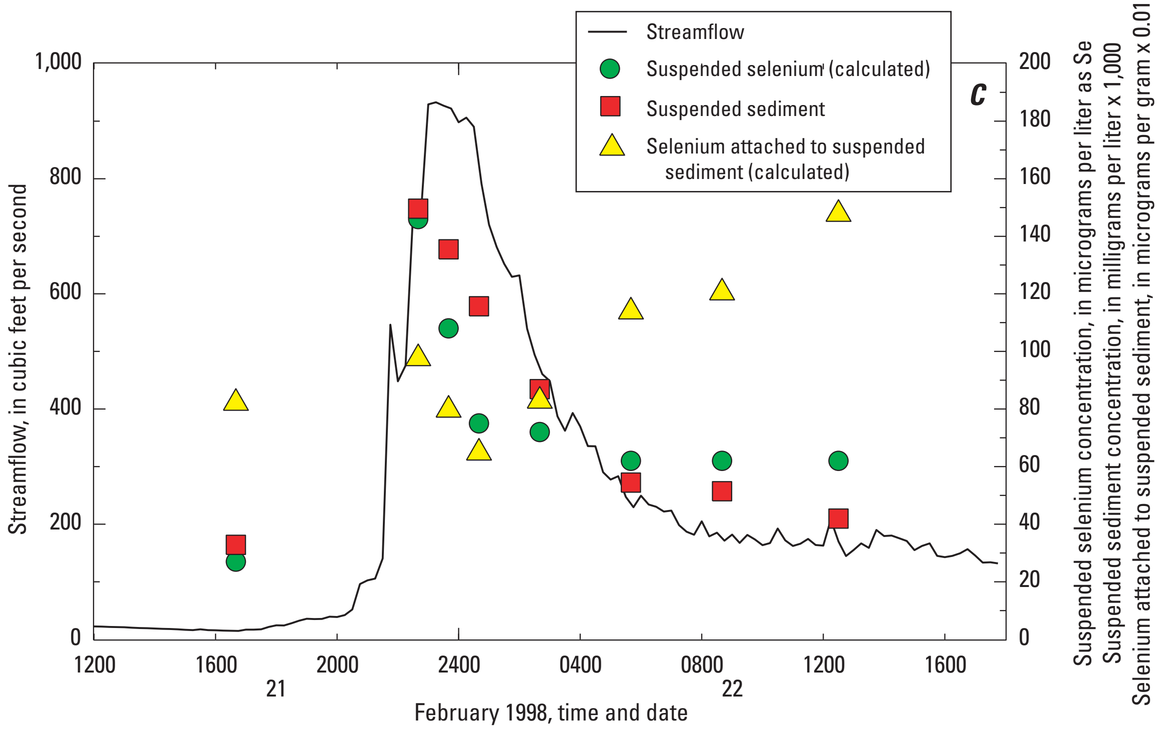


Figure 8. Streamflow, suspended selenium (calculated), suspended sediment, and selenium attached to suspended sediment (calculated) in Panoche Creek, California, for February 1998 storms.

A. February 2–4.
B. February 6 and 7.
C. February 21 and 22.
D. February 23 and 24.



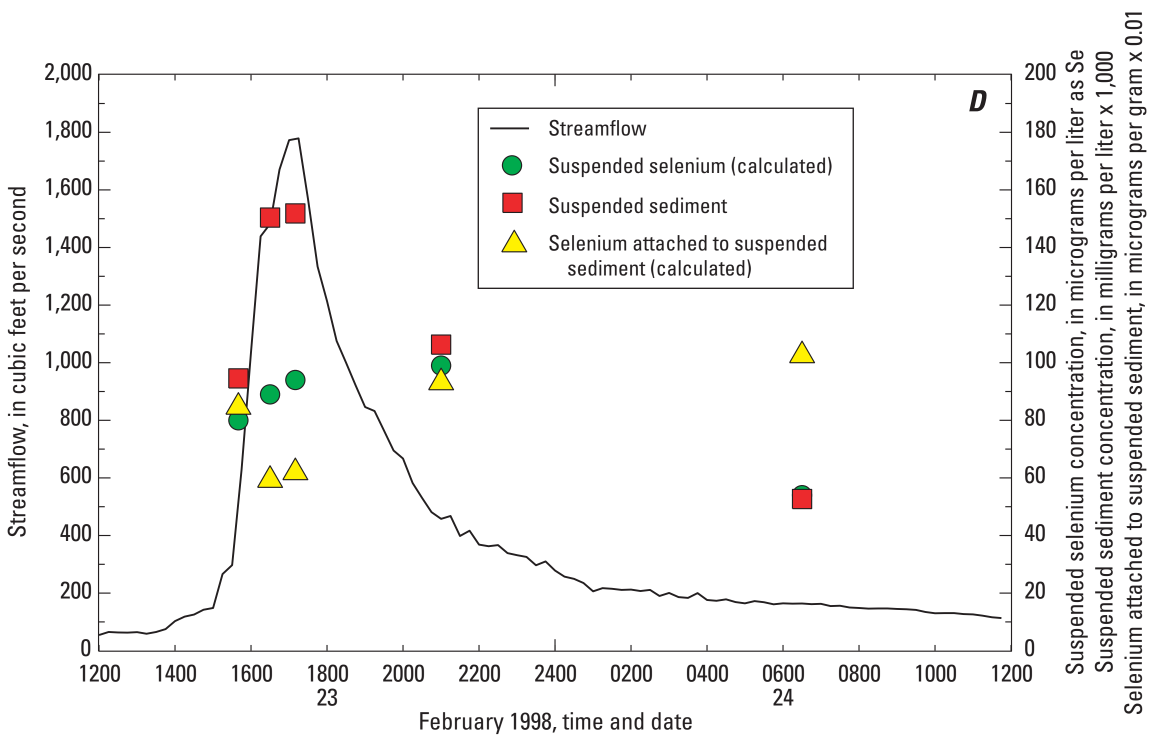


Figure 8. *Continued.*

conductance (fig. 9*G*) were substantially improved. Nonsignificant regressions ($p > 0.05$) became significant ($p < 0.05$) for specific conductance versus log streamflow (fig. 9*A*) and selenium attached to suspended sediment (calculated) versus specific conductance (fig. 9*G*). The goodness of fit (R^2) was substantially improved for dissolved selenium versus specific conductance (fig. 9*B*). No significant regressions became nonsignificant by separating data for storms 2–4 from all storm data. Although still significant, the goodness of fit was substantially worse for log suspended selenium (calculated) versus log streamflow (fig. 9*E*), total selenium versus log streamflow (fig. 9*F*), suspended selenium (calculated) versus suspended sediment (fig. 9*I*), and total selenium versus suspended sediment (fig. 9*J*).

The relations of log suspended sediment to log streamflow (fig. 9*H*), dissolved selenium to specific conductance (fig. 9*B*), dissolved selenium to log streamflow (fig. 9*D*), and total selenium to log streamflow (fig. 9*F*) are the basis for load predictions discussed in the next section. These relations are

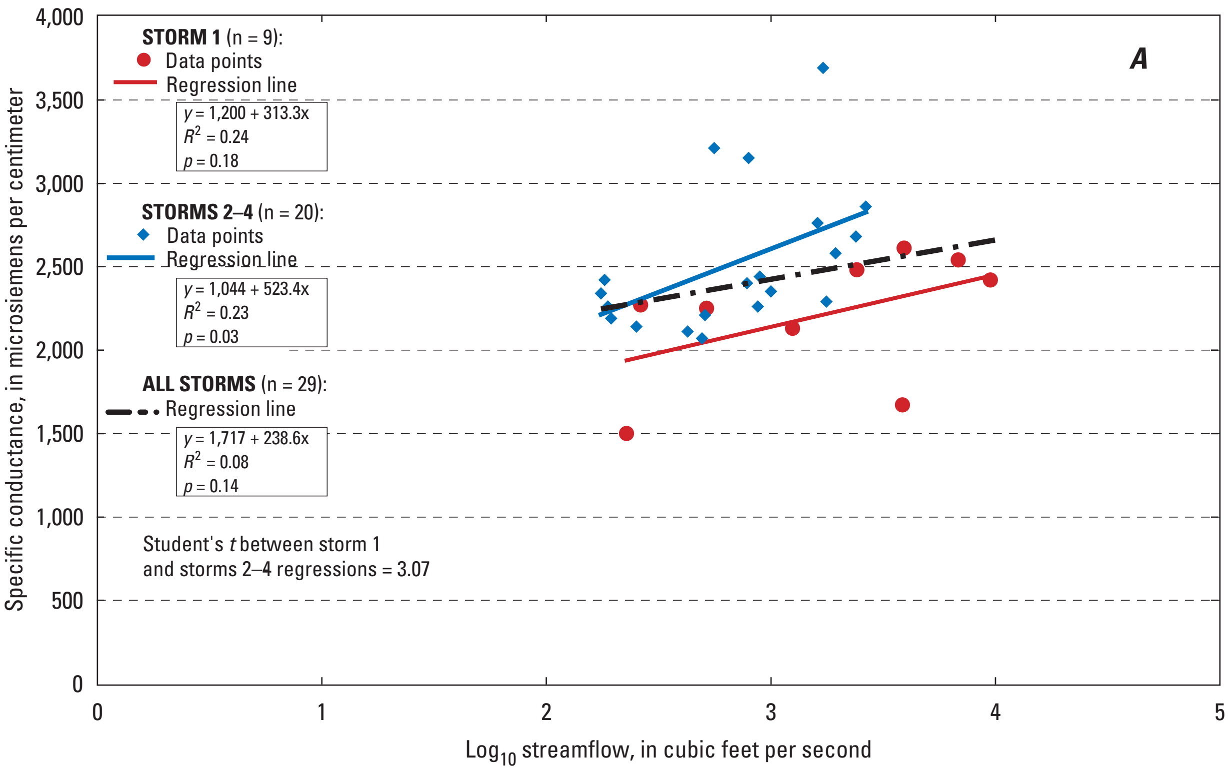
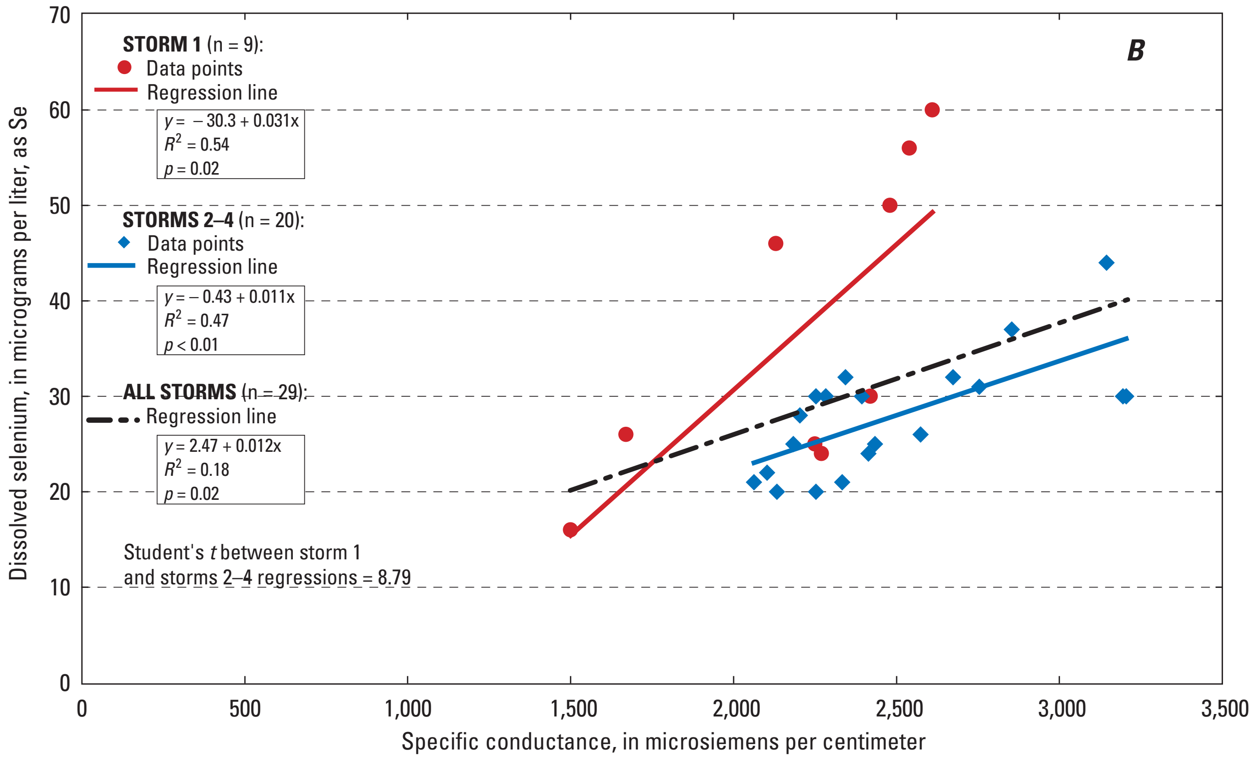


Figure 9. Correlations between water quality constituents and streamflow in Panoche Creek, California, for February 1998 storm data.
A. Specific conductance versus $\log_{10}$ streamflow.
B. Dissolved selenium versus specific conductance.
C. Total selenium versus specific conductance.
D. Dissolved selenium versus $\log_{10}$ streamflow.
E. Log_{10} suspended selenium (calculated) versus $\log_{10}$ streamflow.
F. Total selenium versus $\log_{10}$ streamflow.
G. Selenium attached to suspended sediment (calculated) versus $\log_{10}$ streamflow.
H. Log_{10} suspended sediment versus $\log_{10}$ streamflow.
I. Suspended selenium (calculated) versus suspended sediment.
J. Total selenium versus suspended sediment.
K. Suspended sediment sieve diameter percent finer than 0.062 millimeter versus $\log_{10}$ streamflow.



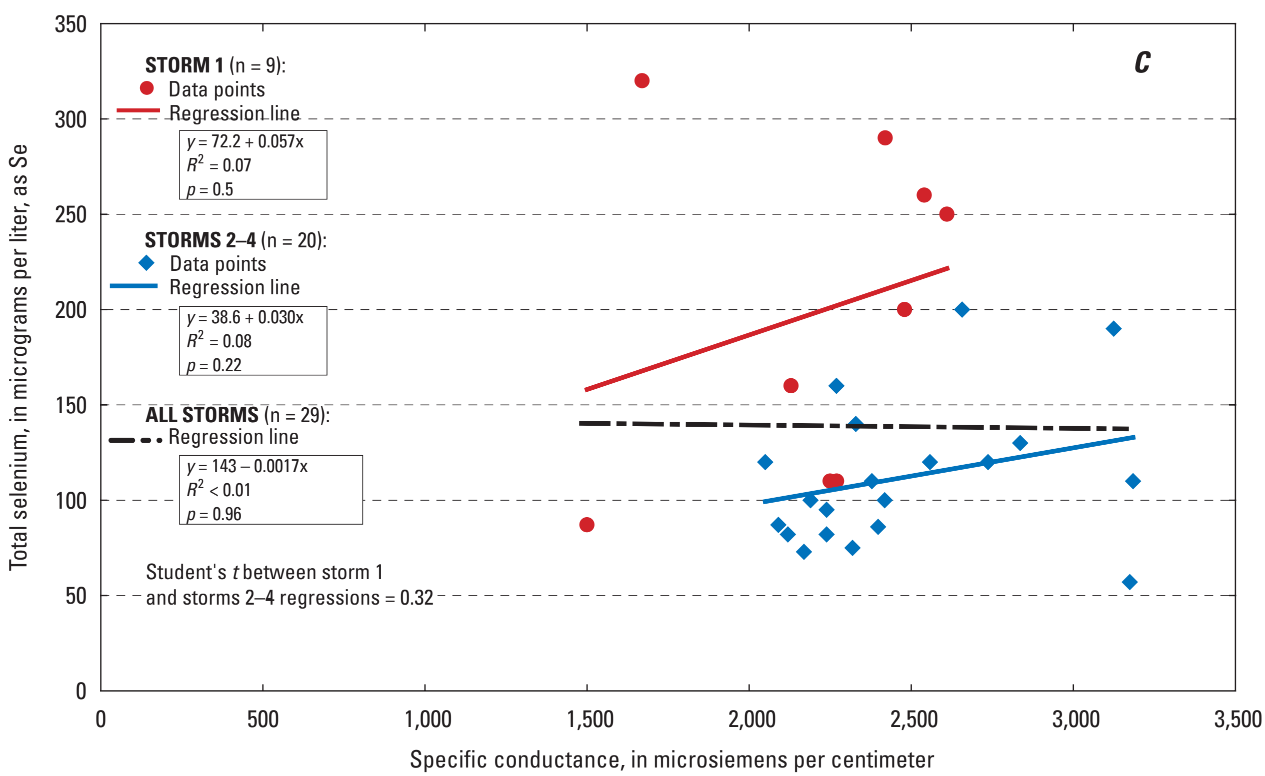
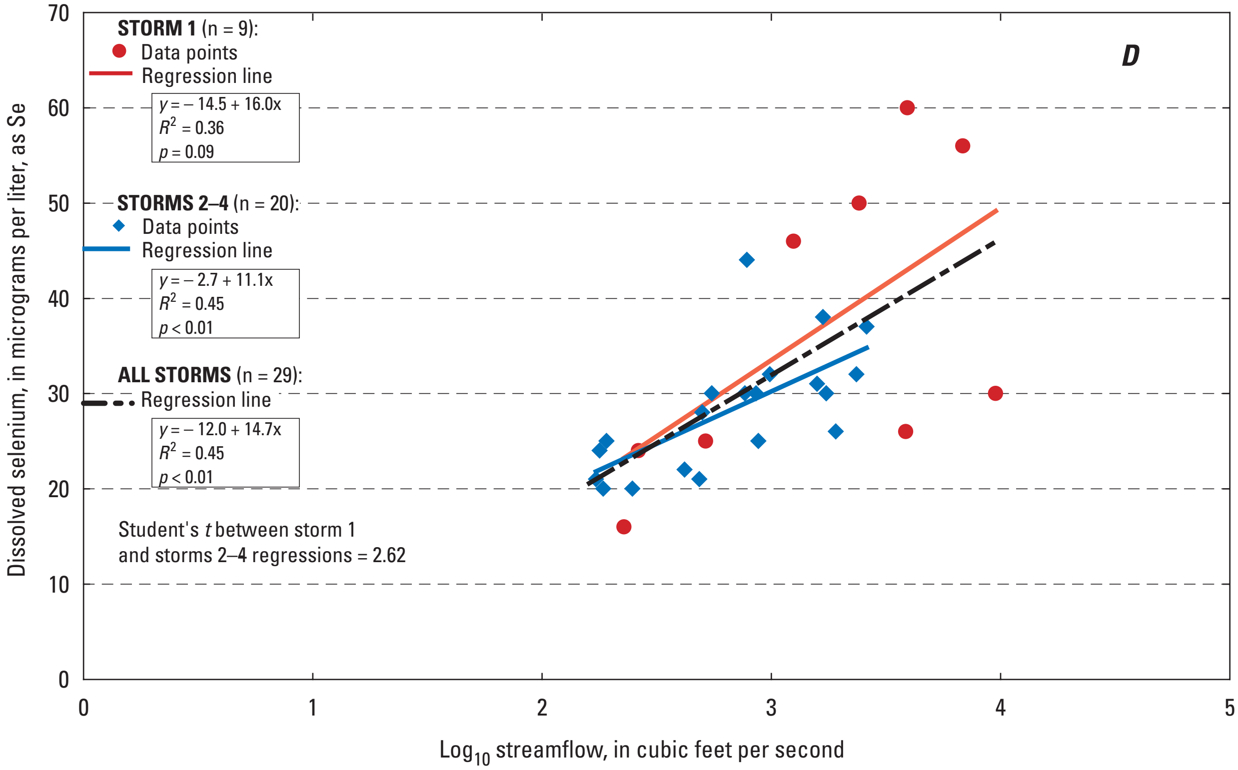


Figure 9. *Continued.*



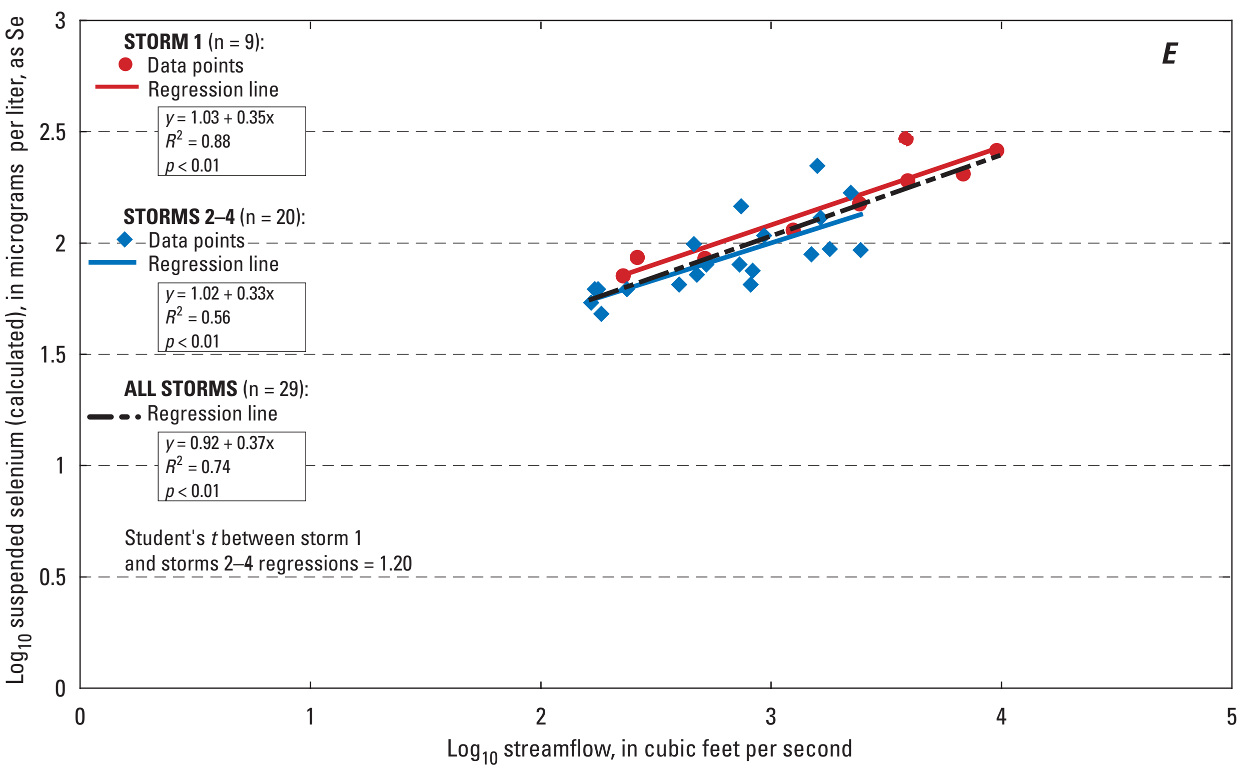


Figure 9. *Continued.*

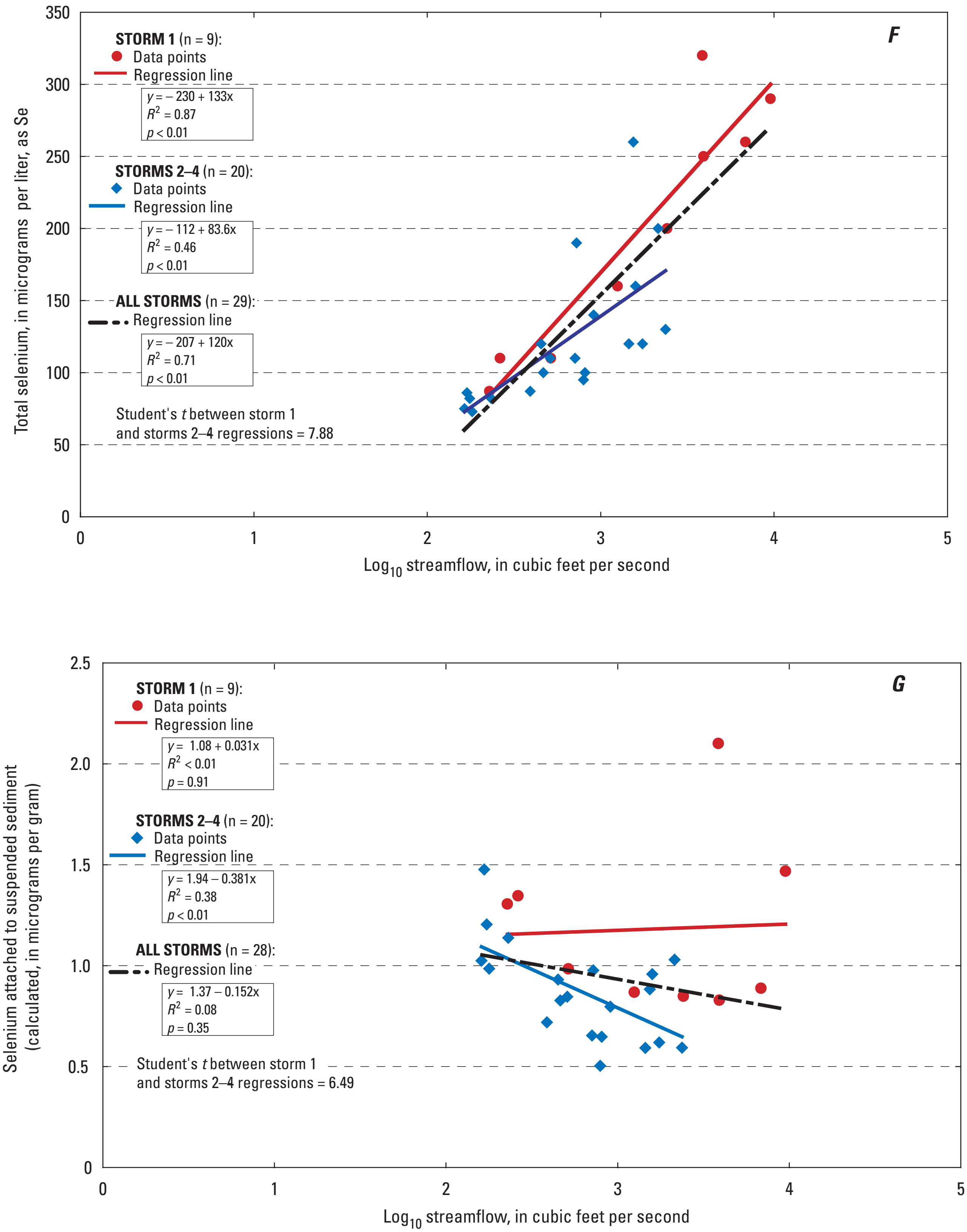
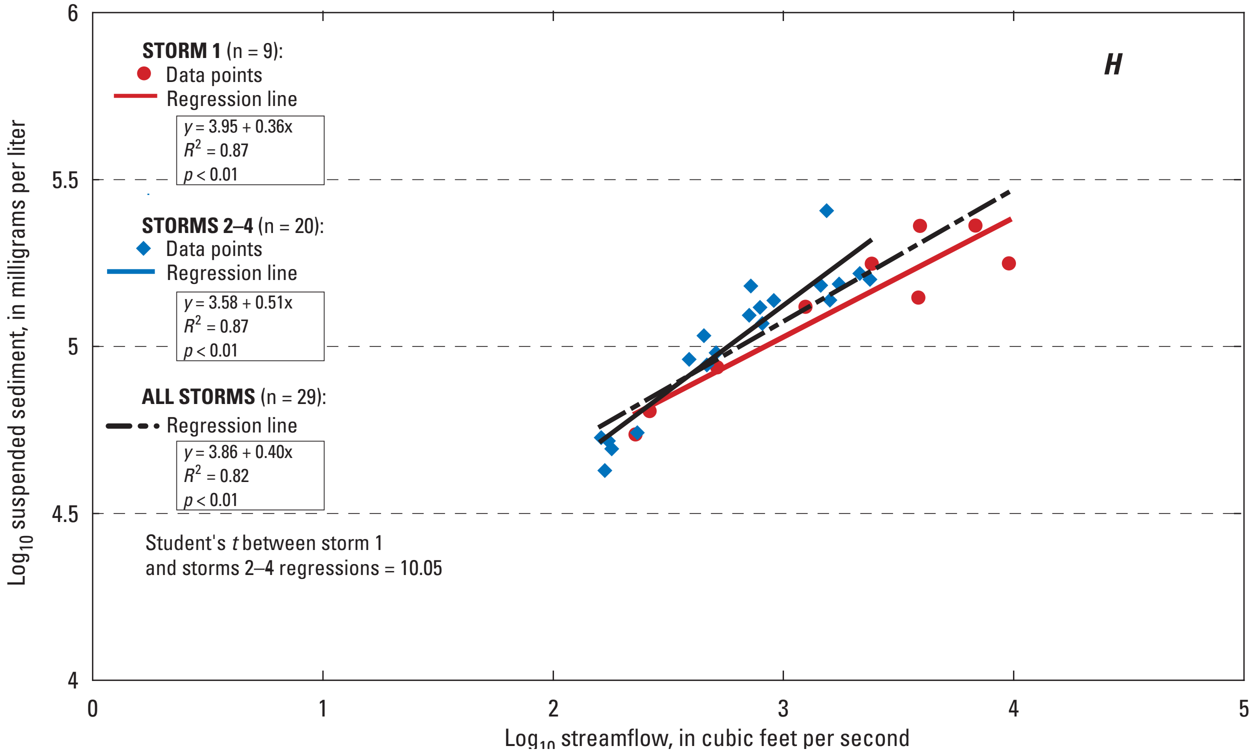


Figure 9. *Continued.*



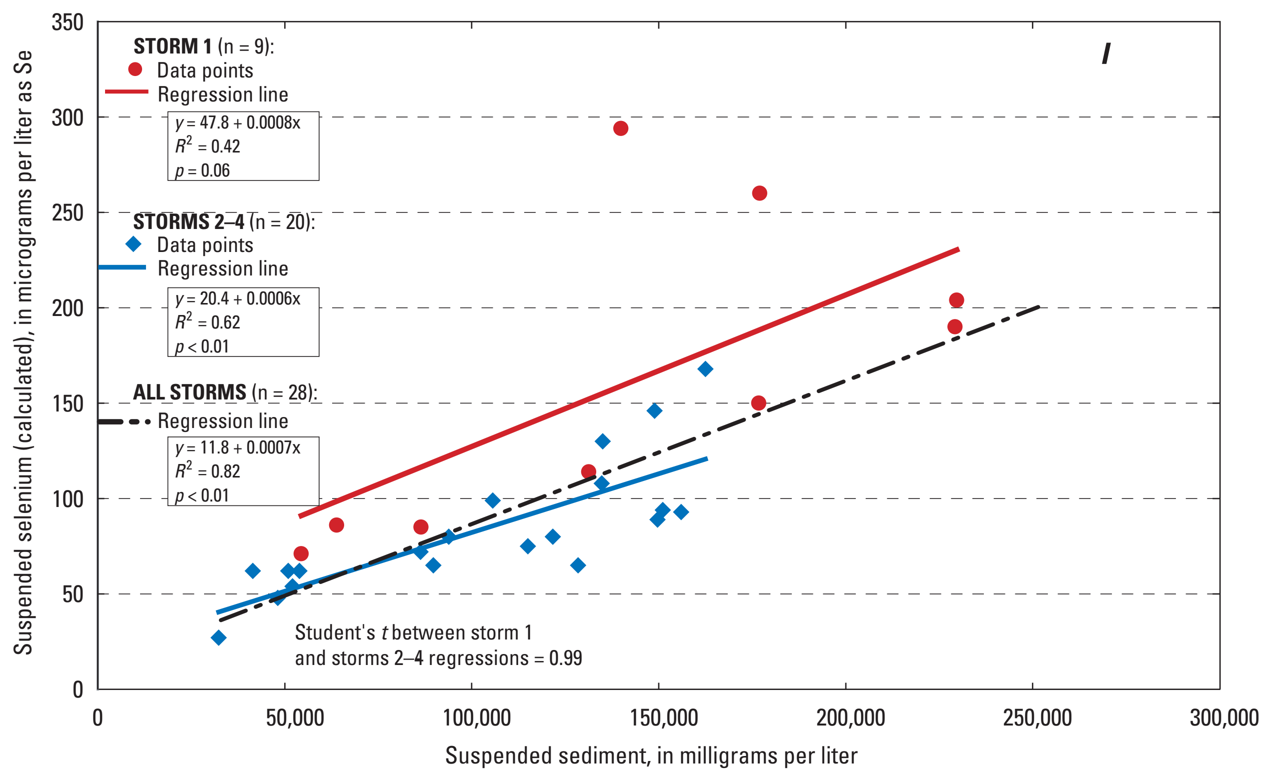
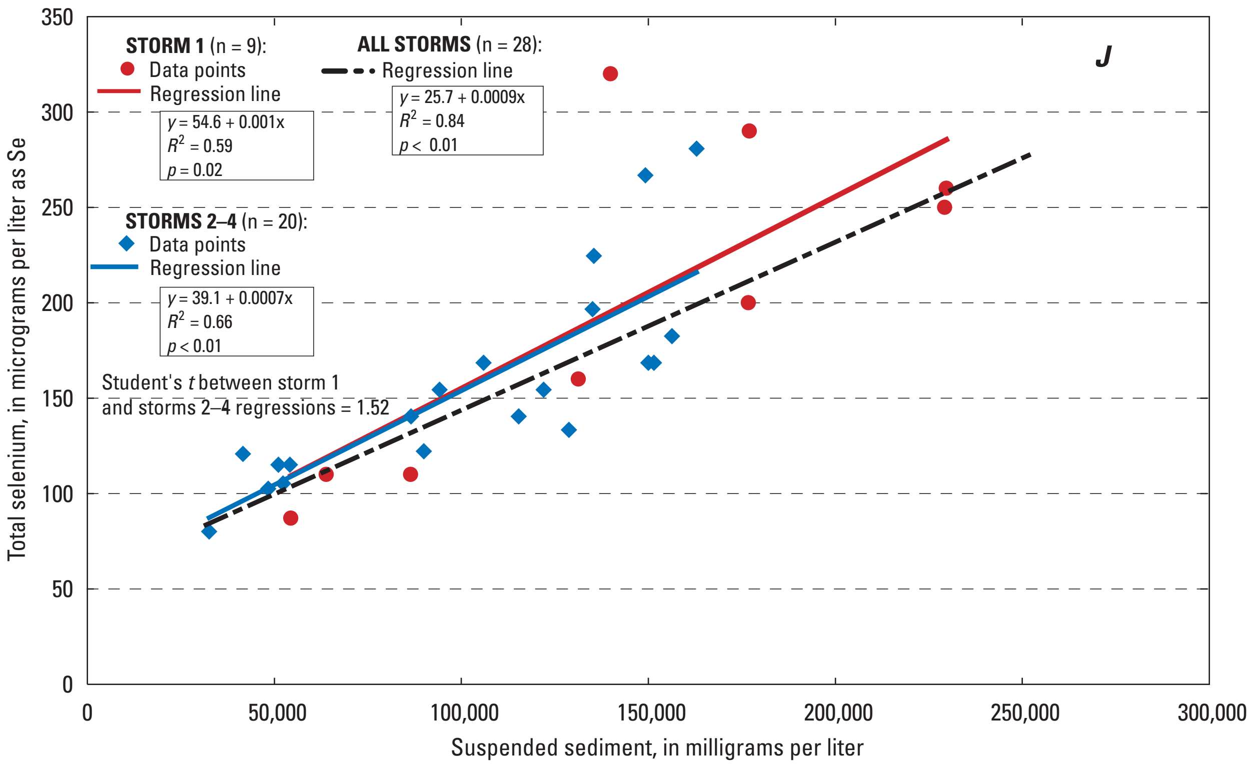


Figure 9. *Continued.*



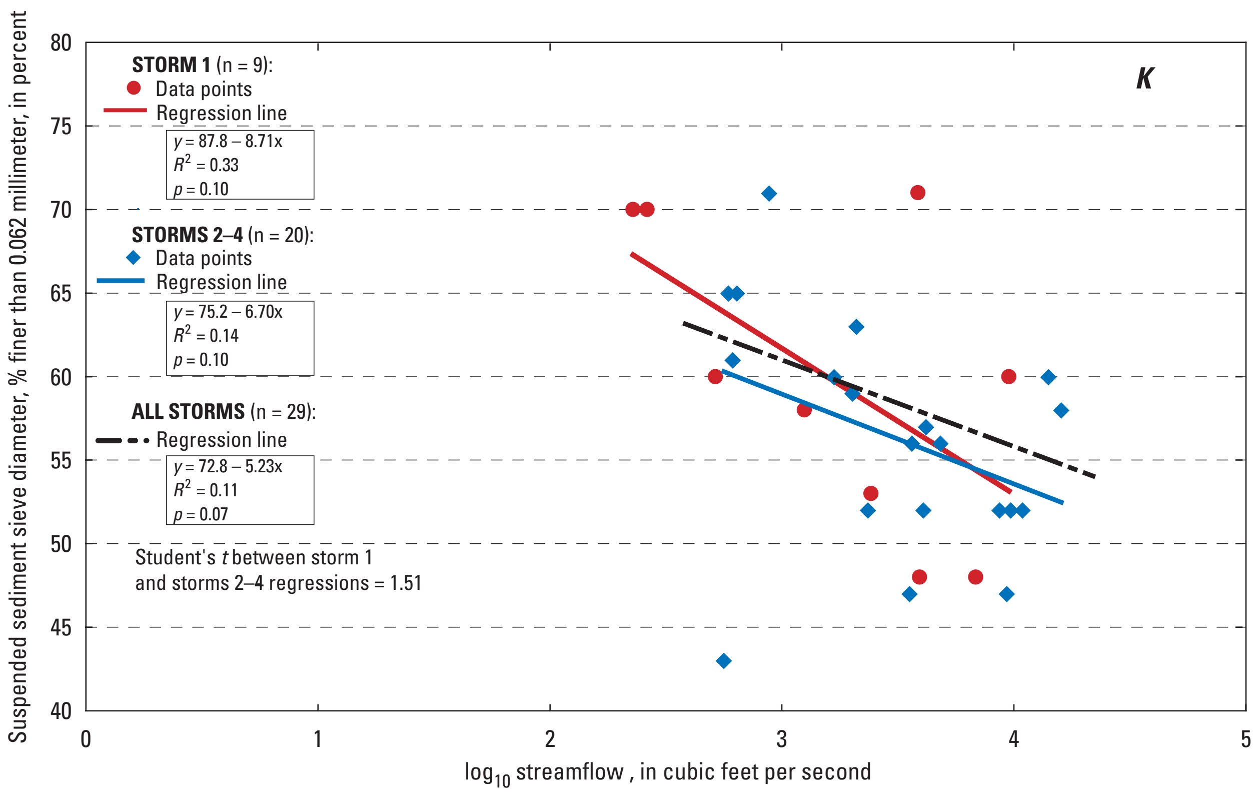


Figure 9. *Continued.*

Table 3. Summary of regressions between water quality constituents

[Storm data (column 3): storm 1, data for 2/3–4, 1998; storm 2, data for 2/6–7, 1998; storm 3, data for 2/21–22, 1998; storm 4, data for 2/23–24, 1998. Cells highlighted in yellow are significantly different at 95-percent confidence level (that is, $t_{\alpha/2,\, n_1 + n_2 - 4}$ >2.06 [for α = 0.05, n_1 = 9, n_2 = 20]). Cells highlighted in green are regression equations and are basis for load predictions. *n*, number of samples; —, not applicable; NA, cannot be calculated for multiple linear regression. *p*, number of coefficients in regression model; R^2, correlation coefficient; Student's *t*, test statistic. mm, millimeter; <, less than]

Dependent variable	Fig. 9	All storm data; storm 1 only; or storms 2–4 only	Regression equation	*n*	R^2	*p*	Student's *t* between storm 1 and storms 2–4
Specific conductance	A	All storm data	1,717 + 238.6 ($\log_{10}$ streamflow)	29	0.08	0.14	—
		Storm 1 only	1,200 + 313.3 ($\log_{10}$ streamflow)	9	0.24	0.18	3.07
		Storms 2–4 only	1,044 + 523.4 ($\log_{10}$ streamflow)	20	0.23	0.03	—
Dissolved selenium	B	All storm data	2.47 + 0.012 (specific conductance)	29	0.18	0.02	—
		Storm 1 only	–30.3 + 0.031 (specific conductance)	9	0.54	0.02	8.79
		Storms 2–4 only	–0.43 + 0.011 (specific conductance)	20	0.47	<0.01	—
Total selenium	C	All storm data	143 – 0.0017 (specific conductance)	29	<0.01	0.96	—
		Storm 1 only	72.2 + 0.057 (specific conductance)	9	0.07	0.5	0.32
		Storms 2–4 only	38.6 + 0.030 (specific conductance)	20	0.08	0.22	—
Dissolved selenium	D	All storm data	–12.0 + 14.7 ($\log_{10}$ streamflow)	29	0.45	<0.01	—
		Storm 1 only	–14.5 + 16.0 ($\log_{10}$ streamflow)	9	0.36	0.09	2.62
		Storms 2–4 only	–2.7 + 11.1 ($\log_{10}$ streamflow)	20	0.45	<0.01	—
		All storm data	–21.3 + 10.1 ($\log_{10}$ streamflow) + 0.0095 (specific conductance)	29	0.48	<0.01	—
		Storm 1 only	–43.3 + 8.46 ($\log_{10}$ streamflow) + 0.024 (specific conductance)	9	0.61	0.06	NA
		Storms 2–4 only	–9.1 + 4.59 ($\log_{10}$ streamflow) + 0.0098 (specific conductance)	20	0.67	<0.01	—
$\log_{10}$ (suspended selenium)	E	All storm data	0.92 + 0.37 ($\log_{10}$ streamflow)	29	0.74	<0.01	—
		Storm 1 only	1.03 + 0.35 ($\log_{10}$ streamflow)	9	0.88	<0.01	1.20
		Storms 2–4 only	1.02 + 0.33 ($\log_{10}$ streamflow)	20	0.56	<0.01	—
Total selenium	F	All storm data	–207 + 120 ($\log_{10}$ streamflow)	29	0.71	<0.01	—
		Storm 1 only	–230 + 133 ($\log_{10}$ streamflow)	9	0.87	<0.01	7.88
		Storms 2–4 only	–112 + 83.6 ($\log_{10}$ streamflow)	20	0.46	<0.01	—
Suspended selenium/ suspended sediment	G	All storm data	1.37 – 0.152 ($\log_{10}$ streamflow)	28	0.08	0.35	—
		Storm 1 only	1.08 + 0.031 ($\log_{10}$ streamflow)	9	<0.01	0.91	6.49
		Storms 2–4 only	1.94 – 0.381 ($\log_{10}$ streamflow)	20	0.38	<0.01	—

Table 3. Summary of regressions between water quality constituents—*Continued*

Dependent variable	Fig. 9	All storm data; storm 1 only; or storms 2–4 only	Regression equation	*n*	R^2	*p*	Student's *t* between storm 1 and storms 2–4
Log_{10} (suspended sediment)	H	All storm data	3.86 + 0.40 (log_{10} streamflow)	29	0.82	<0.01	—
		Storm 1 only	3.95 + 0.36 (log_{10} streamflow)	9	0.87	<0.01	10.05
		Storms 2–4 only	3.58 + 0.51(log_{10} streamflow)	20	0.87	<0.01	—
Suspended selenium	I	All storm data	11.8 + 0.0007 (suspended sediment)	28	0.82	<0.01	—
		Storm 1 only	47.8 + 0.0008 (suspended sediment)	9	0.42	0.06	0.99
		Storms 2–4 only	20.4 + 0.0006 (suspended sediment)	20	0.62	<0.01	—
Total selenium	J	All storm data	25.7 + 0.0009 (suspended sediment)	28	0.84	<0.01	—
		Storm 1 only	54.6 + 0.001 (suspended sediment)	9	0.59	0.02	1.52
		Storms 2–4 only	39.1 + 0.0007 (suspended sediment)	20	0.66	<0.01	—
Suspended sediment sieve diameter <0.062 mm	K	All storm data	72.8 – 5.23 (log_{10} streamflow)	29	0.11	0.07	—
		Storm 1 only	87.8 – 8.71(log_{10} streamflow)	9	0.33	0.1	1.51
		Storms 2–4 only	75.2 – 6.70 (log_{10} streamflow)	20	0.14	0.1	—

highlighted in green in table 3. Log suspended sediment is well-correlated with log streamflow (fig. 9*H*). Total selenium is well-correlated with log streamflow (fig. 9*F*) and is not correlated with specific conductance (fig. 9*C*). Dissolved selenium is about as well-correlated with specific conductance as with log streamflow; the correlation is better with specific conductance for storm 1 (figs. 9*B* and 9*D*). Thus, a simple linear regression with log streamflow is sufficient for explaining suspended sediment and total selenium concentrations, while a multiple linear regression with log streamflow and specific conductance was evaluated for explaining dissolved selenium concentrations. For all storm data, the multiple linear regression was not a substantial improvement over the simple linear regression (table 3). The multiple linear regression improved the goodness of fit for storm 1 and storms 2–4, but did not affect the significance of correlation. The multiple linear regression equation for storm 1 was still nonsignificant (table 3).

LOADS

Suspended Sediment

The instantaneous loading rates of suspended sediment at the time of sampling closely follow the storm hydrographs (fig. 10). These instantaneous loading rates are calculated as:

$$\text{Suspended-sediment loading rate (tons/day)} = 0.0027 \text{ (conversion factor)} \times \text{suspended sediment concentration (mg/L)} \times \text{streamflow (ft}^3\text{/s)}$$

Regressions of the logarithm of suspended-sediment loading rate as a function of the logarithm of streamflow are very strong (fig. 11). The regression using all data points from the four storms (minus one outlier) had an R^2 of 0.982, the regression for storm 1 had an R^2 of 0.990, and the regression for storms 2–4 had an R^2 of 0.983 (table 4).

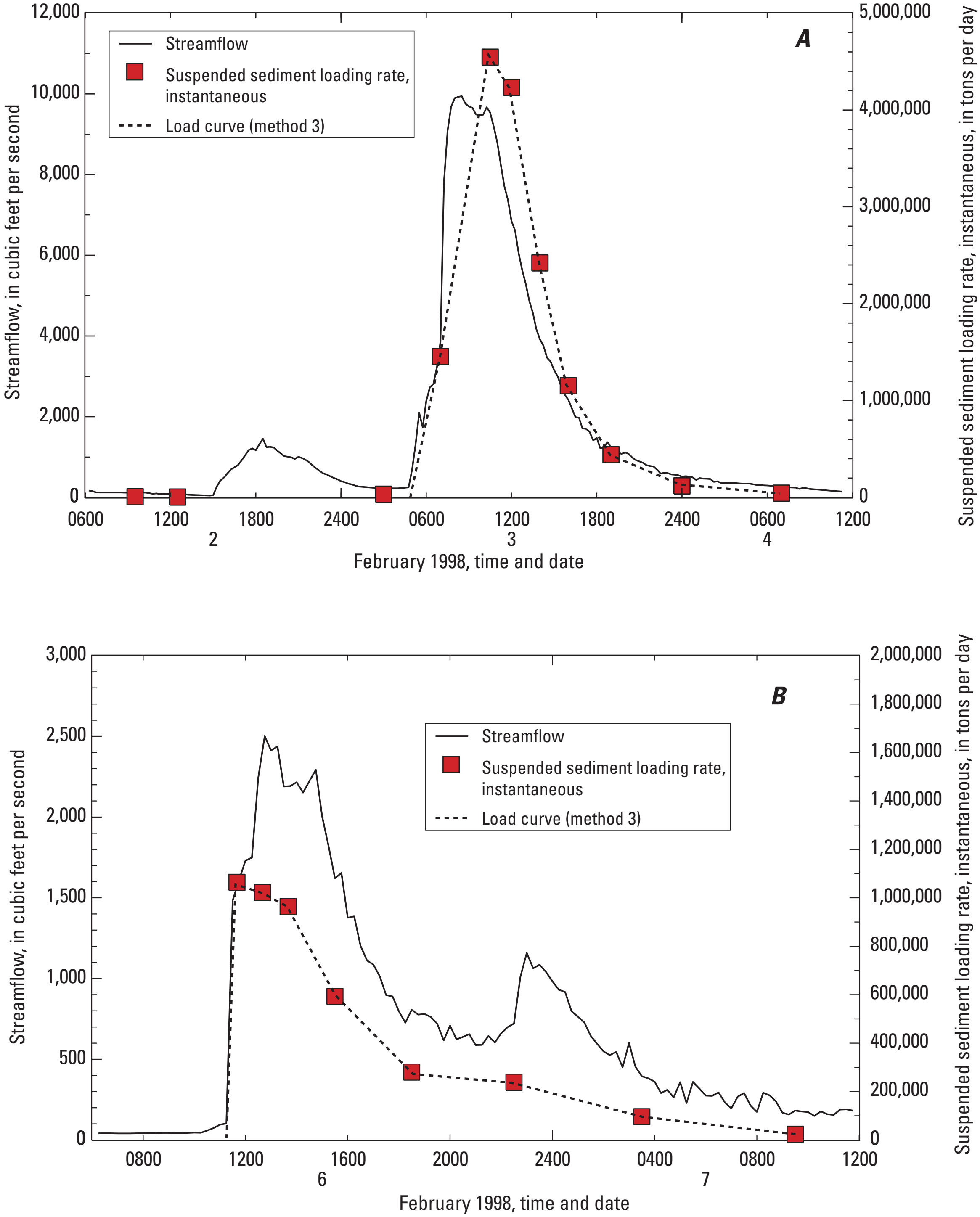
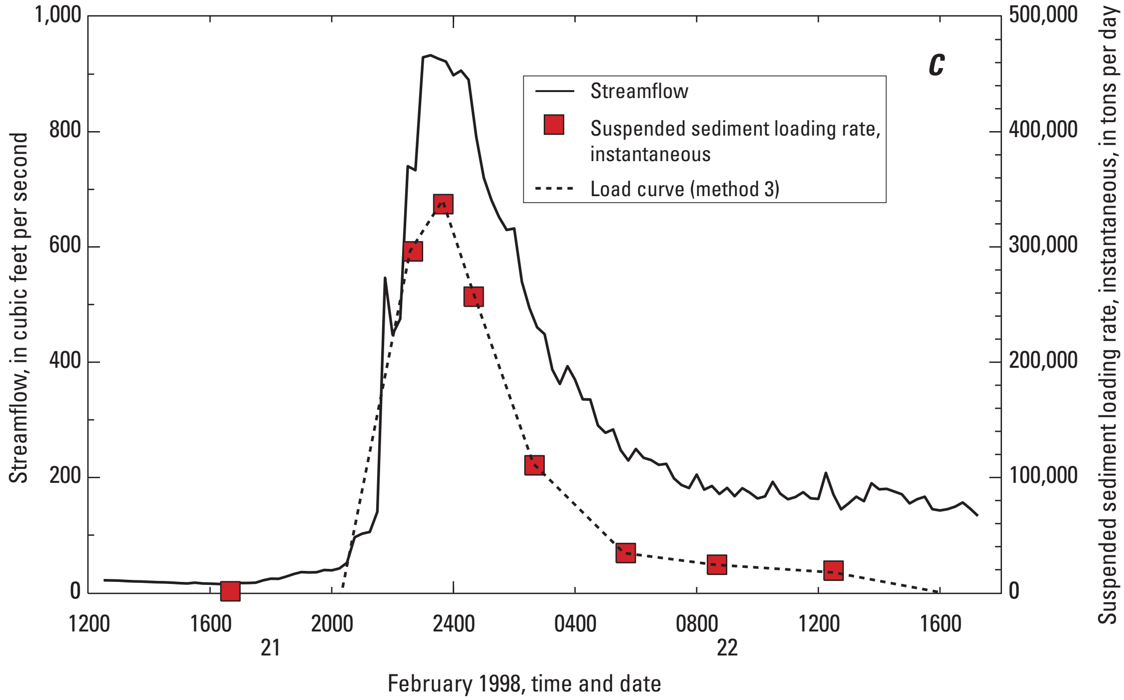


Figure 10. Streamflow and suspended sediment loading rate in Panoche Creek, California, for February 1998 storms.

A. February 2–4.
B. February 6 and 7.
C. February 21 and 22.
D. February 23 and 24.



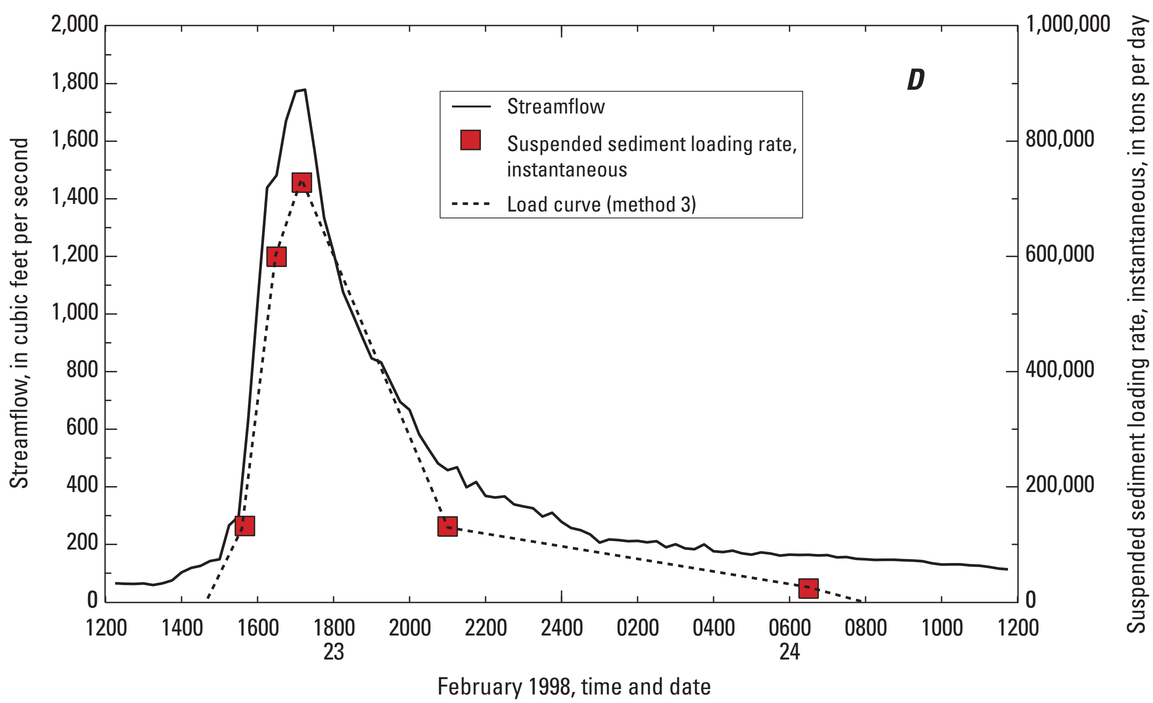


Figure 10. *Continued.*

Suspended-sediment loads for each storm were calculated using three different methods: (1) the regression equation for all data (table 4) with the 15-minute streamflows for the I-5 gage, (2) the regression equations for storm 1 and for storms 2–4 (table 4) with the 15-minute streamflows for the I-5 gage, and (3) connecting instantaneous loads in figures 10*A* through 10*D* and integrating under the curves.

The average suspended-sediment loads calculated using the three methods for the four storms were 1.72, 0.31, 0.06, and 0.11 million tons for a total of 2.21 million tons (table 5). The 26 hours of storm runoff on February 3 and 4 accounted for 78 percent of the total load. The load calculated by method 3 for the first storm was much lower than loads calculated by methods 1 and 2. Because of this, method 3 provided the lowest estimate of total suspended-sediment load overall. The total load estimates of methods 1 and 2 were 42 and 27 percent higher than method 3, respectively. Method 3 is susceptible to considerable errors because of the inadequate sampling frequency, while methods 1 and 2 incorporate a streamflow versus concentration relationship that is applied to 15-minute streamflow data to better describe the loads during the entire storm duration. Because of this and the very strong regressions in methods 1 and 2, these methods are preferable to method 3. Because method 2 incorporates information on the variability between storms, it is probably the preferred method for calculating loads in this circumstance.

Selenium

The instantaneous loading rates of dissolved and total selenium at the time of sampling also closely follow the storm hydrographs (fig. 12). These instantaneous loading rates are calculated as:

$$\text{Selenium loading rate (lb/d)} = 0.0054 \text{ (conversion factor)} \times \text{selenium concentration } (\mu g/L) \times \text{streamflow } (ft^3/s)$$

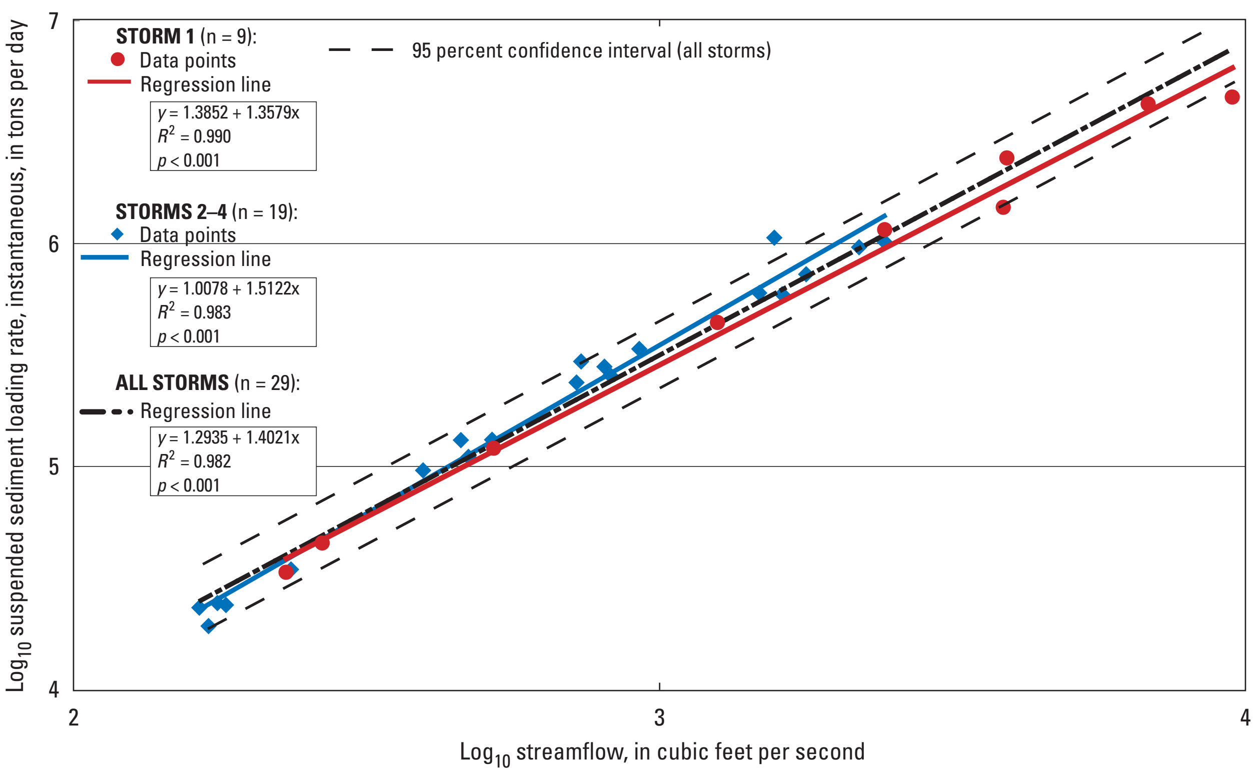


Figure 11. Regressions for suspended sediment loading rate as a function of streamflow in Panoche Creek, California.

Table 4. Summary of regressions for calculating loading rates of suspended sediment, dissolved selenium, and total selenium

[Storm data (column 3): storm 1, data for 2/3–4, 1998; storm 2, data for 2/6–7, 1998; storm 3, data for 2/21–22, 1998; storm 4, data for 2/23–24, 1998. *n*, number of samples; *p*, number of coefficients in regression model; R^2, correlation coefficient; student's *t*, test statistic. <, less than]

Dependent variable	Figure	All storm data; storm 1 only; or storms 2–4 only	Regression equation	*n*	R^2	*p*
Log_{10} (suspended sediment loading rate)	11	All storm data	1.2935 + 1.4021 (log_{10} streamflow)	29	0.982	<0.001
		Storm 1 only	1.3852 + 1.3579 (log_{10} streamflow)	9	0.990	<0.001
		Storms 2–4 only	1.0078 + 1.5122(log_{10} streamflow)	19	0.983	<0.001
Log_{10} (dissolved selenium loading rate)	13	All storm data	–1.3708 + 1.1951 (log_{10} streamflow)	29	0.973	<0.001
		Storm 1 only	–1.4195 + 1.2117 (log_{10} streamflow)	9	0.959	<0.001
		Storms 2–4 only	–1.3198 + 1.1758 (log_{10} streamflow)	20	0.978	<0.001
		All storm data	–1.5768 + 1.1699 (log_{10} streamflow) + 0.0001 (specific conductance)	29	0.979	<0.001
		Storm 1 only	–1.7978 + 1.1180 (log_{10} streamflow) + 0.0003 (specific conductance)	9	0.978	<0.001
		Storms 2–4 only	–1.4405 + 1.1078 (log_{10} streamflow) + 0.0001 (specific conductance)	20	0.988	<0.001
Log_{10} (total selenium loading rate)	14	All storm data	–1.1366 + 1.3374 (log_{10} streamflow)	29	0.982	<0.001
		Storm 1 only	–1.0797 + 1.3317 (log_{10} streamflow)	9	0.995	<0.001
		Storms 2–4 only	–1.0301 + 1.2932 (log_{10} streamflow)	20	0.965	<0.001

Table 5. Loads of suspended sediment, dissolved selenium, and total selenium calculated by three different methods

[Method 1: simple linear regression of load as a function of streamflow using data from all storms. Method 2: simple linear regression of load as a function of streamflow using data from storm 1 and storms 2–4. Method 3: load determined from digitized area under curve for each specific storm]

	Storm 1	Storm 2	Storm 3	Storm 4	Total
Suspended sediment load (tons)					
Method 1	2,106,089	292,392	56,993	99,286	2,554,760
Method 2	1,765,694	334,937	66,127	108,620	2,275,379
Method 3	1,299,697	293,782	69,028	130,456	1,792,963
Average	1,723,827	307,037	64,049	112,787	2,207,701
Dissolved selenium load (pounds)					
Method 1	749	134	39	53	975
Method 2	774	141	39	53	1,007
Method 3	562	125	37	48	773
Average	695	134	38	51	918
Total selenium load (pounds)					
Method 1	4,438	683	159	243	5,523
Method 2	4,813	636	155	226	5,830
Method 3	3,904	600	163	243	4,909
Average	4,385	639	159	237	5,421

Regressions of the logarithm of selenium loading rate (dissolved and total) as a function of the logarithm of streamflow are very strong (figs. 13 and 14). The regression for dissolved selenium using all data points from the four storms had an R^2 of 0.973, the regression for storm 1 had an R^2 of 0.959, and the regression for storms 2–4 had an R^2 of 0.978 (table 4). For total selenium, the regression using all data points had an R^2 of 0.982, the regression for storm 1 had an R^2 of 0.995, and the regression for storms 2–4 had an R^2 value of 0.965 (table 4).

Selenium loads for each storm were calculated using the three different methods discussed for suspended-sediment loads: the average dissolved selenium load for the four storms were 695, 134, 38, and 51 lb for a total of 918 lb (table 5). The first storm accounted for 76 percent of this dissolved selenium load. As for suspended-sediment loads, method 3 gave the lowest estimate overall because of a much lower load for the first storm. The total load estimates of methods 1 and 2 were 26 and 30 percent higher than method 3, respectively. Again, method 2, using the storm-specific regressions, is the preferred method.

Dissolved selenium concentrations were better predicted using storm-specific multiple linear regressions versus storm-specific simple linear regressions (table 3). Thus, a multiple linear regression also was evaluated for dissolved selenium loading rates as a function of log streamflow and specific conductance also. There was only a slight improvement in the fit over the simple linear regression (table 4). However, loading rates cannot presently be calculated with this equation because there is no continuous specific conductance recorder at the site. If a recorder were installed at the site in the future, a slight improvement in predictions of dissolved selenium loading rates might be realized.

The average total selenium load calculated by the three methods for the four storms were 4,385, 639, 159, and 237 lb for a total of 5,421 lb (table 5). The first

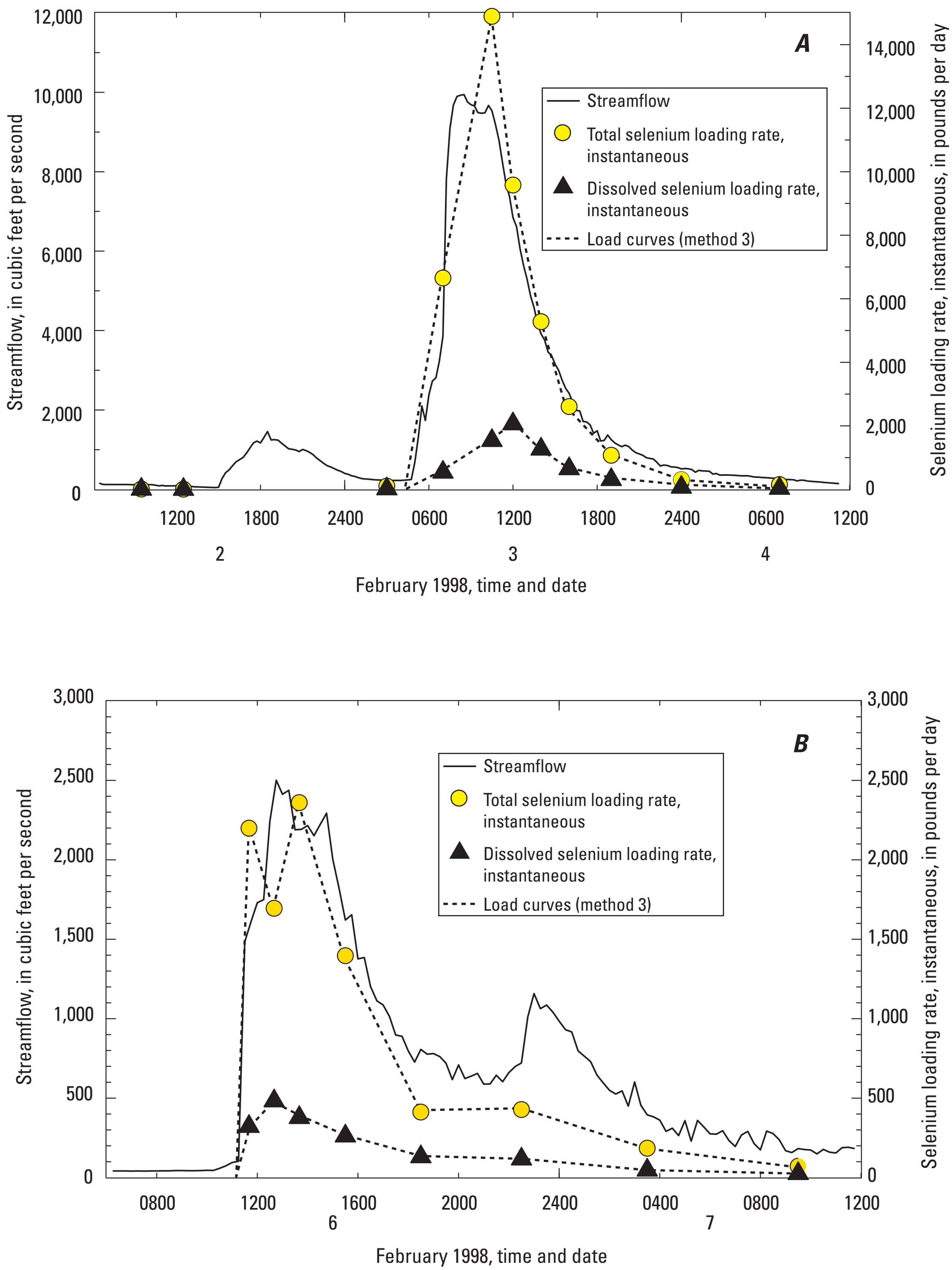


Figure 12. Streamflow and selenium loading rate in Panoche Creek, California, for February 1998 storms.

A. February 2–4.
B. February 6 and 7.
C. February 21 and 22.
D. February 23 and 24.

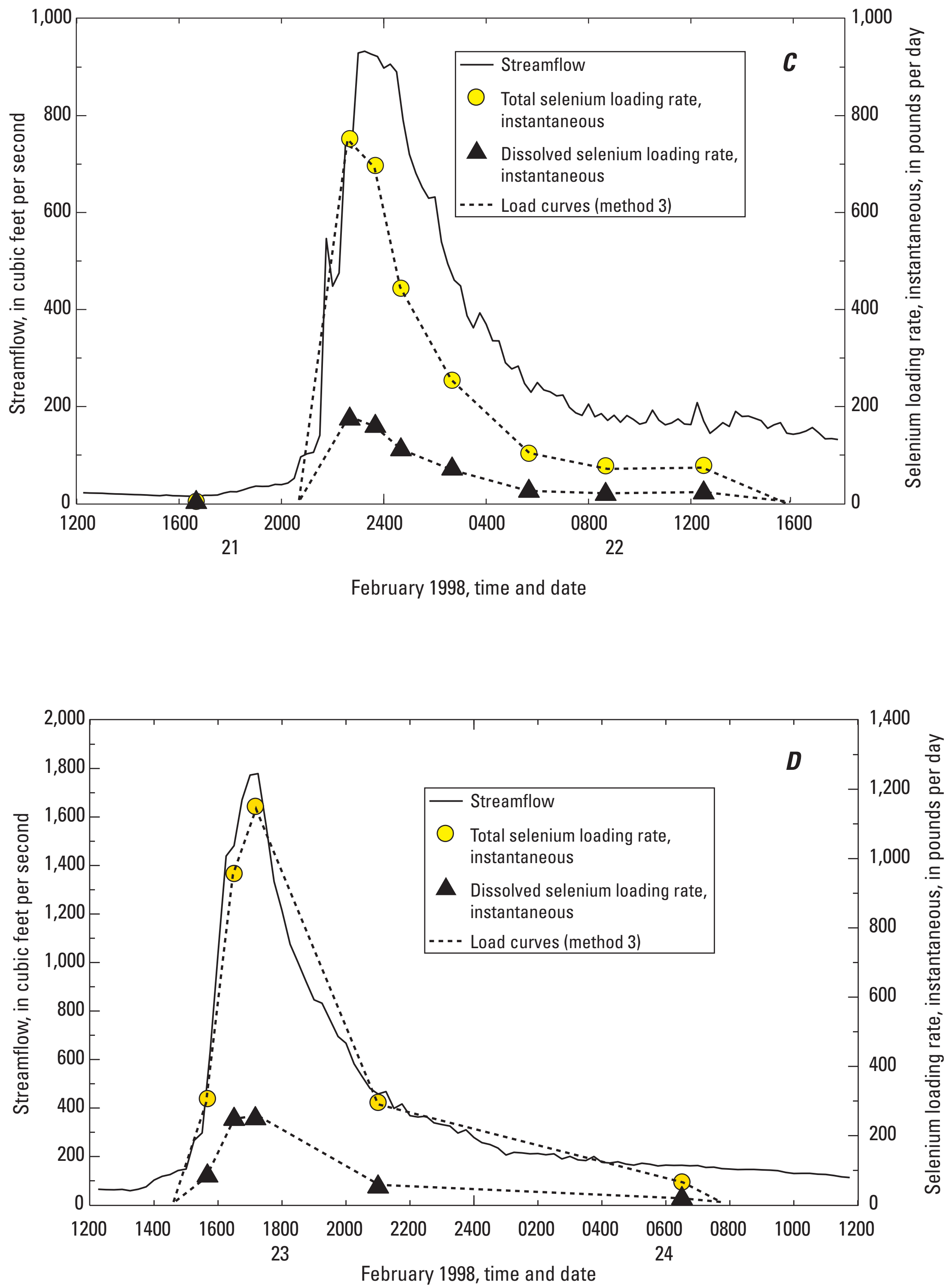


Figure 12. *Continued.*

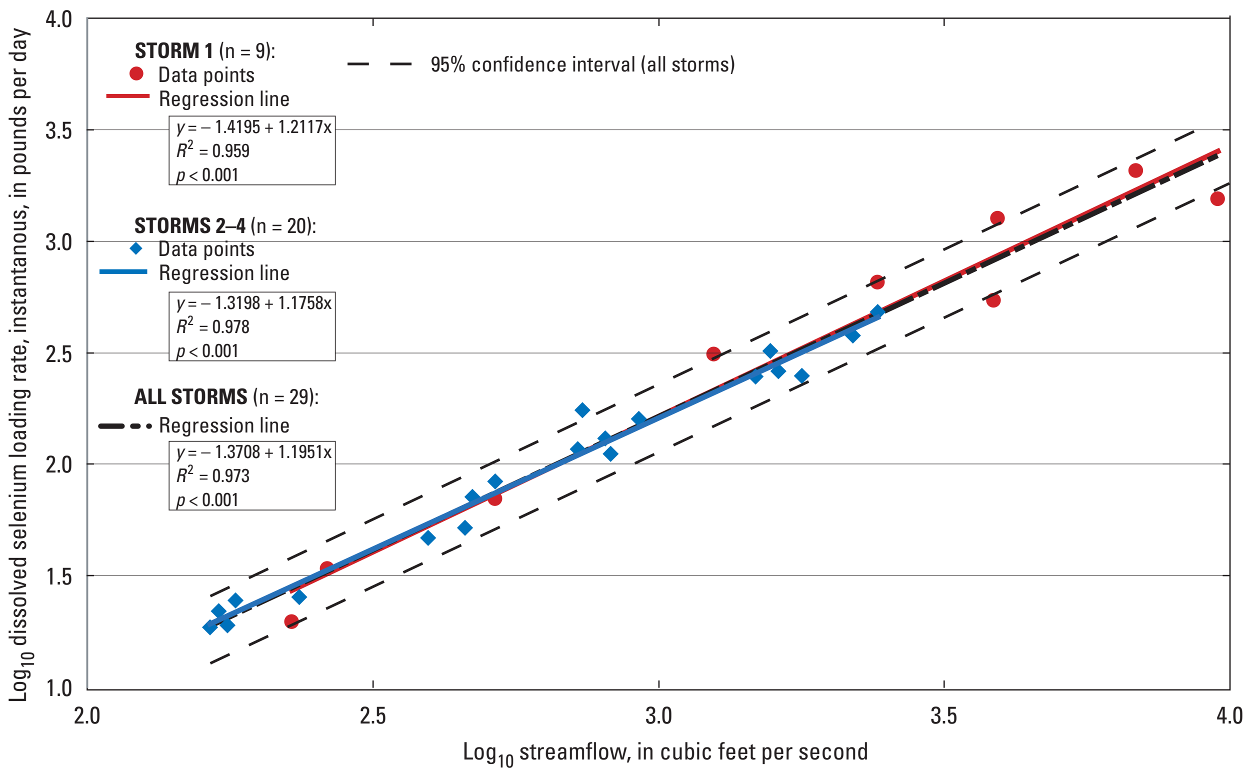


Figure 13. Regressions for dissolved selenium loading rate as a function of streamflow in Panoche Creek, California.

storm accounted for 81 percent of this total selenium load. As for suspended-sediment and dissolved selenium loads, method 3 gave the lowest estimate overall because of a much lower load for the first storm. The total load estimates of methods 1 and 2 were 12 and 19 percent higher than method 3, respectively. Again, method 2, using the storm-specific regressions, is the preferred method. Because suspended selenium was calculated as the difference between total selenium and dissolved selenium, the average suspended selenium load would be 4,503 lb, or 83 percent of the total selenium load.

Load Prediction Methods

Although method 2 is preferred for estimating storm loads after the fact, at this time, method 1 is probably a better prediction tool for estimating loads in future storms. The regression equation used in method 1 incorporates the variability in data from four storms and is likely to be more representative of future storms. All of the regression equations would be greatly enhanced by the addition of more storm data from different years. However, this data is sparse because many years do not have significant storm runoff and the rising limbs of the storm hydrographs are very short-lived. More data showing differences in concentrations between the rising and falling limbs of the storm hydrograph would be especially useful. The data from the February 1998 storms was mixed with respect to this issue and, thus, separation of rising and falling limbs of hydrographs was not incorporated into the prediction equations presented here. In general, most concentrations were greater on the rising limb, but there were enough exceptions to make splitting the regressions problematic. With additional data, it probably would be possible to come up with separate regressions for the rising and falling limbs. Also, storm 1 in February 1998 was extremely unusual, and having more storm data from other years and flow conditions, would help to refine the prediction regressions.

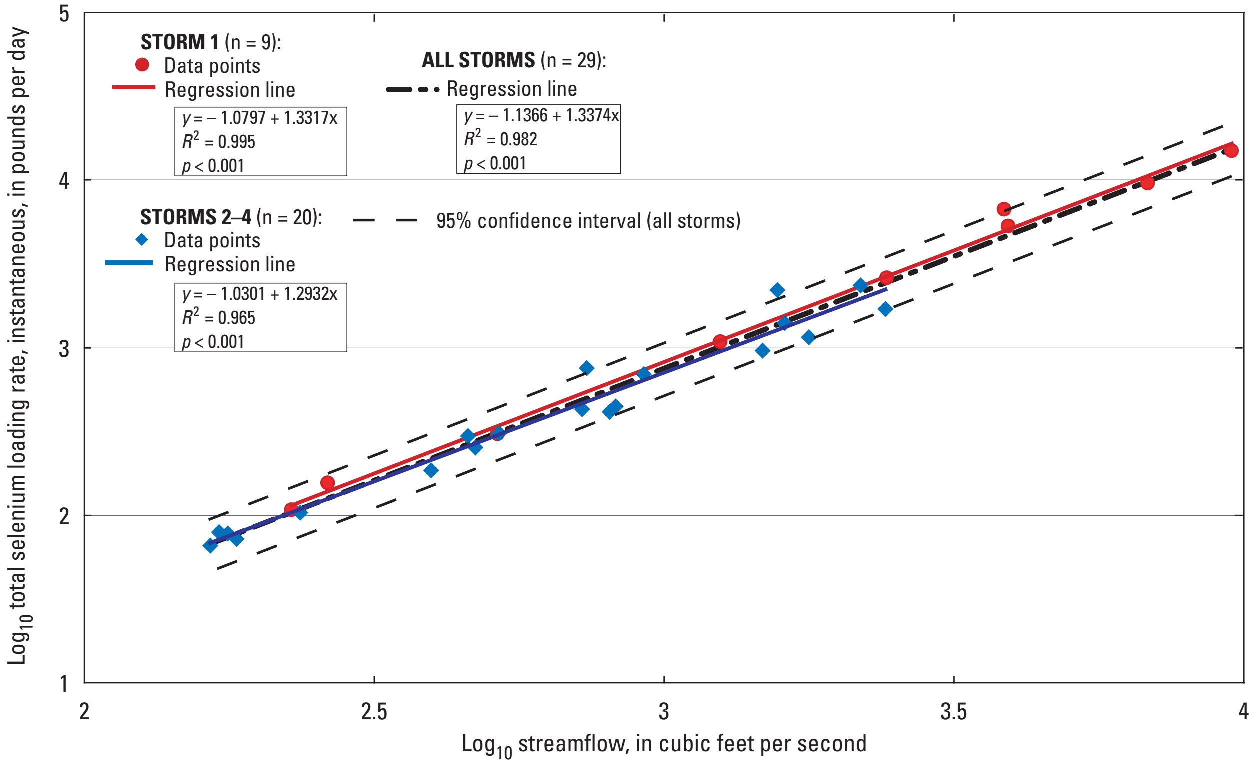


Figure 14. Regressions for total selenium loading rate as a function of streamflow in Panoche Creek, California.**Figure 13.**Regressions for dissolved selenium loading rate as a function of streamflow in Panoche Creek, California.

The suspended-sediment load calculated by method 1 was 12 percent higher than the load calculated by method 2. The loads calculated by method 1 were 3 and 5 percent lower than the loads calculated by method 2 for dissolved selenium and total selenium, respectively. The proposed loading rate prediction equations (from method 1) for suspended sediment, dissolved selenium, and total selenium in Panoche Creek at I-5 are:

$$\log_{10} \text{(suspended sediment loading rate, in tons/day)} = 1.4021 \log_{10} \text{(streamflow, in ft}^3\text{/s)} + 1.2935 \quad (1)$$

$$\log_{10} \text{(dissolved selenium loading rate, in lb/day)} = 1.1951 \log_{10} \text{(streamflow, in ft}^3\text{/s)} - 1.3708 \quad (2)$$

$$\log_{10} \text{(total selenium loading rate, in lb/day)} = 1.3374 \log_{10} \text{(streamflow, in ft}^3\text{/s)} - 1.1366 \quad (3)$$

The applicable range of streamflows for these prediction equations is about 150 to 9,500 ft^3/s. At streamflows below 150 ft^3/s, the predicted loading rates are less than about 22,000 tons/day suspended sediment, 17 lb/d dissolved selenium, and 59 lb/d total selenium. These loading rates are minor compared with the loading rates during relatively high streamflows.

The uncertainty in loading rates calculated using equations (1) through (3) was evaluated by looking at the 95-percent confidence intervals for the regressions. This interval is shown graphically for equations (1) through (3) in figures 11, 13, and 14, respectively. The 95-percent confidence interval expressed in log-transformed units (i.e., where $\hat{y}$ is the predicted $\log_{10}$ of the load) for equations (1) through (3) are $\hat{y} \pm 0.194$, $\hat{y} \pm 0.206$, and $\hat{y} \pm 0.188$, respectively. The 95-percent confidence interval expressed in the original untransformed units (i.e., where $\hat{y}$ is the predicted untransformed load) for equations (1) through (3) are $0.64\hat{y}$ to $1.56\hat{y}$, $0.62\hat{y}$ to $1.61\hat{y}$, and $0.65\hat{y}$ to $1.54\hat{y}$, respectively.

SUMMARY AND CONCLUSIONS

The rainfall and streamflow during February 1998 were exceptionally high. The rainfall total of 10.40 in. for the month was greater than any other month during 1957 to 2000. The peak streamflows on February 3 and 7 (9,940 and 8,550 ft^3/s, respectively) both exceeded the previous peak streamflow of 5,400 ft^3/s at the upstream gage during 1950–53 and 1959–70. The peak streamflow during water years 1999 and 2000 was only 188 ft^3/s.

In addition to 32 environmental samples collected during February 1998, eight quality control samples were collected (four field blanks and four replicates). No contamination was found in the field blanks, and the RPDs for dissolved selenium replicates ranged from 0.0 to 18.2 percent. However, the RPDs for four total selenium replicates and four reruns ranged from 0.0 to 57.1 percent. This variability in total selenium was attributed to the extremely high concentrations of suspended sediment in the samples and to possible interference from other compounds.

The suspended-sediment load transported in the four storms of February 1998 was about 2.21 million tons. About 78 percent of this load was transported during 26 hours of storm runoff on February 3 and 4. The dissolved selenium load transported in the four storms was about 918 lb, with about 76 percent of it transported during the first storm. The total selenium load in the four storms was about 5,421 lb, with about 81 percent transported during the first storm. Suspended selenium accounted for about 83 percent of the overall total selenium load.

Loading rate prediction equations were developed for suspended sediment, dissolved selenium, and total selenium as a function of streamflow at the I-5 gaging station. The utility of these equations would be improved by additional storm sampling data. This improvement would not only provide better estimates, but also possibly would allow development of separate equations for the rising and falling limbs of the storm hydrographs.

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