Prepared in cooperation with the
California State Water Resources Control Board

Evaluation of Methods Used for Estimating Selected Streamflow Statistics, and Flood Frequency and Magnitude, for Small Basins in North Coastal California

Scientific Investigations Report 2004–5068

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

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Conversion Factors, Datum, and Abbreviations

Multiply	By	To obtain
acre	0.4047	hectometer
acre-foot (acre-ft)	0.001233	cubic hectometer
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per kilometer
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

ADAPS	USGS Automated Data Processing System
DEM	Digital Elevation Model
GIS	Geographic Information Systems
LOC	Line of Organic Correlation
OLS	Ordinary Least Squares
PEAKFQ	USGS computer program
USGS	U.S. Geological Survey
SWRCB	State Water Resources Control Board
WRC	U.S. Water Resources Council

Evaluation of Methods Used for Estimating Selected Streamflow Statistics, and Flood Frequency and Magnitude, for Small Basins in North Coastal California

By Michael P. Mann[1], Julé Rizzardo[2], and Richard Satkowski[2]

Abstract

Accurate streamflow statistics are essential to water resource agencies involved in both science and decision-making. When long-term streamflow data are lacking at a site, estimation techniques are often employed to generate streamflow statistics. However, procedures for accurately estimating streamflow statistics often are lacking. When estimation procedures are developed, they often are not evaluated properly before being applied. Use of unevaluated or underevaluated flow-statistic estimation techniques can result in improper water-resources decision-making. The California State Water Resources Control Board (SWRCB) uses two key techniques, a modified rational equation and drainage basin area-ratio transfer, to estimate streamflow statistics at ungaged locations. These techniques have been implemented to varying degrees, but have not been formally evaluated. For estimating peak flows at the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals, the SWRCB uses the U.S. Geological Survey's (USGS) regional peak-flow equations. In this study, done cooperatively by the USGS and SWRCB, the SWRCB estimated several flow statistics at 40 USGS streamflow gaging stations in the north coast region of California. The SWRCB estimates were made without reference to USGS flow data. The USGS used the streamflow data provided by the 40 stations to generate flow statistics that could be compared with SWRCB estimates for accuracy. While some SWRCB estimates compared favorably with USGS statistics, results were subject to varying degrees of error over the region. Flow-based estimation techniques generally performed better than rain-based methods, especially for estimation of December 15 to March 31 mean daily flows. The USGS peak-flow equations also performed well, but tended to underestimate peak flows. The USGS equations performed within reported error bounds, but will require updating in the future as peak-flow data sets grow larger. Little correlation was discovered between estimation errors and geographic locations or various basin characteristics. However, for 25-percentile year mean-daily-flow estimates for December 15 to March 31, the greatest estimation errors were at east San Francisco Bay area stations with mean annual precipitation less than or equal to 30 inches, and estimated 2-year/24-hour rainfall intensity less than 3 inches.

[1]U.S. Geological Survey

[2]California State Water Resources Control Board, Division of Water Rights

Introduction

Better flow-statistic estimation procedures at ungaged locations have long been needed in water-resource science and decision-making. Such procedures are especially lacking for small drainage basin areas (especially less than 30 mi^2) because of a general lack of long-term flow data for small basins. Regional regression equations have been derived in many locales across the United States for such purposes. In California, peak-flow equations were produced by the U.S. Geological Survey (USGS) in 1977 (Waananen and Crippen, 1977), but have not been revised with updated precipitation and flow data. Agencies involved in water-related decision making often have a need for other various streamflow statistics that are not available at ungaged sites. Methods for estimating such statistics are numerous and rarely standardized. In general, the accuracies of various estimation procedures are often not thoroughly evaluated prior to implementation. The California State Water Resources Control Board (SWRCB) has developed flow-statistic estimation procedures for use in water-rights appropriations, but these procedures have not been thoroughly evaluated for accuracy. This study was designed to formally evaluate these SWRCB procedures, as well as to assess the accuracy of the USGS peak-flow equations for the north coast region.

The SWRCB has a need to estimate selected streamflow statistics at ungaged locations in northern coastal California (north coast region) in order to appropriate water rights. Many of these locations are in small drainage basins (30 mi^2 and smaller) where long-term historical flow data tend to be lacking. The statistics of interest, estimated by the SWRCB, include total annual and seasonal runoffs, February median flows, daily mean streamflows, and magnitudes of selected flood frequencies.

Two general methods have been developed by the SWRCB for estimating flow statistics, depending on the availability and applicability of streamflow or precipitation data. These two methods are (1) a modified rational equation, and (2) a drainage-basin-area ratio approach. Both methods are used by the SWRCB for estimating the streamflow statistics, with the exception of the February median flow (for which the SWRCB uses method 2 only) and peak flows (USGS peak-flow equations).

Purpose and Scope

The purpose of this report is to present a characterization of the accuracy and bias of streamflow statistics resulting from application of estimation techniques commonly employed by the SWRCB. In order to evaluate these estimation techniques, 40 actively or previously gaged streamflow study stations were chosen to act as ungaged locations. The SWRCB estimated various streamflow statistics at these gages without reference to the streamgage data. The USGS then used the streamgage data to estimate various streamflow statistics for comparison with SWRCB's estimates. This report presents the results of the comparisons.

The study included tests for parametric and geographic error and bias, with examination of accuracy and bias as related to common basin characteristics (drainage area, mean channel slope, mean elevation, mean annual precipitation, location, etc.). The study was not intended to produce new estimation techniques, but to evaluate whether or not SWRCB methods are accurate and suitable for their needs, and to investigate whether geographic location or basin attributes have an effect upon errors in estimation. The study also was intended to serve as a useful model for future assessments of streamflow-statistic estimation techniques, and may promote future efforts to improve the techniques.

Acknowledgments

The California State Water Resources Control Board's Division of Water Rights provided funding for this study. Kenyatte Williams, Camille Valenti, and Rudolph Akoutey of the California State Water Resources Control Board's Division of Water Rights provided technical assistance in Geographic Information Systems (GIS) analysis and flow-statistic estimation.

Description of Study Area

The north coast region of California is delineated in *figure 1* by the grey, green, and orange shaded areas. The study area covers about 340 mi north to south and ranges in width from about 85 mi in the north to about 45 mi in the south. Major river drainage basins include the Klamath, Trinity, Eel, and Russian Rivers, along with several other smaller drainage basins. These basins drain directly into the Pacific Ocean. Because of both its inland extent and differences in geology and meteorology, the upper Klamath River basin was excluded from the study region, as this area undoubtedly would belong in a different region for the purposes of estimating streamflow statistics. In addition, because of its proximity to the coast and need for a representative geographic distribution of study sites, a small portion of the Sacramento River basin around Clear Lake was added to the study (orange shaded area in *figure 1*).

Elevations range from sea level to over 9,000 ft in the north coast region. The map in *figure 2* shows the median (50-percentile) elevation for the hydrologic units in the study region. The highest elevations are in the Klamath and Coast Ranges in the northern two-thirds of the study region, with peaks ranging from about 6,000 to over 9,000 ft. Most of the crests of these ranges are within 50 mi of the coast. The Coast Ranges extend to the southernmost portion of the study region, with a break in the San Francisco Bay area. Drainage basins typically are steep in their upland portions, and flatten near the coast at the generally narrow coastal plain. The upland portions of the Klamath and northern Coast Ranges are largely coniferous (redwood and Douglas fir) forest cover. Southward, coniferous forests are found at the highest elevations, but mixed pines and hardwoods (oaks, maple, and madrone) are dominant at lower elevations. Also southward, chaparral (manzanita, sage, and scrub oak) tends to be dominant on wind- and sun-exposed slopes. The soils of the Klamath Range are derived largely from plutonic and metamorphic rocks, whereas the Coast Range soils are derived largely from sedimentary rocks.

The semipermanent high-pressure area of the northern Pacific Ocean largely controls the climate of the north coast region. This pressure system moves northward in the summer, holding storm tracks well to the north. In the late fall to early spring, the system migrates southward, bringing storms across California. This results in a markedly wet season from October to April, and a generally dry season the remainder of the year. Most precipitation and associated runoff happens during the October to April period. Pacific Ocean-generated storms are regional and strong during winter months. This can result in regional flooding during winter months. Summer convective thunderstorms are possible in summer months, especially at higher elevations, but usually result in smaller peak flows than the regional wintertime storms. Such summertime storms are also limited to much smaller areas than wintertime storms. Because of oceanic influences, temperatures in the region are moderate year-round and daily fluctuations are limited. Therefore, most precipitation occurs as rain, with snow only at the highest elevations of the Klamath and northern Coast Ranges. Annual precipitation varies from more than 100 inches in the north to 20 inches in the San Francisco Bay area, and generally 40 to 70 inches in the Coast Ranges (Rantz, 1969). The map in *figure 3* shows mean annual precipitation in the north coast region of California.

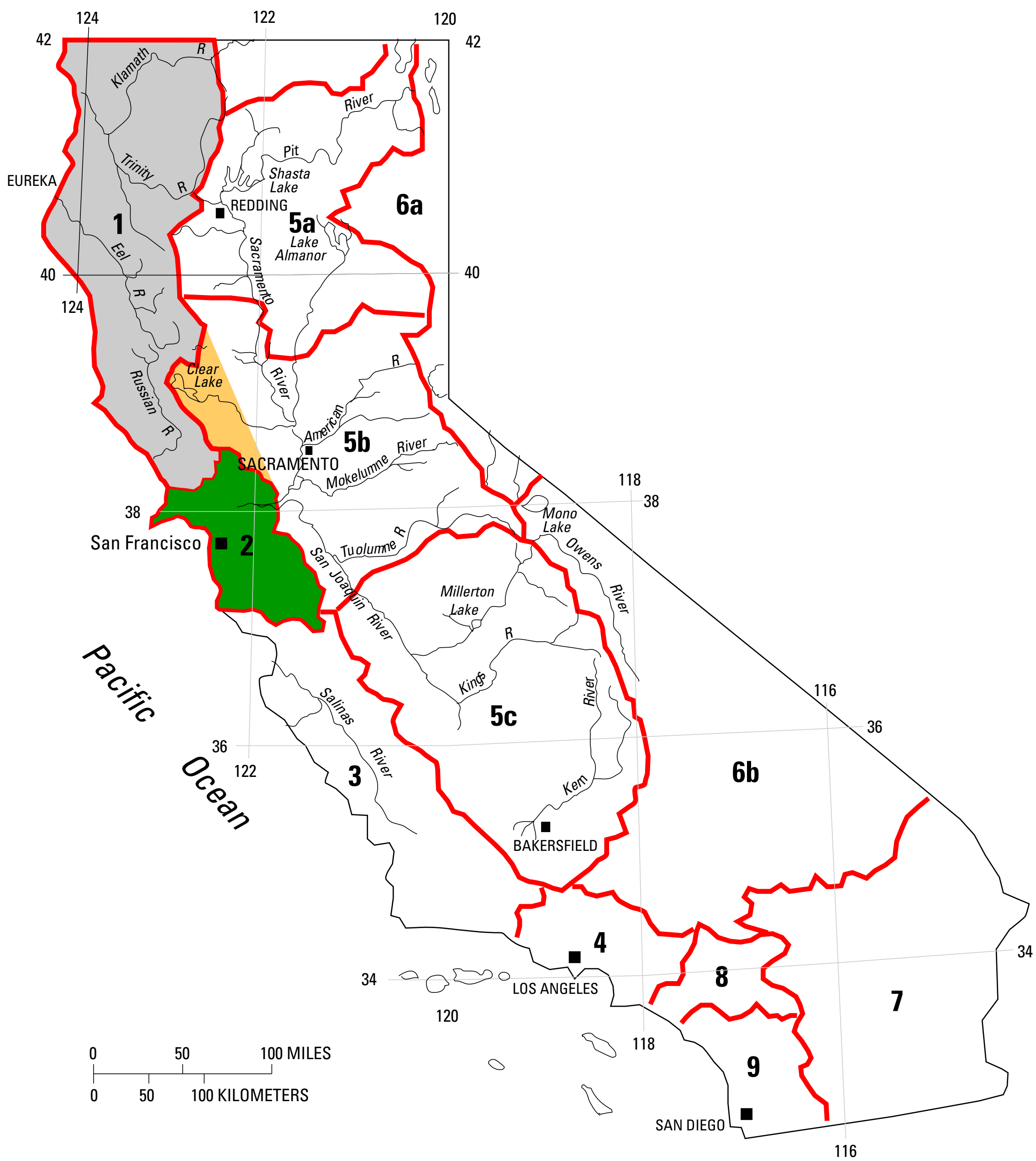

Figure 1. North coast region of California.
Numbered regions are Regional Water Quality Control Board regions. The study area is shaded.

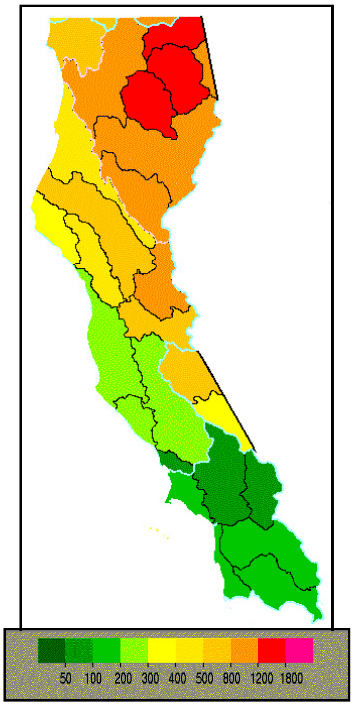

Figure 2. Median elevation (in meters) by hydrologic unit, north coast region of California.
Elevation is shown in meters; 1 meter = 3.281 feet.
Source: *http://www.esg.montana.edu/gl/huc/hucs*.

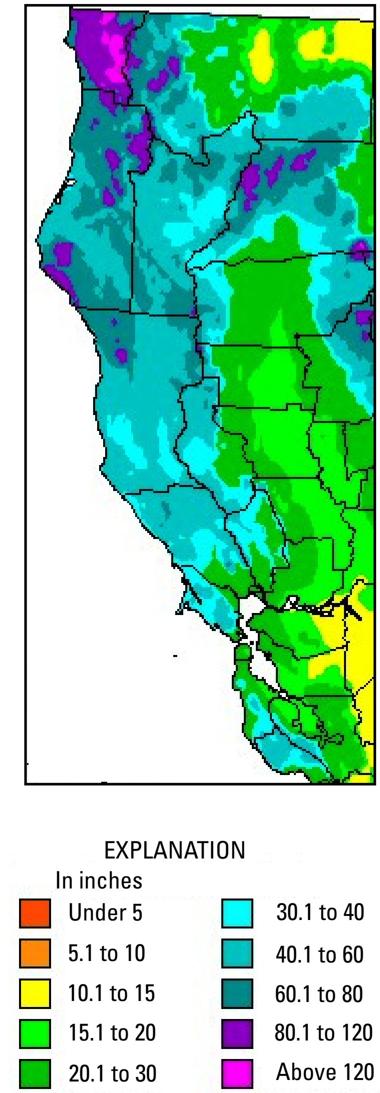

Figure 3. Mean annual precipitation in northern California.

Methods

Forty actively or previously gaged streamflow study stations were chosen to act as ungaged locations. The SWRCB used a modified rational equation method and a drainage-basin-ratio approach to estimate various streamflow statistics at these stations.

Selection of Study Stations

The SWRCB has a need to estimate streamflow statistics at ungaged sites for small drainage basins (30 mi^2 and smaller) in the north coast region. To evaluate the SWRCB estimates, it was necessary to utilize study sites that are either active or previously active gaging stations. A total of 323 streamflow stations (both active and inactive) were available in the north coast region. A good geographic distribution of study stations over the north coast region was desired. Also desired was a good distribution of stations over a broad range of drainage basin areas (less than 30 mi^2), and over the other basin characteristics of interest (*table 1*). The ultimate goal of the station selection was to select a statistically significant number of stations (about 30) that are unaffected by storage, diversions, or urbanization, with drainage basin areas less than 30 mi^2 and at least 10 complete years of daily flow record. However, most of the long-term periods of record for gaging stations in the region are for stations with drainage basin areas greater than 100 mi^2.

More confidence in streamflow-statistic estimation is achieved from longer periods of record (preferably greater than 30 years), which limit the effects of short-term variability in long-term climatic conditions. Because of the lack of long-term periods of record for small basins, the original and desired criteria for station selection had to be altered in order to come up with enough study stations to represent the geographic variability in the region. *Table 2* lists desired and final limits for criteria in station selection. Strict application of the basic criteria (and avoiding duplication of stations in close proximity to one another and with similar basin characteristics) resulted in a selection of 10 stations. Relaxing the drainage-area criterion to 45 mi^2 resulted in only 13 selected stations, and accepting stations with a minimum 5 years of record resulted in only 20 selected stations. Accepting stations with minor regulation, small diversions, and minor urbanization increased the total number of selected stations to 32. However, a reasonable geographic distribution of stations over the region was not achieved with these 32 stations. In order to fill in holes in the distribution, 6 additional stations with drainage basin areas ranging from 45 to 100 mi^2 and 2 stations with periods of records of only 4 years were added. Thus, by relaxing the desired criteria, 40 stations were selected that provided a good geographic distribution over the north coast region and over the range of basin characteristics in the region. *Table 3* lists the 40 selected stations and their basin characteristics. The map in *figure 4* shows the geographic distribution of the 40 stations over the north coast region.

SWRCB Flow-Statistic Estimation Methods

The SWRCB used a modified rational equation, area-ratio methods, and USGS flood-frequency equations (Waananen and Crippen, 1977) to estimate all the streamflow statistics listed in *table 4*. The rational equation was used for annual runoff, wet season (October 1 to March 31) runoff, and winter season (December 15 to March 31) runoff mean daily flows. The area-ratio method was used for all these same statistics and also to estimate February median flows. The USGS regional flood-frequency equations were used for estimating peak flows at the 2-, 5-, 10-, 25, 50-, and 100-year recurrence intervals. The SWRCB does not currently estimate mean daily flows for water-rights appropriations, but these estimates were added to the study in order to evaluate the limitations of such estimates. In order to facilitate comparison between SWRCB estimates of December 15 to March 31 mean daily flows and USGS gaged mean daily flows, it was important to restrict the SWRCB estimates to the period of record at the study station. In determining the 25- and 50-percentile years (dry and median years) for generating December 15 to March 31 mean-daily-flow estimates, the SWRCB ranked annual flows from a nearby streamgage with a period of record that bracketed at least the same period of record as the study station of interest. The SWRCB then selected the years within the period of record at the study station whose ranks were closest to the computed 25- or 50-percentile years at the nearby reference gage.

Table 1. Basin characteristics used in study.

[USGS, U.S. Geological Survey]

Basin characteristic	Units	Source
Drainage area (above gage) (DA)	square miles	USGS Site file
Station altitude (A)	feet	USGS Site file
Mean annual precipitation (1900-1960) (P)	inches	Rantz, 1969[1]
2-year, 24-hour rainfall intensity (I)	inches	U.S. Weather Bureau, 1961[2]
Mean annual Class A pan evaporation (E)	inches	U.S. Weather Bureau, 1959[3]
Mean channel slope (determined between 10% and 85% distances from gage to basin divide) (S)	--	USGS Site file
Channel length (between gage and basin divide) (L)	miles	USGS Site file
Altitude index (determined between 10% and 85% distances from gage to basin divide) (H)	10^3 feet	USGS Site file
Distance from gage to ocean (mean of west-to-ocean and southwest-to-ocean distances) (DO)	miles	Determined from USGS 7.5′ topographic quadrangles

[1]Rantz, S.E., 1969, Mean annual precipitation in the California Region: U.S. Geological Survey open-file map.

[2]U.S. Weather Bureau, 1961, Rainfall frequency atlas of the United States: Technical Paper No. 37, 13 p.

[3]U.S. Weather Bureau, 1959, Evaporation maps for the United States: Technical Paper No. 40, 115 p

Table 2. Desired versus final criteria for study station selection.

Criterion	Desired limit	Final limit
Drainage area	Less than 30 square miles	Less than 100 square miles
Period of streamflow record	Greater than or equal to 30 years	Greater than or equal to 4 years
Degree of regulation and/or urbanization	None	Minor
Number of stations	30	40

Table 3. Study stations and their basin characteristics.

[DA, drainage area above gage; A, station altitude; P, mean annual precipitation (1900–1960); I, 2-year, 24-hour rainfall intensity; E, mean annual Class A pan evaporation; S, mean channel slope (determined between 10 and 85 percent distances from gage to basin divide); L, channel length (between gage and basin divide); H, altitude index (mean of elevations at 10 and 85 percent distances from gage to basin divide); DO, distance from gage to ocean (mean of west-to-ocean and southwest-to-ocean distances). mi^2, square miles; ft, feet; in., inches; mi, miles. See *fig. 4* for location of stations and *table 1* for sources of data]

Station number	Station name	Drainage area, DA (mi^2)	Altitude, A (ft)	Precipi-tation, P (in.)	Rainfall intensity, I (in.)	Pan evapora-tion, E (in.)	Channel slope, S (ft/mi)	Channel length, L (mi)	Altitude index, H (1,000 ft)	Distance to ocean, DO (mi)
11162540	Butano Creek near Pescadero, CA	18.3	70.0	38	4.5	49	126	11.2	0.6	2.9
11162600	Purisima Creek near Half Moon Bay, CA	4.83	380.0	38	3.4	49	336	3.8	0.9	3.8
11172100	Upper Penitencia Creek at San Jose, CA	21.5	265.3	16	2.0	56	303	7.7	1.3	32.8
11180500	Dry Creek at Union City, CA	9.39	85.1	22	2.9	57	233	5.1	0.6	28.0
11182500	San Ramon Creek at San Ramon, CA	5.89	530.0	23	2.3	58	102	5.7	0.8	31.3
11183700	Little Pine Creek near Alamo, CA	1.22	520.0	22	2.3	59	920	2.2	1.3	36.7
11449500	Kelsey Creek near Kelseyville, CA	36.6	1,475.4	45	5.0	61	80	15.9	2.0	41.9
11451100	North Fork Cache Creek at Hough Spring near Clear-lake Oaks, CA	60.2	1,840.0	50	3.0	63	53	17.1	2.0	57.8
11453200	Dry Creek near Middletown, CA	8.35	1,172.2	80	5.8	62	466	3.9	1.9	39.5
11458200	Redwood Creek near Napa, CA	9.79	166.2	30	2.4	61	258	8.9	1.1	36.9
11460100	Arroyo Corte Madera del Pre-sidio at Mill Valley, CA	4.69	1.9	38	2.6	52	181	3.3	0.3	4.8
11460800	Walker Creek near Tomales, CA–Pre-regulation (1979)	40.1	56.7	38	2.8	52	24	19.3	0.3	6.7
11460920	Salmon Creek at Bodega, CA	15.7	81.0	44	4.5	52	50	10.9	0.3	4.2
11463900	Maacama Creek near Kel-logg, CA	43.4	188.9	60	5.5	58	166	10.6	0.9	29.4
11464860	Warm Springs Creek near Asti, CA	12.2	625.0	67	6.0	54	128	6.4	0.9	16.9
11465150	Pena Creek near Geyser-ville, CA	22.3	195.0	50	6.0	56	48	11.1	0.4	22.4
11465800	Santa Rosa Creek near Santa Rosa, CA	12.5	318.6	36	3.2	57	150	8.2	1.0	26.6
11467600	Garcia River near Point Arena, CA	98.5	55.3	65	5.0	44	32	35.1	0.5	4.6
11467850	Soda Creek Tributary near Boonville, CA	1.53	1,551.3	55	4.3	54	284	1.9	1.8	21.7
11468070	South Fork Big River near Comptche, CA	36.2	500.0	50	3.8	53	91	9.2	0.9	16.9
11468540	Pudding Creek near Fort Bragg, CA	12.5	88.9	51	3.3	48	90	7.5	0.4	6.1
11469500	North Fork Mattole River at Petrolia, CA	37.6	50.0	90	4.0	40	126	12.8	0.7	4.0

Table 3. Study stations and their basin characteristics.—Continued

[DA, drainage area above gage; A, station altitude; P, mean annual precipitation (1900–1960); I, 2-year, 24-hour rainfall intensity; E, mean annual Class A pan evaporation; S, mean channel slope (determined between 10 and 85 percent distances from gage to basin divide); L, channel length (between gage and basin divide); H, altitude index (mean of elevations at 10 and 85 percent distances from gage to basin divide); DO, distance from gage to ocean (mean of west-to-ocean and southwest-to-ocean distances). mi², square miles; ft, feet; in., inches; mi, miles. See *fig. 4* for location of stations and *table 1* for sources of data]

Station number	Station name	Drainage area, DA (mi²)	Altitude, A (ft)	Precipitation, P (in.)	Rainfall intensity, I (in.)	Pan evaporation, E (in.)	Channel slope, S (ft/mi)	Channel length, L (mi)	Altitude index, H (1,000 ft)	Distance to ocean, DO (mi)
11471800	Tomki Creek near Willits, CA	43.4	1,591.9	48	4.0	57	43	16.9	1.9	33.4
11473600	Short Creek near Covelo, CA	15.2	1,438.2	43	3.3	58	150	7.7	1.9	41.7
11474781	Combined flow of 11474750 + 11474780	20.66	1,480.0	57	4.5	54	135	10.0	2.1	31.6
11475560	Elder Creek near Branscomb, CA	6.5	1,391.1	80	4.3	50	420	5.0	2.4	10.2
11475940	East Branch South Fork Eel River near Garberville, CA	74.3	385.3	65	5.7	50	87	22.7	1.2	15.4
11476600	Bull Creek near Weott, CA	28.1	269.4	100	5.0	46	136	9.9	0.8	18.1
11477700	Little Van Duzen River near Bridgeville, CA	36.2	2,283.0	70	4.3	50	119	13.7	3.0	36.7
11480000	Jacoby Creek near Freshwater, CA	5.8	50.0	58	3.4	41	299	3.8	1.5	19.6
11480390	Mad River above Ruth Reservoir near Forest Glen, CA	93.8	2,700.0	60	3.7	59	58	23.8	3.2	48.1
11481200	Little River near Trinidad, CA	40.5	17.6	55	4.0	41	139	15.2	0.9	2.3
11481500	Redwood Creek near Blue Lake, CA	67.7	850.0	80	3.9	47	131	22.1	2.0	30.3
11482125	Panther Creek near Orick, CA	6.07	400.0	85	5.0	44	435	3.8	1.1	15.1
11482468	Little Lost Man Creek at Site No 2 near Orick, CA	3.46	50.0	75	5.8	39	392	4.4	1.0	4.6
11522200	Elk Creek near Happy Camp, CA	90.4	1,300.0	65	3.8	45	209	18.1	2.9	50.0
11522260	Ti Creek near Somes Bar, CA	9.46	700.0	70	5.3	45	677	6.0	2.5	37.2
11529800	Willow Creek near Willow Creek, CA	40.9	585.5	75	4.0	47	207	13.2	2.2	39.0
11532620	Mill Creek near Crescent City, CA	28.6	180.0	85	6.0	38	84	9.1	0.5	3.2
11533000	Lopez Creek near Smith River, CA	0.92	38.8	80	4.8	37	375	2.0	0.6	0.3
	Maximum	**98.5**	**2,700.0**	**100**	**6.0**	**63**	**920**	**35.1**	**3.2**	**57.8**
	Minimum	**0.9**	**1.9**	**16**	**2.0**	**37**	**24**	**1.9**	**0.3**	**0.3**

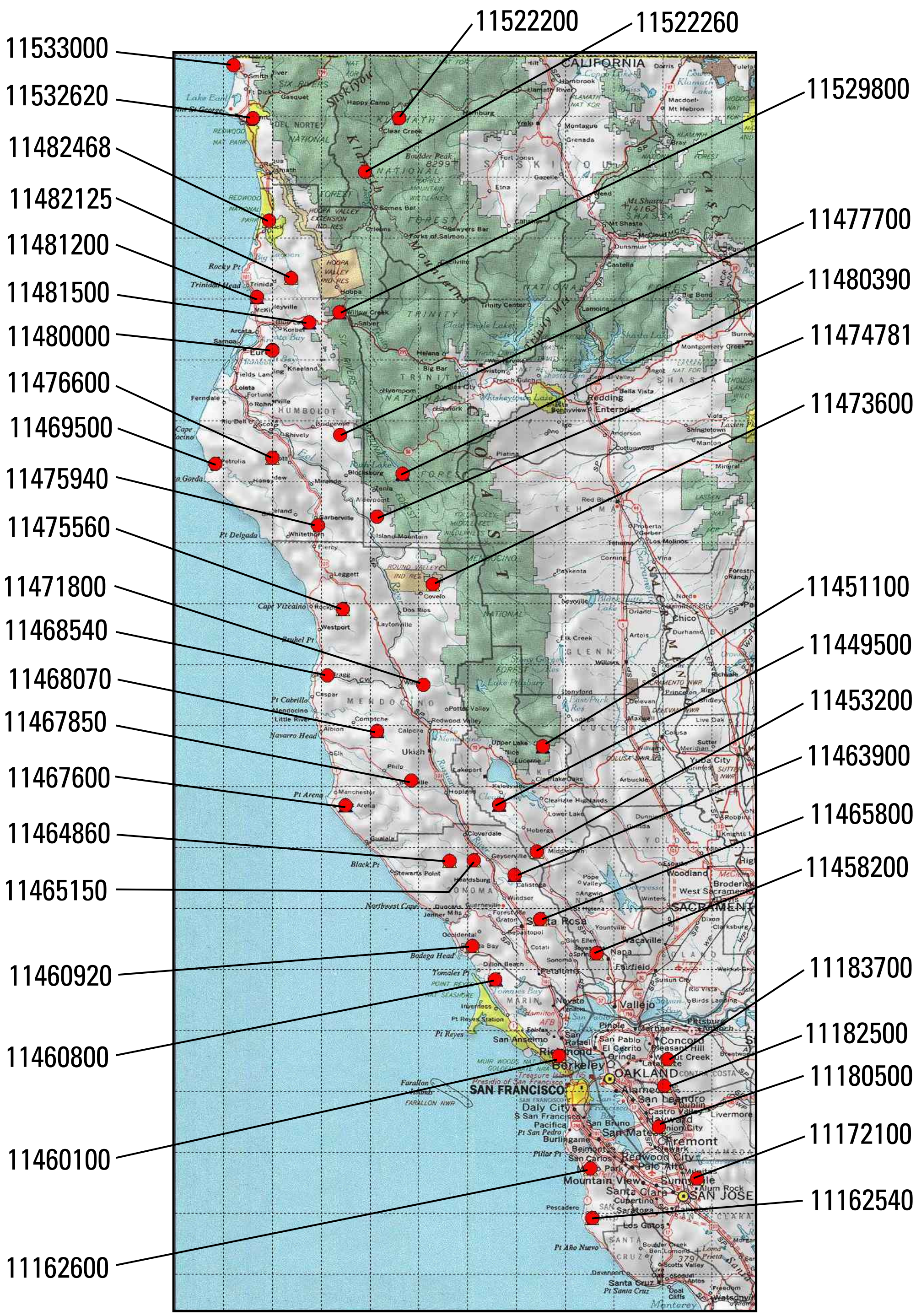

Figure 4. Geographic distribution of selected study stations, north coast region of California.

Table 4. Streamflow statistics estimated by State Water Resources Control Board.

Streamflow statistic	Units
Annual runoff	acre-feet
October 1 to March 31 runoff (wet season runoff)	acre-feet
December 15 to March 31 runoff (winter season runoff)	acre-feet
February median flow (50-percentile of February daily flows)	cubic feet per second
50-percentile (median) year December 15 to March 31 mean daily streamflows	cubic feet per second
25-percentile (dry) year December 15 to March 31 mean daily streamflows	cubic feet per second
Peak flows at 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals	cubic feet per second

SWRCB Rational Equation Method

The rational equation is a simple rainfall-runoff equation designed for estimating peak flows in small (less than 1 mi^2) drainage basins (Bendient and Huber, 1992). The rational equation is defined as:

$$Q_{peak} = C \times I \times A \tag{1}$$

where

Q_{peak} is peak flow (ft^3/s),

C is a dimensionless runoff coefficient, less than or equal to 1,

I is rainfall intensity (inches per hour), and

A is watershed area above point of interest (acres).

The SWRCB used two different modifications of the rational formula for streamflow-statistic estimates in this study. For estimating runoff volumes (annual and seasonal runoffs), the rational equation appears similar to the equation above, but the parameter *I* was defined differently:

$$Q_{runoff} = C \times I \times A \tag{2}$$

where

Q_{runoff} is total runoff (acre-ft) and

I is rainfall total depth for period of interest (ft).

For estimating mean daily flows, a conversion factor was added to the equation and the parameter *I* was again defined differently:

$$Q_{mean} = K \times C \times I \times A \tag{3}$$

where

Q_{mean} is mean daily streamflow (cubic feet per second),

K is a conversion factor used to convert acre-feet to cubic feet per second, and

I is daily rainfall total depth from a nearby raingage (ft).

SWRCB Drainage Basin Area-Ratio Method

The drainage basin area-ratio method assumes that the streamflow at an ungaged site is the same per unit area as at a nearby hydrologically similar streamgaging station. The area-ratio method is used for transferring known flows from one point to another location where flow is not known. This method is generally best used for transferring flows within the same drainage basin; however, the SWRCB also used area-ratio methods to transfer flow statistics from one basin to another. Typically, the SWRCB selected a streamgage that is closest in distance to the point of interest for transfer of the streamflow statistic from the gaged location to the ungaged location. The SWRCB incorporated not only a drainage basin area-ratio for statistic transfer, but also a precipitation ratio in order to account for differences in precipitation between basins. The area-ratio equation used by the SWRCB to estimate streamflow statistics is:

$$Q_{ug} = Q_g \times \frac{A_{ug}}{A_g} \times \frac{I_{ug}}{I_g} \tag{4}$$

where

Q_{ug} is flow volume (acre-ft), mean daily flow (ft^3/s), or February median flow (ft^3/s) at ungaged location,

Q_g is flow volume (acre-ft), mean daily flow (ft^3/s), or February median flow (ft^3/s) at gaged location,

A_{ug} is watershed area above ungaged site (acres),

A_g is watershed area above gaged site (acres),

I_{ug} is mean annual precipitation above ungaged site, from GIS-based isohyetal map (ft), and

I_g is mean annual precipitation above gaged site, from GIS-based isohyetal map (ft).

USGS Flood-Frequency Equations

The USGS regional peak-flow equations for specified regions in California (Waananen and Crippen, 1977) were used by the SWRCB for peak-flow estimates at the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. These equations were derived through multiple regressions of peak-flow data and basin characteristics (*table 1*) for estimating peak flows in specified hydrologic regions in California. The general form of the USGS's California regional peak-flow equations is as follows:

$$Q_{peak} = C \times A^a \times P^b \times H^c \quad (5)$$

where

- Q_{peak} is peak flow at specified recurrence interval (ft^3/s),
- C is a regression constant based upon return period and region,
- A is watershed area above point of interest (square miles),
- P is mean annual precipitation (inches),
- H is altitude index (mean of altitude taken at points 10 percent and 85 percent distance between point of interest and basin divide; 10^3 ft), and
- a, b, c are regression exponents based upon return period and region.

Table 5 lists the values of the regression coefficient (C) and regression exponents (a, b, and c) for the north coast and central coast hydrologic regions at the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. *Table 6* lists the average standard errors associated with peak-flow estimates at the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals using the USGS California flood-frequency equations. The isohyetal precipitation map "Mean Annual Precipitation in the California Region" for the years 1900 to 1960 (Rantz, 1969) was used to derive the USGS's regional flood-frequency equations. The SWRCB did not use Rantz's map for their estimates, but used a Geographic Information Systems (GIS) coverage based upon similar isohyetal precipitation data (1900-1960).

USGS Flow-Statistic Determination Methods

Annual and seasonal runoff and February median flow can be determined directly using USGS streamflow data available in the USGS's Automated Data Processing System (ADAPS). However, as 34 of the 40 study stations had periods of record shorter than desired (less than at least 30 years of streamflow record), streamflow statistics generated from short-record stations were not considered to be representative of long-term conditions. For these stations, the runoff and February median streamflow statistics were adjusted to long-term conditions via correlation with long-term reference (index) gaging stations. For the years selected by the SWRCB as the 25- and 50-percentile (dry and median) years, mean daily streamflows available in ADAPS were used as generated.

Table 5. Values of regression constants and exponents for U.S. Geological Survey's California peak-flow equations, North Coast and Central Coast hydrologic regions.

[From Waananen and Crippen, 1977, USGS Water-Resources Investigations Report 77-21. Peak flow, Q_{peak}, at a specified recurrence interval = $C \times A^a \times P^b \times H^c$, where C is a regression constant based upon return period and region, A is watershed area above point of interest, P is mean annual precipitation, H is altitude index, and a, b, c are regression exponents based upon return period and region]

Recurrence interval (years)	Regression constant	Regression exponents		
	C	*a*	*b*	*c*
North Coast Hydrologic Region				
2	3.52	0.90	0.89	-0.47
5	5.04	0.89	0.91	-0.35
10	6.21	0.88	0.93	-0.27
25	7.64	0.87	0.94	-0.17
50	8.57	0.87	0.96	-0.08
100	9.23	0.87	0.97	0
Central Coast Hydrologic Region				
2	0.0061	0.92	2.54	-1.10
5	0.118	0.91	1.95	-0.79
10	0.583	0.90	1.61	-0.64
25	2.91	0.89	1.26	-0.50
50	8.20	0.89	1.03	-0.41
100	19.7	0.88	0.84	-0.33

Table 6. Average standard errors for U.S. Geological Survey's California peak-flow equations.

Recurrence interval (years)	Average standard error (percent)
2	54.8
5	44.9
10	44.0
25	44.7
50	46.6
100	49.4

Flood-frequency analysis was used to determine peak flows at the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals. Flood-frequency analysis was performed at 30 of the 40 study stations using U.S. Water Resources Council (WRC) methods outlined in Guidelines for Determining Flood Flow Frequency, Bulletin 17B (U.S. Interagency Advisory Committee on Water Data, 1982). Annual peak-flow records of less than 10 years prevented flood-frequency analysis at 10 study stations.

Extension of Study-Station Statistics to Long-Term Conditions

The SWRCB estimates of annual flow, winter season flow, wet season flow, and February median flow were made with the assumption that these flows are representative of long-term conditions for each station. That is, the estimates of these statistics are not necessarily representative of the period of record of the USGS gaging station. Therefore, it was important that the USGS-generated statistics were not calculated from short periods of record and compared with SWRCB estimates of these statistics for long-term conditions. Of the 40 study stations, 34 stations had periods of records shorter than desired (longer than 30 years) to be representative of long-term conditions.

Searcy (1959) recognized that for gaging-station record comparison, each record must represent, or be adjusted to, concurrent periods. Thus, the differences between records will be due to differences in climatic or drainage basin characteristics and not to the fact that different periods of time are represented. Searcy suggested using gaging-station correlation with concurrent-record flow-duration curves to effectively extend the periods of record from a short-record (study) station to that of a long-term (reference or index) station. Ries and Friesz (2000) used a similar approach in extending the effective record length of various estimated flow statistics in Massachusetts.

In this study, flow-duration-curve coordinates between short-record and long-record stations were either regressed using the MOVE-1 regression technique or graphically if curvature was noticeable in the relation. Because several of the north coast region stations had very short periods of record (as short as 4 years of record), it was decided that computed flow-duration statistics would not be reliable for these record extension techniques. The method of record extension used in this study is similar to Searcy's and Ries and Frieszs' methods; however, the statistic used for station correlation was the concurrent period of mean-daily-flow values. This significantly increased the number of points for station-to-station correlation, and better defined the relation between short- and long-record gaging stations.

Several long-record stations with drainage basin areas in excess of 100 mi^2 were available in the region to serve as reference, or index, stations for adjustment of flow statistics at short-term stations to long-term conditions. The six study stations with periods of record greater than 30 years also served as index stations. The streamflow statistics were not adjusted at these stations. Station-to-station linear (Ordinary Least Squares) or second-order polynomial regression of concurrent daily values served as the methods for adjustment.

Selection of Index Stations

Several long-term reference, or index, stations (periods of record ranging from 30 to 89 years) were available throughout the north coast region for adjustment of short-record statistics at study stations. To serve as a useful index station, preference was given to index stations similar in size and characteristic to a study station. However, as most index stations are from larger drainage basins than many of the study stations, index stations were selected based upon proximity to study stations. Two criteria were required to be met: (1) The regression coefficient of determination (R^2) for index-station daily mean flows versus study-station daily mean flows was required to be greater than 0.8 for concurrent flow data, and (2) the index station was required to have at least twice the years of record of the study station (Ries and Friesz, 2000). Of the 34 short-record stations, 2 stations did not have index stations that met these criteria (11460100 did not meet criterion 1, and 11481500 did not meet criterion 2). The streamflow statistics at these two stations were not adjusted to long-term conditions. If more than one potential index station was identified for a particular study station, all were used for record extension at that site. Results from multiple index stations were combined into a single streamflow-statistic estimate.

In order to adjust study-station flow statistics using long-term index stations, tests for trends in flow data should be considered. Improper regression can result if trends are evident in the long-term record for the north coast region, or for individual index stations. If regional trends are indicated, station-to-station correlation techniques would be required to first employ 'de-trending' of the streamflow data. It is also undesirable to adjust short-record statistics to individual long-term stations if trends are indicated at a particular index station but not for the region. Trend tests involved first plotting mean annual flow versus year for each potential index station for qualitative detection of trends in mean annual flow data. Kendall τ correlation tests, at 0.05 significance (Helsel and Hirsch, 1993), were run on each index station's mean annual flows to quantitatively determine if any long-term trends were evident. No regional long-term trends were detected, so no de-trending was required. However, slight trends in annual mean flow data were indicated at two potential index stations (11451500 and 11475800); these index stations were dropped from the analysis, as several other index stations were available for adjustment. A matrix of study-station and index-station pairings used in daily-value regression analysis for short-record streamflow-statistic adjustment is shown in *Appendix 1*.

Mean-Daily-Flow Regression Analyses

Concurrent mean-daily-flow values at study stations were plotted versus mean-daily-flow values at index stations. This relation was used to develop a regression equation (that described the study-station streamflows as a function of the index-station streamflows) that could be used to compute long-term study-station statistics from index-station statistics. The Ordinary Least Squares (OLS) fit was used if the relation was determined to be linear, and second order polynomial fit was used for curved relations. OLS regression was selected in lieu of the MOVE-1 (also known as line of organic correlation) technique because all statistics of interest generally were close to the center of the distribution of daily flows, rather than over a wide range of flows as MOVE-1 is recommended for. OLS also was chosen because of its more similar computational methodology to the polynomial regression. The criterion used in determining curvature was that if the R^2 for the polynomial fit was larger by 0.01 than that of the OLS fit, then the polynomial fit was used for adjustment. Degree of linearity or curvature was also evaluated qualitatively by graphical evaluation of study-station flow versus index-station flow plotting. It was found that stations with curved relationships met the R^2 criteria well. *Figure 5* shows such a curved relationship and resulting higher R^2 value for the polynomial fit. It was found that because most of the streamflow statistics of interest were not at the extremes (low or high) of the distribution of mean daily streamflows, the polynomial fits were not drastically different than the OLS in the region of interest, but that the polynomial trend lines matched the curvature better. *Figure 5* demonstrates this point as well.

For each regression, the computed residuals (the difference between regression-equation predicted and observed dependent variables) were plotted versus time in order to qualitatively evaluate possible issues with heteroscedasicity (nonconstant variance in datasets with respect to time). Residual plots from only a few sites indicated possible heteroscedasicity. The residual versus time plot in *figure 6* demonstrates possible heteroscedasicity; the residuals appear to slightly decrease over time in this example. Quantitative trend tests (Kendall τ correlation test, at 0.05 significance) were run between computed residuals and time. Only very slight trends (τ values within (+/-) 0.5) were indicated at the stations that had indicated possible heteroscedasicity in residual-versus-time plotting. Due to the short-term periods of record when restricted to concurrent flow data, the cyclical nature of hydrologic data was determined to be more the cause of this phenomenon than improper regression approach. Hydrologic data sets that do not indicate long-term trends may have detectable trends in subsets of the data set. This is due to the tendency for short-term below- and above-average periods of flow seen in most hydrologic time-series data. Therefore, regressions that indicate slight heteroscedasicity were still used for statistic adjustments, as trends were determined to be nonpersistent with time, and as no alternate means for record extension were available.

Adjustment of Flow Statistics via Regression Equations

The regression equations derived from the daily-value regressions were used in the adjustment of the study-station streamflow statistics. The first step in study-station statistics adjustment involved computation of the long-term streamflow statistics at each index station. These values were then used in the regression equation developed between each study and index station in order to compute long-term statistics for each study station. *Figure 7* demonstrates the use of this record extension technique for estimating long-term streamflow statistics at short-record study stations. For study stations that have multiple index stations, the individually computed long-term statistics were averaged by weighting via the regression coefficients of determination (R^2) and length of period of record, as the following equation indicates:

$$Q_{study} = \frac{\sum \{(R^2_{study-index} - 0.8)(POR)(Q_{study-index})\}}{\sum (R^2_{study-index} - 0.8)(POR)} \tag{6}$$

where

Q_{study} is the long-term streamflow statistic at the study station,

$R^2_{study\text{-}index}$ is the regression coefficient of determination from regression of each study-index pairing,

POR is the period of record (in years) of each index station used in study-index pairing, and

$Q_{study\text{-}index}$ is the streamflow statistic of interest computed from the regression equation developed in each study-index pairing.

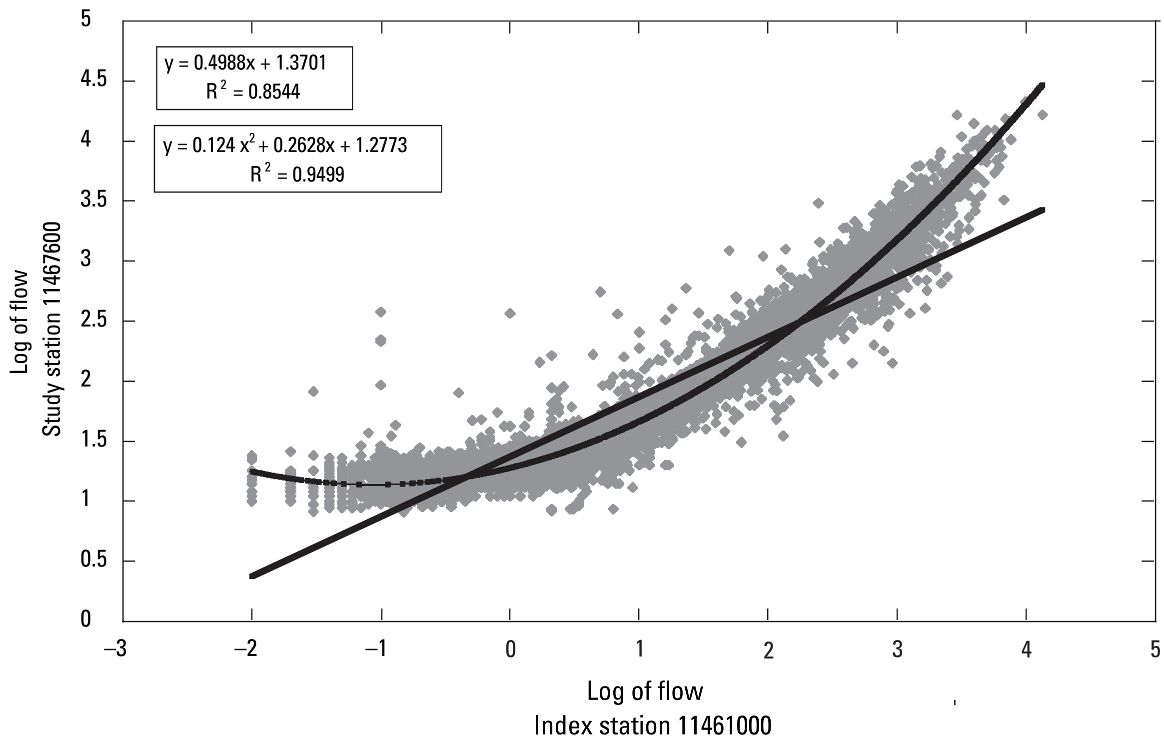

Figure 5. Example of curved versus straight-line relationship of study-station flow and index-station flow.

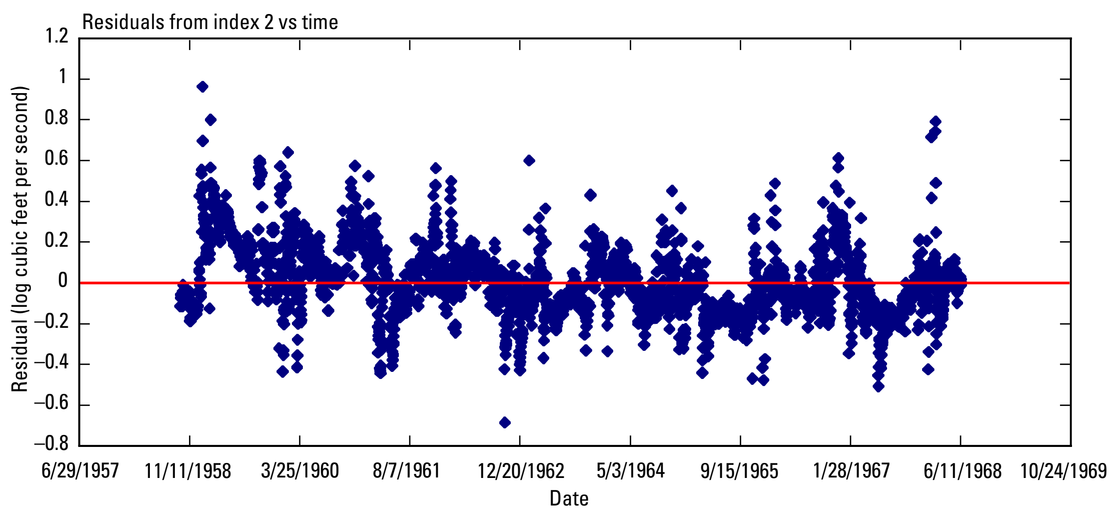

Figure 6. Example of regression residuals plotted versus time.

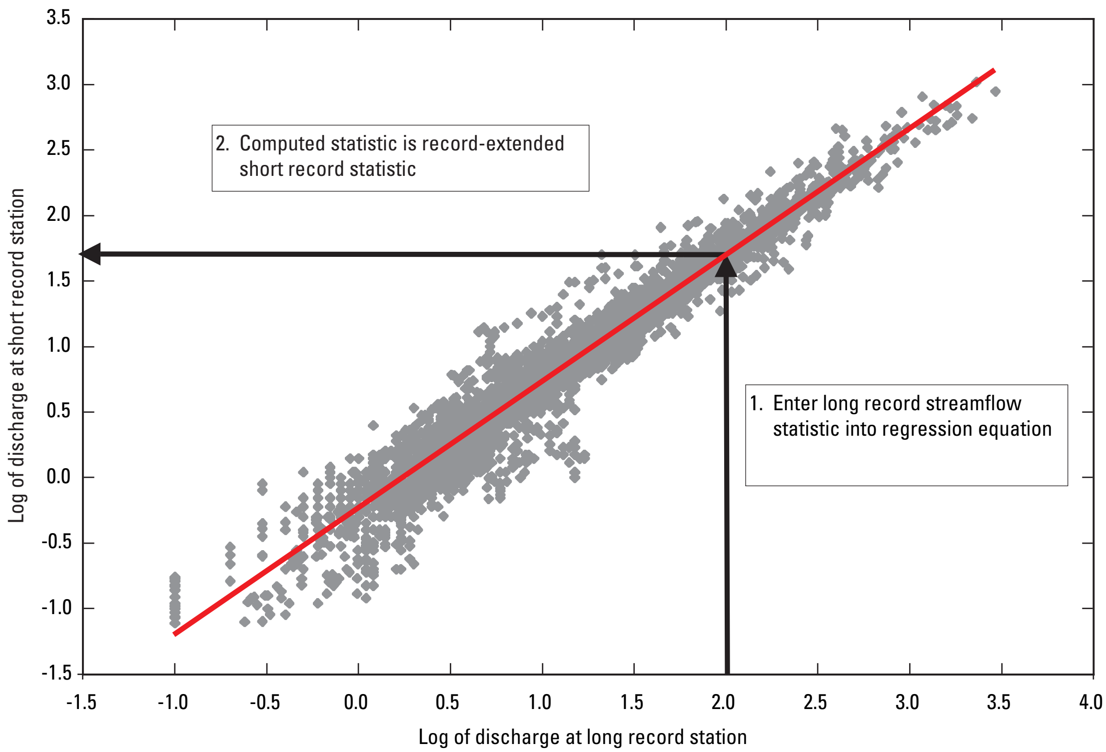

Figure 7. Example of extension of streamflow statistics for a short record station, using streamflow statistics from a long-record station.

December 15 to March 31 Mean Daily Flows for 25- and 50-Percentile Years

The SWRCB determined the specific years, as described in a preceding section, used to estimate the December 15 to March 31 mean daily streamflows for 25- and 50-percentile (dry and median) years. The USGS mean daily streamflows used for comparison with SWRCB estimated mean daily streamflows were obtained directly from ADAPS.

Flood-Frequency Analysis

Flood-frequency analysis was performed on 30 of the 40 study stations using U.S. Water Resources Council (WRC) methods outlined in Guidelines for Determining Flood Flow Frequency, Bulletin 17B (U.S. Interagency Advisory Committee on Water Data, 1982). A minimum of 10 years of peak-flow data is required under WRC guidelines for flood-frequency analysis. Of the 40 study stations, 10 stations did not meet this requirement, and were dropped from the analysis. WRC methods assume that the logarithms of annual peak flows at a given station follow a log-Pearson Type III probability distribution. A log-Pearson Type III frequency curve is calculated based on the mean, standard deviation, and skewness of the logarithms of annual peak flows. These procedures were implemented using the USGS computer program PEAKFQ (Thomas and others, 1998). PEAKFQ uses WRC methods for flood-frequency computations. Additional adjustments to the frequency curve recommended in Bulletin 17B, but not available in PEAKFQ, are described in the following sections.

Low-Outlier Thresholds

Outliers are data points that depart significantly from the trend of the remaining data. Low annual peak values that depart significantly from the trend of the remaining peaks are excluded from the systematic record used to define the frequency curve. A conditional probability adjustment, as described in Bulletin 17B, is applied to account for peaks below the low-outlier threshold. Flood-frequency analysis first was computed with default parameter values in PEAKFQ using the systematic record. An adjustment to the low-outlier threshold then was determined graphically from the resulting frequency plot of annual peaks generated by PEAKFQ. This value was selected on the basis of the point at which the lower-magnitude annual peak values began to depart from the trend of the plot of the annual peaks. *Figure 8* shows an example of graphical determination of a low-outlier threshold. Low-outlier threshold analysis was performed for each of the 30 study stations used for flood-frequency analysis (and for each long-term index station for the methods described in following sections). If a low-outlier threshold was determined, this value was entered into the input file for subsequent PEAKFQ computations. Of the 30 study stations, 18 stations were determined to have low-outlier thresholds.

Two-Station Comparison

Bulletin 17B recommends adjusting the logarithmic mean and standard deviation of a short-record flood-frequency distribution to a station with a longer period of record. As long-record index stations were available for each of the 30 study stations used for flood-frequency analysis, all stations were pre-determined to be suitable candidates for two-station comparison. However, two-station comparisons were applied only for study stations where a suitable index station had at least double the period of record of the study station and where the R^2 from the study-station versus index-station annual peak regression was greater than 0.8. A total of 24 study stations met these requirements.

As with the index stations used for streamflow-statistic adjustment, trend tests were run for annual peak flows versus time for all potential long-term index stations to determine if long-term trends in peak data were evident. Trend tests involved first plotting annual peak flows versus year, and then running Kendall τ correlation tests at 0.05 significance. No regional long-term trends were evident for annual peak flows. At one potential index station (11482500), a slight negative trend in annual peak flows over time was detected. This station was dropped from this analysis, as several other index stations were available that did not indicate trends.

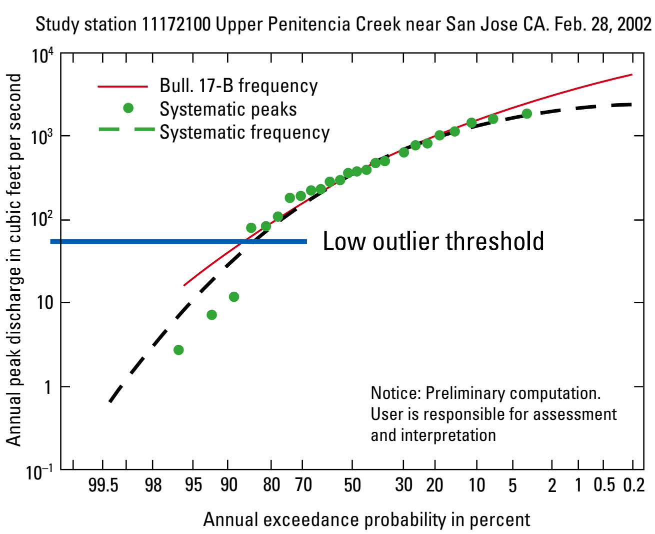

Figure 8. Example of graphical determination of low-outlier threshold for flood-frequency analysis.

The matrix of study-station and index-station pairings in *Appendix 1* also shows the index stations used for two-station adjustment. For index-station selections, mean-daily-flow records and peak-flow records did not always result in similar index-station selection for study-station correlations with mean-daily-flow regressions and two-station analysis. For a given study station, a given index station can correlate well with either mean-daily-flow records or peak-flow records, but not necessarily with both. Thus several study stations have different assigned index stations for two-station comparison than for short-record extension via mean-daily-flow regressions.

A spreadsheet program, previously developed and used by the USGS California District (Robert W. Meyer, U.S. Geological Survey, written commun., 2002), was used for two-station computations. Two-station comparison requires flood-frequency analysis for the following periods of record, as applicable, in order to adjust the mean and standard deviation for the short-term (study) station: (1) short-record station systematic period of record, (2) short-term station concurrent record with long-term station record (in many cases this is the same as the study-station systematic period of record), (3) long-term station systematic period of record, (4) long-term station concurrent record with short-term station record, and (5) long-term station nonconcurrent record with short-term record. *Table 7* lists the required input parameters for the two-station spreadsheet program. The routines performed by the two-station spreadsheet program are the same as detailed in Appendix 7 of Bulletin 17B. The logarithmic means, logarithmic standard deviations, and station skew were computed using PEAKFQ for each of the five required peak records for each two-station adjustment. The value ‘b’ refers to the slope of the regression line computed between concurrent short- and long-record peak flows. This value was computed using the Program for Robust Regression (PROGRESS) (Rousseeuw and Leroy, 1987) with the re-weighted least median of squares method (Rousseeuw, 1984). The generalized skew values for the north coast were taken from a map developed by the USGS of median skew values for six hydrologic regions in California (Richard M. Bloyd, U.S. Geological Survey, written commun., 1979). Values for generalized skew in the north coast region were either –0.2 (north of San Francisco Bay) or –0.5 (San Francisco Bay and south).

Historical Adjustment

Historical adjustment of frequency distributions is also recommended in Bulletin 17B. This analysis involves extending the record of the largest events to a historic period longer than that of the systematic record. As PEAKFQ has built-in capability for historic adjustment of frequency curves, this process involved only determination of the high-outlier threshold and historic period for input into PEAKFQ. The historic period and high-outlier threshold work in combination in flood-frequency analysis. The historic period is a period beyond the systematic gaging record in which there is confidence that no unknown peaks exceed the magnitude of

Table 7. Required input parameters for two-station adjustment.

Parameter	Description
N_1	Number of years of concurrent flow between short- and long-term stations.
N_2	Number of years of flows observed at long-record station for nonconcurrent period.
N_3	Number of years of flows at short-record station.
S_{x1}	Standard deviation, $\log_{10}$ of flows at long-record station, for concurrent period.
S_{x2}	Standard deviation, $\log_{10}$ of flows at long-record station, for nonconcurrent period.
S_{y1}	Standard deviation, $\log_{10}$ of flows, at short-record station, for concurrent period.
S_{y3}	Standard deviation, $\log_{10}$ of flows, at short-record station, for nonconcurrent period.
$\overline{X}_1$	Mean, $\log_{10}$ of flows, at long-record station, for concurrent period.
$\overline{X}_2$	Mean, $\log_{10}$ of flows, at long-record station, for nonconcurrent period.
$\overline{X}_3$	Mean, $\log_{10}$ of flows, at long-record station, for entire period of record.
$\overline{Y}_1$	Mean, $\log_{10}$ of flows, at short-record station, for concurrent period.
$\overline{Y}_3$	Mean, $\log_{10}$ of flows, at short-record station, for entire period of record.
b	Regression coefficient (slope) from robust regression long- versus short-record flows.
G_s	Station skew, $\log_{10}$ of flows, computed from entire short-record period of record.
G	Generalized skew, from map.

a threshold value (high-outlier threshold). A peak that occurs outside of the systematic gaging record is defined as a historic peak, and is flagged as such in the USGS annual peak-flow (highest peak occurring each year) dataset, or peak-flow file. Peaks that occur within the systematic gaging record are treated as a random sample of events, as per the fundamental assumptions of flood-frequency analysis. Peaks outside of the systematic gaging record are not considered to be random. If any historic peaks are greater in magnitude than the high-outlier threshold and a historic period is defined, then those peaks are considered to be the only peaks that exceed the threshold during the historic period. However, if no historic period is defined, or if any historic peaks are less in magnitude than the high-outlier threshold, those peaks are dropped from the flood-frequency calculations in PEAKFQ.

For two-station comparisons, all five required peak records received historical analysis. Historical analysis was performed using a spreadsheet program previously developed and used by the USGS California District. Many gaging stations, including the long-record stations used for two-station comparison, have periods of record that are not representative of long-term conditions. Long-term stations were used to determine the high-outlier threshold and historic periods for short- and long-record stations. This process involves plotting concurrent annual peak-flow records from long-term index stations against the peak-flow record of the study station. Six index stations were chosen for peak comparison with each study station. The Line of Organic Correlation (LOC) (also known as MOVE-1) regression technique was used to adjust the index-station peak record to study-station peak magnitudes. The LOC regression technique was selected over OLS due to its usefulness over a large range of values. For LOC, a high-outlier threshold value is determined such that no peaks outside the systematic record exceed the threshold for the period of time specified. The resulting plot of adjusted multiple-index-station and station-of-interest peak flows versus time was used to determine appropriate high-outlier thresholds and historic periods, as shown in *figure 9*.

If two-station analysis was not appropriate or possible at a given study station (owing to above criteria for appropriateness), historical analysis was used as the final adjustment for flood frequency at that study station. A total of five study stations not suitable for two-station analysis received only historical analysis. Two stations were not suitable for historic adjustment due to either poor index-station relationships or gaps in the annual peak-flow record that

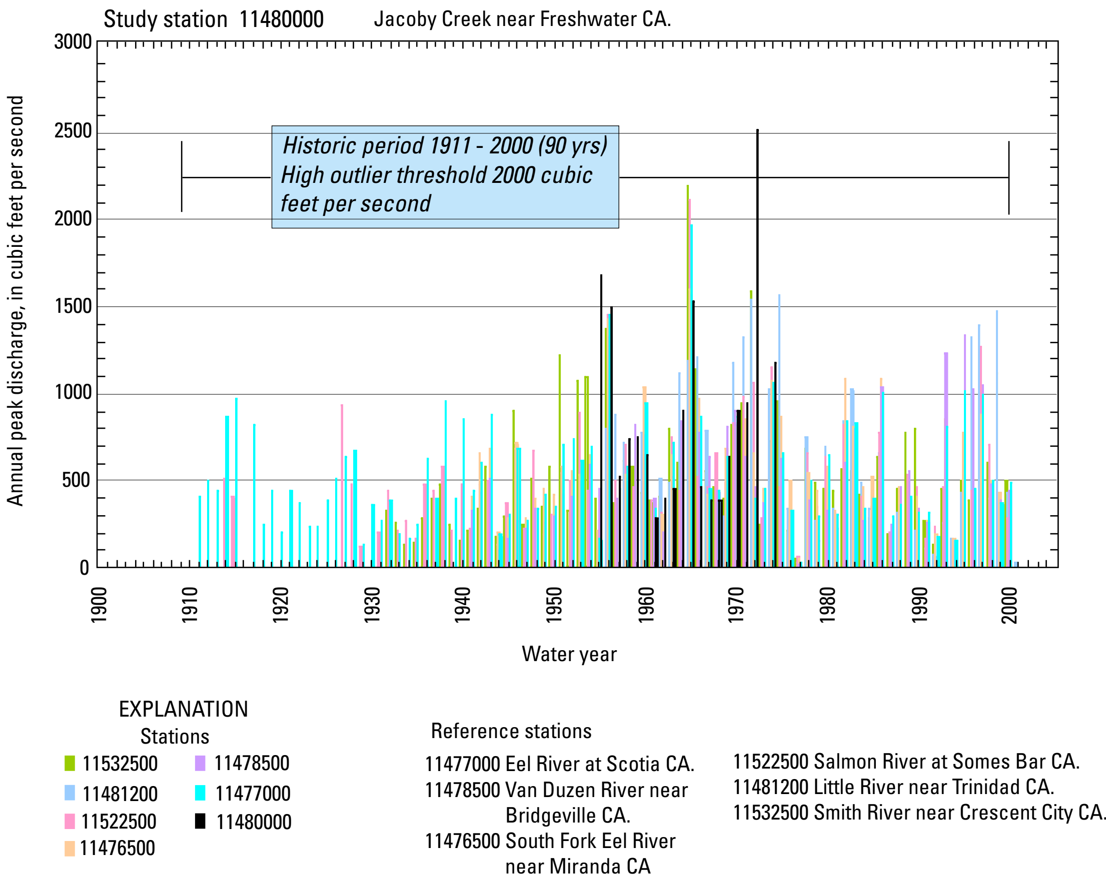

Figure 9. Graphical determination of high-outlier threshold and historic period for flood-frequency analysis.

missed important regional flood events. Of these two stations, station 11481500 did receive two-station adjustment. This left only station 11180500 that received no frequency curve adjustment aside from low-outlier threshold determination. *Table 8* summarizes the flood-frequency methods used for each of the 30 study stations that were used for flood-frequency analysis. If two-station analysis was done for a particular study station, the index station that was used is identified in *table 8*. *Table 8* also lists the number of years of record of annual peak flows for each study station.

Comparison Between SWRCB Estimated Flow Statistics and USGS Flow Statistics

Three comparative statistics (relative bias, relative standard error, and percent difference) were computed between SWRCB streamflow-statistic estimates and USGS streamflow statistics, or multi-station averages for a given statistic. All three statistics are expressed as percentages. Bias is a measure of the average difference between two data sets, while standard error describes the error of the fit of the two data sets. Bias is defined as the systematic error that is manifested as a consistent positive or negative deviation from the known or true value. Bias is a measure of precision, and standard error and percent difference are measures of accuracy. The bias and standard errors are expressed in relative form because data varies over orders of magnitude and the relative forms of these statistics are less affected by over-weighting of a relatively few large values. Percent difference (relative error) is the measured percentage difference between estimated and known or true values. Standard error is an estimate of the population error, while percent difference (relative error) is simply the error between estimated and known or true values. Computations for relative bias and percent difference are similar in form, but relative bias can be computed over a range of estimates while percent difference can be computed for individual estimates or for the averages of ranges of estimates. For example, relative bias was used for comparison of December 15 to March 31 mean daily flows, while percent difference was used for comparison of the average December 15 to March 31 mean

Table 8. Summary of flood-frequency methods applied and years of annual peak-flow record at 30 study stations with flood-frequency analysis.

[See *fig. 4* for station locations]

Station number	Two-station adjustment (index station)	Historic adjustment	Low-outlier threshold	Number of years of annual peak flows
11162540	11162500	X	X	13
11162600	11182500	X	--	11
11172100	11176000	X	X	27
11180500	--	--	X	45
11182500	--	X	X	48
11183700	11160500	X	--	15
11449500	--	X	X	54
11451100	11456000	X	X	29
11453200	11456000	X	X	15
11458200	11456000	X	X	15
11460100	11182500	X	X	18
11460800	--	X	X	20
11463900	11453500	X	X	20
11464860	11456000	X	X	10
11465150	11456000	X	--	12
11465800	11456000	X	--	11
11467600	11468000	X	X	26
11468070	11468000	X	--	12
11473600	11476500	X	--	12
11475560	11477000	X	X	34
11476600	11477000	X	X	40
11477700	11477000	X	--	12
11480000	--	X	X	19
11480390	11478500	X	--	20
11481200	11477000	X	--	45
11481500	11532500	--	X	29
11482125	11522500	X	--	12
11482468	11532500	X	--	13
11529800	11532500	X	--	15
11533000	--	X	X	12

daily flows. Computed relative bias and average percent difference usually are similar in magnitude. However, for mean daily flow estimates, when flow can be estimated as zero, relative bias and percent difference can vary from one another. In the following equations, Q_{SWRCB} refers to a given SWRCB estimate of a streamflow statistic or multi-station average of estimates and Q_{USGS} refers to the USGS streamflow statistic or multi-station average of statistics. In this analysis, relative bias is computed as

$$\text{R.bias}(\%) = 100\left(\frac{\sum \frac{Q_{SWRCB} - Q_{USGS}}{Q_{USGS}}}{n-1}\right) \tag{7}$$

the relative standard error is computed as:

$$\text{Std.error}(\%) = 100\sqrt{\frac{\sum \left[\frac{Q_{SWRCB} - Q_{USGS}}{Q_{USGS}}\right]^2}{n-1}} \tag{8}$$

and the percent difference (relative error) is computed as:

$$\%.\text{difference} = 100\left(\frac{Q_{SWRCB} - Q_{USGS}}{Q_{USGS}}\right) \tag{9}$$

Annual and Seasonal Runoff and February Median Flow Statistics

The mean annual runoffs, mean wet season (October 1 to March 31) runoffs, mean winter season (December 15 to March 31) runoffs, and February median flow estimated by the SWRCB were compared against USGS calculated statistics. SWRCB estimates of these statistics were plotted against USGS statistics for an overall qualitative evaluation of SWRCB results and to help detect trends in results. Relative biases and relative standard errors for each statistic (lumped-station) and percent differences for each station (per statistic) were computed for comparison between SWRCB peak-flow estimates and USGS peak-flow statistics. Percent differences between SWRCB and USGS estimates were mapped to determine whether or not SWRCB estimation errors were associated with geographic locations. Percent differences were also plotted against basin characteristics (drainage-basin area, station altitude, mean annual precipitation, 2-year/24-hour rainfall intensity, mean annual Class A pan evaporation, mean channel slope, channel length, altitude index, and distance to ocean) in order to test for estimation errors resulting from basin attributes.

SWRCB Annual and Seasonal Runoff and February Median Flow-Statistics Estimates versus USGS Statistics

The computed average relative biases and relative standard errors between SWRCB runoff and February median flow estimates and USGS flow statistics are tabulated in *table 9*. *Tables 10* and *11* list the computed percent differences between SWRCB estimated streamflow statistics and USGS streamflow statistics for all 40 stations, including summary statistics, for rain-based (*table 10*) and flow-based (*table 11*) estimates. Plots of SWRCB estimates of annual and seasonal runoff and February median flow statistics versus USGS statistics are shown in *figures 10* to *16*. Percent differences were scattered across the north coast region, but mean percent differences for each recurrence interval were similar in magnitude to relative biases.

Table 9. Computed errors between State Water Resources Control Board and U.S. Geological Survey annual and seasonal runoffs and February median flows.

[N/A, not applicable]

Flow statistic	Rain-based		Flow-based	
	Relative bias (percent)	Standard error (percent)	Relative bias (percent)	Standard error (percent)
Annual flow	-6.4	46.8	6.6	42.1
Oct. 1- March 31 flow	-4.5	46.7	2.0	41.4
Dec. 15- March 31 flow	-24.3	44.1	0.4	39.9
February median flow	N/A[1]	N/A[1]	-0.5	50.3

[1]The State Water Resources Control Board uses only flow-based methods for this statistic.

Table 10. Percent differences between State Water Resources Control Board rain-based flow-statistic estimates and U.S. Geological Survey flow statistics at 40 study stations.

[See *fig. 4* for station locations]

Station	Annual runoff	Oct. 1 – March 31 runoff	Dec. 15 – March 31 runoff
11162540	-1.1	4.0	-17.3
11162600	-25.1	-13.0	-28.5
11172100	-51.5	-50.4	-62.6
11180500	97.8	96.8	46.8
11182500	16.8	23.8	-4.7
11183700	140.5	159.7	104.3
11449500	-44.9	-42.8	-54.9
11451100	-44.9	-43.6	-52.6
11453200	-37.9	-38.8	-51.1
11458200	12.6	9.7	-16.0
11460100	-11.1	-13.4	-29.9
11460800	-6.9	-27.4	-51.5
11460920	59.6	51.1	9.5
11463900	-8.1	-7.1	-27.0
11464860	-25.1	-22.8	-36.3
11465150	-4.9	-9.4	-26.0
11465800	-7.3	-4.7	-23.8
11467600	-45.7	-43.4	-55.3
11467850	108.8	95.6	46.1
11468070	9.9	11.4	-10.7
11468540	42.9	22.6	-15.0
11469500	-32.4	-29.6	-41.3
11471800	-24.4	-30.7	-47.8
11473600	62.3	37.8	-1.1
11474781	-1.6	-0.1	-26.6
11475560	-18.5	-14.7	-33.3
11475940	-20.5	-18.7	-34.3
11476600	-53.0	-53.6	-61.8
11477700	-48.1	-45.6	-54.6
11480000	-14.6	-8.4	-24.7
11480390	-4.6	-7.4	-26.5
11481200	-36.1	-36.5	-44.9
11481500	-37.0	-34.6	-45.5
11482125	-43.7	-37.8	-45.7
11482468	-12.5	-13.6	-29.1
11522200	-12.3	28.9	9.8
11522260	-16.3	17.6	1.9
11529800	13.8	43.4	56.0
11532620	-91.7	-92.1	-93.7
11533000	-34.3	-36.3	-49.5
Maximum	**140.5**	**159.7**	**104.3**
Minimum	**-91.7**	**-92.1**	**-93.7**
Median	**-13.5**	**-13.2**	**-28.8**
Number of stations within +/- 25 percent	**19**	**18**	**11**
Number of stations within +/- 10 percent	**8**	**8**	**5**

Table 11. Percent differences between State Water Resources Control Board flow-based flow-statistic estimates and U.S. Geological Survey flow statistics at 40 study stations.

[See *fig. 4* for station locations]

Station	Annual runoff	Oct. 1 – March 31 runoff	Dec. 15 – March 31 runoff	February median runoff
11162540	-36.7	-37.3	-37.1	-51.8
11162600	-56.5	-51.1	-47.2	-62.3
11172100	-65.5	-66.3	-67.6	-88.4
11180500	-51.4	-52.6	-53.6	-86.5
11182500	-4.2	-6.5	-13.0	-48.0
11183700	117.3	117.4	105.7	55.2
11449500	-4.2	1.2	2.4	-39.3
11451100	-34.5	-77.3	-76.8	-94.7
11453200	13.6	8.7	8.2	8.3
11458200	12.5	5.4	6.1	58.4
11460100	96.6	97.9	103.5	75.0
11460800	64.6	33.3	13.3	12.3
11460920	25.6	23.8	16.7	16.7
11463900	-19.7	-18.4	-23.9	-46.3
11464860	2.8	7.5	6.8	21.4
11465150	9.4	5.7	4.2	31.2
11465800	1.5	6.4	2.7	6.3
11467600	-43.9	-40.9	-39.2	-45.7
11467850	5.6	-6.9	-9.3	170.6
11468070	21.3	22.2	23.4	8.4
11468540	73.9	49.8	36.3	39.6
11469500	3.7	5.8	7.0	-1.6
11471800	-26.6	-31.9	-36.2	-29.2
11473600	85.3	61.0	52.5	26.9
11474781	29.3	26.0	31.2	21.7
11475560	-2.2	-0.3	-0.3	-22.7
11475940	17.4	17.5	18.0	16.1
11476600	-4.3	-5.5	-4.1	-19.3
11477700	10.8	11.9	9.9	5.3
11480000	21.1	26.1	24.1	34.5
11480390	41.3	33.6	22.2	21.9
11481200	0.3	-2.2	-5.3	12.5
11481500	-15.8	-13.2	-19.8	-22.2
11482125	-5.7	2.4	10.9	3.7
11482468	14.1	10.6	12.6	20.7
11522200	36.7	52.9	58.7	48.5
11522260	-3.8	-37.4	-30.0	-9.8
11529800	-7.8	-10.7	-6.3	11.9
11532620	-79.2	-82.9	-82.3	-80.8
11533000	13.7	-9.0	-7.4	2.6
Maximum	**117.3**	**117.4**	**105.7**	**170.6**
Minimum	**-79.2**	**-82.9**	**-82.3**	**-94.7**
Median	**3.3**	**3.9**	**3.4**	**7.3**
Number of stations within +/- 25 percent	**23**	**22**	**25**	**20**
Number of stations within +/- 10 percent	**13**	**14**	**14**	**8**

Rain-based estimates generally were biased low (ranging from -4.5 percent to -24.3 percent), with standard error bounds ranging from 44.1 percent to 46.8 percent. Flow-based estimates generally were biased slightly high for annual and seasonal runoffs (ranging from 0.4 percent to 6.6 percent), with standard error bounds ranging from 39.9 percent to 42.1 percent. For the February median flow estimates, notable scatter in errors was apparent, but relative bias was -0.5 percent with a standard error bound of 50.3 percent. Thus, SWRCB rain-based estimates of annual and seasonal runoff totals were biased low with standard errors of estimation of about 45 percent. SWRCB flow-based estimates of annual and seasonal runoffs were biased slightly high with standard errors of estimation of about 40 percent. February median flow estimates were biased slightly low, but with notable scatter throughout the north coast region, and with standard errors of estimate of about 50 percent. Therefore, flow-based estimation methods performed better than rain-based methods in the north coast region, but either method is subject to large standard error. No geographic trends for estimation errors were apparent with any of the annual and seasonal runoff and February median flow statistics, as the errors appeared randomly distributed across the north coast region when mapped.

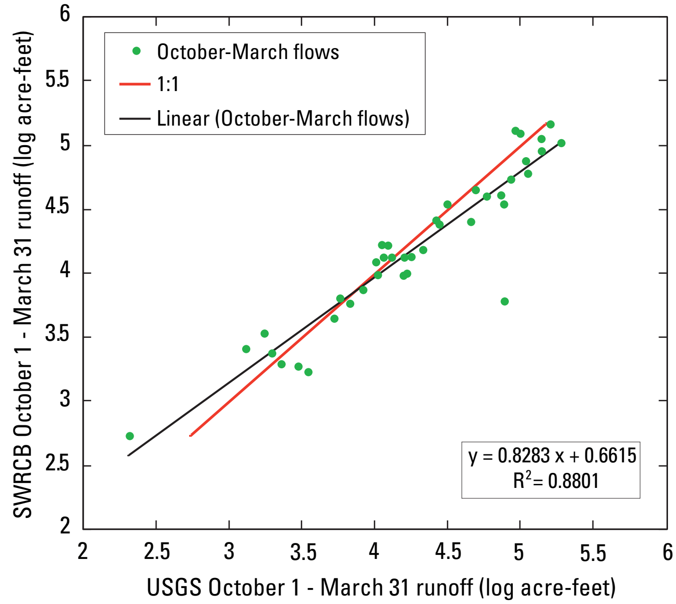

Figure 11. SWRCB rain-based October 1 to March 31 runoff estimates versus USGS October 1 to March 31 runoffs for all 40 study stations.

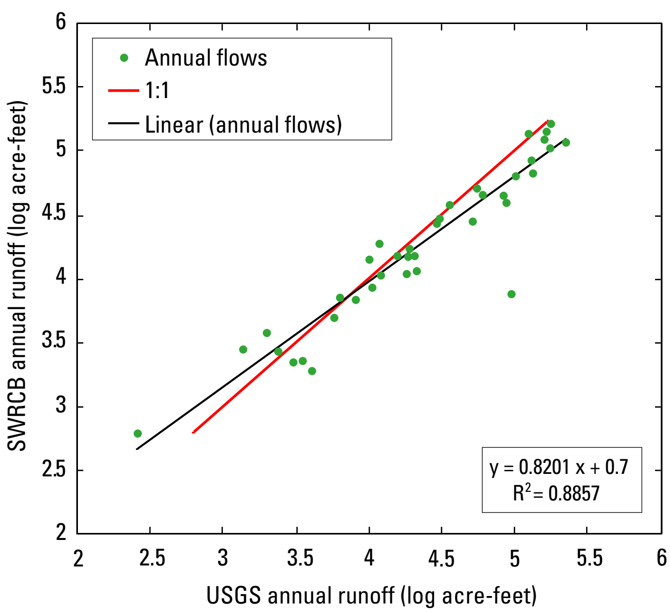

Figure 10. SWRCB rain-based annual runoff estimates versus USGS annual runoffs for all 40 study stations.

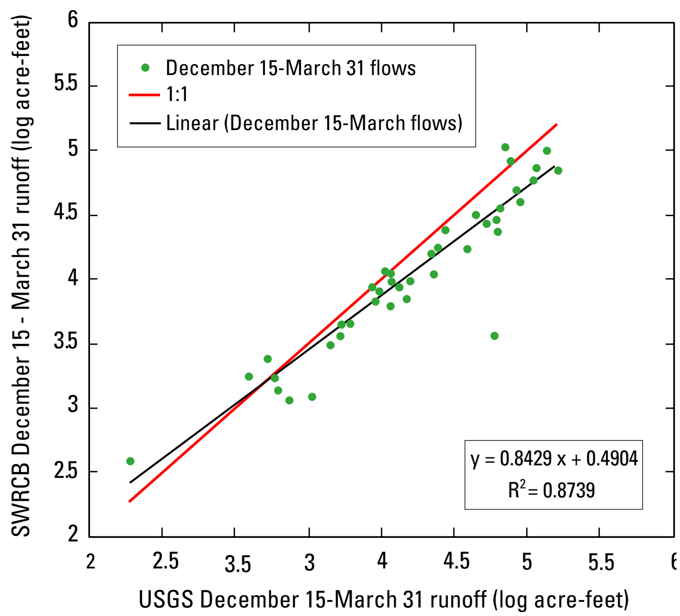

Figure 12. SWRCB rain-based December 15 to March 31 runoff estimates versus USGS December 15 to March 31 runoffs for all 40 study stations.

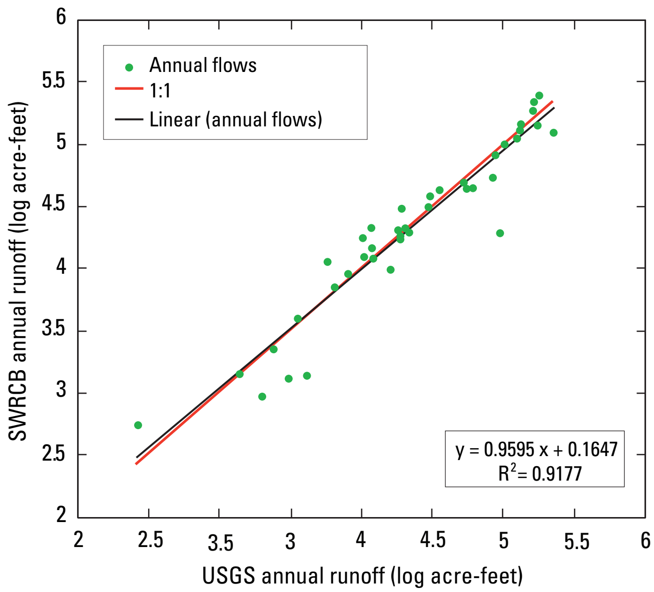

Figure 13. SWRCB flow-based annual runoff estimates versus USGS annual runoffs for all 40 study stations.

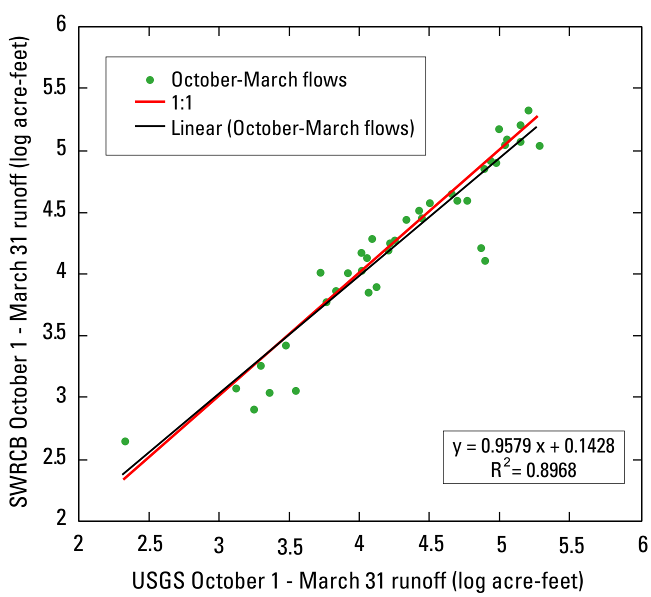

Figure 14. SWRCB flow-based October 1 to March 31 runoff estimates versus USGS October 1 to March 31 runoffs for all 40 study stations.

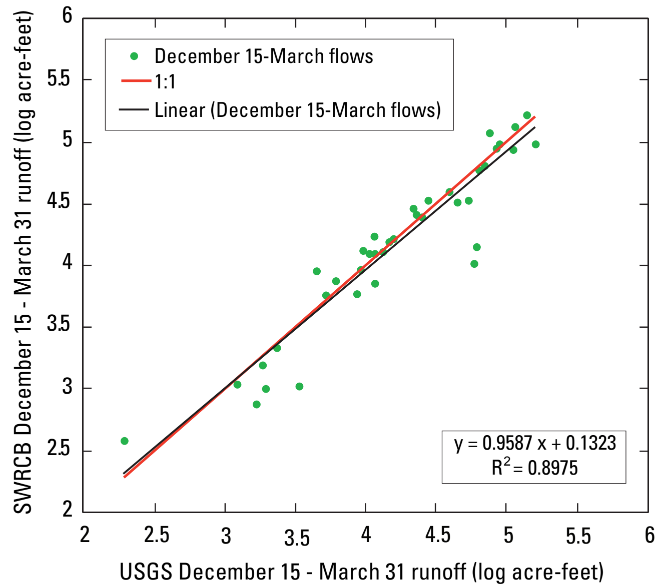

Figure 15. SWRCB flow-based December 15 to March 31 runoff estimates versus USGS December 15 to March 31 runoffs for all 40 study stations.

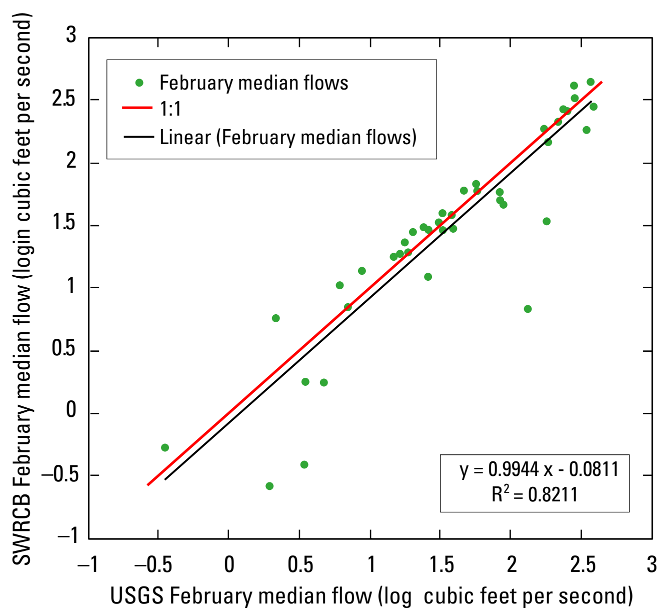

Figure 16. SWRCB flow-based February median flow estimates versus USGS February median flows for all 40 study stations.

Annual and Seasonal Runoff and February Median Flow Estimates: Station Percent Differences versus Basin Characteristics

Computed station percent differences for annual and seasonal runoffs and February median flows were plotted against station basin characteristics (drainage-basin area, station altitude, mean annual precipitation, 2-year/24-hour rainfall intensity, mean annual Class A pan evaporation, mean channel slope, channel length, altitude index, and distance to ocean) in order to qualitatively determine error correlation related to basin characteristics. Correlation tests (Kendall τ correlation test, at 0.05 significance) also were calculated between station percent differences for each statistic of interest and stations' basin characteristics to quantitatively determine if errors are correlated with basin characteristics. If a correlation coefficient signifies a trend, a scatter plot (error versus basin characteristic) should also confirm the correlation (Helsel and Hirsch, 1993). Therefore, Kendall τ correlation test results that signified a trend were disregarded if the correlation was not apparent in plotting. No significant correlations between estimation errors and basin characteristics could be identified from these analyses. Thus, none of the basin characteristics available to this study have an effect upon errors in estimation of annual and seasonal runoffs or February median flows.

Peak-Flow Statistics

Peak flows at the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals estimated by the SWRCB were compared against the USGS peak-flow statistics determined using flood-frequency analysis. SWRCB peak-flow estimates were plotted against USGS peak-flow statistics for an overall qualitative evaluation of SWRCB results. Relative biases and relative standard errors for each statistic (lumped-station) and percent differences for each station (per statistic) were computed for comparison between SWRCB peak-flow estimates and USGS peak-flow statistics. Percent differences between SWRCB and USGS estimates were mapped to determine whether or not there was geographic bias and error associated with SWRCB methods. Percent differences were also plotted against basin characteristics (drainage basin area, station altitude, mean annual precipitation, 2-year/24-hour rainfall intensity, mean annual Class A pan evaporation, mean channel slope, channel length, altitude index, and distance to ocean) in order to detect error or bias throughout the north coast region.

SWRCB Peak-flow Estimates vs. USGS Peak Flows

The computed average relative biases and relative standard errors between SWRCB's peak-flow estimates and USGS's peak-flow statistics are tabulated in *table 12*. The computed percent differences between SWRCB estimates and USGS statistics for each of the 30 stations used for flood-frequency analysis are tabulated in *table 13* along with summary statistics. Plots of SWRCB peak-flow estimates versus USGS peak-flow statistics are shown in *figures 17* to *22*. Percent differences had a wide range for study sites in the north coast region. Computed mean percent differences for each recurrence interval were similar in magnitude to computed relative biases.

SWRCB peak-flow estimates were biased low for 2-, 5-, 10-, 25-, 50-, and 100-year peak-flow estimates. However, negative relative bias was strongest for 2-year estimates and weakest for 100-year estimates. This is also indicated in the plots in *figures 17* to *22*. A reasonable explanation for this is that the USGS flood-frequency regional regression equations (Waananen and Crippen, 1977) are lacking the last two decades of peak-flow records since they were developed. Regionally, the largest floods were the 1956 and 1964 floods, and these were incorporated in the USGS equations; therefore, 50- and 100-year estimates may be more accurate. However, because more than two decades of smaller floods have occurred, the lower recurrence interval floods may be subject to the greatest error as the USGS equations become further out of date. Relative standard errors were fairly similar for all recurrence intervals, and ranged from 46.3 percent to 55.3 percent, and were similar to reported values for the USGS peak-flow equations (*table 6*). Thus, SWRCB estimates, in general, for 2-, 5-, 10-, 25-, 50-, and 100-year peak flows in the north coast region tended to be underestimated and subject to errors averaging about 50 percent. Mean percent differences for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals were plotted on maps of the north coast region in order to

Table 12. Average computed errors between State Water Resources Control Board and U.S. Geological Survey peak flows.

Recurrence interval (years)	Average relative bias (percent)	Average relative standard error (percent)
2	-24.3	55.3
5	-23.9	49.5
10	-19.0	47.7
25	-16.0	46.3
50	-8.5	47.3
100	-5.7	48.6

Table 13. Percent differences between State Water Resources Control Board peak-flow estimates and U.S. Geological Survey peak-flow statistics at 30 study stations used for flood-frequency analysis.

[See *fig. 4* for station locations]

Station	Recurrence interval (years)					
	2	5	10	25	50	100
11162540	-19.7	23.7	49.3	78.7	103.4	124.1
11162600	20.2	39.9	46.6	49.6	51.8	53.4
11172100	-94.0	-89.7	-86.5	-82.7	-79.6	-76.7
11180500	-65.7	-61.1	-56.5	-50.5	-44.3	-38.8
11182500	-86.7	-78.3	-72.0	-64.1	-57.3	-50.9
11183700	-59.7	-45.6	-35.3	-23.9	-14.6	-4.6
11449500	-70.8	-67.2	-63.0	-59.1	-53.1	-49.6
11451100	-41.6	-50.1	-50.9	-53.0	-50.6	-50.9
11453200	-68.1	-66.2	-62.3	-59.0	-48.5	-50.9
11458200	-56.8	-41.9	-29.3	-17.2	-4.5	2.7
11460100	-24.5	-33.5	-33.0	-35.0	-33.0	-34.6
11460800	-96.0	-89.4	-82.9	-72.7	-62.2	-51.5
11463900	-69.9	-62.8	-55.5	-47.6	-36.4	-28.5
11464860	-58.8	-53.0	-45.8	-38.9	-28.4	-22.1
11465150	-23.2	-32.8	-33.8	-37.8	-36.8	-39.4
11465800	-35.5	-40.5	-39.8	-41.6	-39.8	-41.3
11467600	-59.8	-60.3	-58.0	-56.9	-52.9	-51.6
11468070	-0.1	-14.9	-18.1	-25.2	-25.5	-29.7
11473600	-22.1	-15.1	-8.3	-6.5	0.2	-0.2
11475560	20.0	1.7	-0.8	-8.8	-7.3	-12.0
11476600	-9.4	-19.0	-18.4	-21.0	-17.4	-18.6
11477700	-55.2	-43.4	-30.7	-16.7	3.2	17.9
11480000	-23.9	-24.7	-21.4	-22.5	-19.3	-21.5
11480390	-23.8	-11.0	3.9	18.6	43.0	59.3
11481200	-24.3	-25.3	-20.7	-18.9	-11.9	-10.2
11481500	5.5	17.0	29.5	37.3	54.5	61.2
11482125	115.4	69.9	64.1	52.7	56.1	50.6
11482468	70.7	48.5	47.8	39.5	41.5	35.1
11529800	85.1	82.4	92.5	92.7	110.7	113.3
11533000	19.8	1.8	0.7	-6.0	-6.0	-11.5
Maximum	**115.4**	**82.4**	**92.5**	**92.7**	**110.7**	**124.1**
Minimum	**-96.0**	**-89.7**	**-86.5**	**-82.7**	**-79.6**	**-76.7**
Median	**-24.4**	**-33.1**	**-30.0**	**-23.2**	**-18.4**	**-20.0**
Number of stations within +/- 25 percent	**13**	**9**	**8**	**10**	**9**	**10**
Number of stations within +/- 10 percent	**3**	**2**	**4**	**3**	**5**	**3**

detect whether or not there was geographic bias with SWRCB estimation methods. Magnitudes of percent differences were randomly distributed across the north coast region, and no geographic bias was detected.

Peak-flow Estimates: Station Percent Differences versus Basin Characteristics

Computed station percent differences for 2-, 5-, 10-, 25-, 50-, and 100-year peak flows for the 30 stations used for flood-frequency analysis were plotted against basin characteristics for each of these stations in order to qualitatively determine error correlation related to basin characteristics. Correlation tests (Kendall τ correlation test, at 0.05 significance) also were run between station percent differences for each peak-flow statistic and stations' basin characteristics to quantitatively determine if errors are correlated with basin characteristics. No significant correlations between estimation errors and basin characteristics could be identified from these analyses. Thus, none of the basin attributes examined in this study have an important effect upon peak-flow estimation errors.

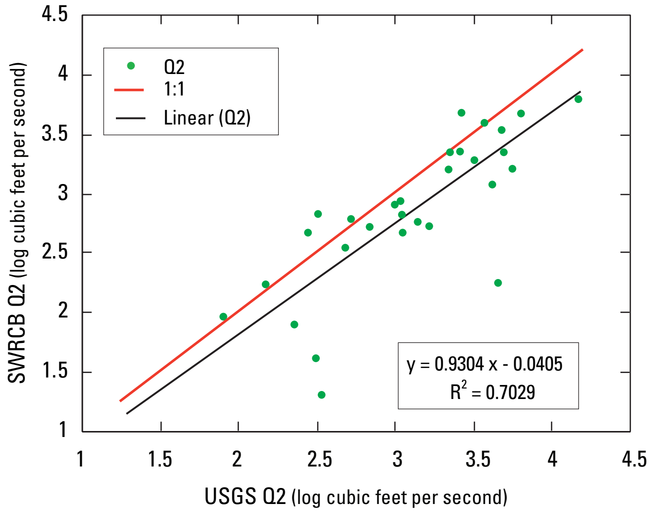

Figure 17. SWRCB estimated 2-year peak flows versus USGS 2-year peak-flow statistics.

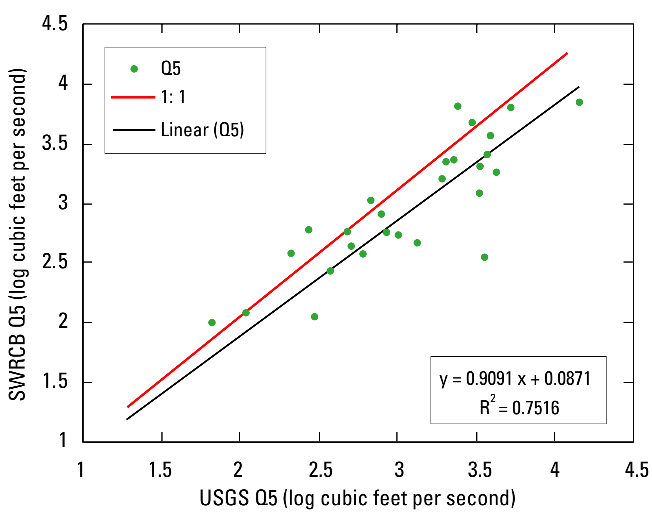

Figure 18. SWRCB estimated 5-year peak flows versus USGS 5-year peak-flow statistics.

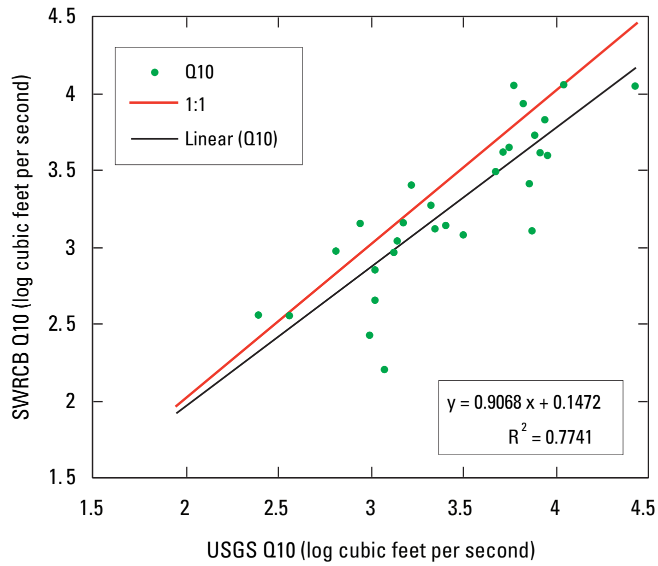

Figure 19. SWRCB estimated 10-year peak flows versus USGS 10-year peak-flow statistics.

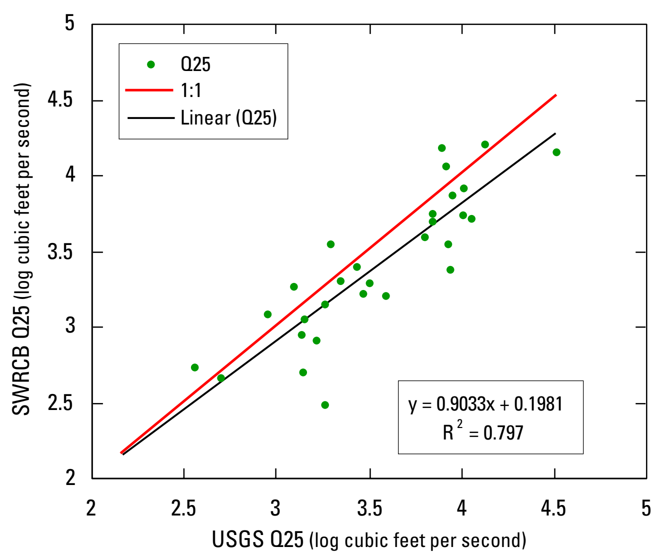

Figure 20. SWRCB estimated 25-year peak flows versus USGS 25-year peak-flow statistics.

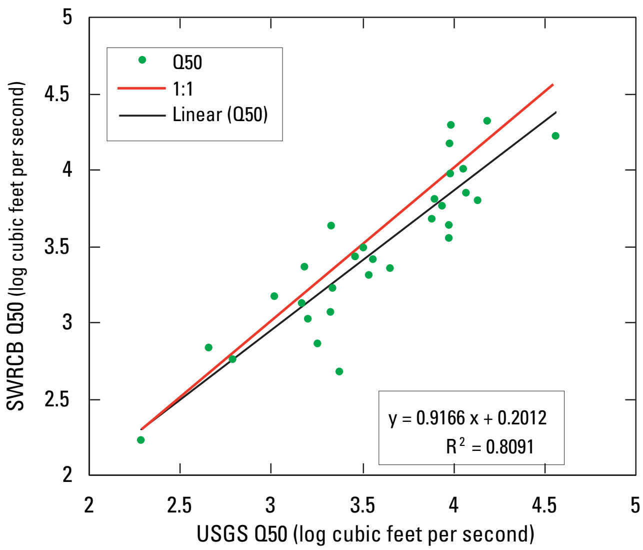

Figure 21. SWRCB estimated 50-year peak flows versus USGS 50-year peak-flow statistics.

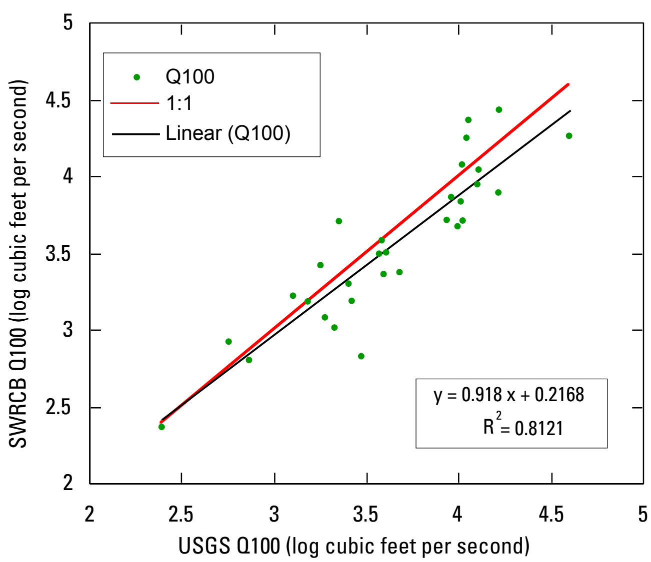

Figure 22. SWRCB estimated 100-year peak flows versus USGS 100-year peak-flow statistics.

December 15 to March 31 Mean Daily Flows for 25- and 50-Percentile Years

December 15 to March 31 rain-based and flow-based mean daily flows for 25- and 50-percentile years for all stations with estimates provided by the SWRCB were compared with USGS published mean daily flows. The SWRCB was not able to provide mean-daily-flow estimates for all 40 study stations owing to the unavailability of nearby concurrent raingage or streamflow gage data when restricted to the study-station period of record. *Table 14* lists the water year of the December 15 to March 31 mean-daily-flow estimates provided by the SWRCB for 25- and 50-percentile rain- and flow-based estimates. For some stations no nearby raingage or streamgage data were available, and for some no concurrent study-station data were available. For both 25- and 50-percentile rain-based methods, a total of 32 stations had estimates provided by the SWRCB that were comparable with USGS streamflow data. For both 25- and 50-percentile flow-based methods, a total of 34 stations had estimates provided by the SWRCB that were comparable with USGS streamflow data. Hydrographs (plotting SWRCB rain- and flow-based estimates and USGS published data) of 25- and 50-percentile year December 15 to March 31 mean daily flows were plotted for each station with estimates provided by the SWRCB.

For each station with estimates provided by the SWRCB, relative biases, relative standard errors, and percent differences were computed for both rain- and flow-based 25- and 50-percentile years' mean daily flows. Percent differences for each station for the average mean daily flow for the period of interest were calculated between SWRCB estimates and USGS published data. The computed relative biases, relative standard errors, and percent differences for each station were mapped in order to determine whether or not there was any geographic bias and error associated with SWRCB estimates. The computed relative standard errors from all stations' rain- and flow-based estimates, for both 25- and 50-percentile years, were plotted versus the various basin characteristics in order to qualitatively determine correlation between estimate errors and basin attributes. Kendall τ correlation tests, at 0.05 significance, were also run between standard errors and basin characteristics in order to quantitatively verify correlation between estimation error and basin characteristics.

SWRCB Mean-Daily-Flow Estimates versus USGS Published Mean Daily Flows

Appendix 2 contains hydrographs of combined SWRCB and USGS December 15 to March 31 mean daily flow for both 25- and 50-percentile years, for each station that had estimates provided by the SWRCB. Inspection of the December 15 to March 31 mean-daily-flow hydrographs provided the following general qualitative information about SWRCB estimation techniques. For flow-based estimates, the SWRCB mean-daily-flow hydrograph generally followed the trend of

Table 14. Water year for 25- and 50-percentile rain- and flow-based December 15 to March 31 mean-daily-flow estimates.

[See *fig. 4* for station locations. POR, period of record]

Station	25-percentile		50-percentile	
	Rain-based	Flow-based	Rain-based	Flow-based
11162540	1964	1964	1971	1971
11162600	1968	1968	1967	1967
11172100	1972	1972	1970	1970
11180500	1990	1990	1971	1971
11182500	1988	1988	1985	1985
11183700	1976	1976	1975	1975
11449500	1959	1959	1971	1971
11451100	1985	1985	1989	1989
11453200	1972	1972	1971	1971
11458200	1959	1959	1962	1962
11460100	Outside POR	Outside POR	Outside POR	Outside POR
11460800	1972	No Data	1970	No Data
11460920	1972	1972	1971	1971
11463900	1968	1968	1965	1965
11464860	1979	1979	1975	1975
11465150	1979	1979	Outside POR	Outside POR
11465800	1961	1961	1967	1967
11467600	1979	1979	1965	1965
11467850	Outside POR	Outside POR	1967	1967
11468070	1962	1962	1965	1965
11468540	1968	1968	1965	1965
11469500	1957	1957	Outside POR	Outside POR
11471800	1964	1964	1970	1970
11473600	1960	1960	1969	1969
11474781	No Data	1990	No Data	1995
11475560	1970	1970	1968	1968
11475940	Outside POR	Outside POR	1970	1970
11476600	1964	1964	1961	1961
11477700	1962	1962	1963	1963
11480000	1962	1962	1961	1961
11480390	1985	1985	1984	1984
11481200	1962	1962	1961	1961
11481500	No Data	1987	No Data	1984
11482125	1985	1985	Outside POR	Outside POR
11482468	1985	1985	1979	1979
11522200	1962	1962	1961	1961

the USGS hydrograph for most of the stations. Overall, the SWRC flow-based methods tended to underestimate mean daily flows, but results were variable by station. During lower-flow conditions there tended to be greater differences between SWRCB flow-based hydrographs and the USGS hydrographs. Overall, the SWRCB flow-based methods for estimating mean daily flows appeared viable, but subject to varying degrees of error. This may indicate the need for additional adjustment parameters beyond drainage basin area and precipitation ratios, in order to achieve greater accuracy with the flow-based method. For rain-based mean daily flows, the most important limitation with the rational method is that for days with no precipitation, streamflow also was calculated as zero. Thus for each day lacking rainfall, the rational method cannot be used to compute streamflow. During low-flow periods with low antecedent moisture conditions, SWRCB rain-based estimates were generally tremendously overestimated. For back-to-back storms, when antecedent moisture conditions are higher, the SWRCB rain-based estimates were generally closer to USGS streamflow data, but estimates were variably high or low with little consistency. Temporal changes in antecedent moisture conditions appeared to invalidate the use of a single value for the '*C*' parameter in the rational equation. Overall, SWRCB rain-based methods for estimating mean daily flow did not appear to be a viable method for estimating mean-daily-flow hydrographs.

Tables 15 and *16* list (for 25- and 50-percentile years, respectively) the computed relative bias and relative standard

Table 15. Computed relative bias and standard error between State Water Resources Control Board estimates and U.S. Geological Survey published data for 25-percentile year, for each station.

[See *fig. 4* for station locations. N/A, not applicable]

25-percentile year	Rain-based		Flow-based	
	Relative bias (percent)	Standard error (percent)	Relative bias (percent)	Standard error (percent)
11162540	64.7	416.9	-38.4	45.9
11162600	34.3	350.1	-42.7	52.9
11172100	94.5	794.8	-12.9	276.7
11180500	9,038.7	62,365.4	552.2	2,940.6
11182500	290.6	1,357.4	151.4	191.9
11183700	1,131.3	5,294.7	894.7	1,043.5
11449500	-27.2	216.7	-50.1	61.8
11451100	-34.9	262.6	-67.3	76.3
11453200	-59.0	126.7	-12.8	33.7
11458200	1,167.4	7,770.1	72.4	110.1
11460100	N/A	N/A	N/A	N/A
11460800	-71.6	128.7	N/A	N/A
11460920	2.6	273.0	12.7	71.7
11463900	-26.2	211.2	-14.1	18.2
11464860	44.6	553.4	9.2	41.9
11465150	5.1	269.2	70.2	97.9
11465800	26.9	395.8	38.8	63.8
11467600	23.6	576.3	-44.9	46.4
11467850	N/A	N/A	N/A	N/A
11468070	19.4	309.8	11.9	41.2
11468540	-16.6	180.7	55.7	68.7
11469500	-24.9	211.3	3.4	51.7
11471800	-16.1	172.1	-24.6	36.7
11473600	163.9	728.6	0.8	46.6
11474781	N/A	N/A	4.2	35.0
11475560	93.6	378.8	-11.8	26.0
11475940	N/A	N/A	N/A	N/A
11476600	-47.4	111.4	-16.4	29.2
11477700	-50.7	113.3	31.3	45.2
11480000	13.6	437.6	28.1	39.7
11480390	-16.3	257.3	70.8	91.6
11481200	-62.0	105.6	2.9	19.0
11481500	N/A	N/A	-2.3	21.5
11482125	-49.6	112.9	-12.1	26.0
11482468	0.6	241.6	50.6	62.7
11522200	154.2	554.7	77.0	83.8
11522260	N/A	N/A	N/A	N/A
11529800	N/A	N/A	-5.1	17.2
11532620	-96.4	96.3	-83.3	83.1
11533000	N/A	N/A	N/A	N/A
Maximum	**9,038.7**	**62,365.4**	**894.7**	**2,940.6**
Minimum	**-96.4**	**96.3**	**-83.3**	**17.2**
Median	**3.9**	**271.1**	**3.1**	**49.1**

Table 16. Computed relative bias and standard error between State Water Resources Control Board estimates and U.S. Geological Survey published data for 50-percentile year, for each station.

[See *fig. 4* for station locations. N/A, not applicable]

50-percentile year	Rain-based		Flow-based	
	Relative bias (percent)	Standard error (percent)	Relative bias (percent)	Standard error (percent)
11162540	-10.7	190.4	-29.6	31.1
11162600	-66.7	124.4	-67.0	67.8
11172100	77.0	598.7	-48.6	123.1
11180500	74.0	621.5	-72.9	76.4
11182500	36.2	352.6	-1.6	41.5
11183700	326.0	1,270.3	207.6	318.2
11449500	-72.2	94.3	-30.1	47.3
11451100	18.6	256.1	-80.5	83.1
11453200	-79.9	100.3	27.8	41.2
11458200	29.0	519.2	11.7	32.2
11460100	N/A	N/A	N/A	N/A
11460800	-74.9	112.2	N/A	N/A
11460920	-52.2	132.8	-8.0	42.3
11463900	-40.1	171.1	-43.2	45.8
11464860	-36.8	198.8	15.8	36.3
11465150	N/A	N/A	N/A	N/A
11465800	-62.3	126.5	-2.7	27.1
11467600	-57.8	124.5	-39.0	41.9
11467850	946.8	6,164.9	977.2	2,354.4
11468070	-18.8	217.3	9.2	44.7
11468540	-44.7	146.9	65.0	76.4
11469500	N/A	N/A	N/A	N/A
11471800	-61.1	104.6	-20.2	26.2
11473600	-61.7	82.9	6.6	21.5
11474781	N/A	N/A	50.3	73.5
11475560	112.8	491.9	-17.7	31.8
11475940	-53.2	109.5	32.8	66.9
11476600	-71.1	92.8	-19.6	38.2
11477700	-59.7	126.0	12.9	20.6
11480000	14.0	241.0	45.5	59.2
11480390	-43.5	179.9	40.1	49.2
11481200	-50.2	83.3	-2.2	19.0
11481500	N/A	N/A	-15.1	20.9
11482125	N/A	N/A	N/A	N/A
11482468	-2.9	237.2	19.5	45.9
11522200	3.6	315.4	41.6	57.7
11522260	-7.3	124.7	-10.6	21.6
11529800	N/A	N/A	4.6	21.2
11532620	-95.9	95.9	-83.0	82.7
11533000	N/A	N/A	N/A	N/A
Maximum	**946.8**	**6,164.9**	**977.2**	**2,354.4**
Minimum	**-95.9**	**82.9**	**-83.0**	**19.0**
Median	**-41.8**	**159.0**	**-1.9**	**43.5**

error between SWRCB rain- and flow-based estimates and USGS published data for each station, and summary statistics. For individual stations, relative biases and relative standard errors for mean-daily-flow estimates were variable across the north coast region. In order to detect geographic effects on estimate error, relative bias and relative standard error for each study station were plotted on north coast region maps. Geographic effect upon estimation error was indeterminate for most of the north coast region. However, very large estimation errors were found at the four east San Francisco Bay stations (11183700, 11182500, 11180500, and 11172100) and at station 11458200 to the north of these stations.

Average December 15 to March 31 Mean-Daily-Flow Comparisons

Computing the average December 15 to March 31 mean daily flow provided another useful comparison between SWRCB estimates and USGS published data. *Figures 23* to *26* show SWRCB average December 15 to March 31 mean daily flows versus USGS average December 15 to March 31 mean daily flows for the 25- and 50-percentile years for both rain- and flow-based estimates. Percent differences between SWRCB estimates and USGS data were computed for average mean daily flow for each station's 25- and 50-percentile rain- and flow-based estimates. *Table 17* lists the computed percent difference between average December 15 to March 31

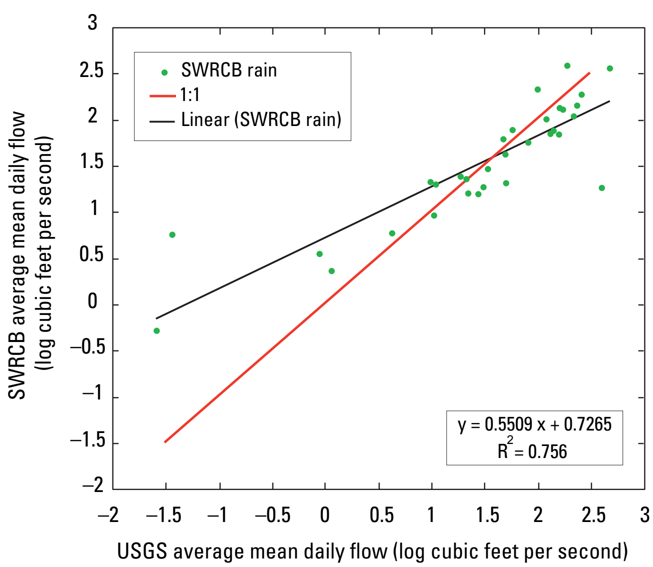

Figure 23. Rain-based dry (25 percent) year SWRCB average December 15 to March 31 mean daily flows versus USGS average December 15 to March 31 mean daily flows.

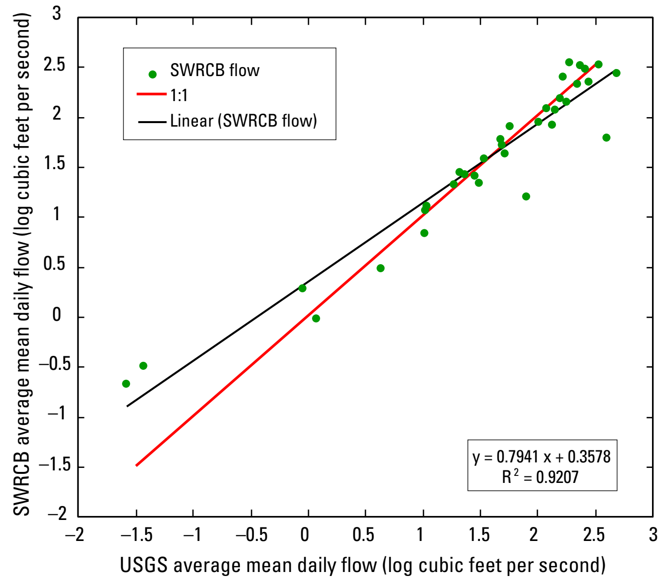

Figure 24. Flow-based dry (25 percent) year SWRCB average December 15 to March 31 mean daily flows versus USGS average December 15 to March 31 mean daily flows.

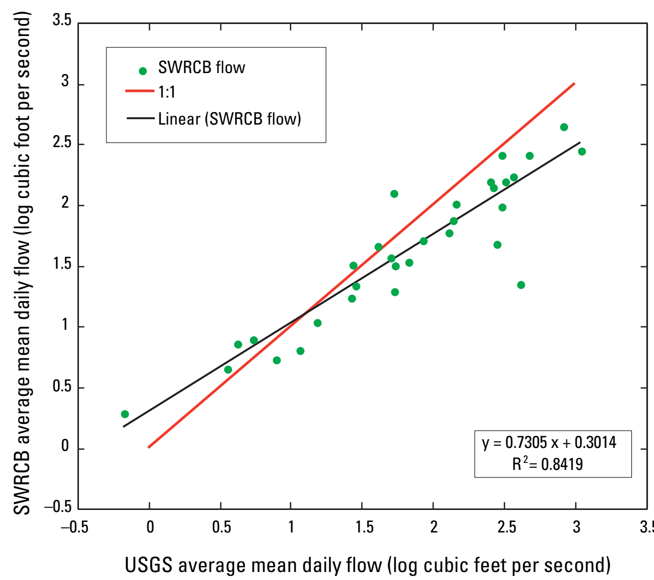

Figure 25. Rain-based median (50 percent) year SWRCB average December 15 to March 31 mean daily flows versus USGS average December 15 to March 31 mean daily flows.

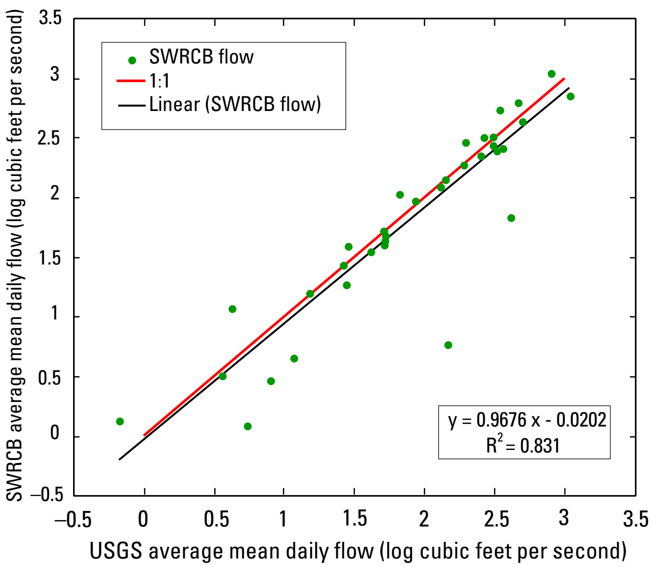

Figure 26. Flow-based median (50 percent) year SWRCB average December 15 to March 31 mean daily flows versus USGS average December 15 to March 31 mean daily flows.

mean daily flows for SWRCB rain- and flow-based estimates and USGS published data for each station, and summary statistics. For the 25-percentile year rain-based estimates, 25 of the 32 stations had percent differences between SWRCB estimates and USGS data that were within (+/-) 25 percent and 13 were within (+/-) 10 percent. For the 25-percentile flow-based estimates, 28 of the 34 percent differences were within (+/-) 25 percent and 24 were within (+/-) 10 percent. For the 50-percentile rain-based estimates, 28 of the 32 percent differences were within (+/-) 25 percent and 10 were within (+/-) 10 percent. For the 50-percentile flow-based estimates, 27 of the 34 percent differences were within (+/-) 25 percent and 25 were within 10 percent. Therefore, both rain- and flow-based methods generally would be viable methods for estimating average December 15 to March 31 mean daily flows.

December 15 to March 31 Mean-Daily-Flow Estimates for 25- and 50-Percentile Years: Relative Standard Errors versus Basin Characteristics

Relative standard errors for each station's mean-daily-flow estimates were plotted versus basin characteristics in order to detect errors correlated to specific basin characteristics. These plots are shown in *Appendix 3*. Standard errors plotted versus both mean annual precipitation and 2-year/24-hour rainfall intensity demonstrate a negative correlation for both 25-percentile rain- and flow-based estimates. For 50-percentile rain- and flow-based estimates, mean annual precipitation, 2-year/24-hour rainfall intensity, and channel length demonstrate negative correlation with standard error. That is, standard errors tend to decrease for increasing mean annual precipitation, 2-year/24-hour rainfall intensity, and channel length (50-percentile estimates only).

Kendall τ correlation tests, at 0.05 significance, also were run to quantitatively demonstrate any correlation between relative standard errors and specific basin characteristics. Results of the correlation tests between 25- and 50-percentile rain- and flow-based standard errors and basin characteristics are tabulated in *table 18*. If a correlation coefficient signifies a trend, a scatter plot (error versus basin characteristic) also should confirm the correlation (Helsel and Hirsch, 1993). Therefore, Kendall τ correlation test results that signified a trend were disregarded if the correlation was not apparent in plotting.

In summary, the greatest relative biases and standard errors between the 25-percentile year SWRCB estimated mean daily flows and USGS actual mean daily flows were for stations with mean annual precipitation less than or equal to 30 inches, and for estimated 2-year/24-hour rainfall intensity less than 3 inches. All of these stations are in the east San Francisco Bay area. For the 50-percentile year mean-daily-flow estimates, standard errors were various across the north coast region, but the east San Francisco Bay stations had large estimation errors for rain-based estimates. Mean annual precipitation and 2-year/24-hour rainfall intensity appeared to be the most important basin characteristics in correlation with estimation errors associated with 25- and 50-percentile year December 15 to March 31 mean-daily-flow estimates.

Table 17. Computed percent difference between December 15 to March 31 average mean daily flows for State Water Resources Control Board estimates and U.S. Geological Survey published data for each station.

[See *fig. 4* for station locations]

Station	25-percentile		50-percentile	
	Rain-based (percent)	Flow-based (percent)	Rain-based (percent)	Flow-based (percent)
11162540	31.21	-15.20	4.89	-11.24
11162600	24.02	-19.57	-23.41	-37.98
11172100	602.65	-114.66	-18.48	-47.19
11180500	-153.20	-66.78	22.09	-86.38
11182500	-1,096.75	-649.02	19.00	-8.34
11183700	-82.58	-59.07	-269.38	-177.52
11449500	-11.49	-2.20	-15.79	-0.07
11451100	-7.08	-35.59	-7.50	-64.03
11453200	-13.13	-8.78	-24.85	-0.50
11458200	27.08	8.73	-12.88	1.04
11460100	No Data	No Data	No Data	No Data
11460800	-21.56	No Data	-31.12	No Data
11460920	10.75	7.75	-8.36	-6.03
11463900	-5.06	-2.64	-12.29	-5.01
11464860	-2.88	2.82	-11.29	2.45
11465150	8.07	9.18	No Data	No Data
11465800	3.41	10.70	-13.28	-2.45
11467600	-4.17	-8.50	-19.15	-5.87
11467850	No Data	No Data	38.53	73.39
11468070	-2.75	1.92	-8.89	-2.06
11468540	-3.45	5.11	-15.83	11.20
11469500	-4.92	3.58	No Data	No Data
11471800	-11.97	-8.46	-12.66	-5.46
11473600	8.29	7.44	-11.84	0.43
11474781	No Data	-2.37	No Data	7.77
11475560	17.33	-1.35	23.24	-4.01
11475940	No Data	No Data	-8.32	4.72
11476600	-15.64	0.16	-19.92	-2.29
11477700	-8.43	6.72	-11.08	3.59
11480000	-11.25	6.55	-7.32	9.85
11480390	-2.82	9.49	-9.11	4.83
11481200	-12.26	1.03	-2.64	0.62
11481500	No Data	0.52	No Data	-1.78
11482125	-16.37	-0.73	No Data	No Data
11482468	-4.05	7.38	-11.59	2.32
11522200	14.22	12.27	-3.83	7.75
11522260	No Data	No Data	3.43	-3.72
11529800	No Data	-2.89	No Data	0.26
11532620	-50.92	-30.17	-47.73	-29.64
11533000	No Data	No Data	No Data	No Data
Maximum	**602.65**	**12.27**	**38.53**	**73.39**
Minimum	**-1,096.75**	**-649.02**	**-269.38**	**-177.52**
Median	**-4.55**	**-0.28**	**-11.44**	**-1.92**

Table 18. Results of the 25- and 50-percentile year rain- and flow-based average December 15 to March 31 mean-daily-flow estimates' relative standard errors versus basin characteristics' Kendall τ correlation tests.

[Bold indicates significant correlation at α = 0.05]

Basin characteristic	25-percentile year Rain-based		25-percentile year Flow-based		50-percentile year Rain-based		50-percentile year Flow-based	
	Kendall τ	p-value	Kendall τ	p-value	Kendall τ	p-value	Kendall τ	p-value
DA, drainage area (above gage)	-0.21	0.088	-0.14	0.25	**-0.26**	**0.036**	-0.14	0.24
A, station altitude	0.02	0.99	-0.02	0.84	0.01	0.91	-0.05	0.70
P, mean annual precipitation (1900-1960)	**-0.46**	**0.0002**	**-0.43**	**0.0003**	-0.23	0.06	-0.21	0.08
I, 2-year/24-hour rainfall intensity	**-0.36**	**0.004**	**-0.33**	**0.0065**	**-0.30**	**0.016**	-0.13	0.26
E, mean annual Class A pan evaporation	0.23	0.059	0.20	0.09	0.15	0.23	0.11	0.36
S, mean channel slope (determined between 10% and 85% distances from gage to basin divide)	0.16	0.20	-0.12	0.32	**0.27**	**0.031**	0.02	0.84
L, channel length (between gage and basin divide)	-0.17	0.17	-0.07	0.54	**-0.28**	**0.023**	-0.21	0.08
H, altitude index (determined between 10% and 85% distances from gage to basin divide)	0.04	0.72	-0.16	0.19	0.09	0.45	-0.12	0.30
DO, distance from gage to ocean (mean of west-to-ocean and southwest-to-ocean distances)	0.18	0.14	0.10	0.38	0.12	0.35	-0.01	0.92

Summary and Conclusions

While no new streamflow-statistic estimation techniques were developed in this study, a thorough evaluation of the SWRCB's estimation techniques has identified problems with currently used procedures. In order to properly allocate water rights, it is vital that the streamflow statistics used for such allocation are as accurate as possible and also are representative of long-term conditions. In general, the SWRCB's flow-based methods had smaller errors for flow-statistic estimation than rain-based methods. This was most apparent in mean-daily-flow estimation. Rain-based methods were universally unsuccessful in generating valid individual December 15 to March 31 mean-daily-flow hydrographs. However, for estimating the overall average of the December 15 to March 31 mean daily flow, both rain-based and flow-based methods performed well. For annual and seasonal runoffs, the flow-based methods performed better than the rain-based methods, but the errors between the two methods were not as large as for mean-daily-flow estimates. In general, both methods performed reasonably well, but with notable scattering in results across the north coast region. Rain-based methods for annual and seasonal runoff estimation were biased low with standard errors of estimation of about 45 percent. Flow-based methods for annual and seasonal runoff estimation were biased slightly high with standard errors of estimation of about 40 percent. The flow-based methods for estimating February median flow resulted in a greater range of values, but overall the estimates were slightly low with standard errors of estimation of about 50 percent.

The SWRCB used the USGS peak-flow equations (Waananen and Crippen, 1977) for estimating 2-, 5-, 10-, 25-, 50-, and 100-year peak flows in the north coast region. Thus, this study provided an opportunity to evaluate the accuracy of the USGS regional peak-flow equations. It was found that errors were greatest with lower recurrence interval (2-, 5-, and 10-year) peak flows and least with higher recurrence interval (25-, 50-, and 100-year) peak flows. Peak flows generally were underestimated with the USGS equations, and standard errors were about 50 percent. The standard errors computed in this study are similar to the standard errors associated with the USGS peak-flow equations. Relative bias ranged from -24.3 percent for 2-year peak flows to -5.7 percent for 100-year peak flows. The USGS equations likely are out of date, because they lack more than two decades of peak-flow data. Because the largest recorded floods are contained in the peak-flow data sets used to derive the USGS peak-flow equations, the lower recurrence interval peak-flow equations appear to be the most out of date. Revision of the USGS peak-flow equations with updated peak-flow data sets would be a valuable effort for the future. Nevertheless, the USGS peak-flow equations performed reasonably well in this study.

Little correlation was found between estimation errors and geographic location or various basin characteristics (drainage basin area, station altitude, mean annual precipitation, 2-year/24-hour rainfall intensity, mean annual Class A pan evaporation, mean channel slope, channel length, altitude index, and distance to ocean). For both rain- and flow-based annual and seasonal runoff estimates, February median flow estimates, and 2-, 5-, 10-, 25-, 50-, and 100-year peak-flow estimates, no important correlations were identified between estimation errors and geographic location or basin characteristics. For 25-percentile mean-daily-flow estimates, the greatest estimation errors were at stations with mean annual precipitation less than or equal to 30 inches, and estimated 2-year/24-hour rainfall intensity less than 3 inches. All of these stations are in the east San Francisco Bay area. For 50-percentile mean-daily-flow estimates, estimation errors varied more widely across the north coast region, but the east San Francisco Bay stations had larger estimation errors for rain-based estimates. Mean annual precipitation and 2-year/24-hour rainfall intensity appeared to be the most important basin characteristics in correlation with estimation errors associated with 25- and 50-percentile year December 15 to March 31 mean-daily-flow estimates.

Recommendations for Future Studies

This study was designed as a three-phase study, under which the work described in this report was the first phase. This phase was designed to be an evaluation of current flow-statistic estimation techniques, and a lead-in to future phases that would provide improved estimation techniques. Phases 2 and 3 were designed to produce improved estimation techniques in a format widely available to both the public and water resources agencies. Because of funding constrictions, phases 2 and 3 presently have been abandoned. However, future funding may allow for implementation of these phases.

The second phase was designed to develop multiple regression equations for estimating streamflow statistics by using basin characteristics developed with Geographic Information Systems (GIS). The GIS application was intended to develop a more robust set of various basin characteristics, than are currently available, using various topographic GIS coverages and Digital Elevation Models (DEMs). The basin characteristics then could be combined with published flow data, using multiple regression techniques, to produce improved estimation equations. Included in this phase, the north coast regional flood-frequency equations (Waananen and Crippen, 1977) would have been revised with updated peak-flow data and would have used the basin characteristics developed by GIS. The regression equations from phase 2 would be a valuable tool for the many agencies involved in water resources decision-making in the north coast region of California. Phase 2 efforts also could be expanded to other regions in California if a more statewide approach were desired.

The third phase was designed to use the USGS's StreamStats software to couple the multiple regression streamflow-estimating procedures from phase 2 with GIS coverages and software in a World Wide Web (Web) application (Ries and Friesz, 2000; Ries and others, 2000). StreamStats incorporates a map-based user interface for site selection, a database that provides streamflow statistics, and other information for data-collection stations, and a GIS program that measures physical characteristics of the drainage basins for ungaged sites and solves regression equations to estimate streamflow statistics for the sites. StreamStats users simply point and click on a map to get information for data-collection sites and ungaged sites. If phase-2 work were to be expanded into a statewide effort, the StreamStats Web application would be a valuable tool for use by both the general public and various water resources agencies in California. As future funding allows, implementation of phases 2 and 3 would provide valuable information and flow estimation techniques in a user-friendly format to a variety of interests in California.

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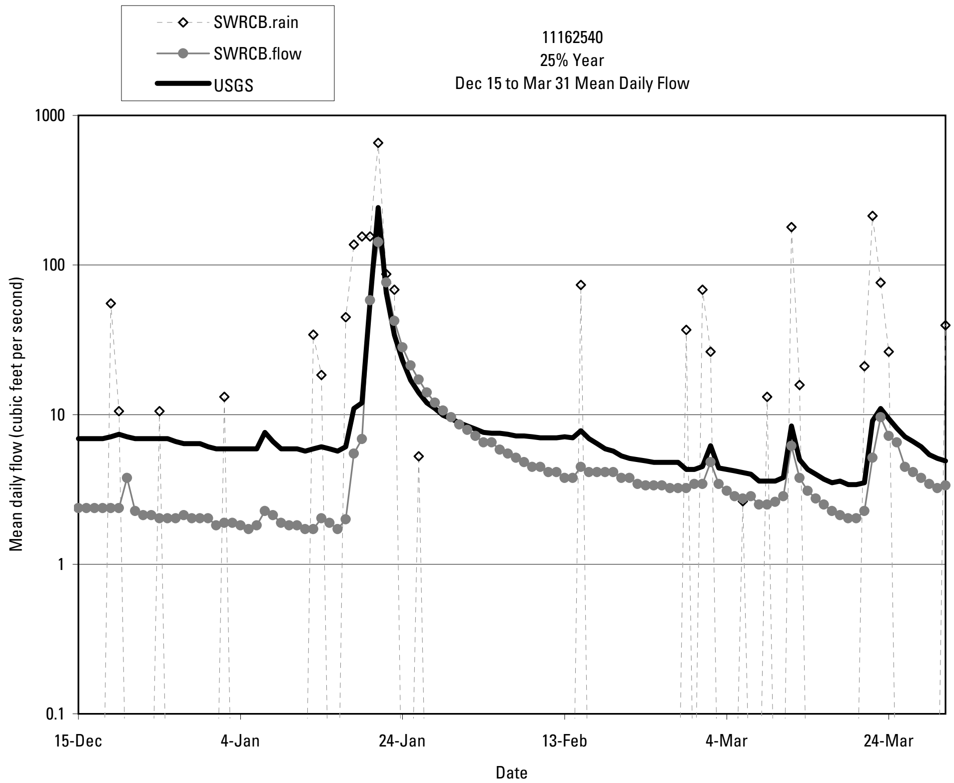
Appendixes

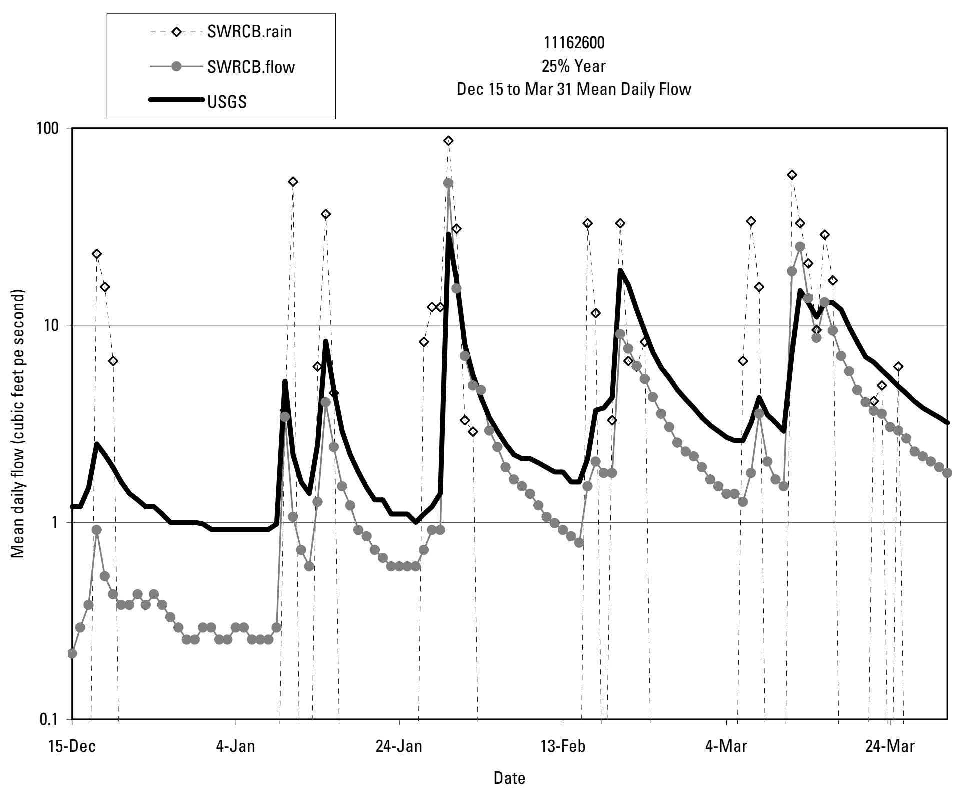
Appendix 1. Matrix of study station and index station pairings for both daily value regressions for streamflow statistic adjustment and two-station adjustment for flood-frequency analysis.

Study stations		Regional index stations																													
Number	Name	11160500	11162500	11176000	11176400	11180500	11182100	11182500	11449500	11451500 *	11453500	11456000	11461000	11464500	11468000	11468500	11469000	11472200	11473900	11475560	11475800 *	11476500	11476600	11477000	11478500	11481200	11482500 **	11521500	11522500	11528700	11532500
11162540	Butano C nr Pescadero	D	DP																												
11162600	Purisima C nr Half Moon Bay	D	D					P																							
11172100	Up Penitencia C at San Jose			DP	D	D																									
11180500	Dry C at Union City***																														
11182500	San Ramon C at San Ramon***																														
11183700	Little Pine C nr Alamo	P					D	D																							
11449500	Kelsey C nr Kelseyville***																														
11451100	NF Cache C at Hough Spring nr Clearlake Oaks								D			P	D																		
11453200	Dry C nr Middletown										D	P		D																	
11458200	Redwood C nr Napa											DP																			
11460100	Arroyo Corte Madera D Pres at Mill Valley ****							P																							
11460800	Walker C nr Tomales-Pre-regulation											D																			
11460920	Salmon C at Bodega@											D																			
11463900	Maacama C nr Kellogg										DP	D		D																	
11464860	Warm Springs C nr Asti										D	DP		D																	
11465150	Pena C nr Geyserville											DP		D																	
11465800	Santa Rosa C nr Santa Rosa										D	DP		D																	
11467600	Garcia R nr Point Arena												D	D	DP																
11467850	Soda C Trib nr Boonville #												D		D																
11468070	SF Big R nr Comptche												D		DP	D															
11468540	Pudding C nr Fort Bragg #															D				D											
11469500	NF Mattole R at Petrolia #																D														
11471800	Tomki C nr Willits #												D					D													
11473600	Short C nr Covelo																	D	D	D		P									
11474781	Combined flow of 11474750 + 11474780 #																	D	D	D		D			D						
11475560	Elder C nr Branscomb***																							P							
11475940	EB SF Eel R nr Garberville #																	D		D		D			D						
11476600	Bull C nr Weott***																							P							
11477700	Little Van Duzen R nr Bridgeville																					D	D	P	D						
11480000	Jacoby C nr Freshwater																								D	D					
11480390	Mad R abv Ruth Res nr Forest Glen																					D			P					D	
11481200	Little R nr Trinidad***																							P							
11481500	Redwood C nr Blue Lake****																														P
11482125	Panther C nr Orick																									D	D		P		
11482468	Little Lost Man C at Site No 2 nr Orick																									D	D				P
11522200	Elk C nr Happy Camp #																											D	D		
11522260	Ti C Nr Somes Bar #																											D			
11529800	Willow C nr Willow C																										D			D	P
11532620	Mill C nr Crescent City #																										D				D
11533000	Lopez C nr Smith R																										D				D

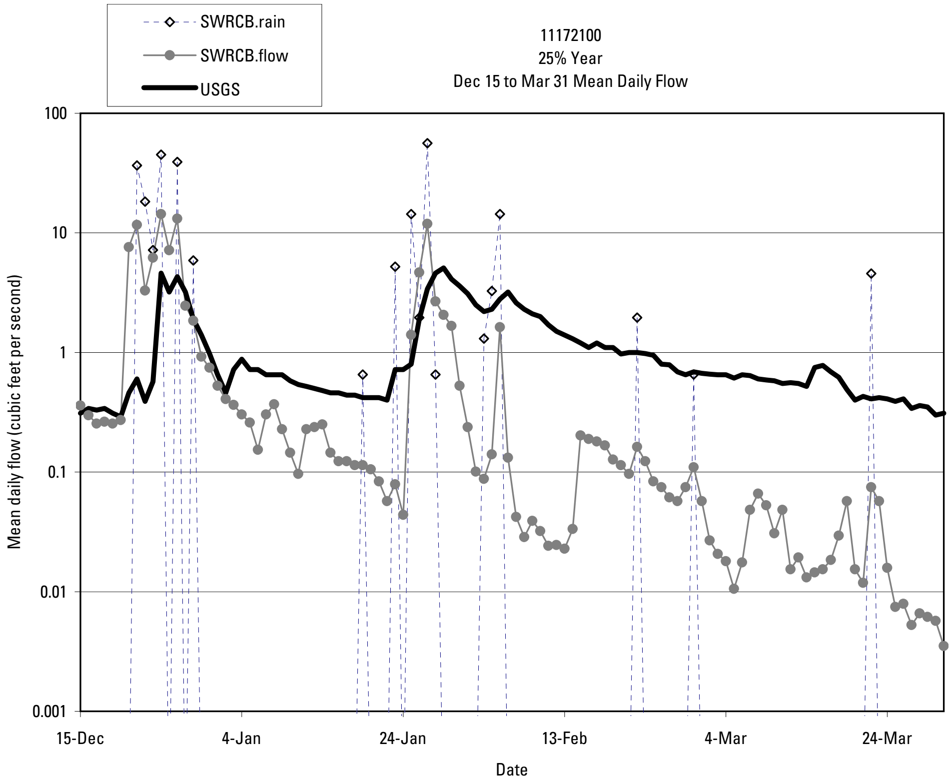
D Index station used to improve daily-values flow statistics (may be several per study station).
P Index station used to improve flood-frequency statistics (one per study station).
* Trend in daily-values. Not suitable for use as index station for daily-value flow statistics adjustments.
** Trend in annual peak flows. Not suitable for use as index station for flood-frequency statistics adjustments.
*** Also used as an index station. Daily-values flow statistics computed directly from station data, without adjustment.
**** No suitable index station for daily-values flow statistics. Flow statistics computed directly from station data, without adjustment.
# Insufficient annual peak flow data. Flood-frequency statistics not determined.
@ Questionable peaks in record. Flood-frequency statistics not determined.

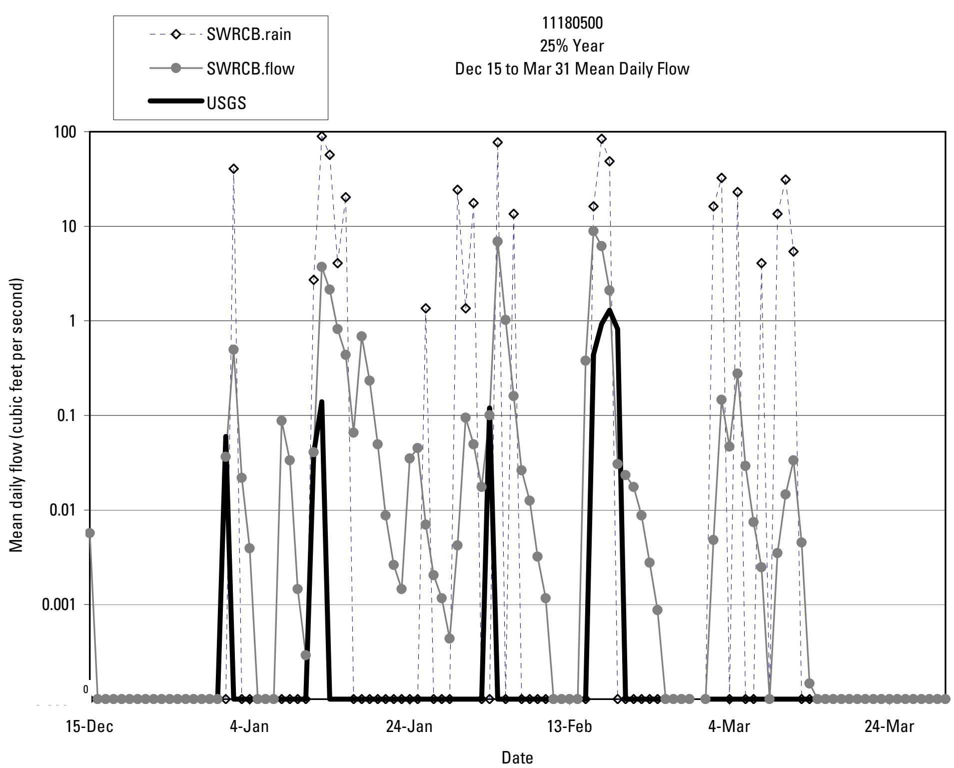
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.



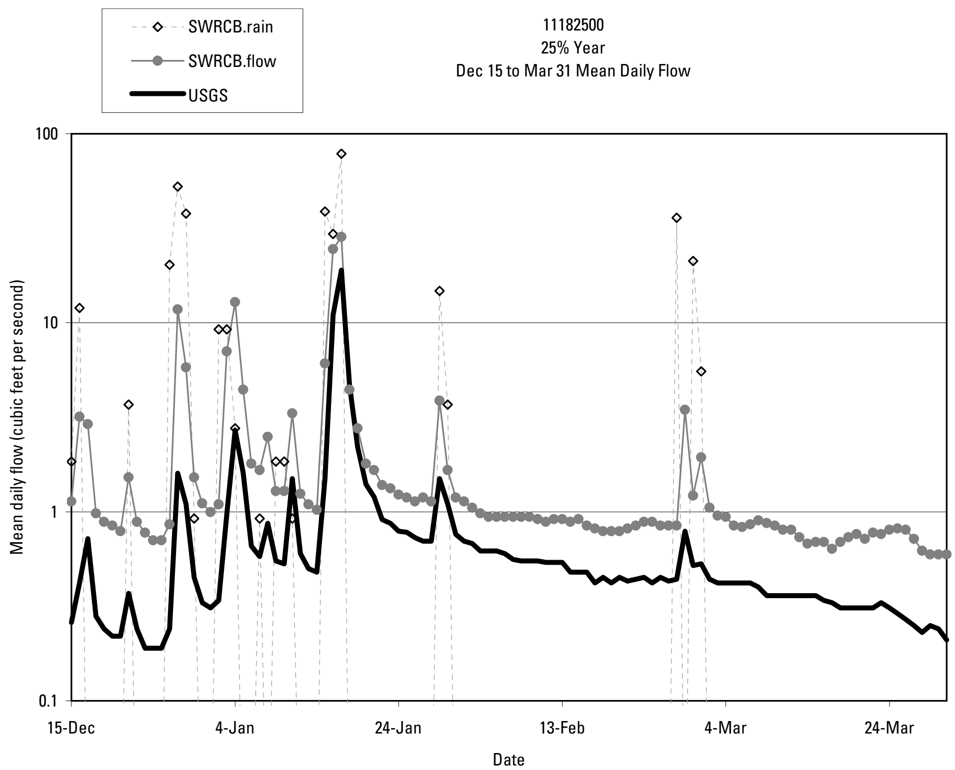


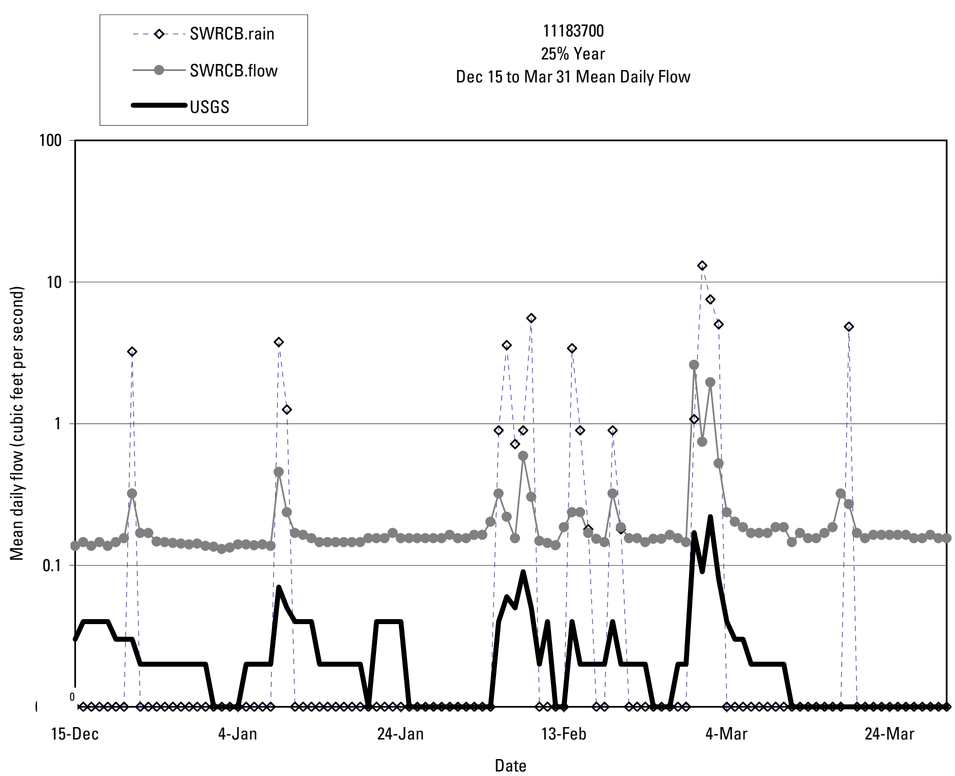
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



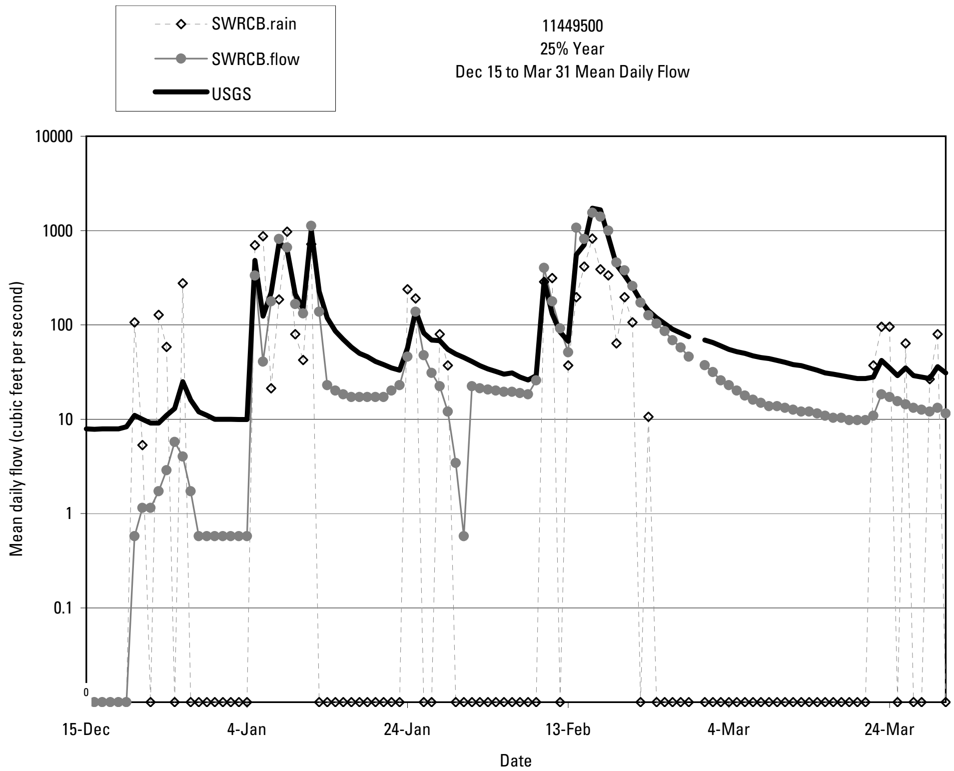


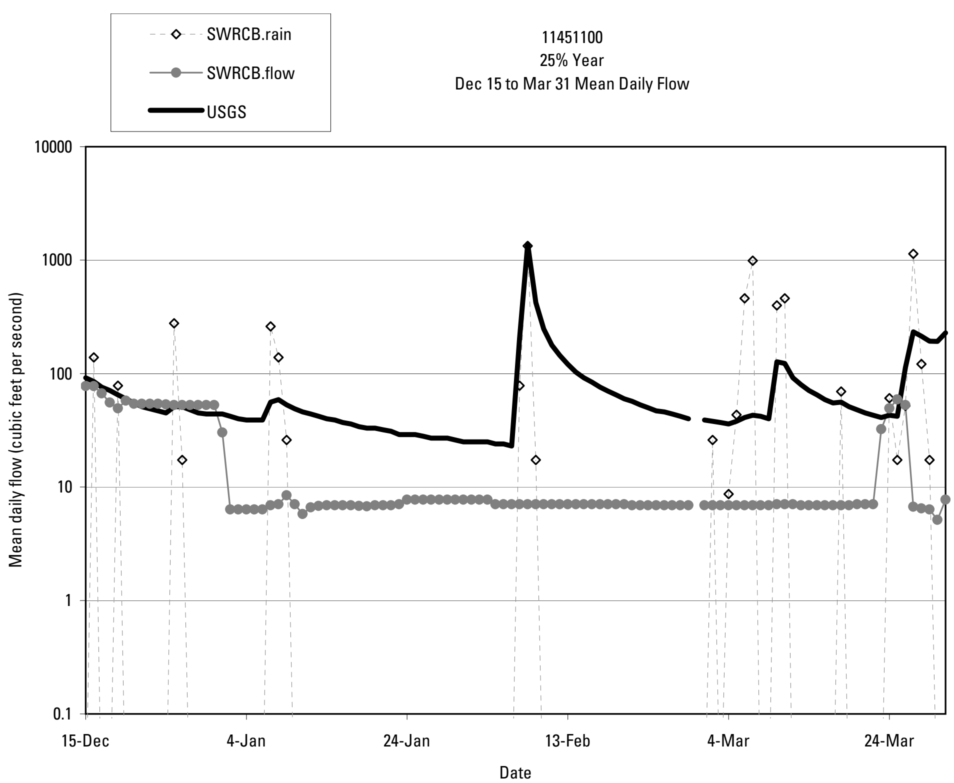
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



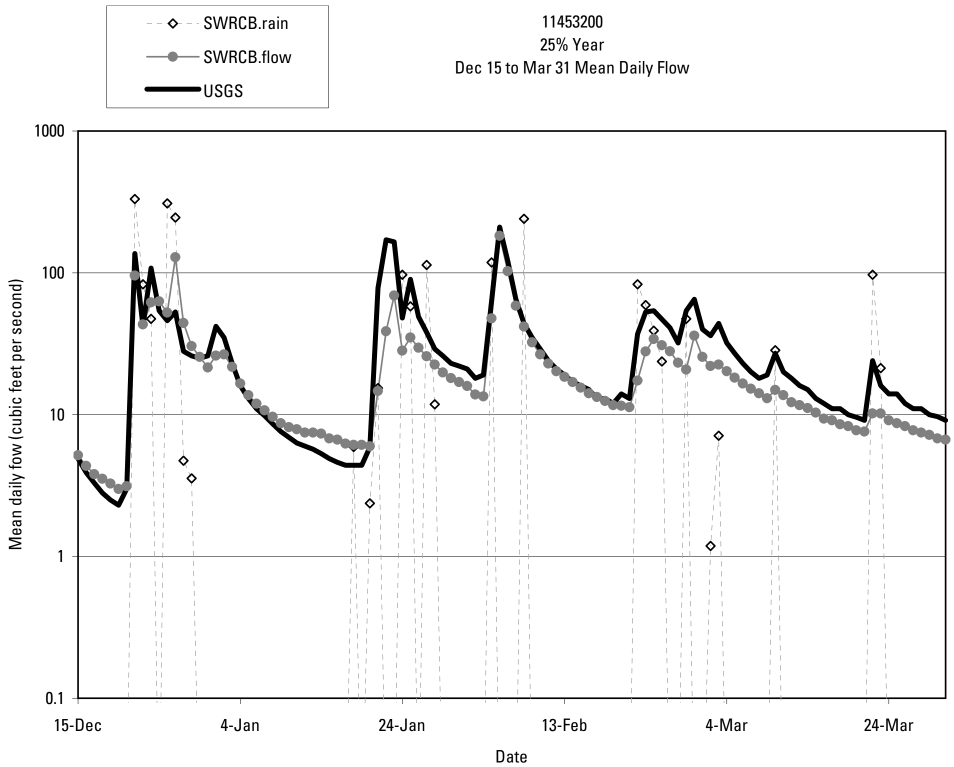


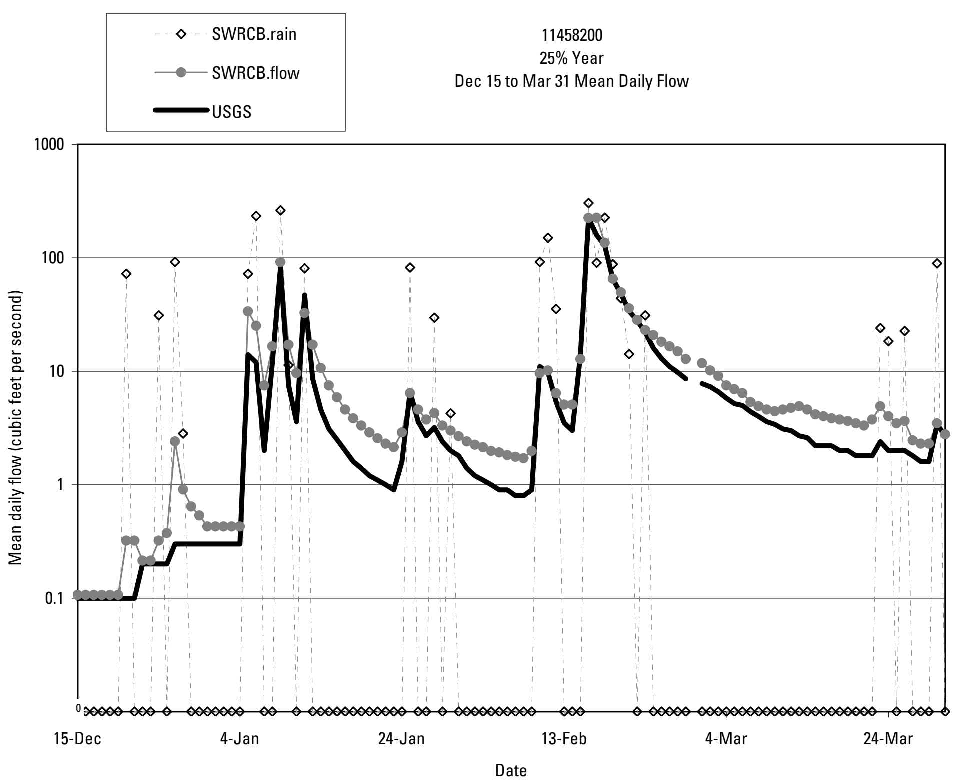
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



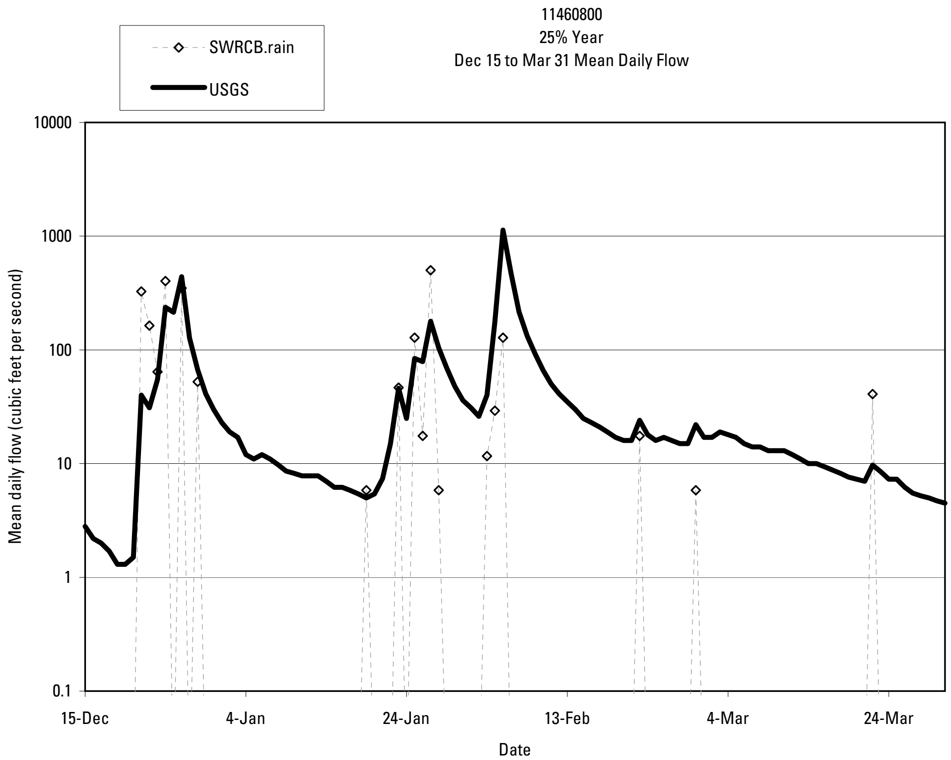


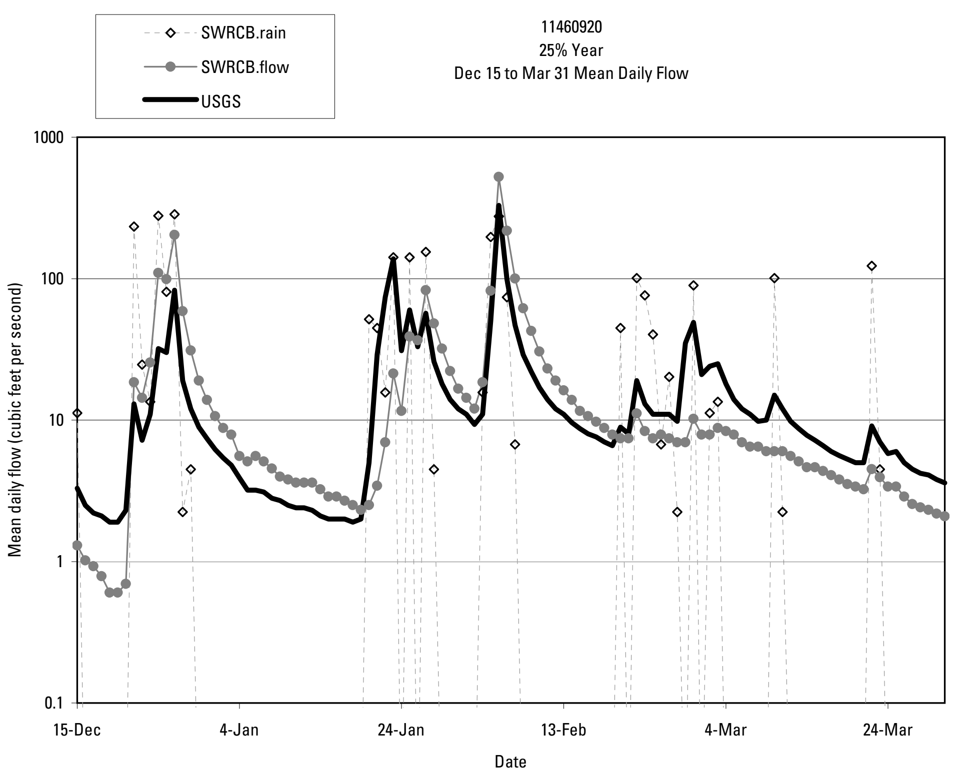
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



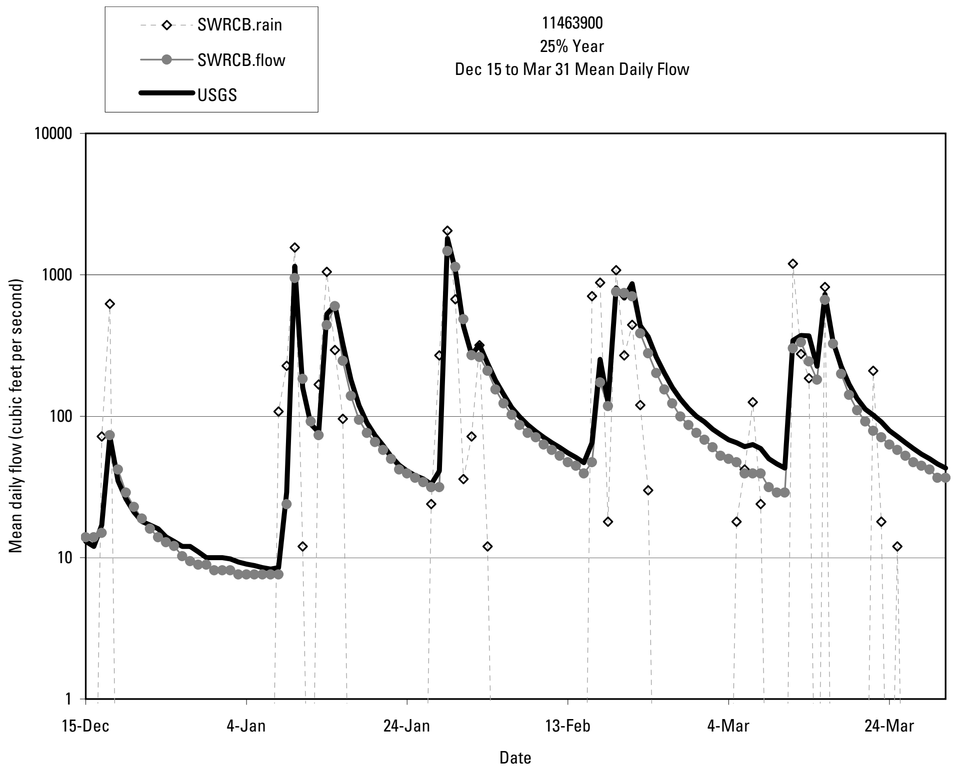


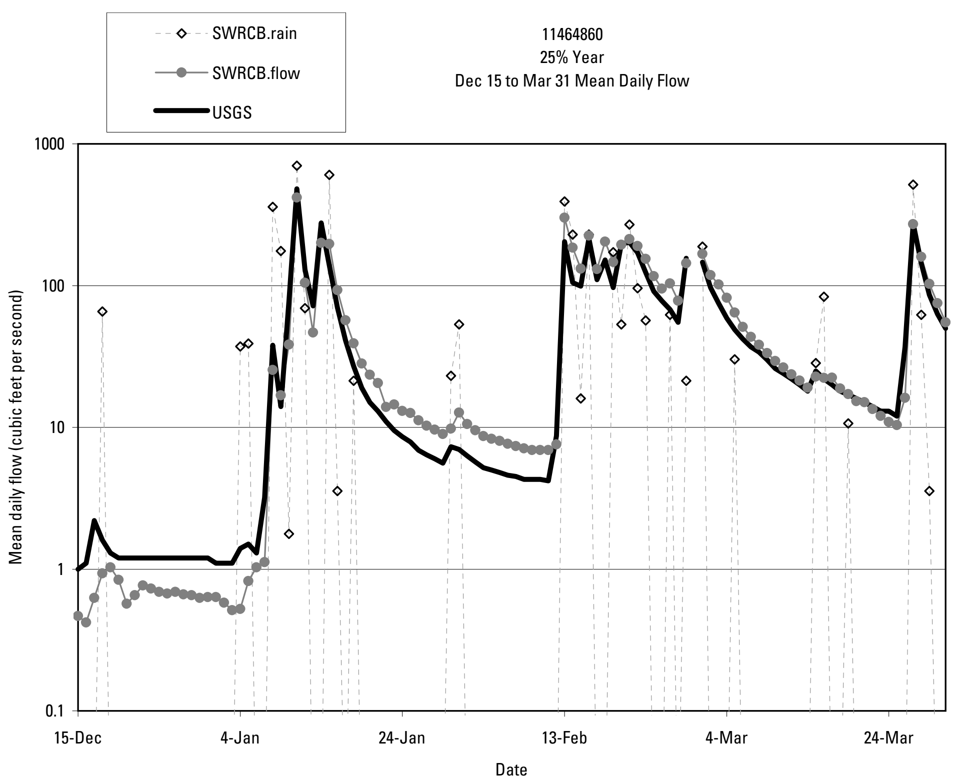
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



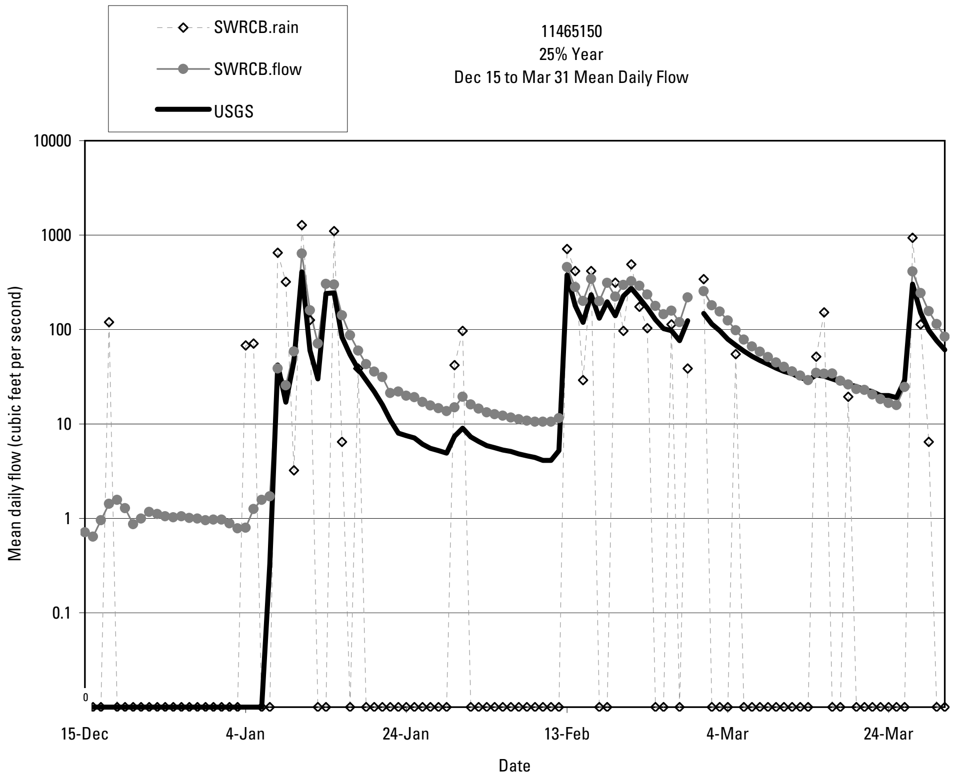


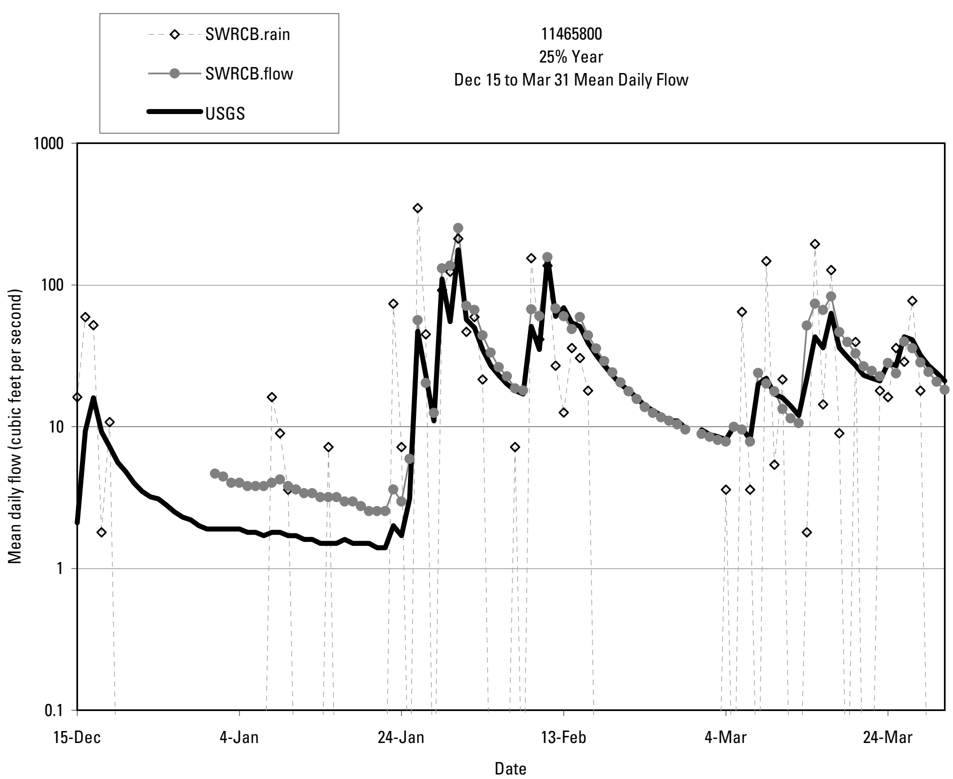
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



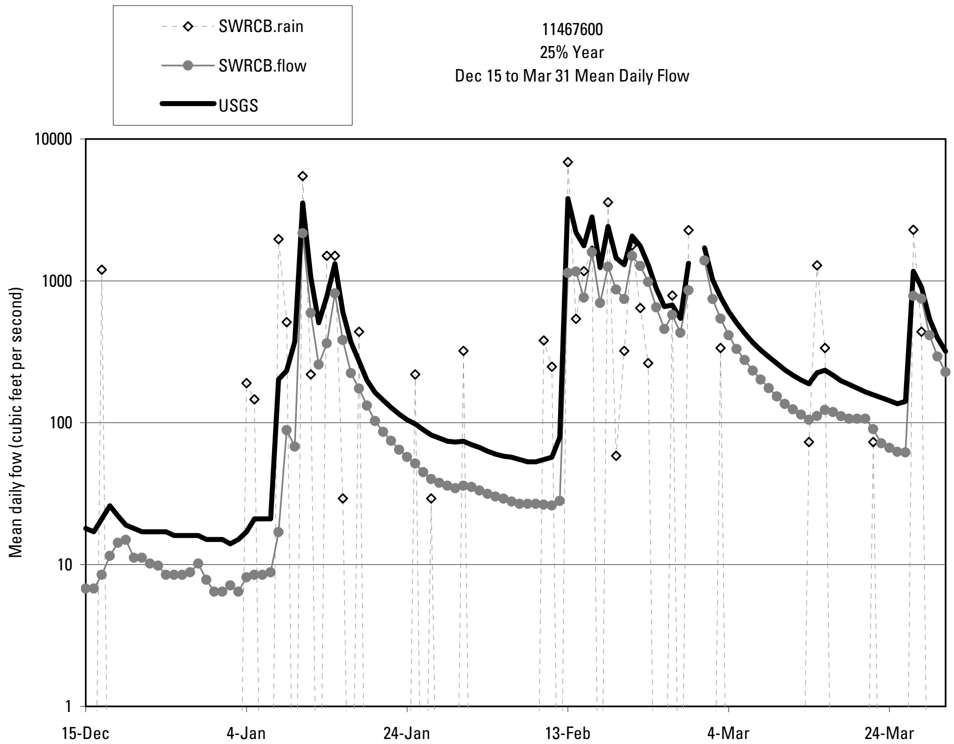


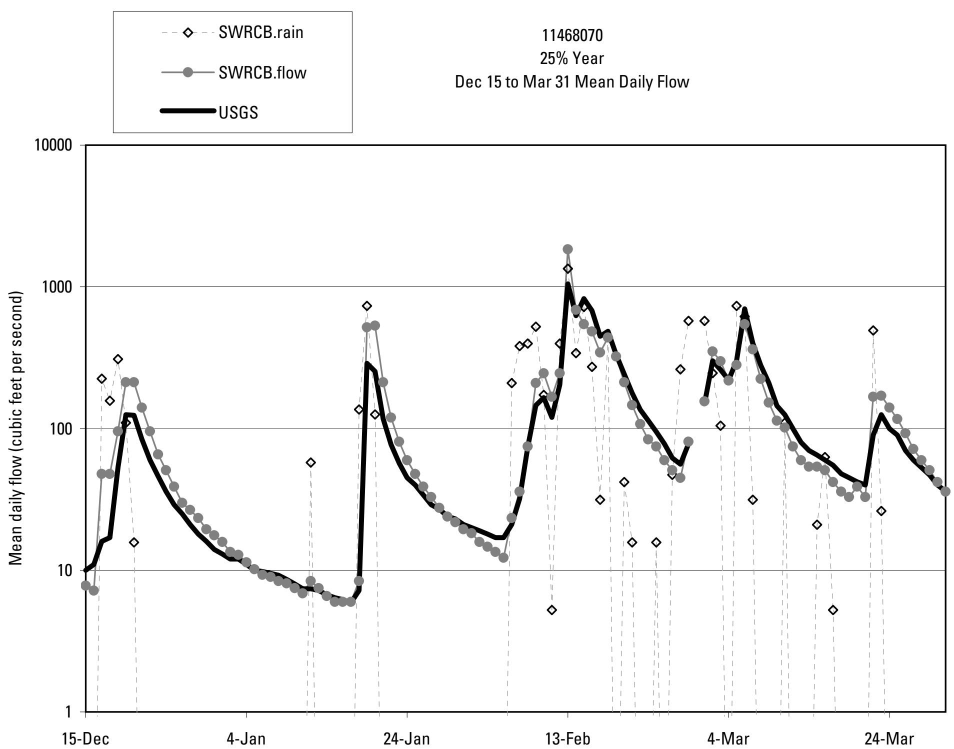
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



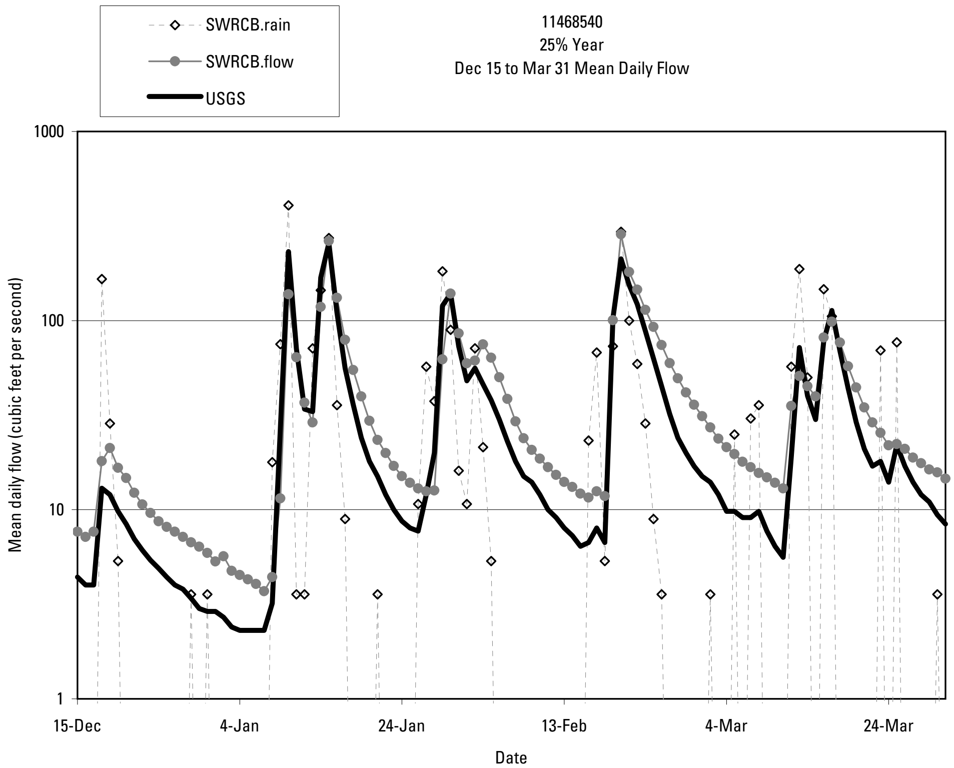


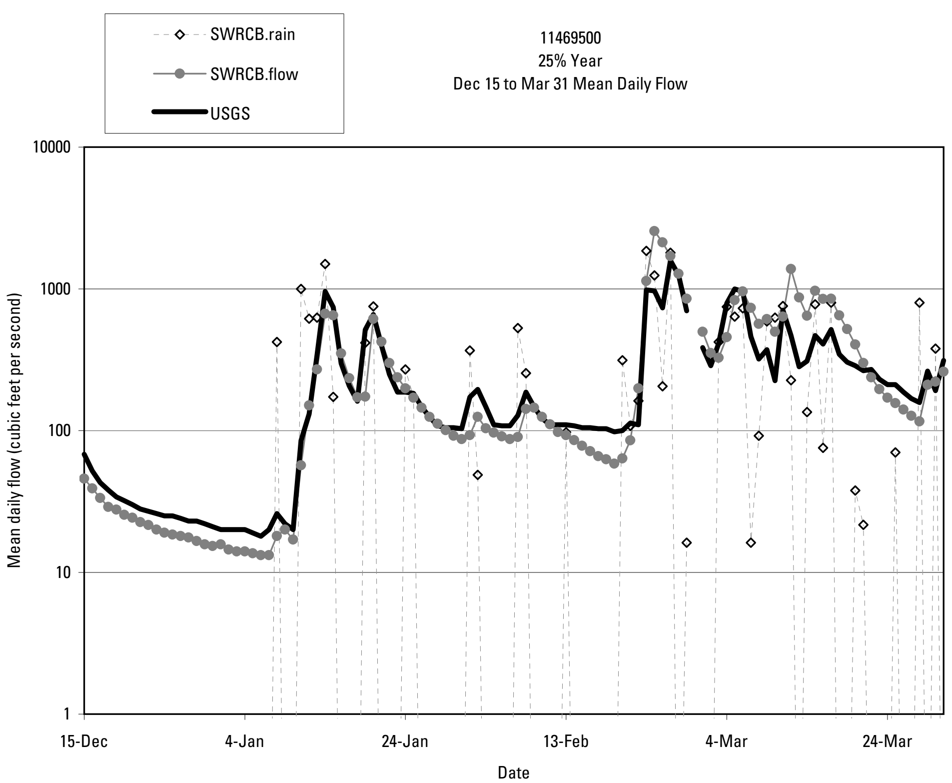
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



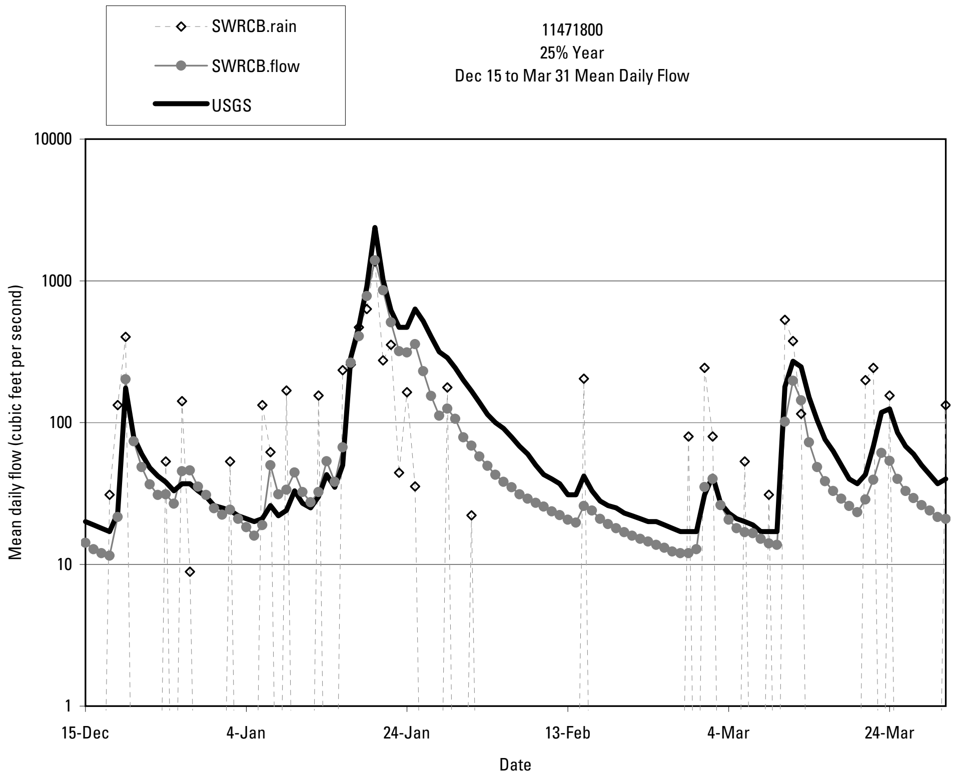


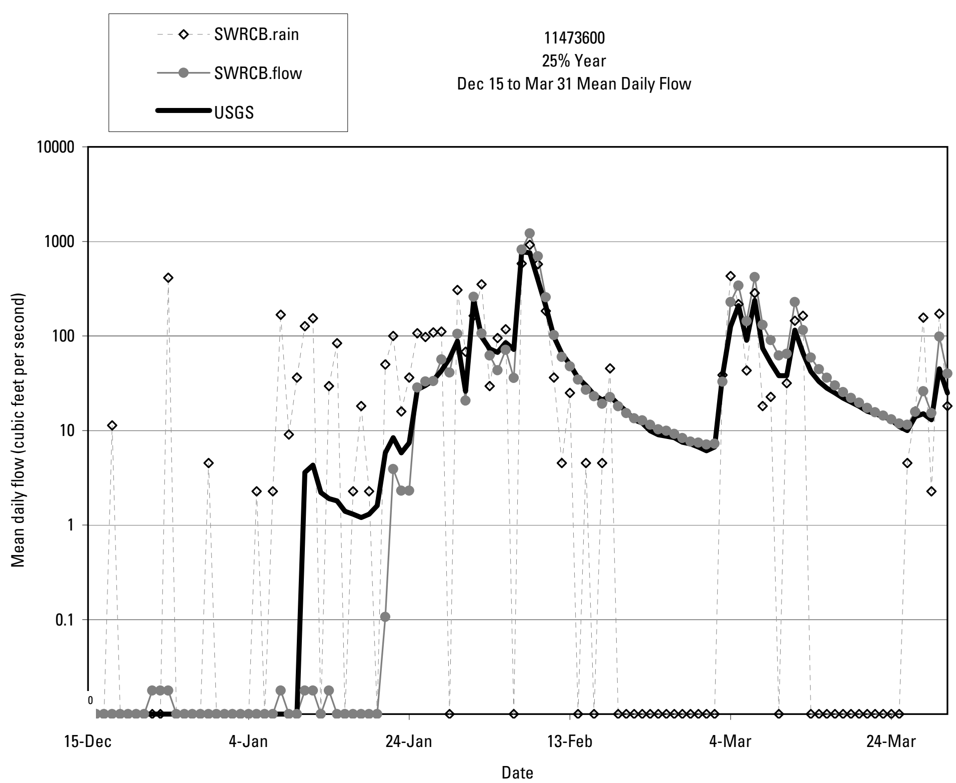
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



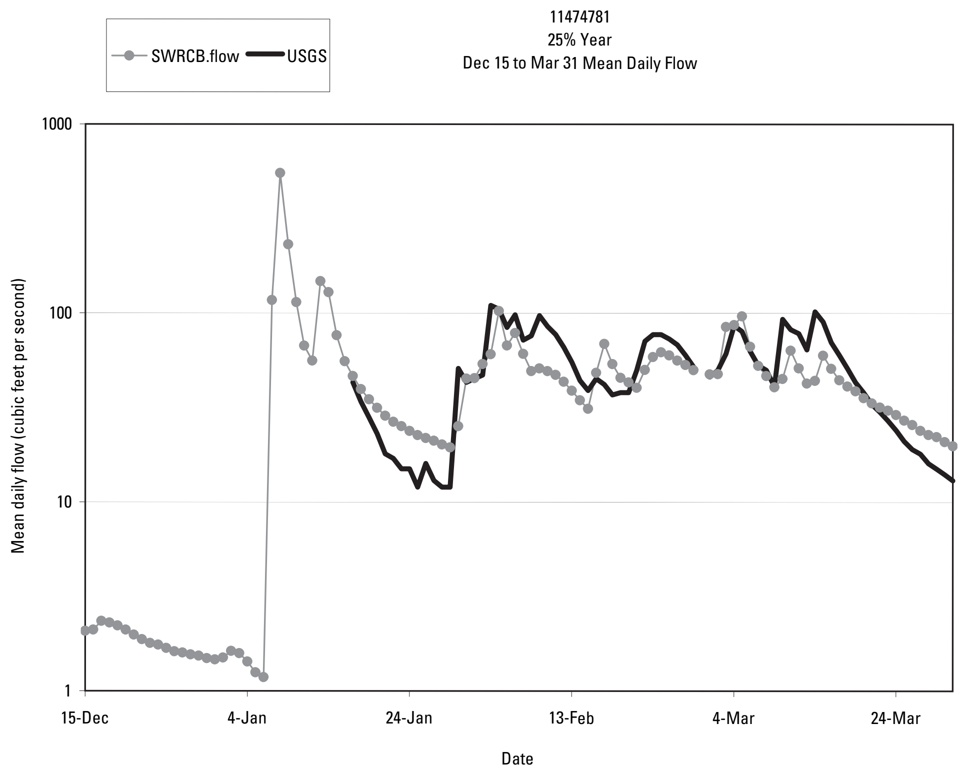


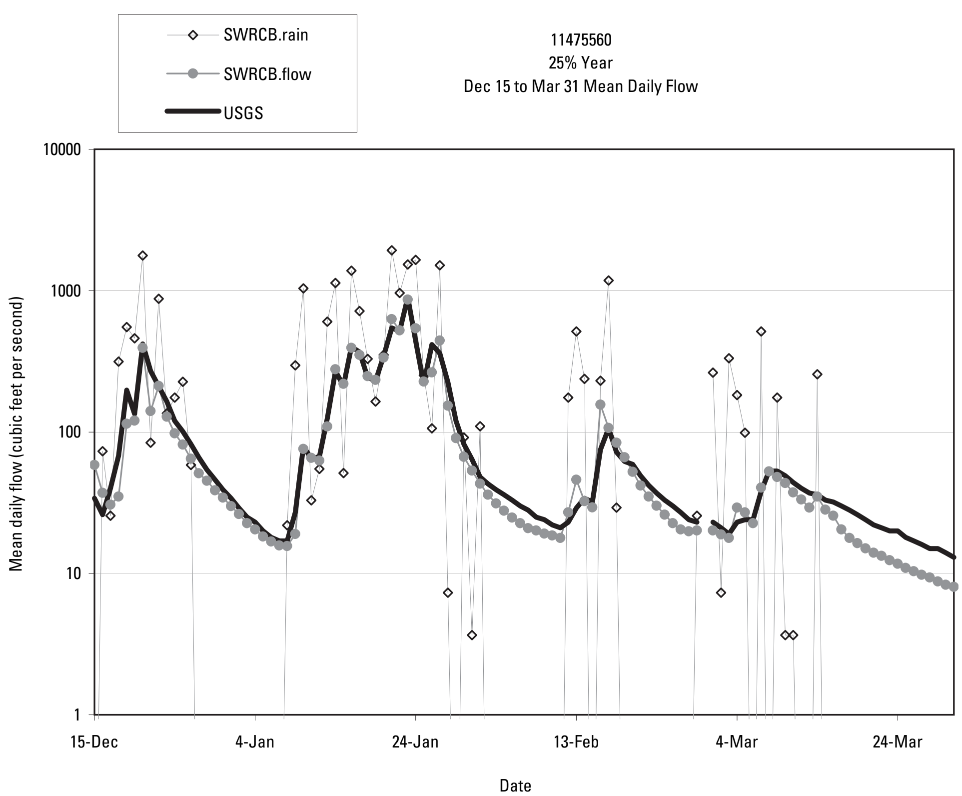
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



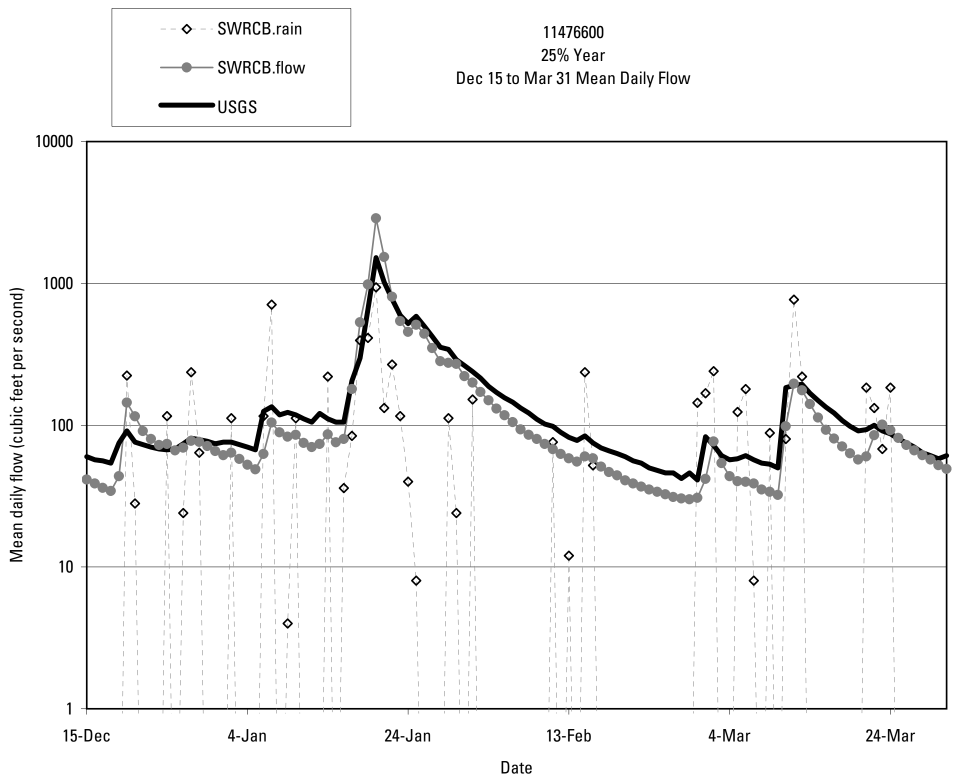


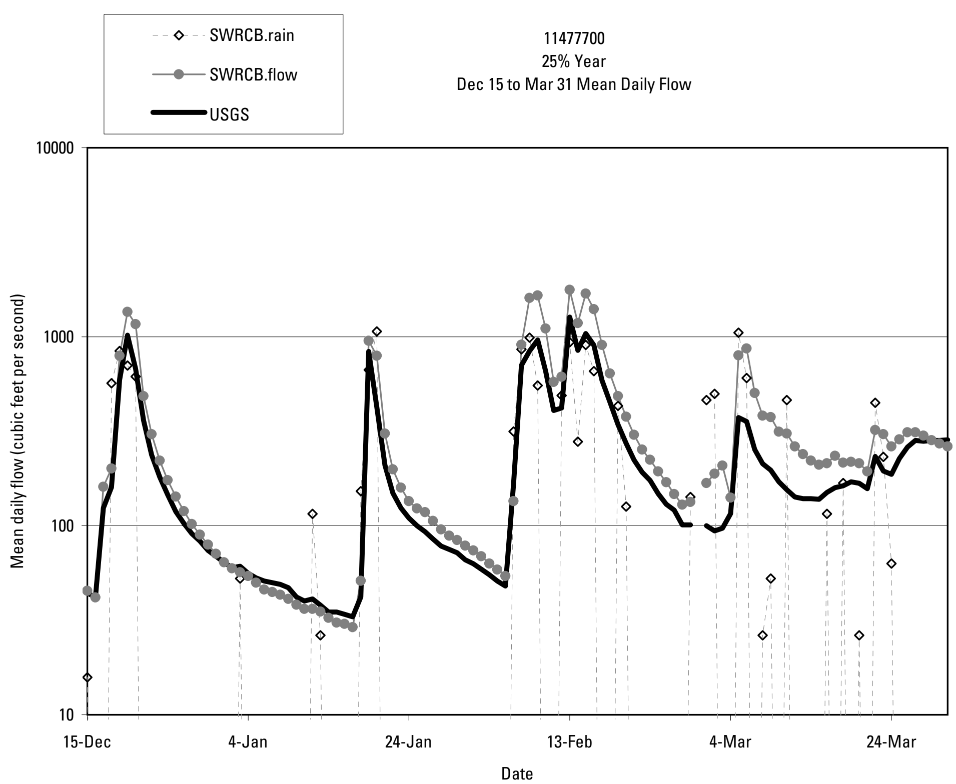
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



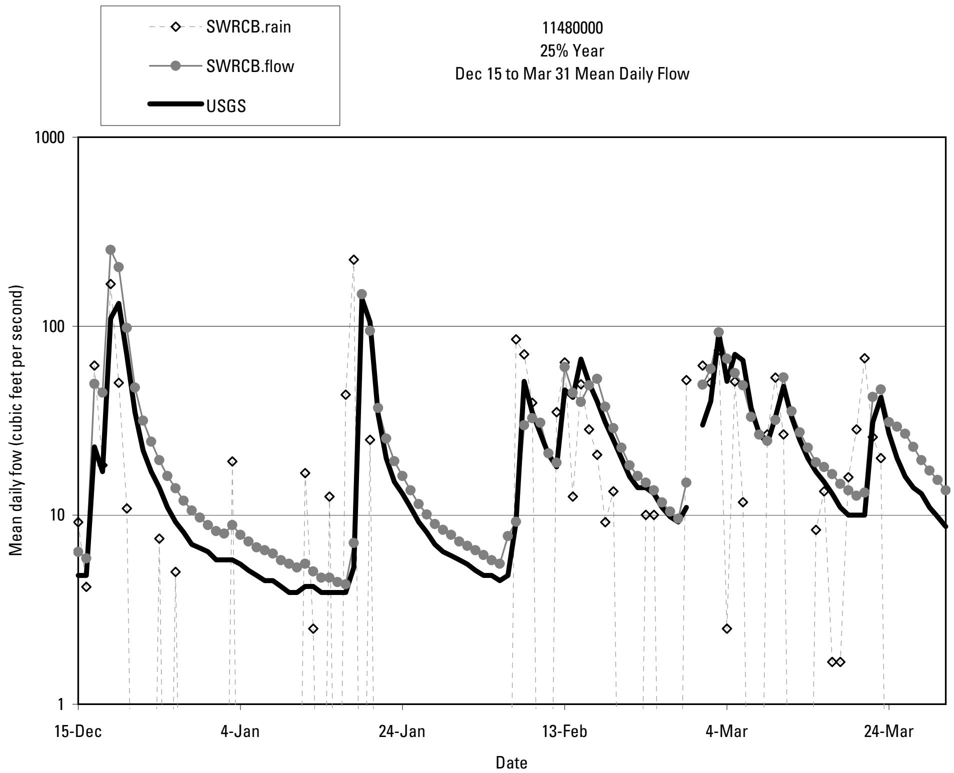


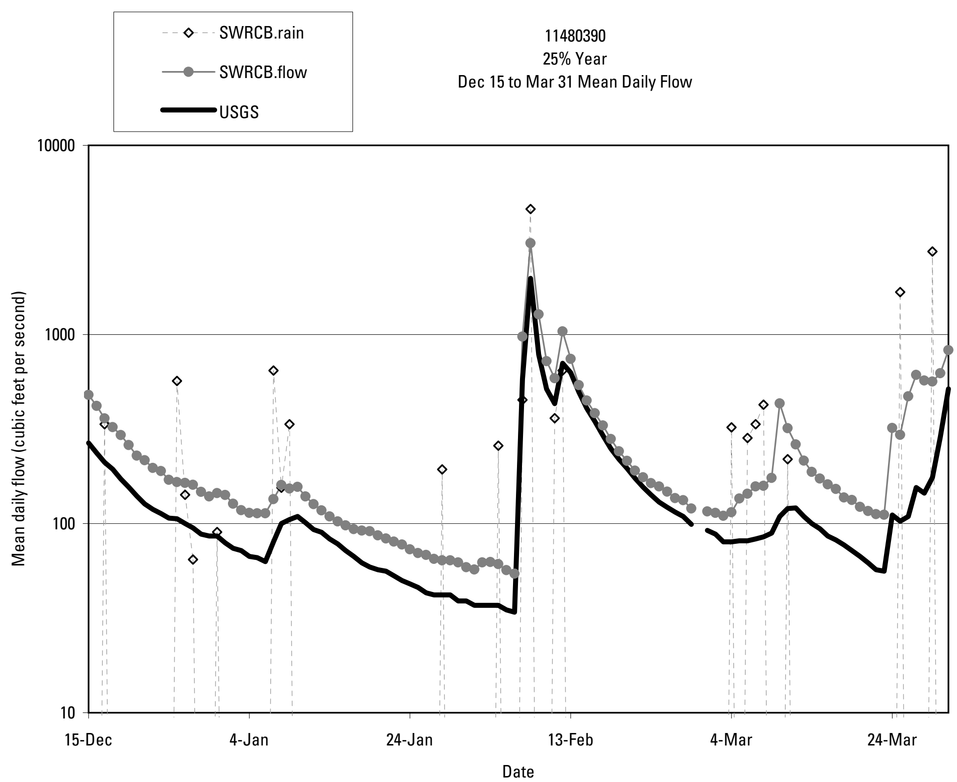
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



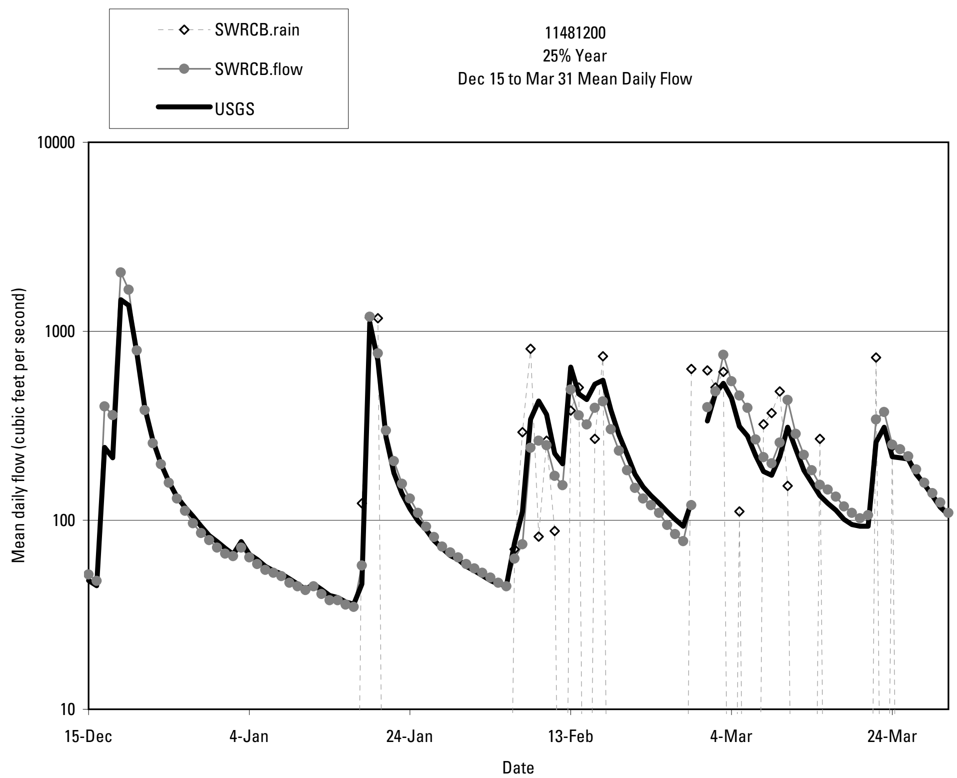


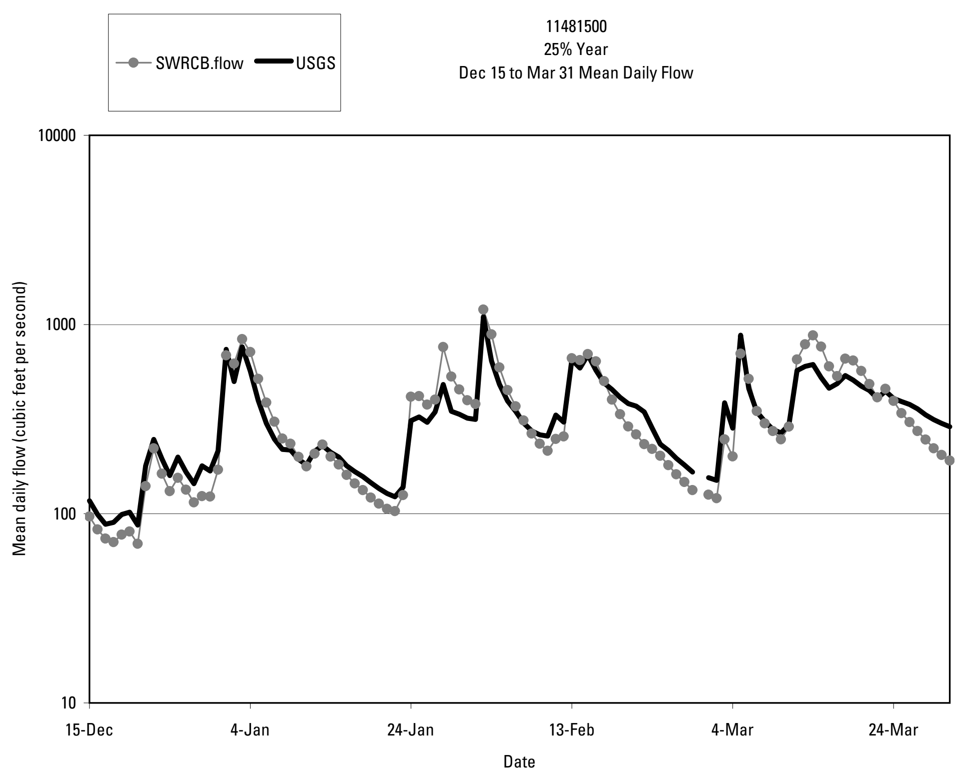
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



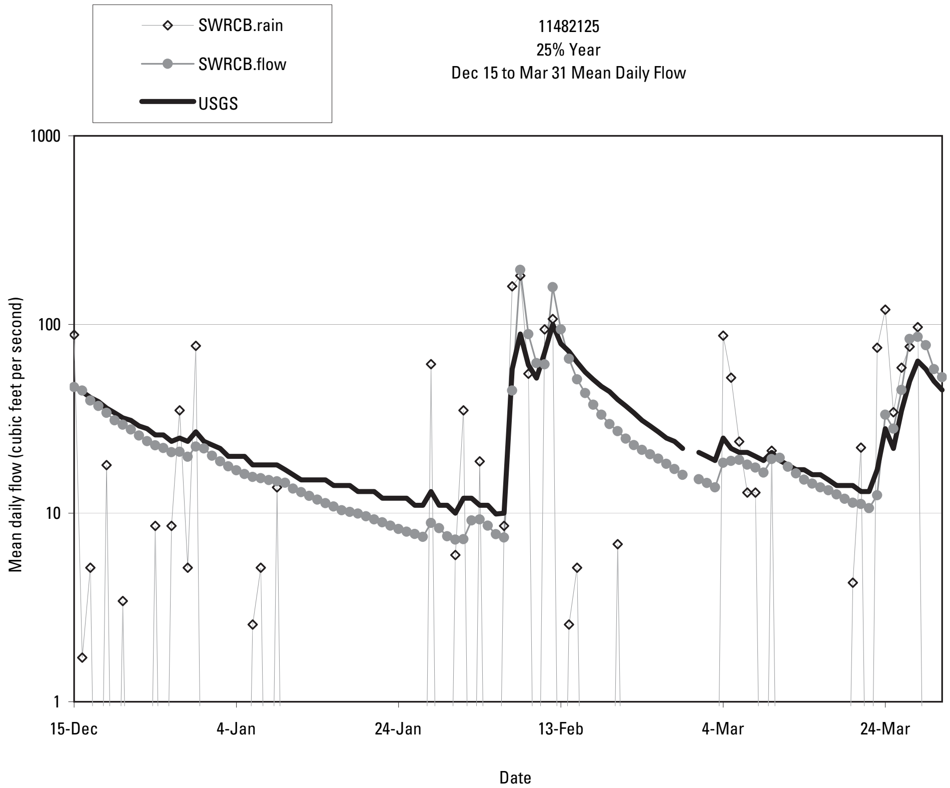


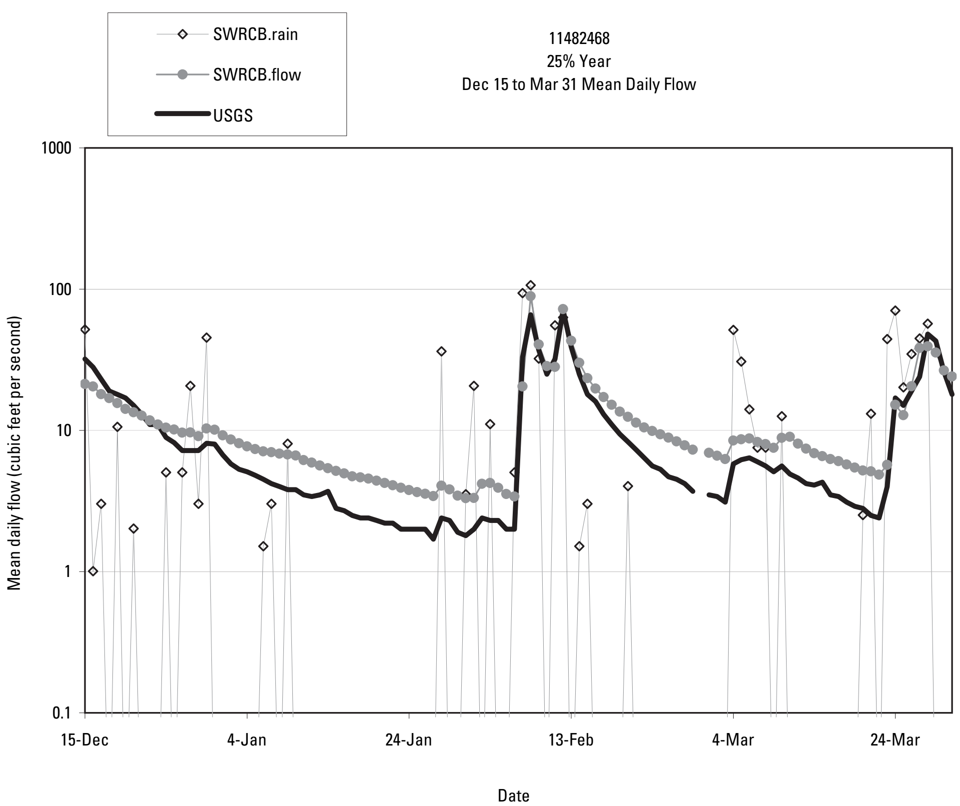
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



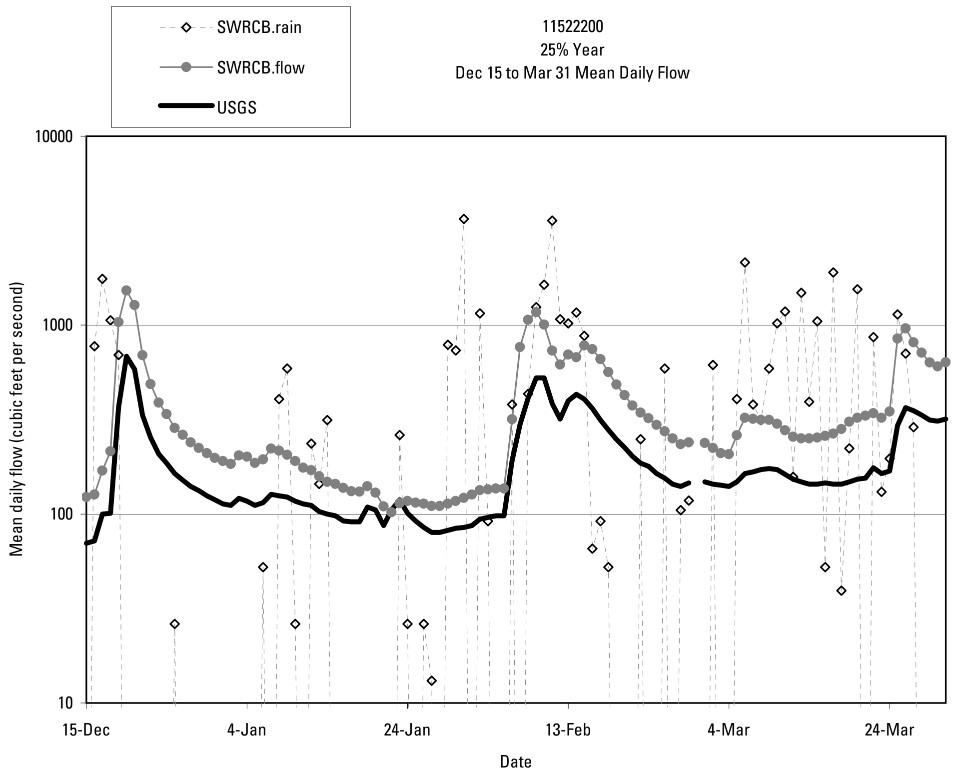


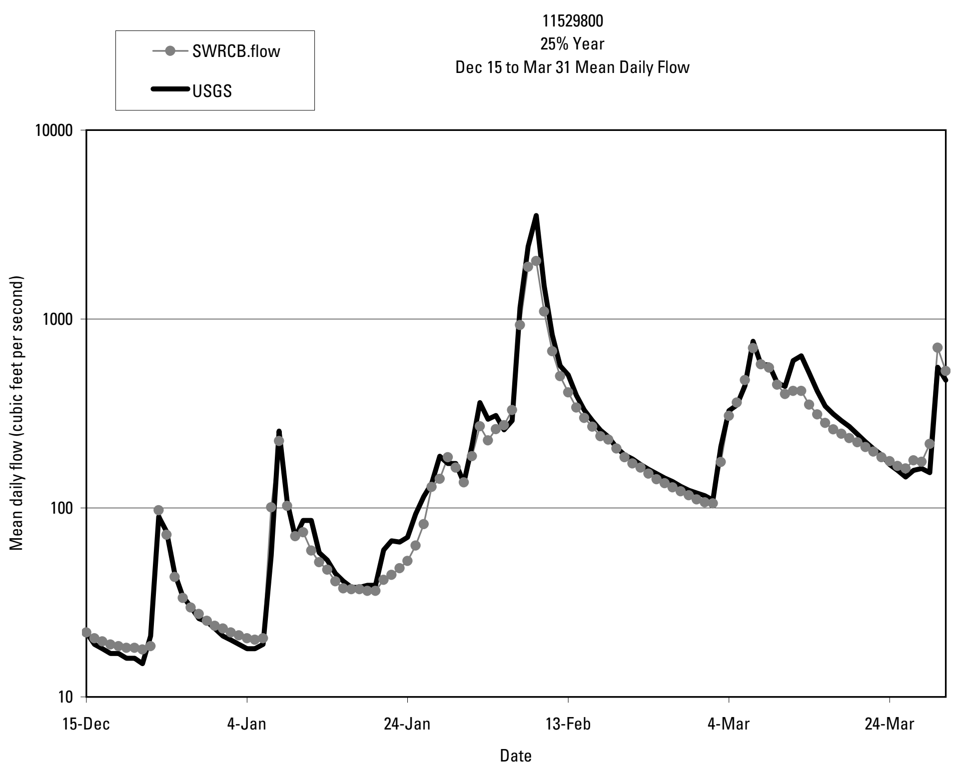
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



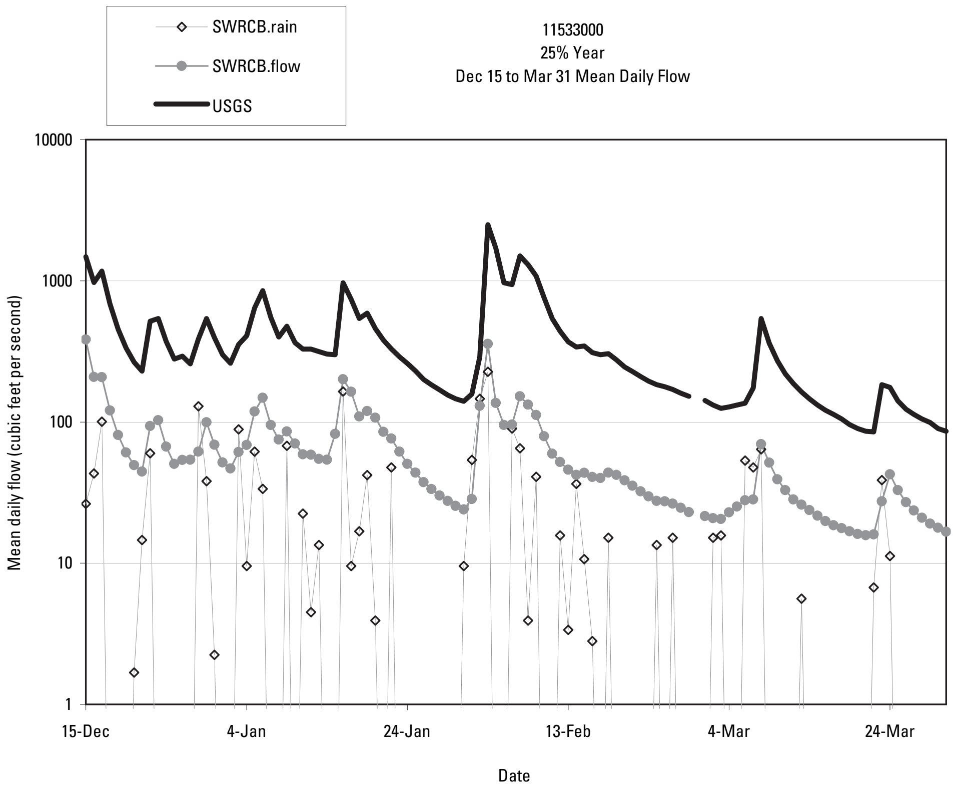


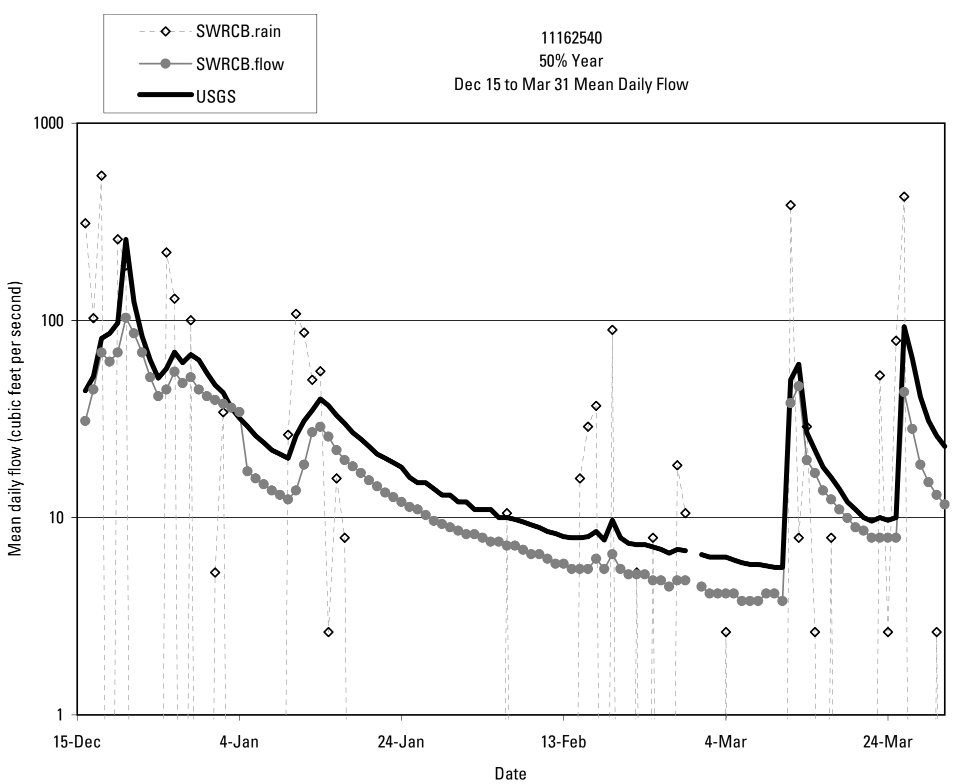
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



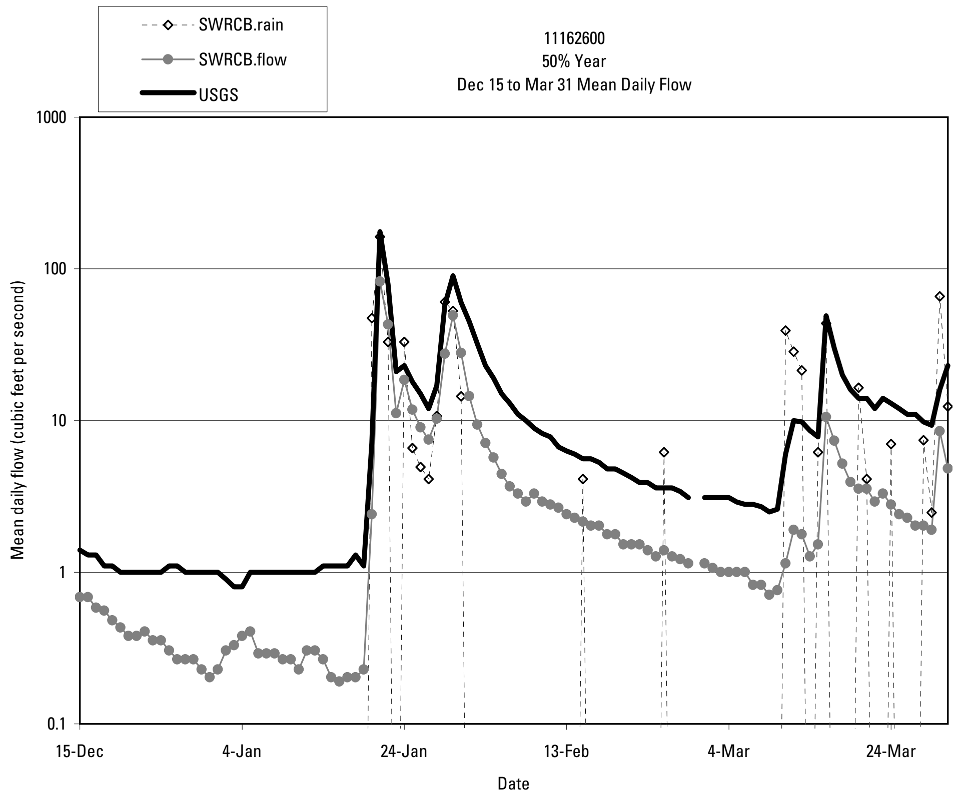


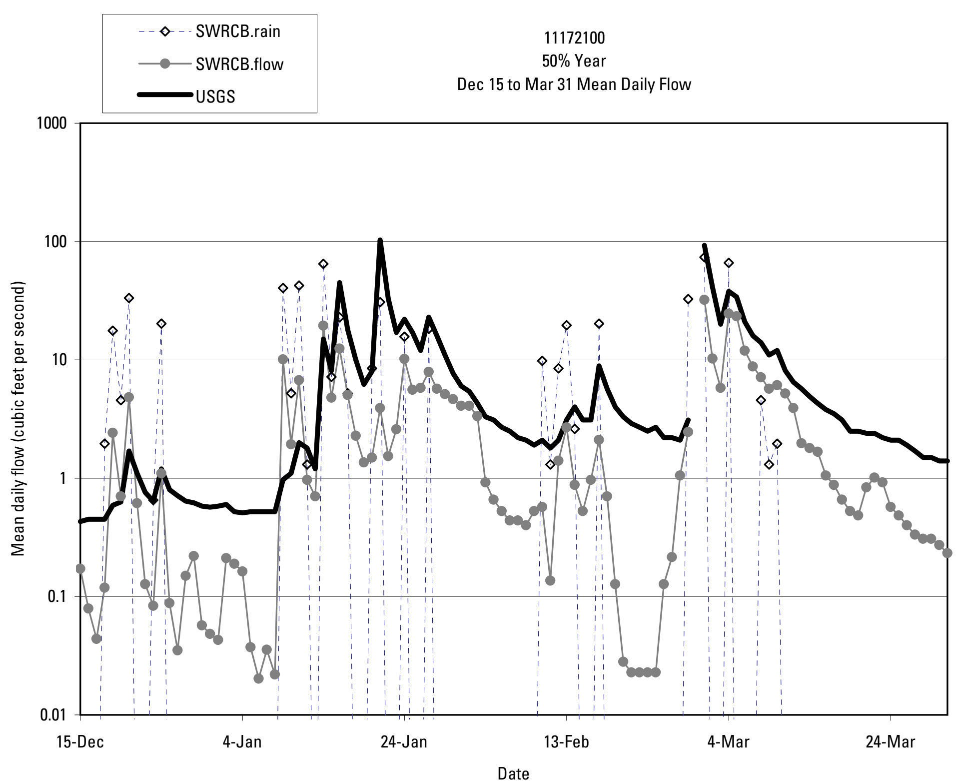
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



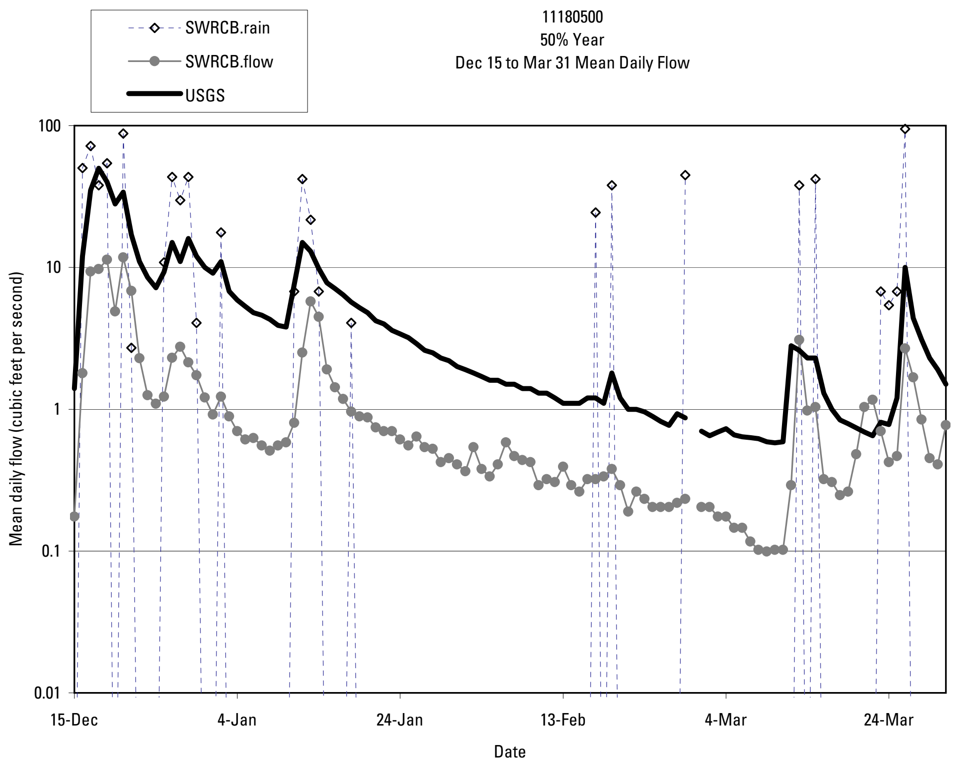


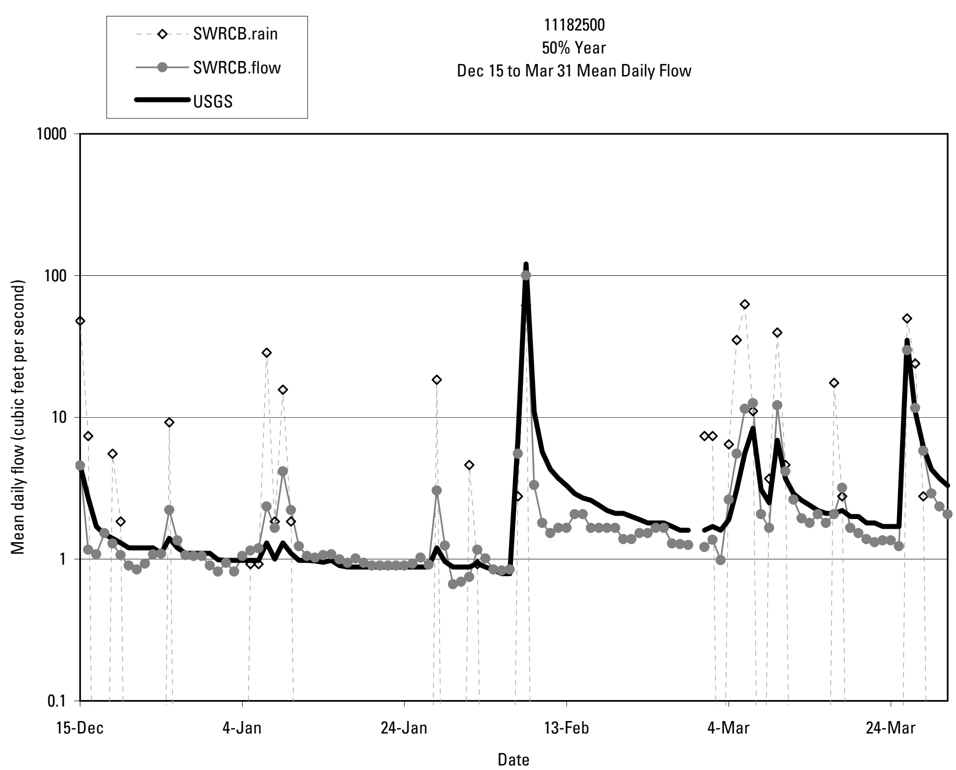
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



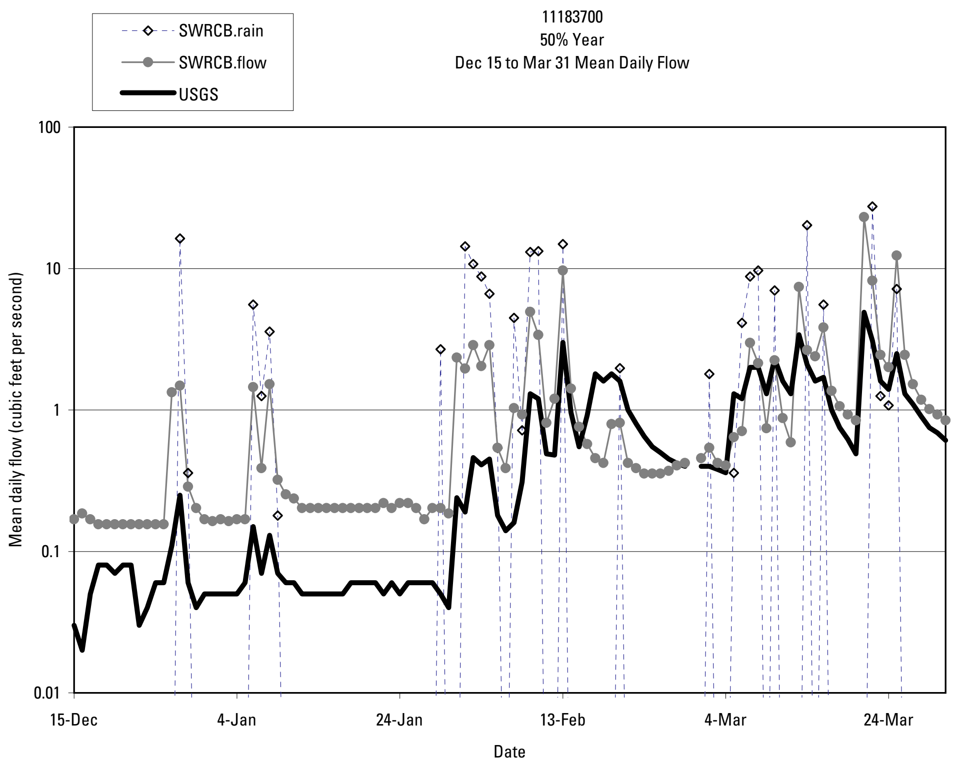


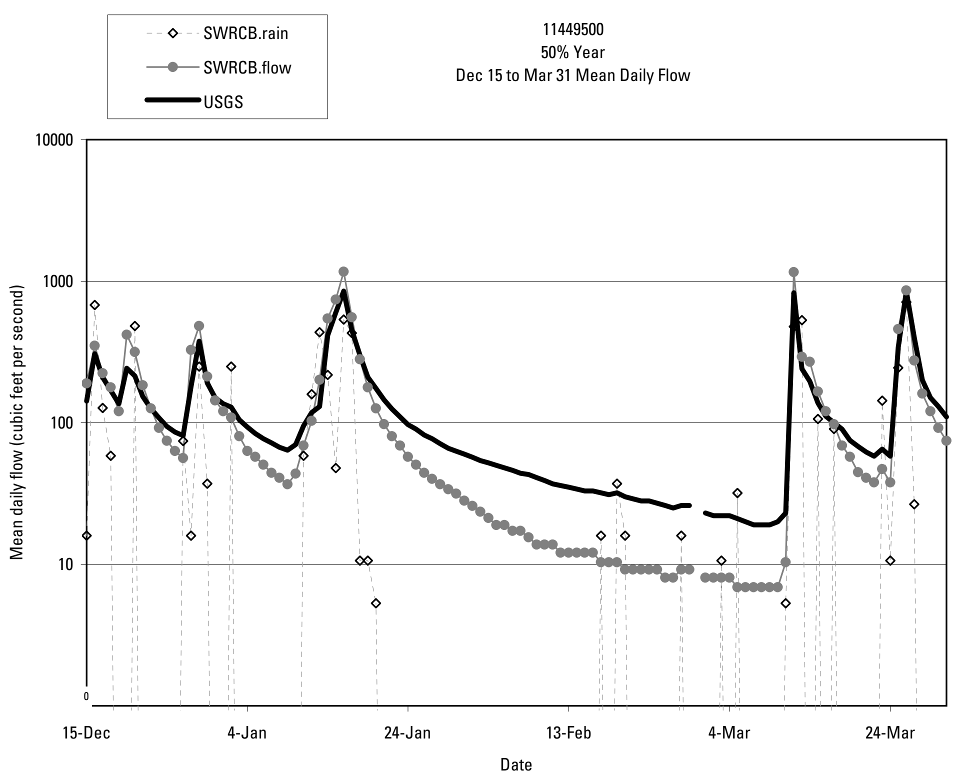
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



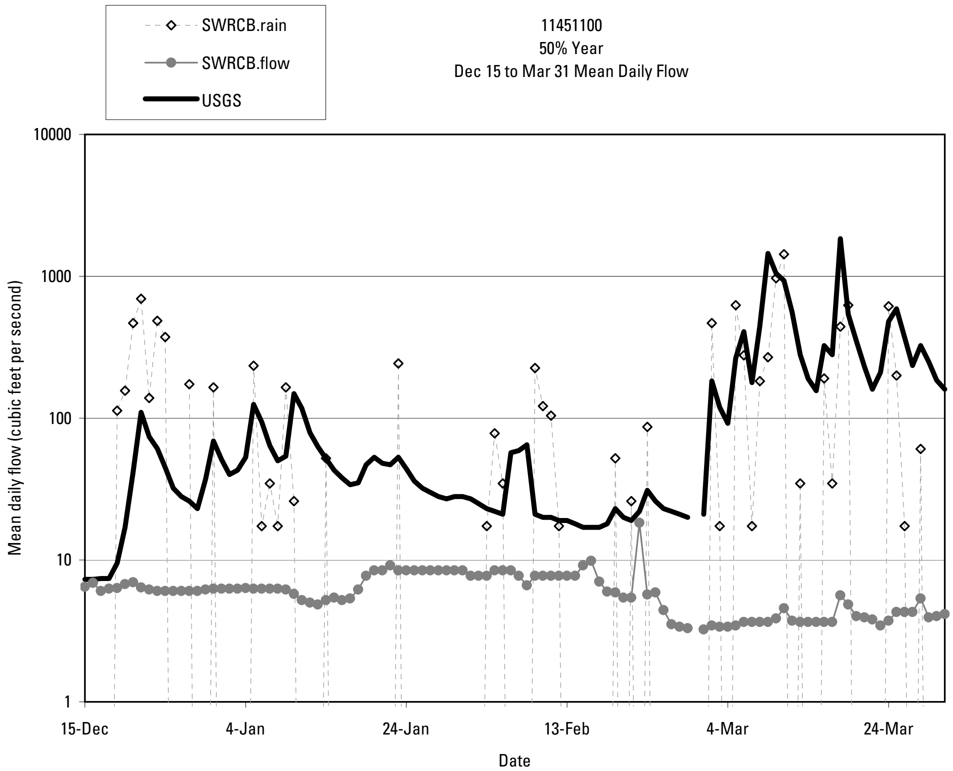


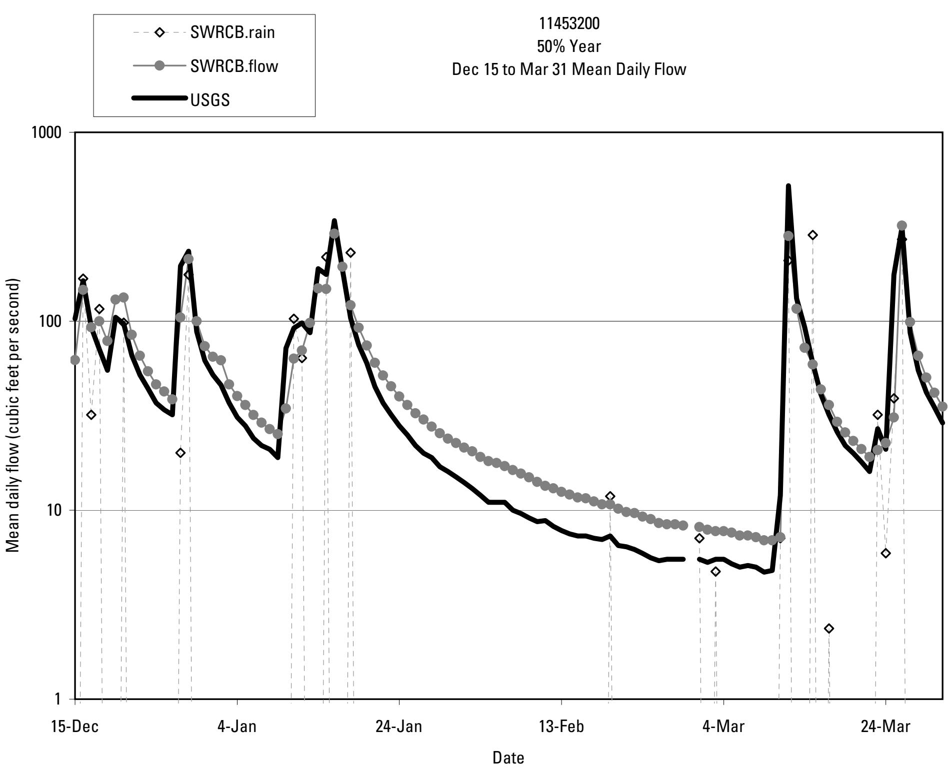
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



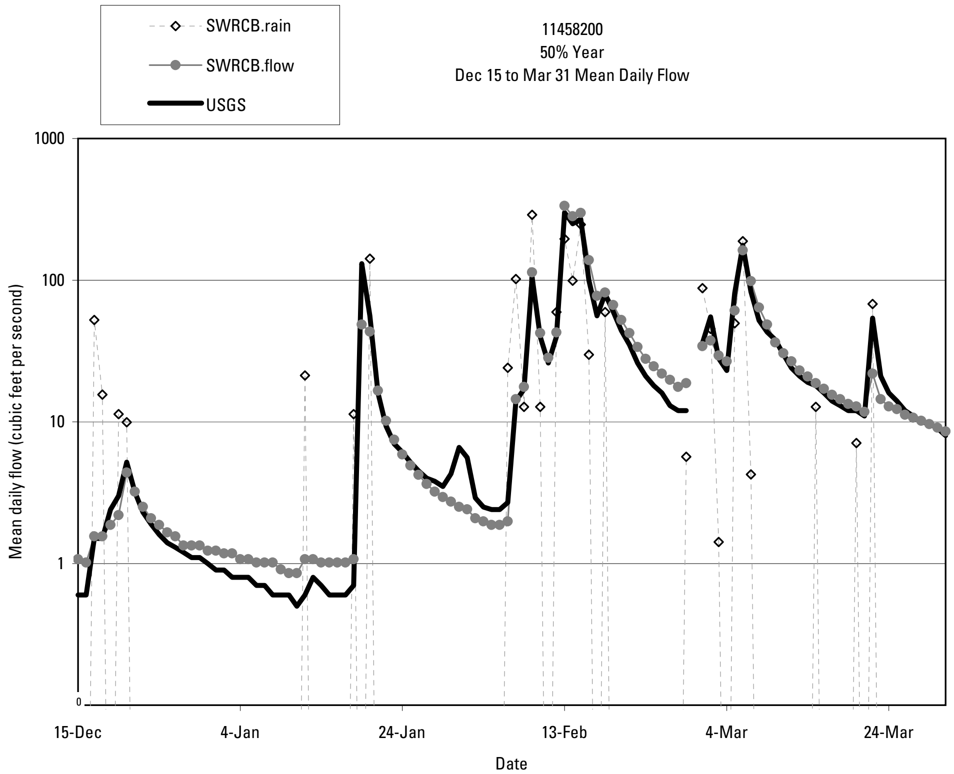


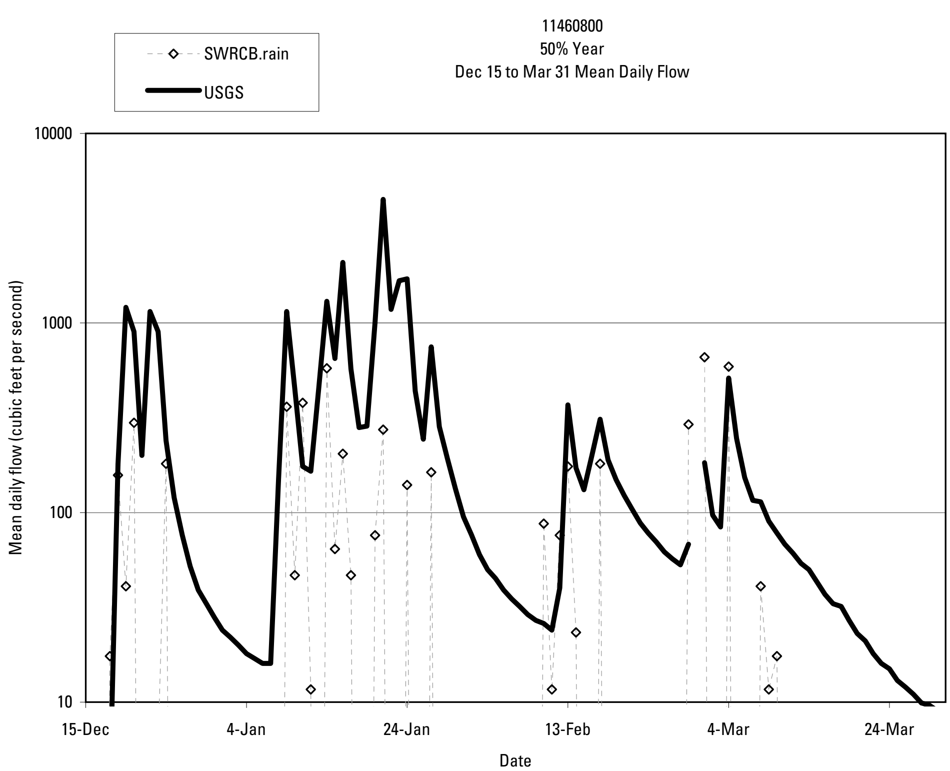
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



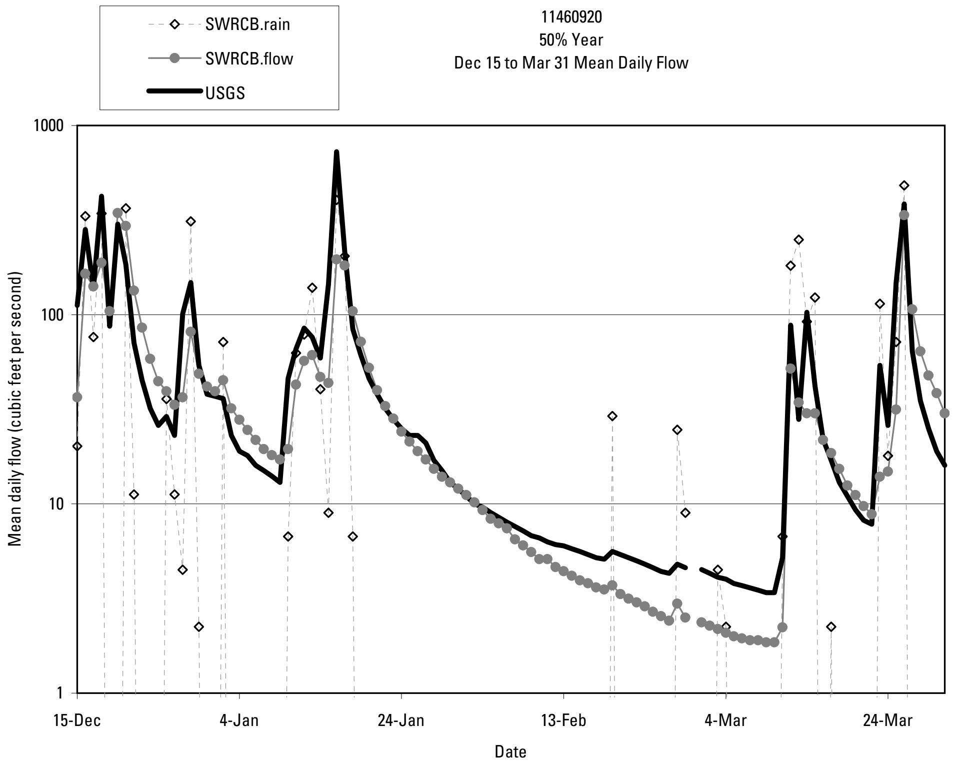


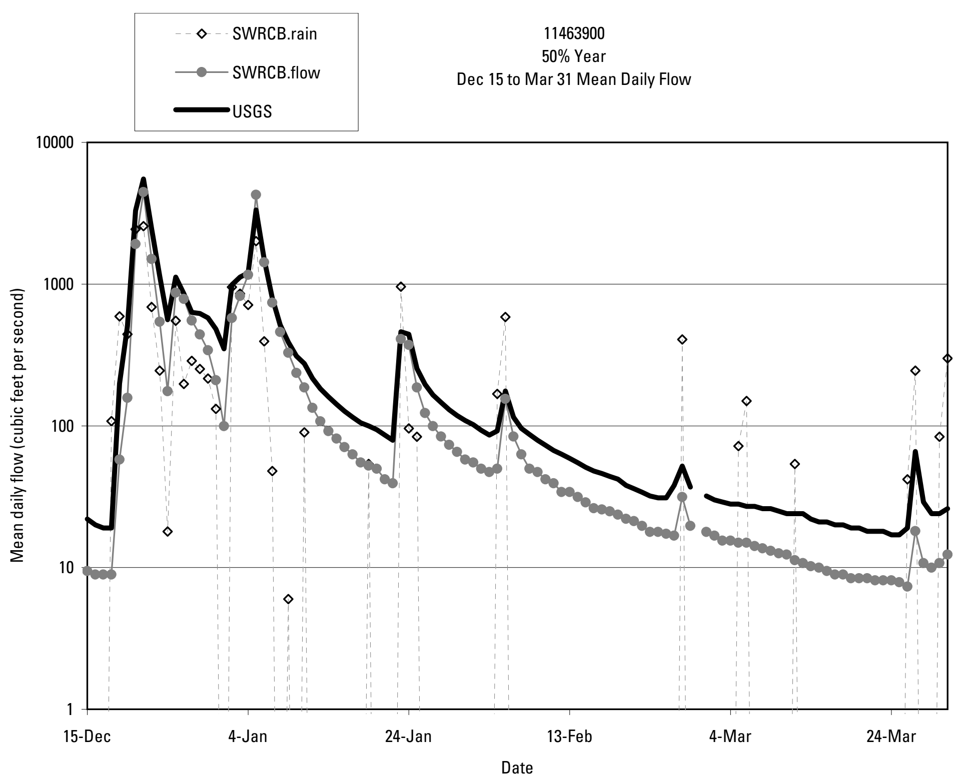
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



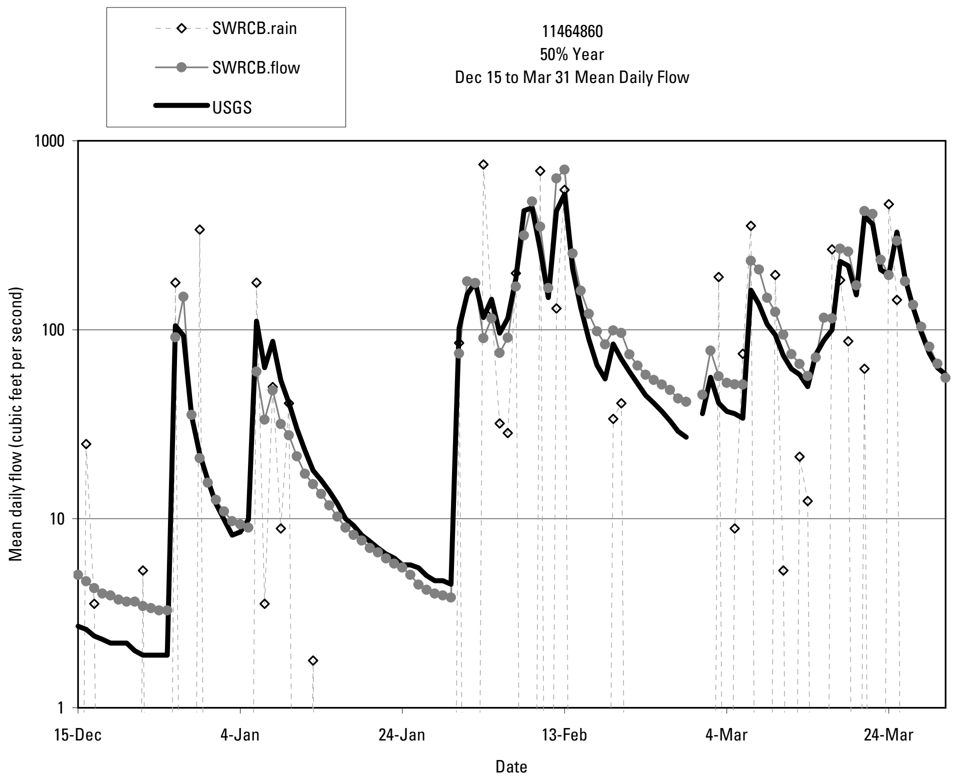


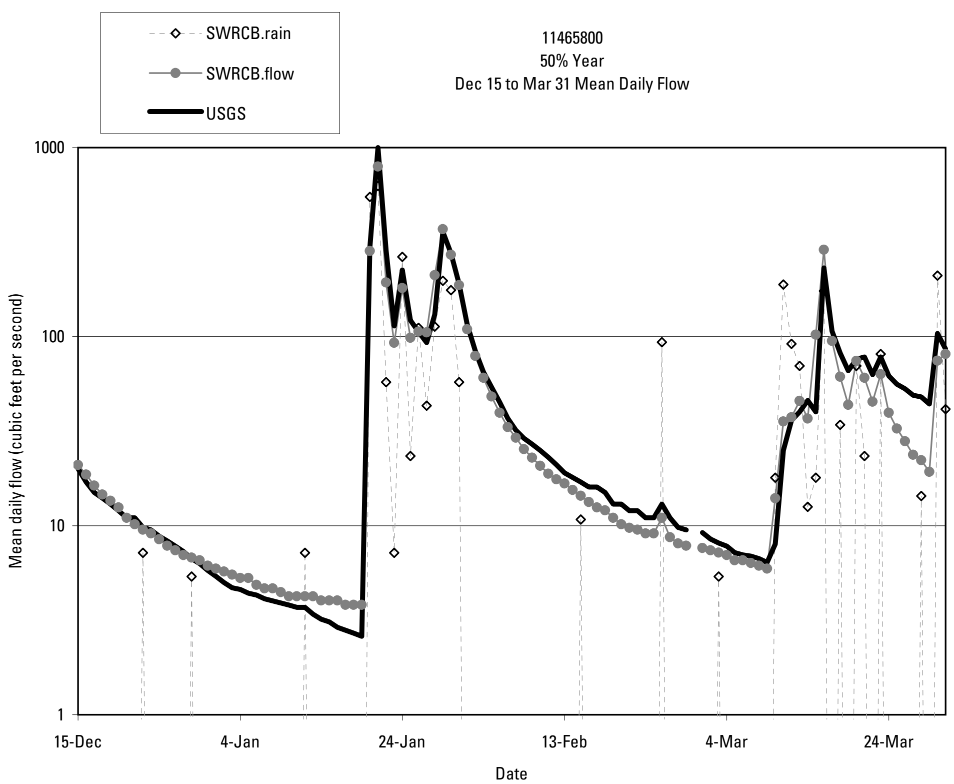
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



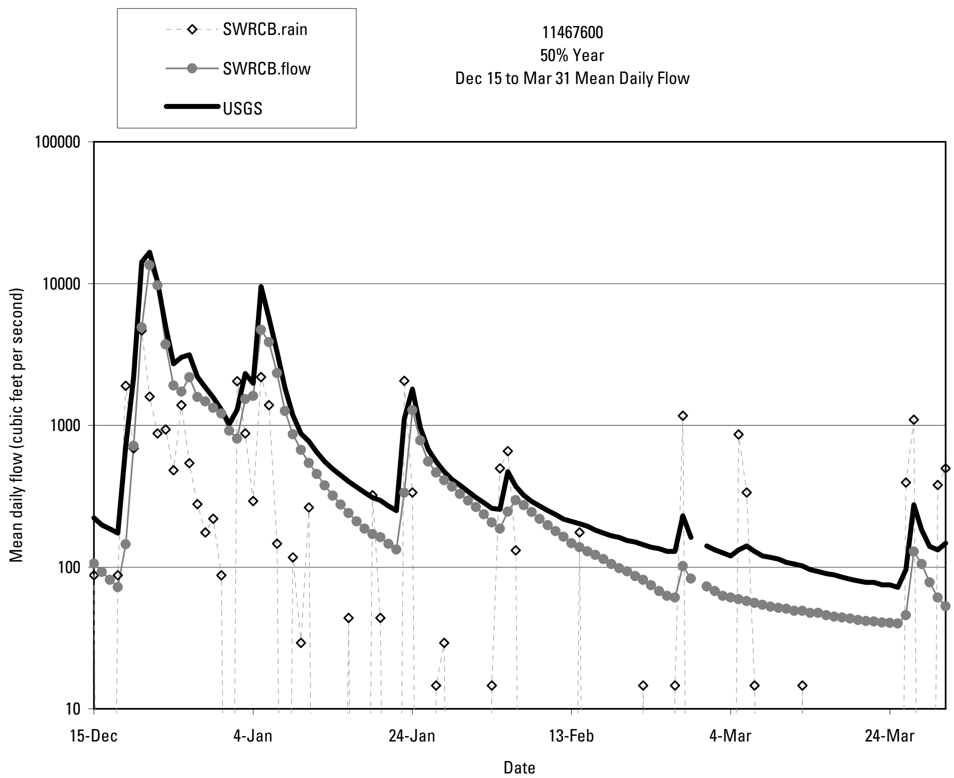


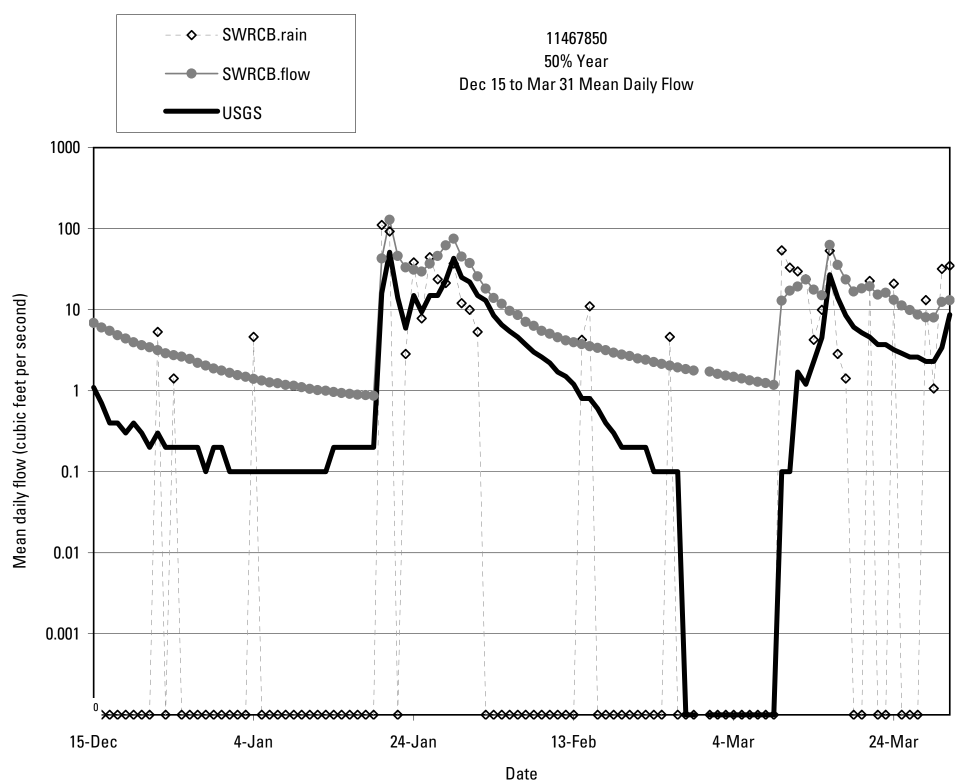
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



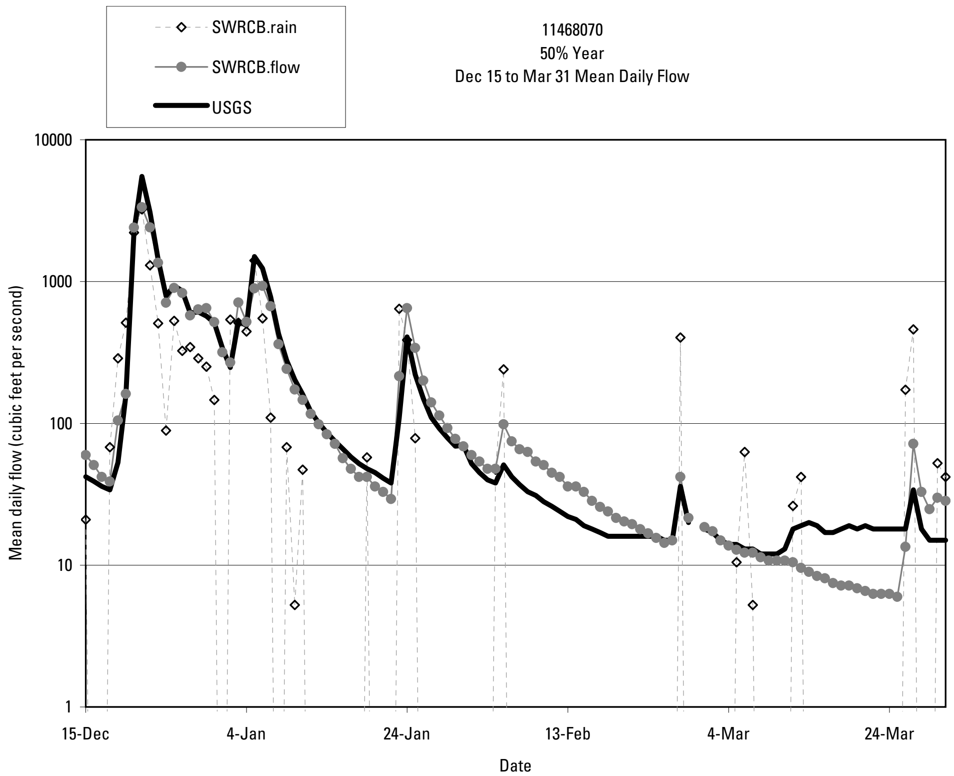


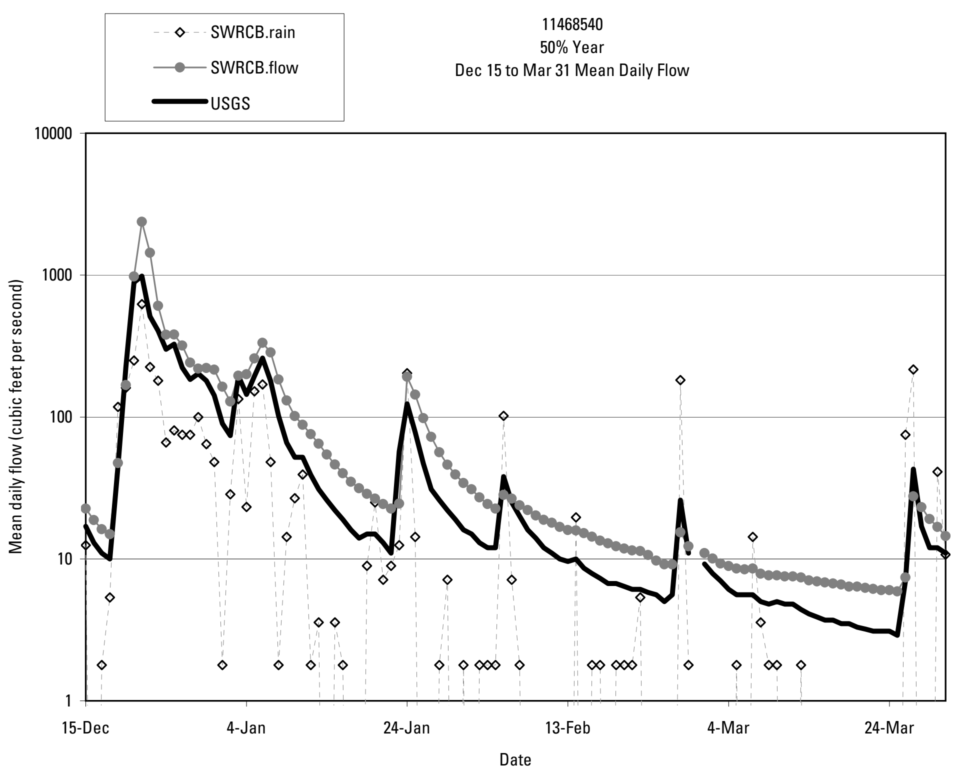
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



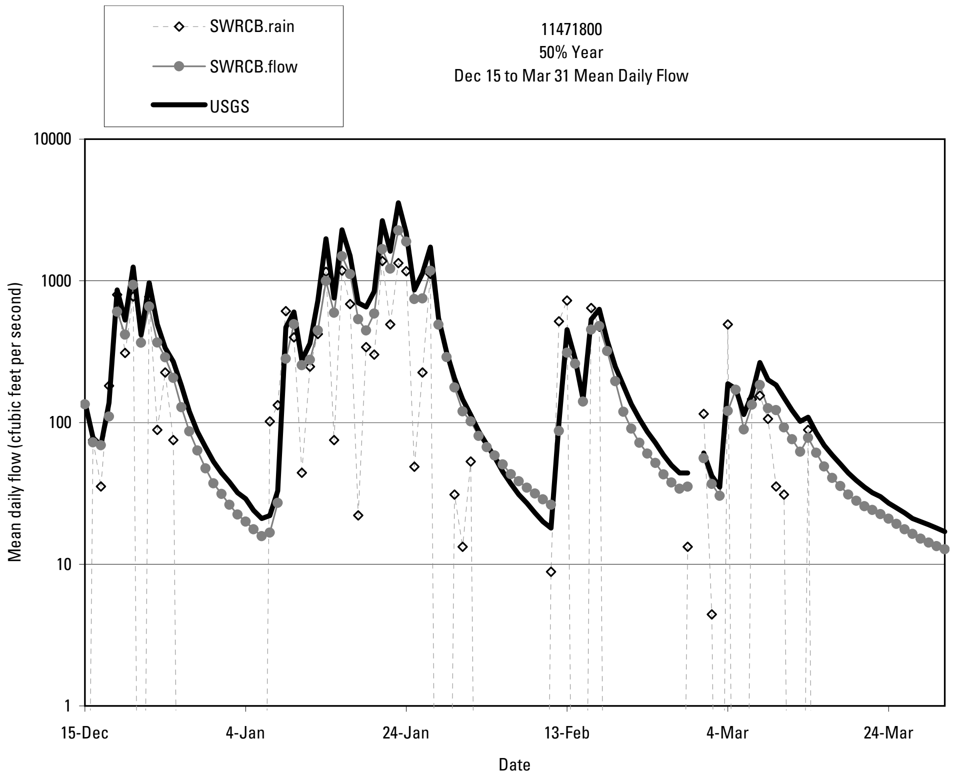


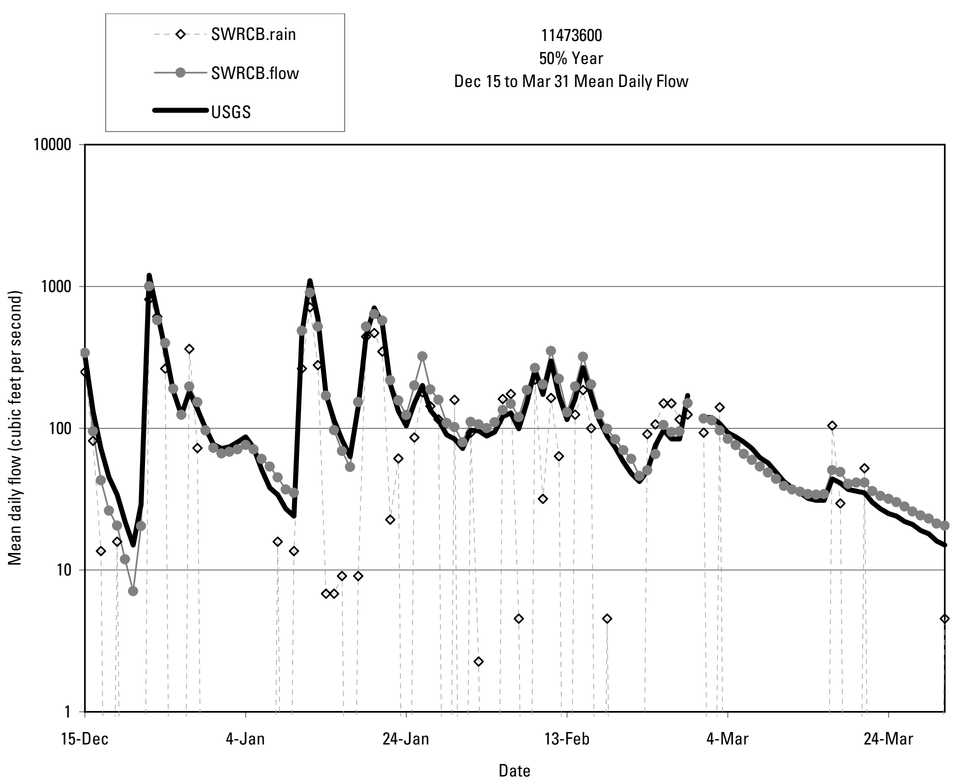
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



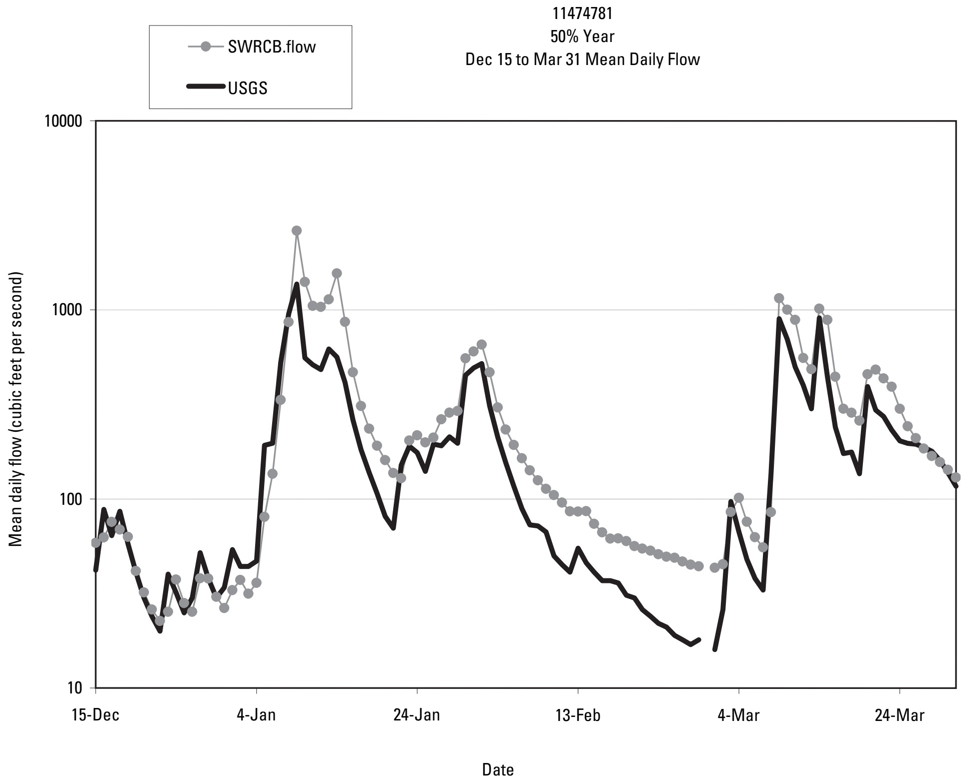


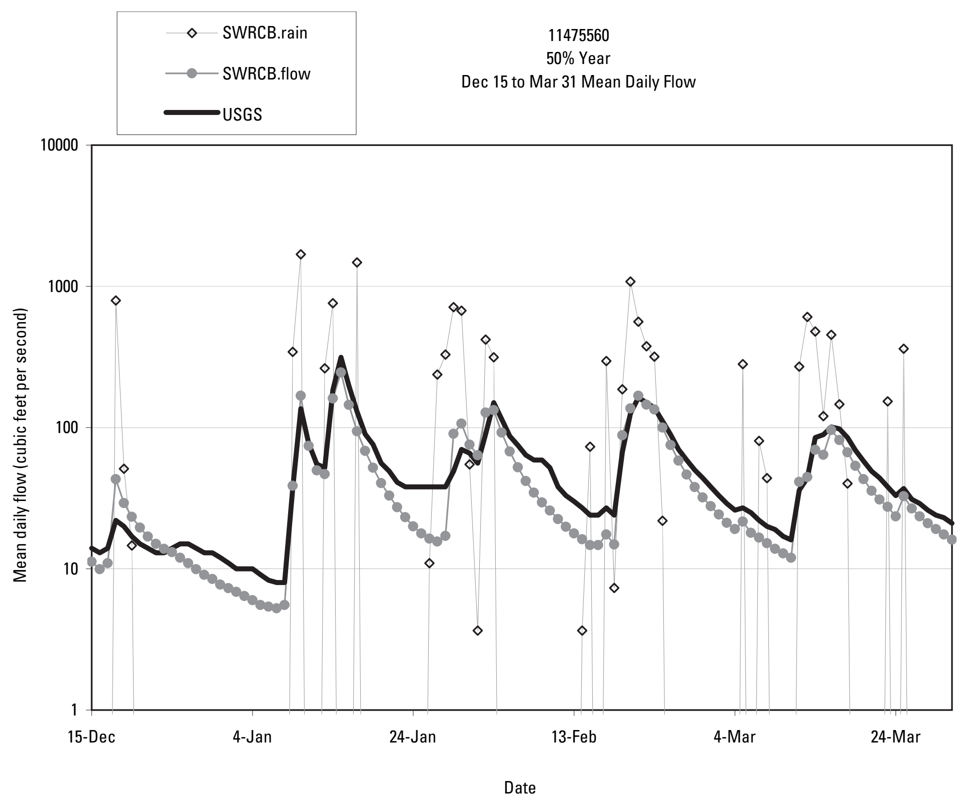
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



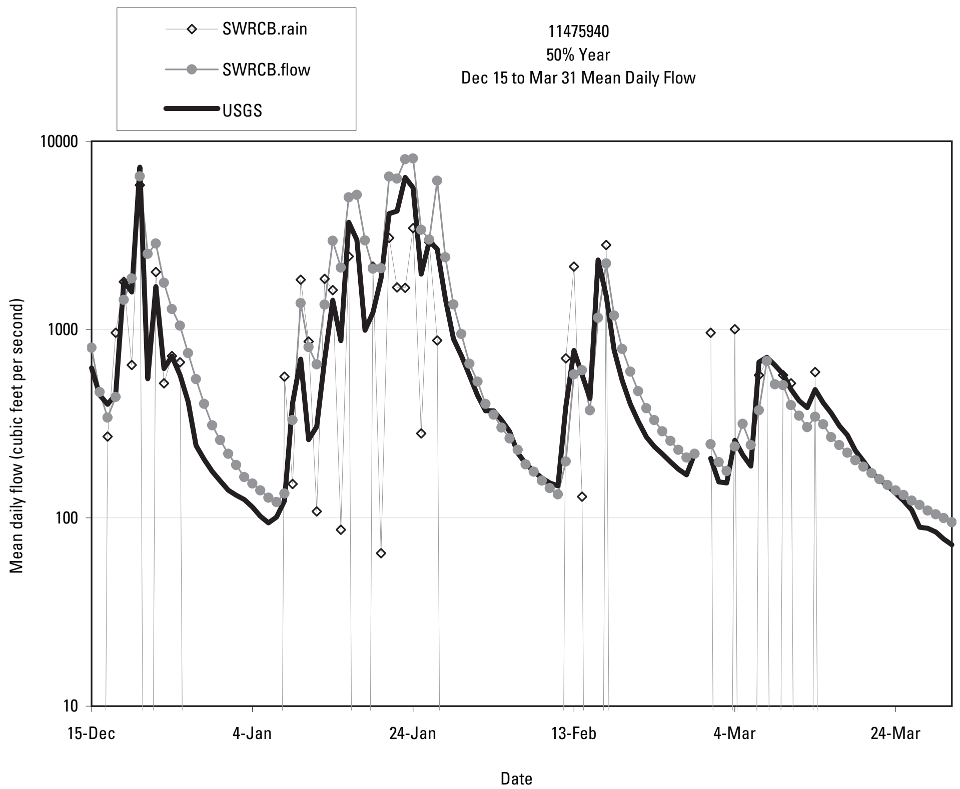


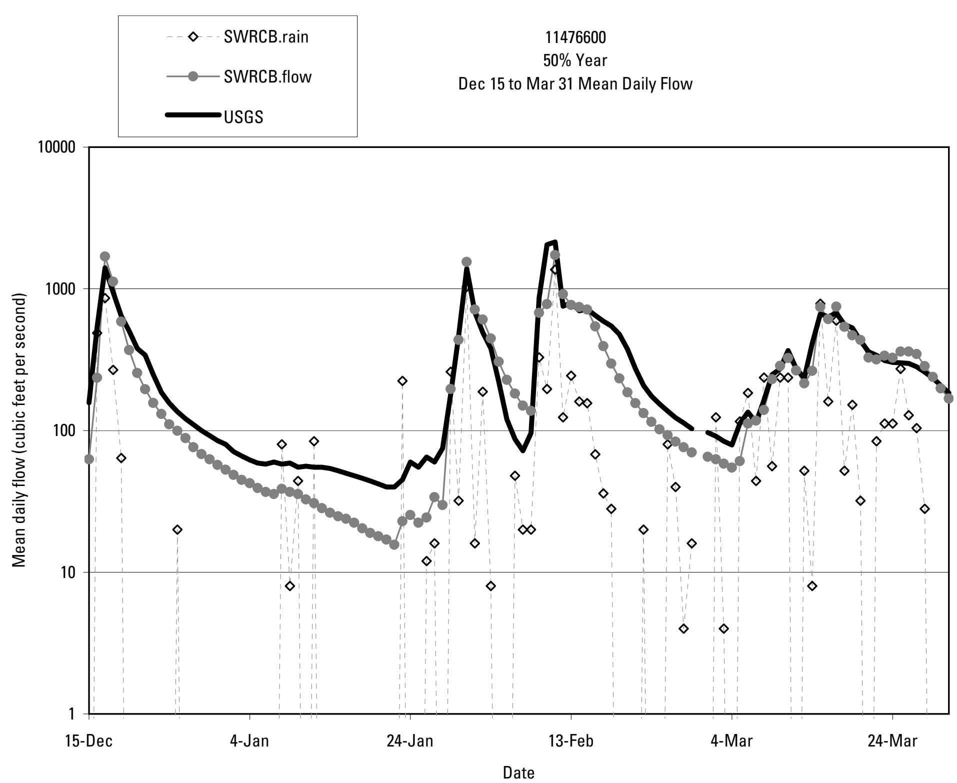
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



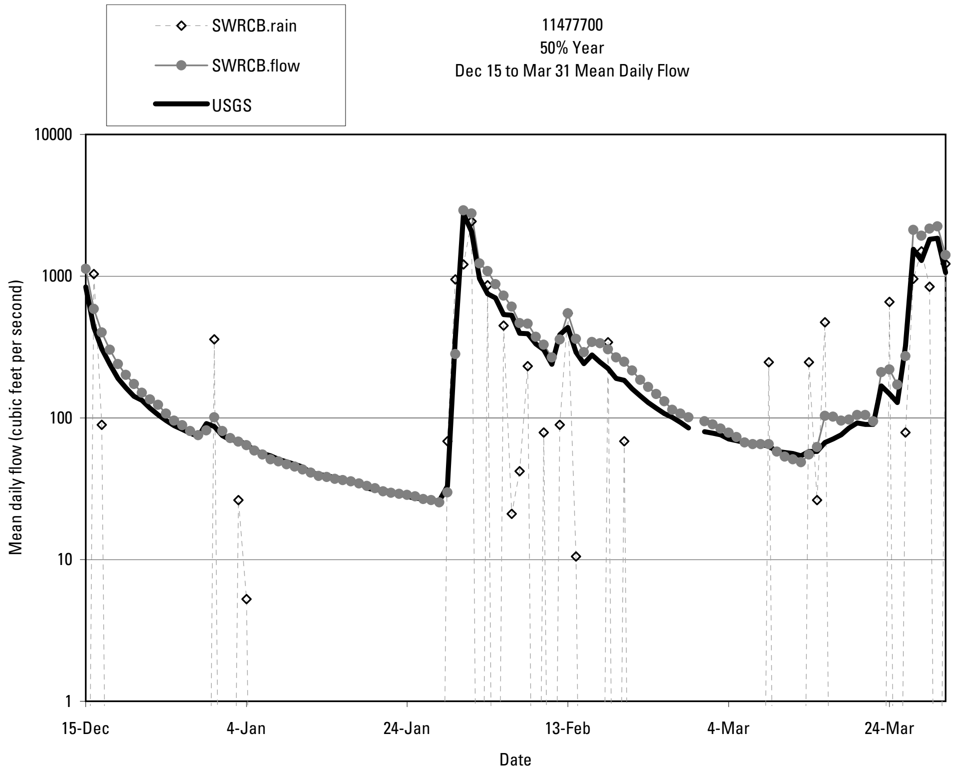


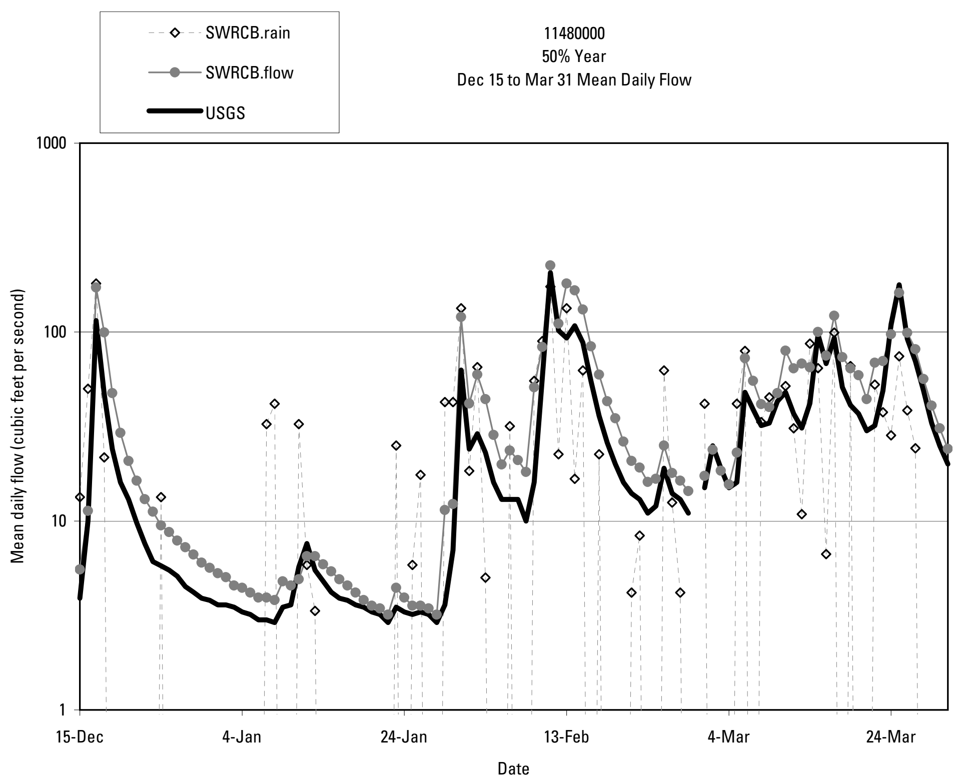
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



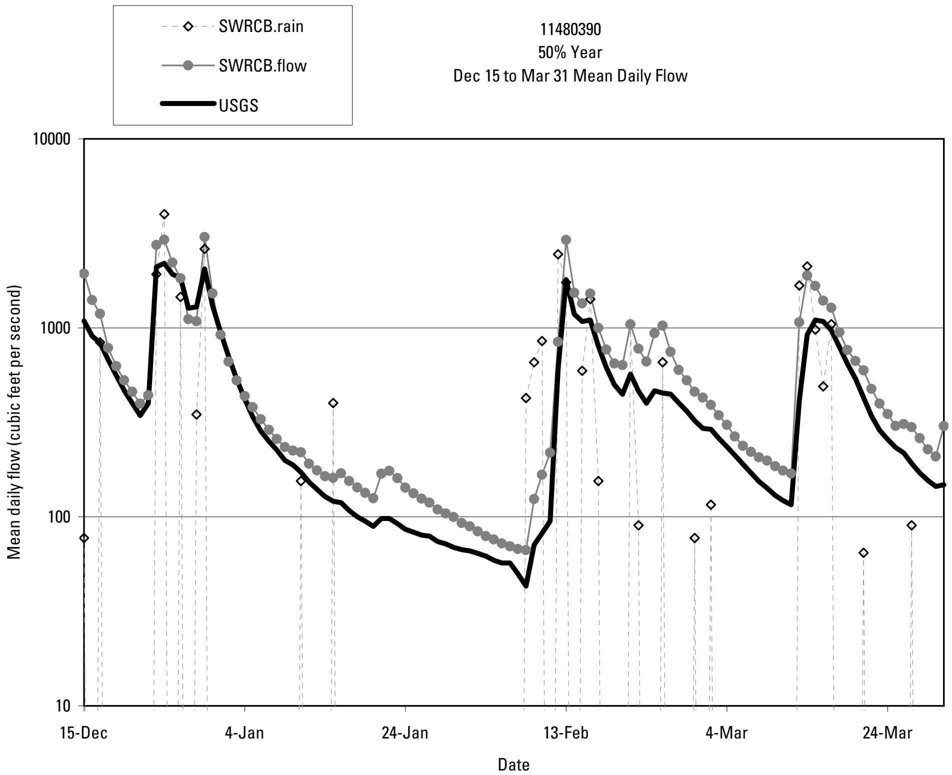


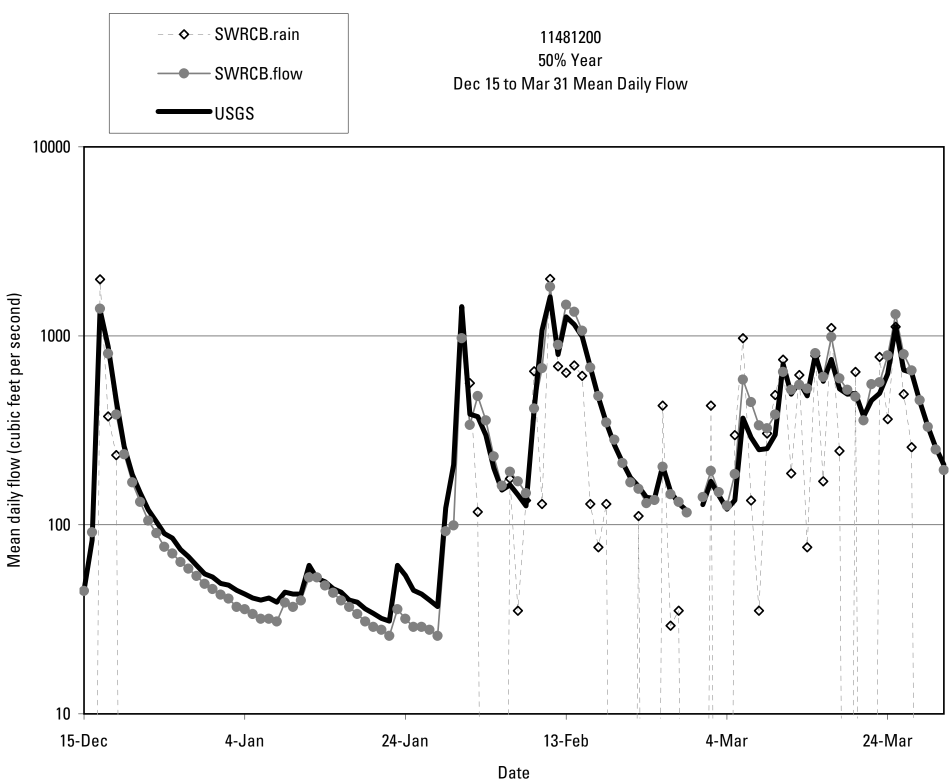
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



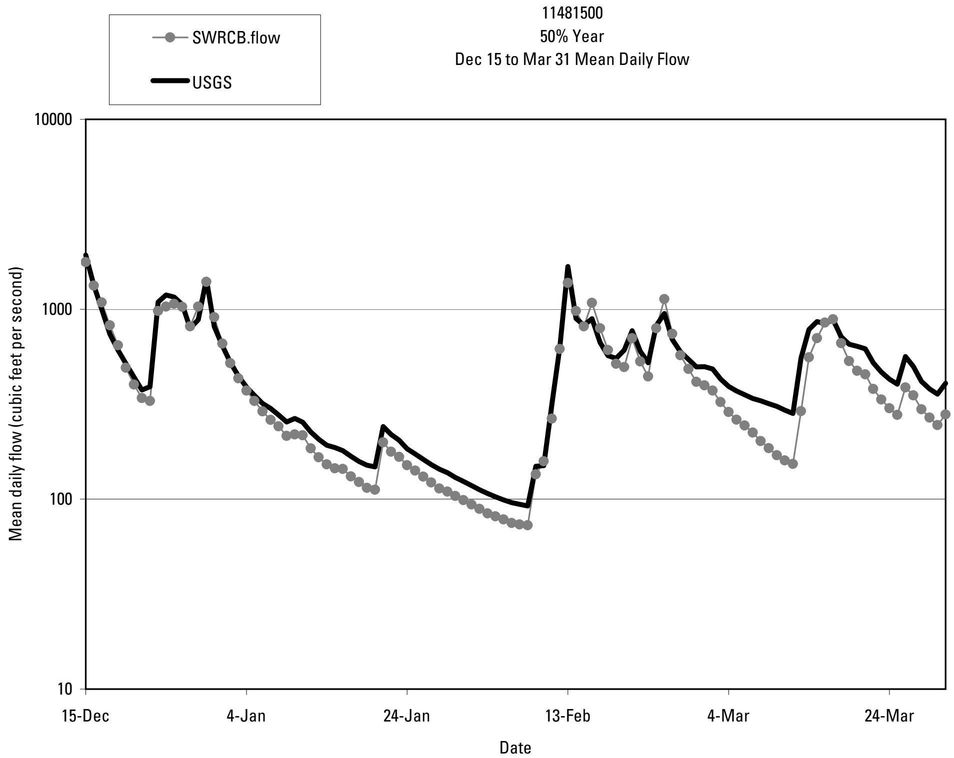


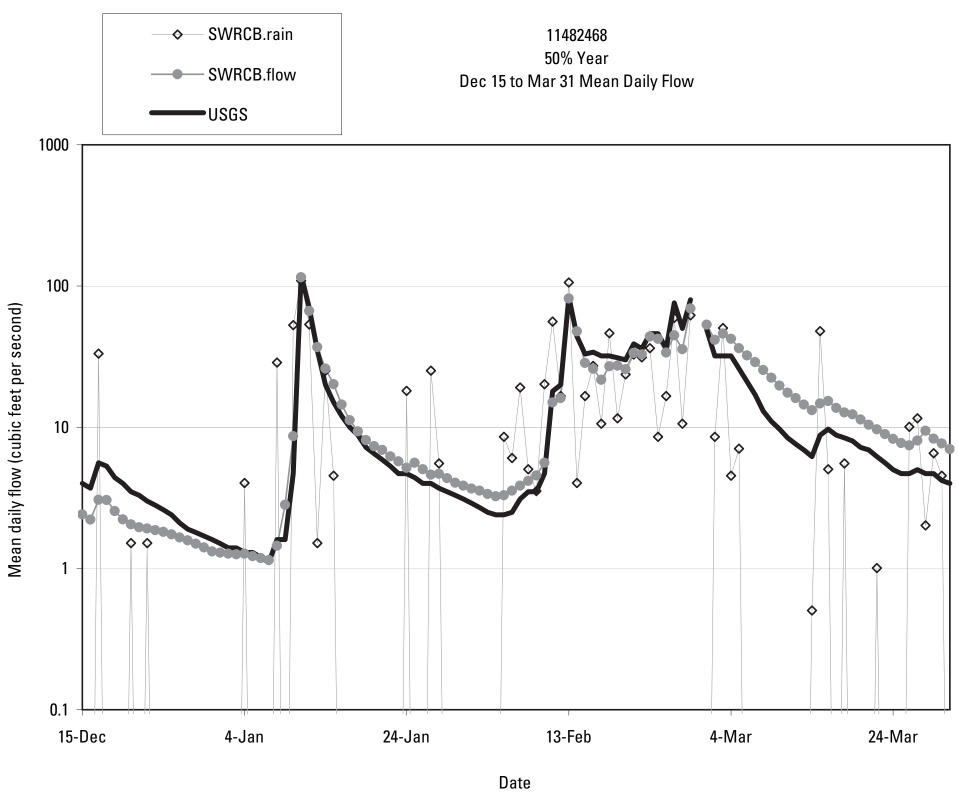
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



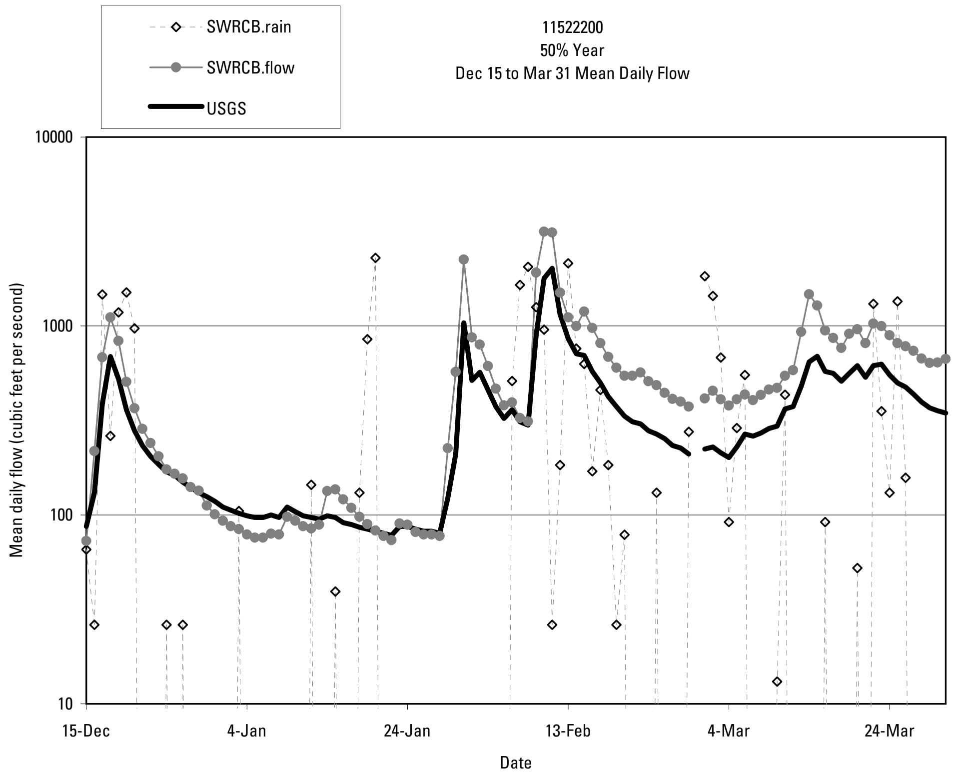


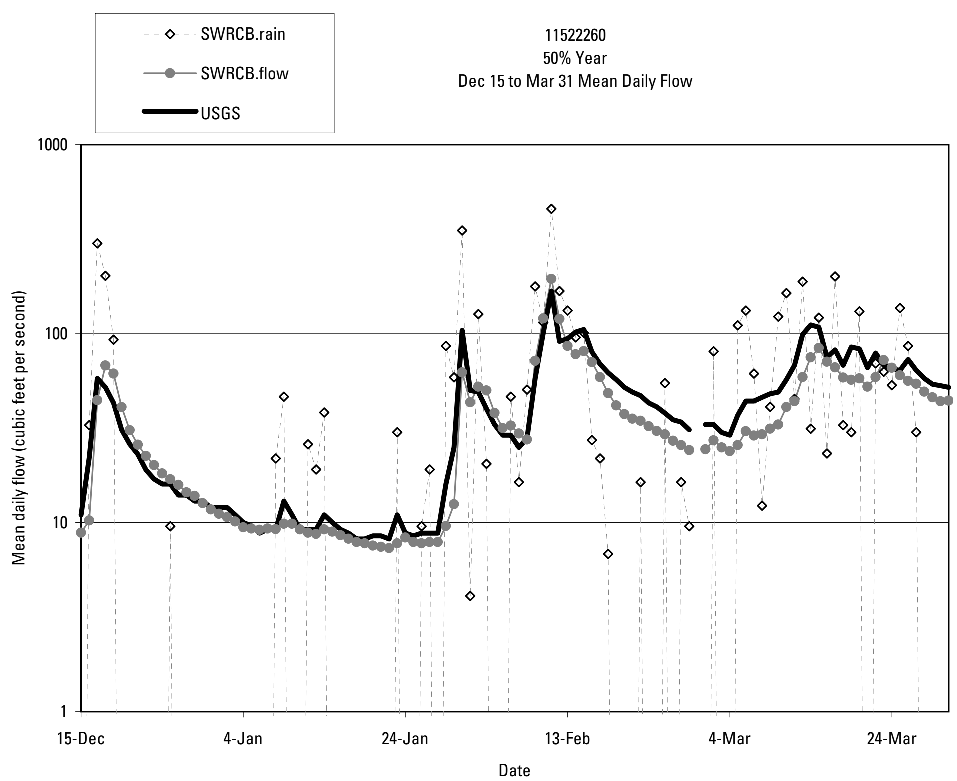
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



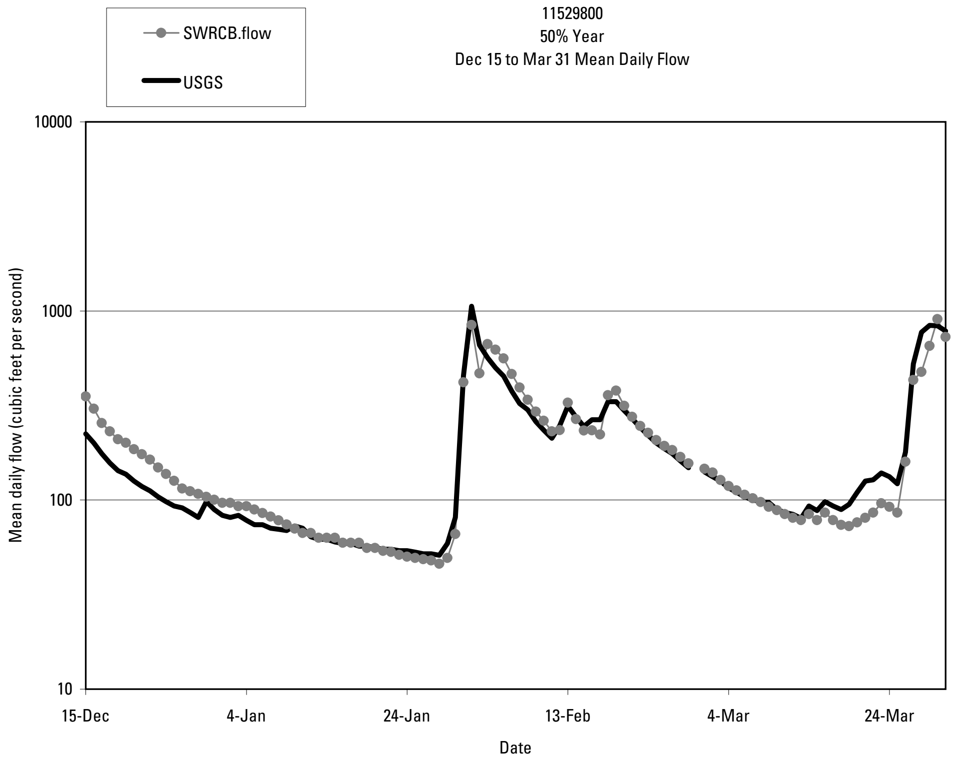


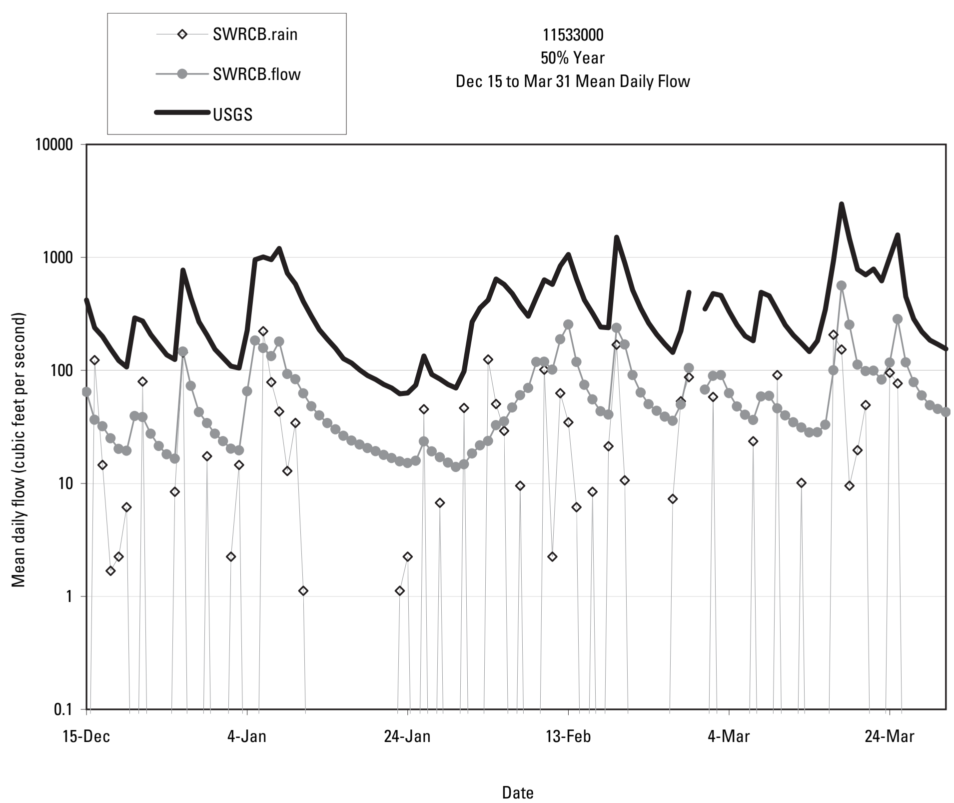
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



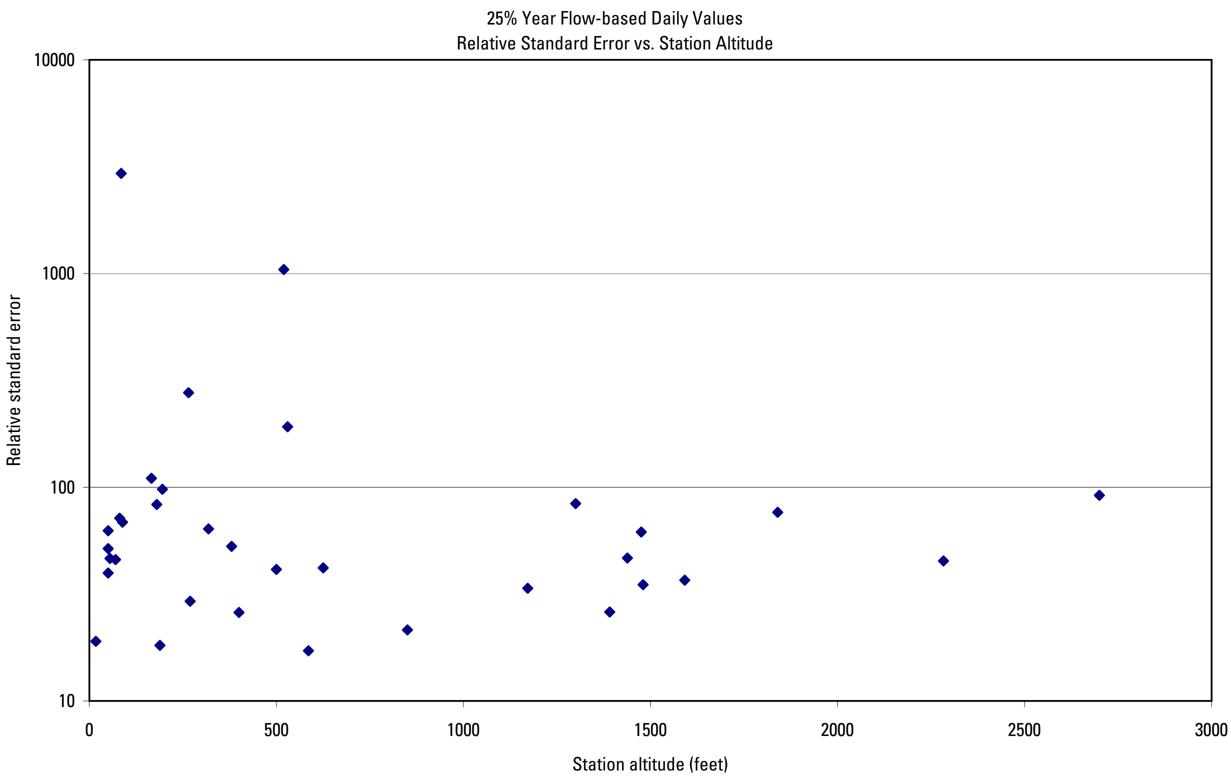


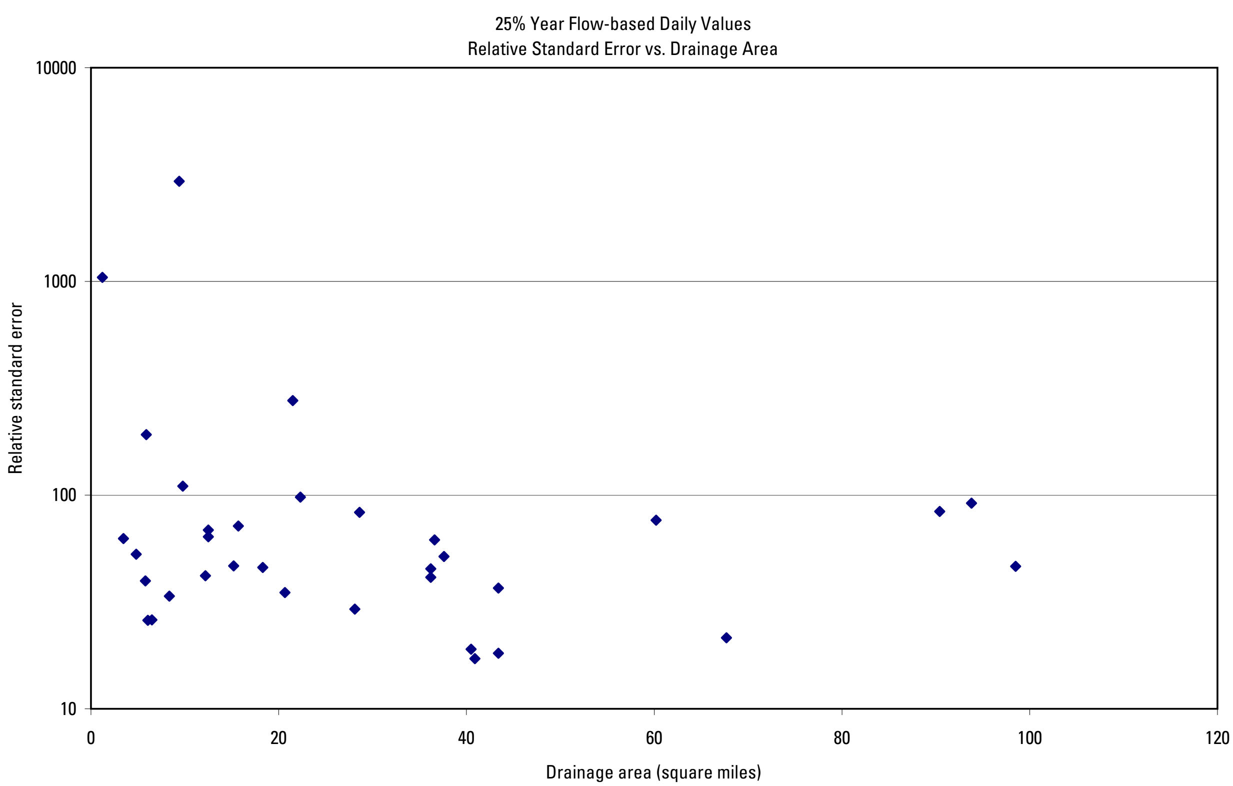
Appendix 2. SWRCB and USGS hydrographs of mean daily flows for all stations with estimates provided by SWRCB.—Continued



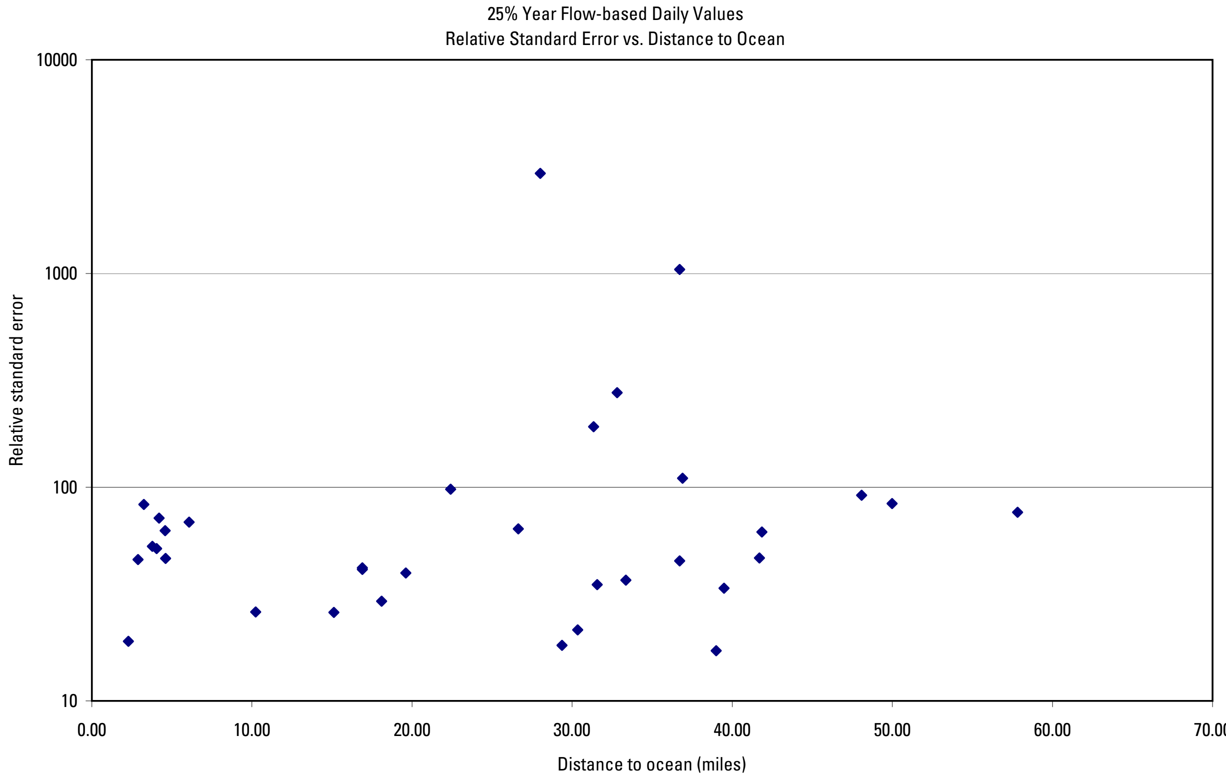


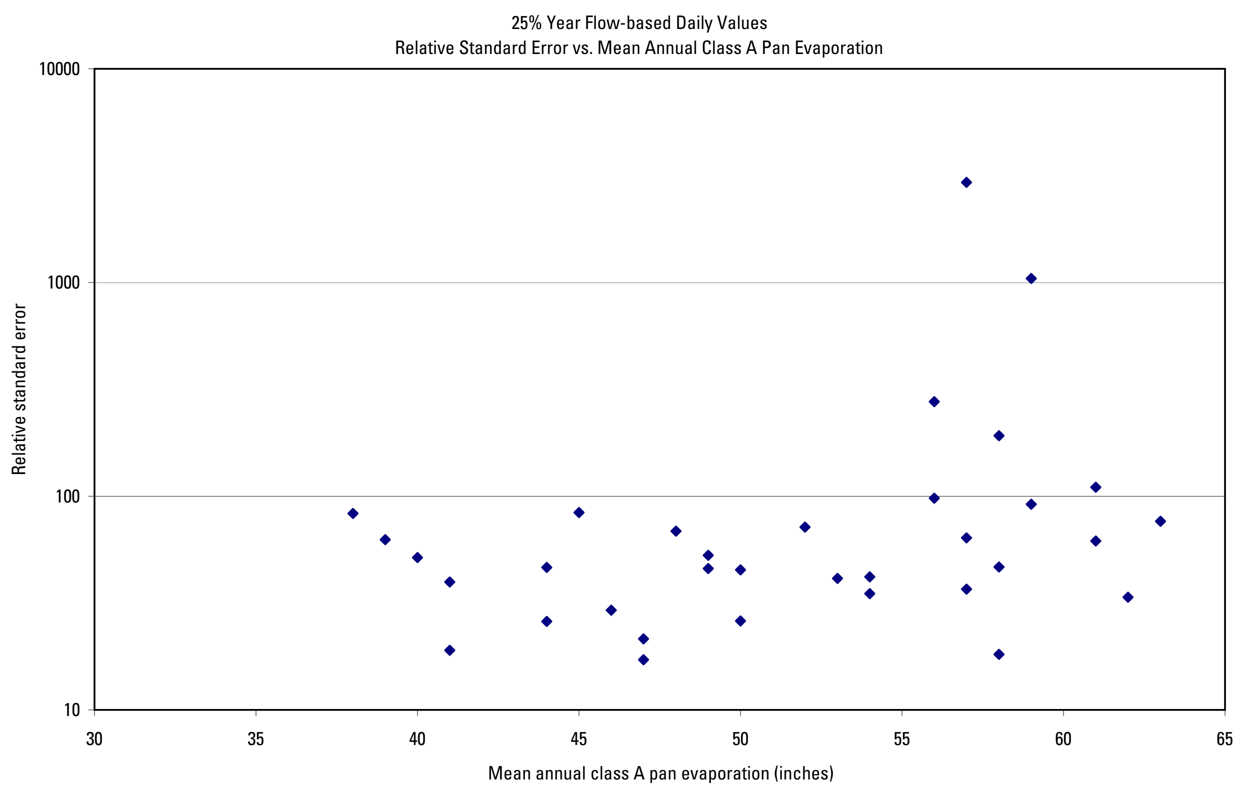
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.



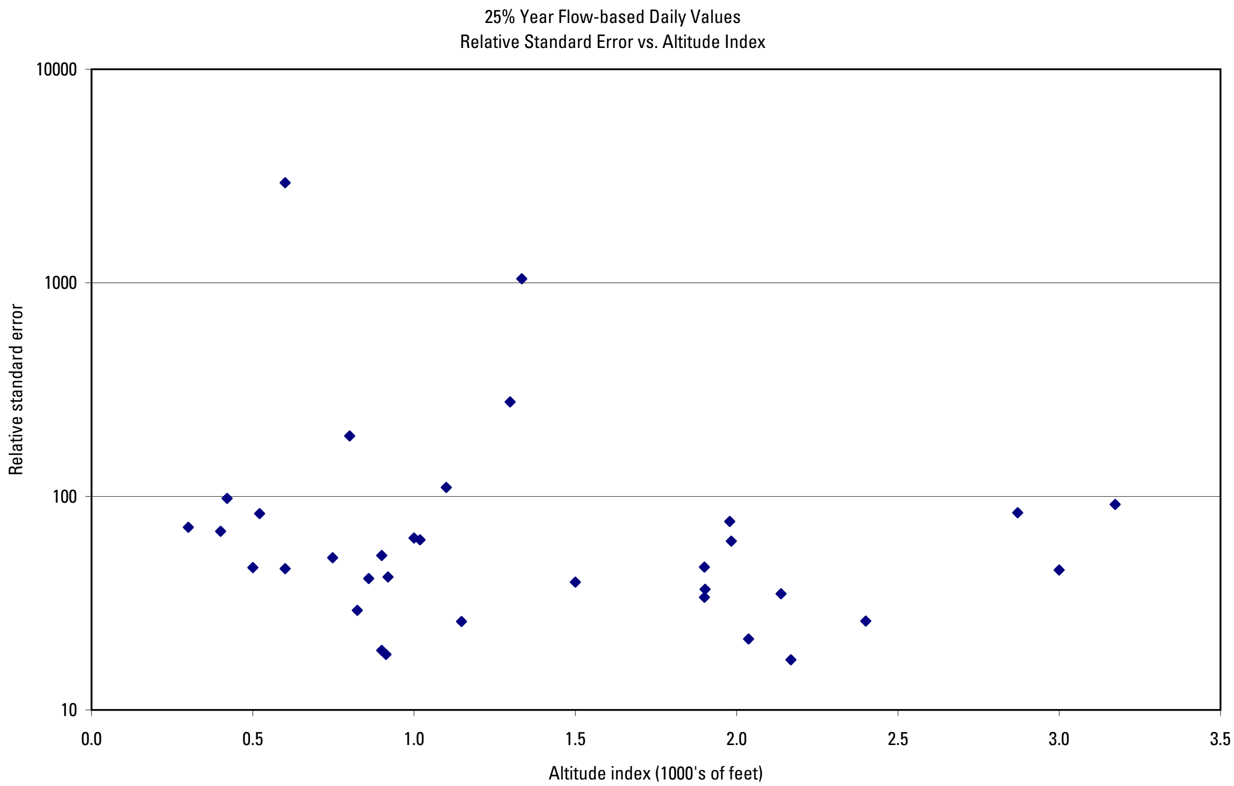


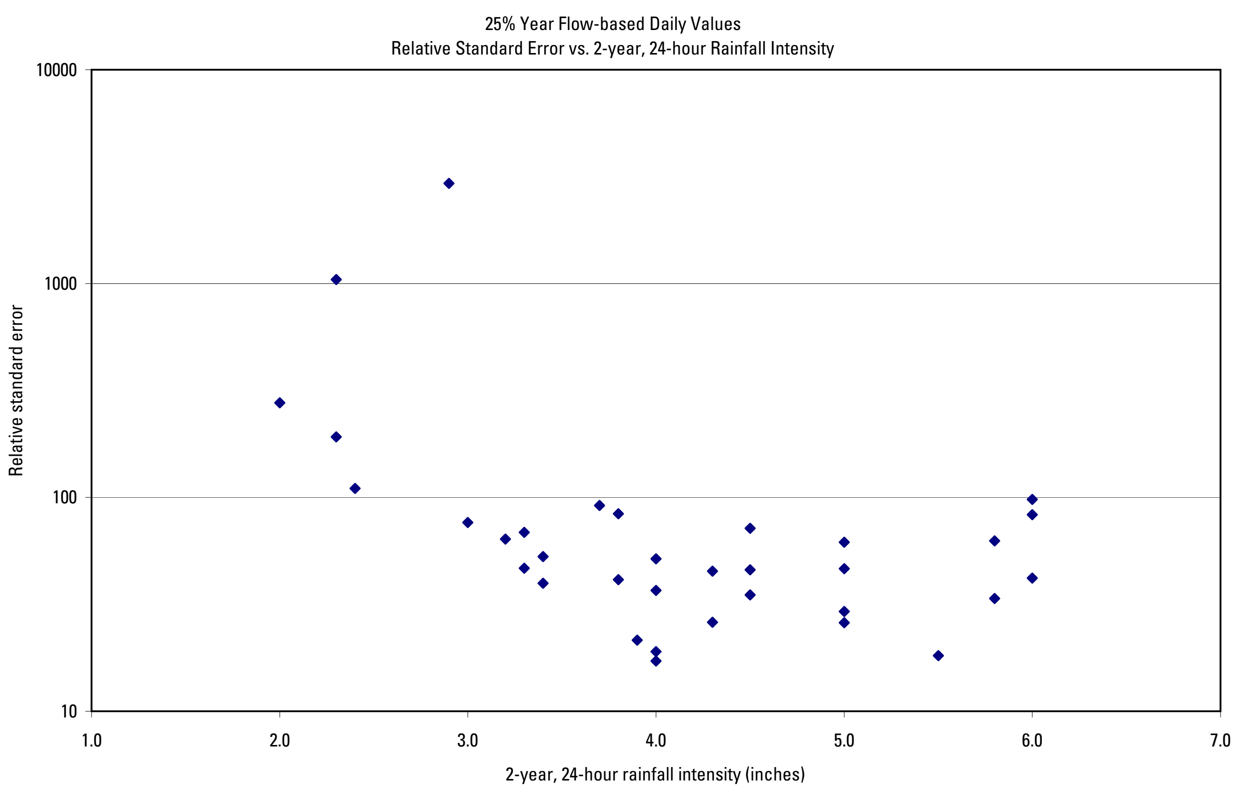
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



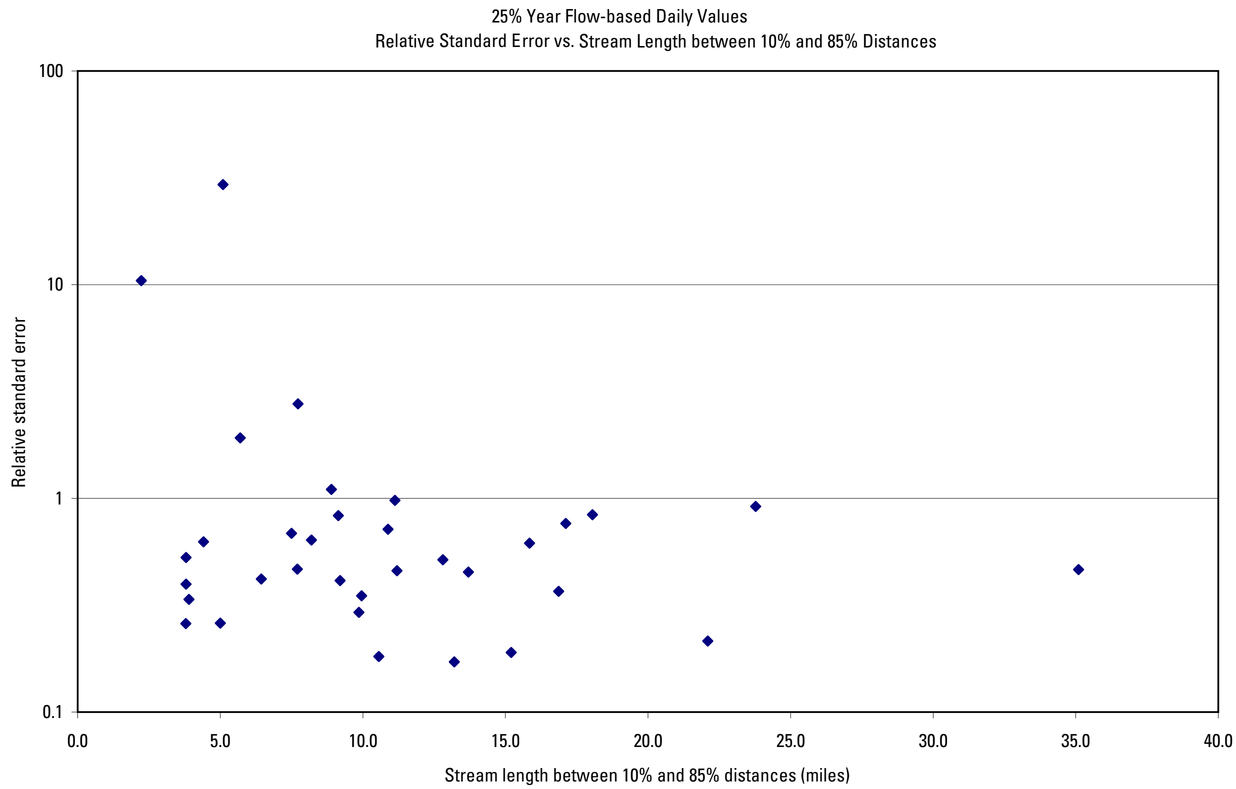


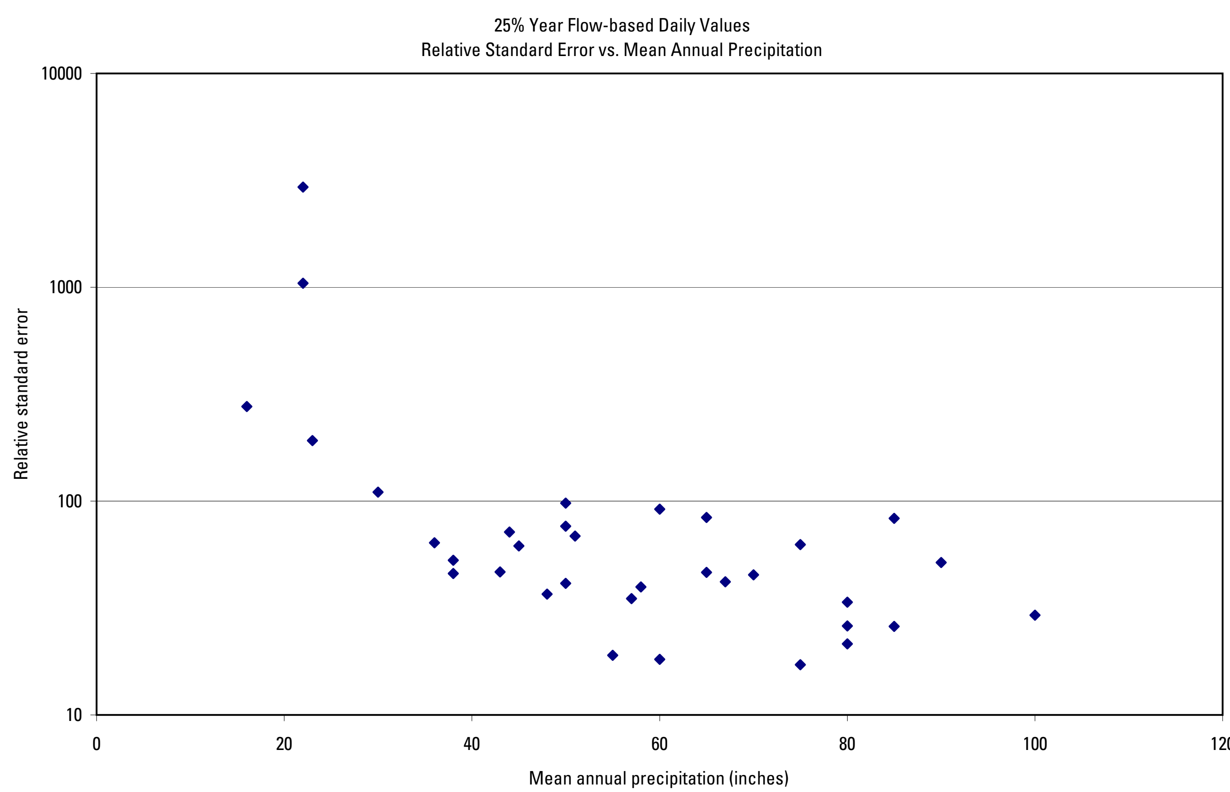
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



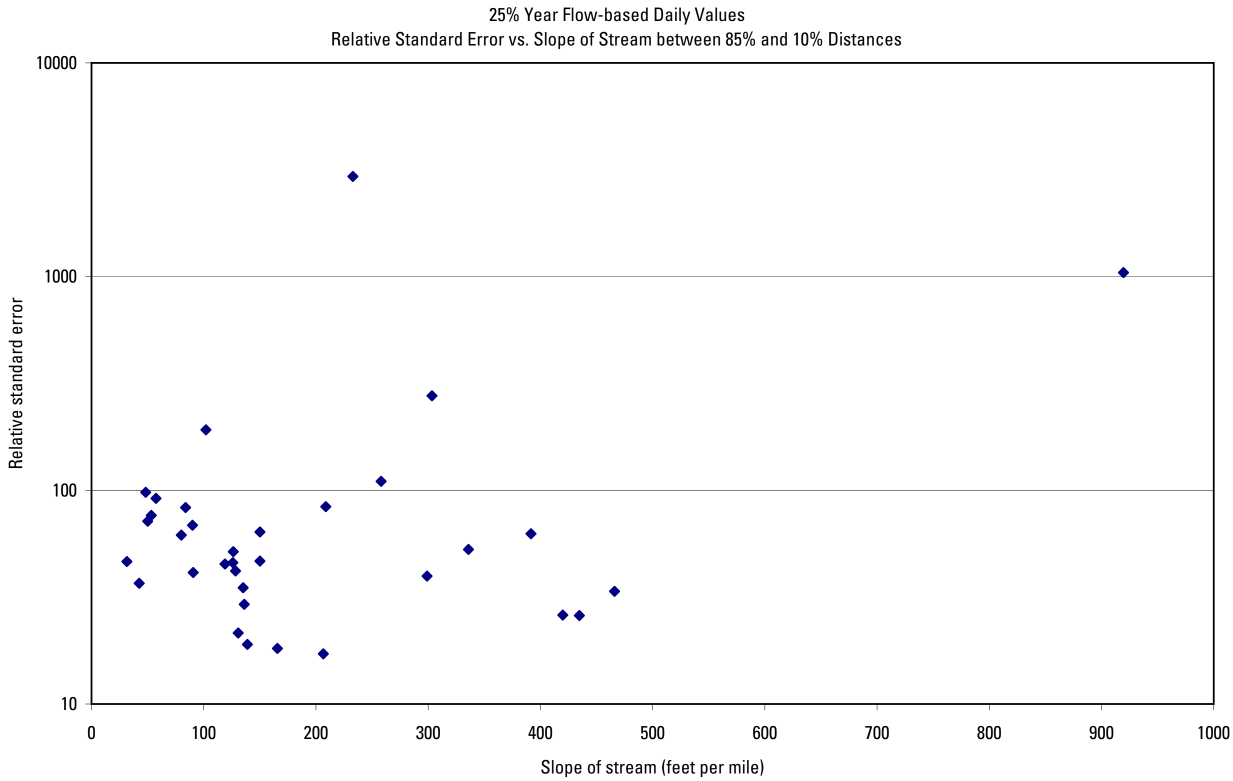


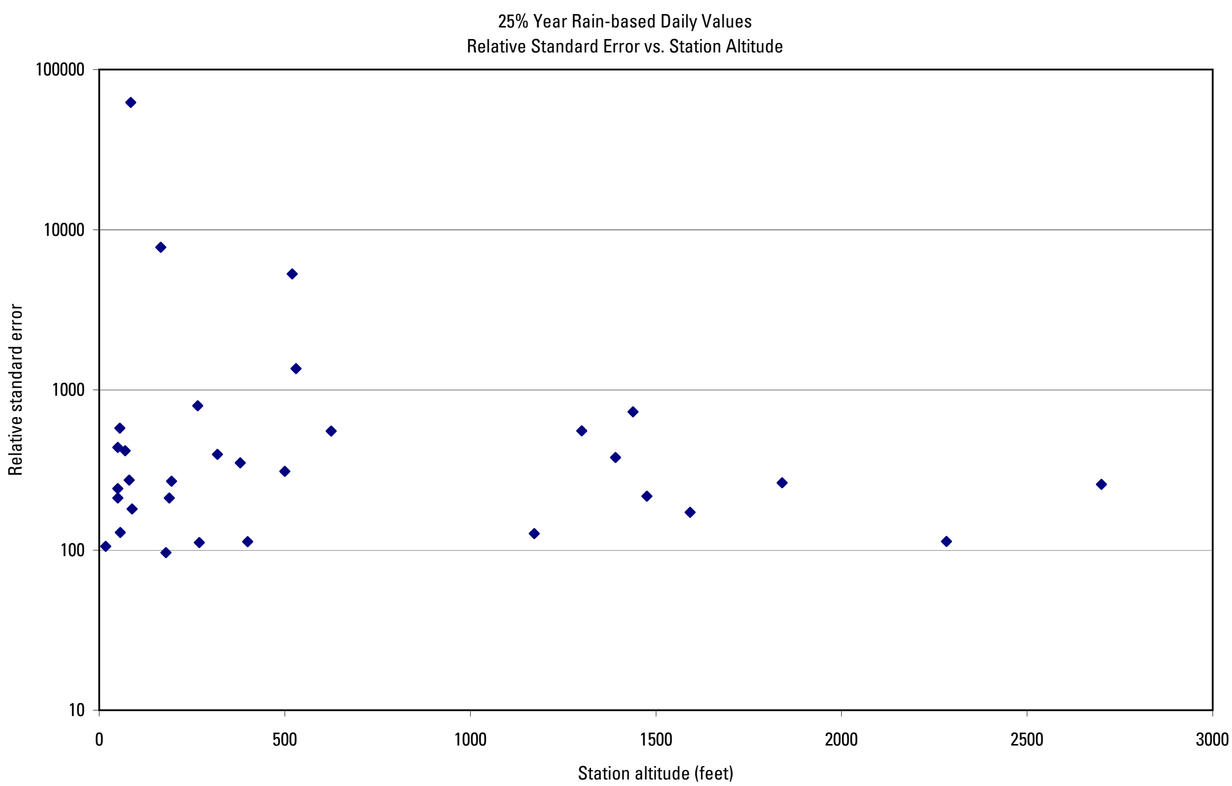
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



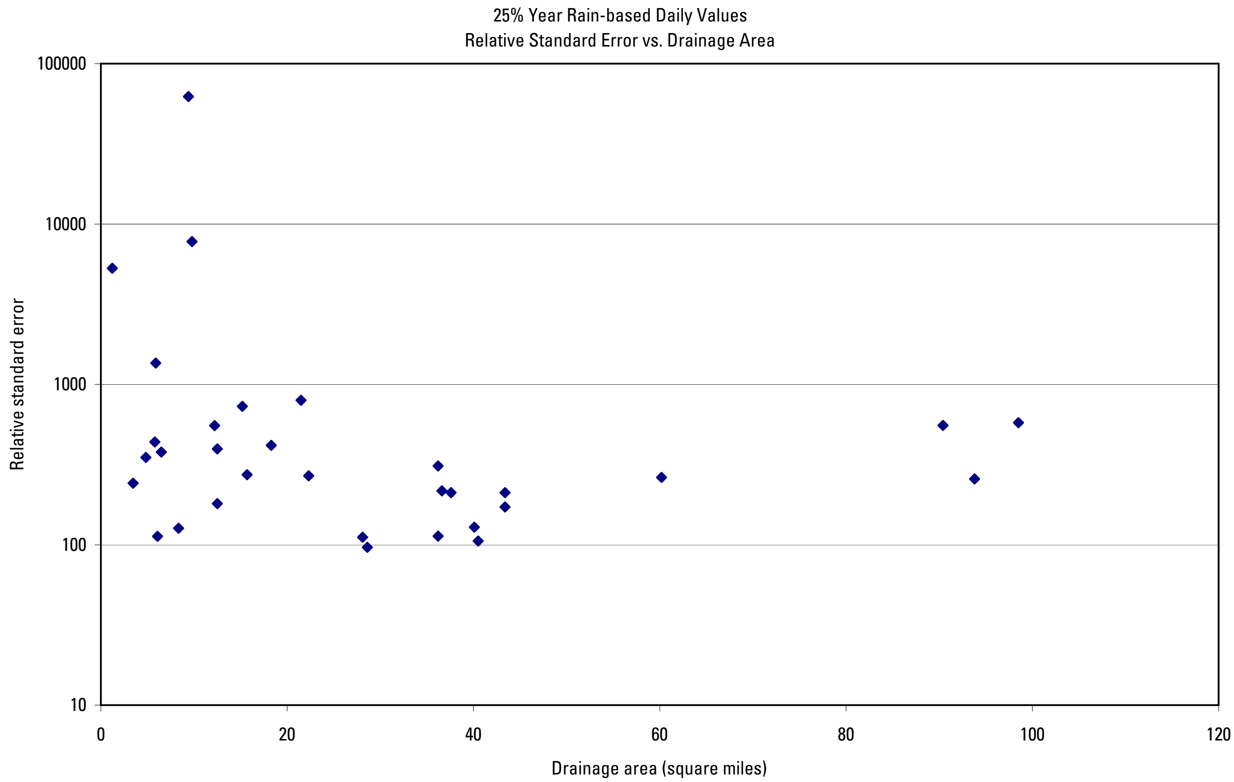


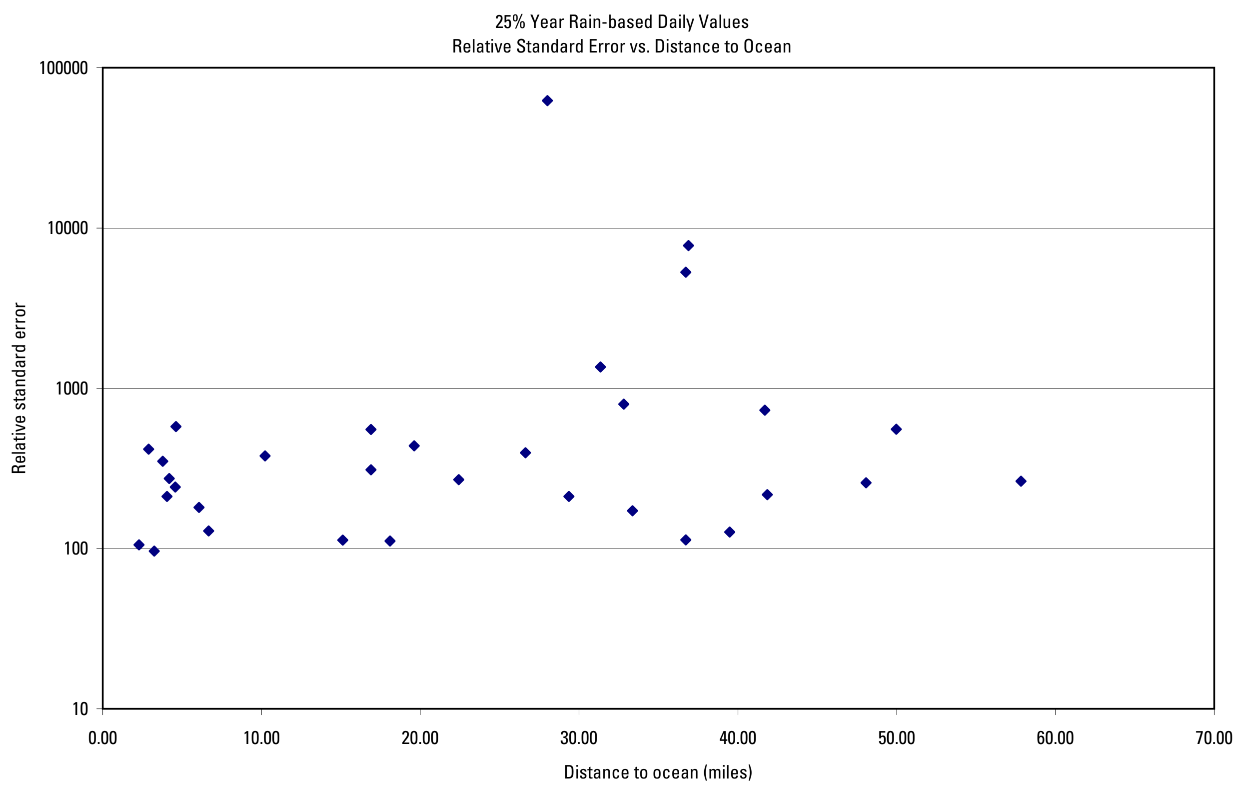
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



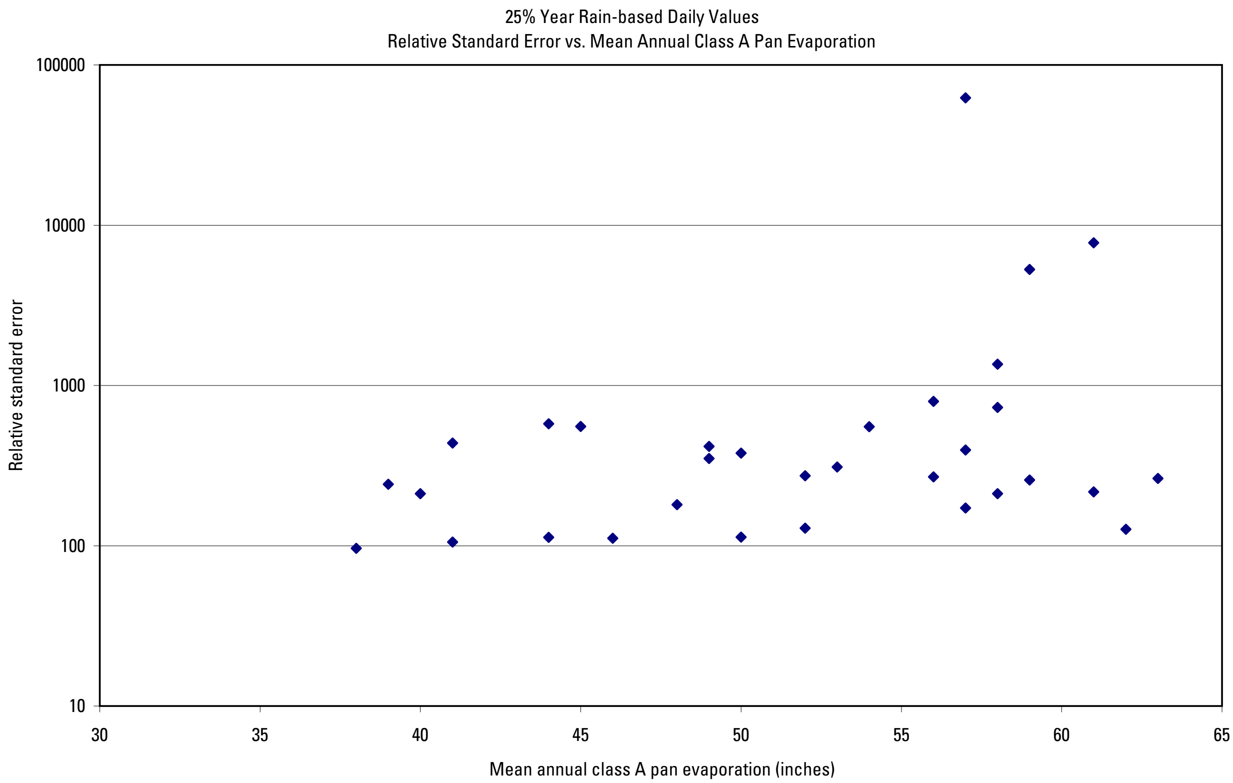


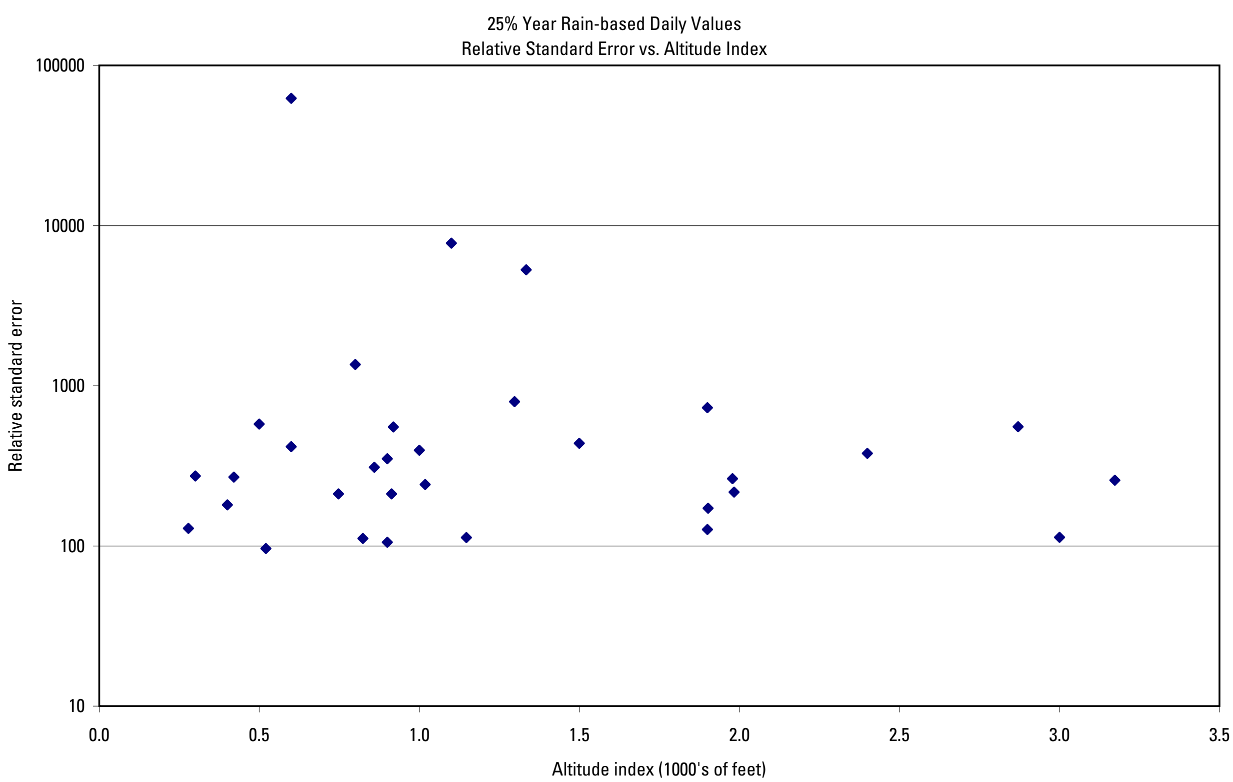
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



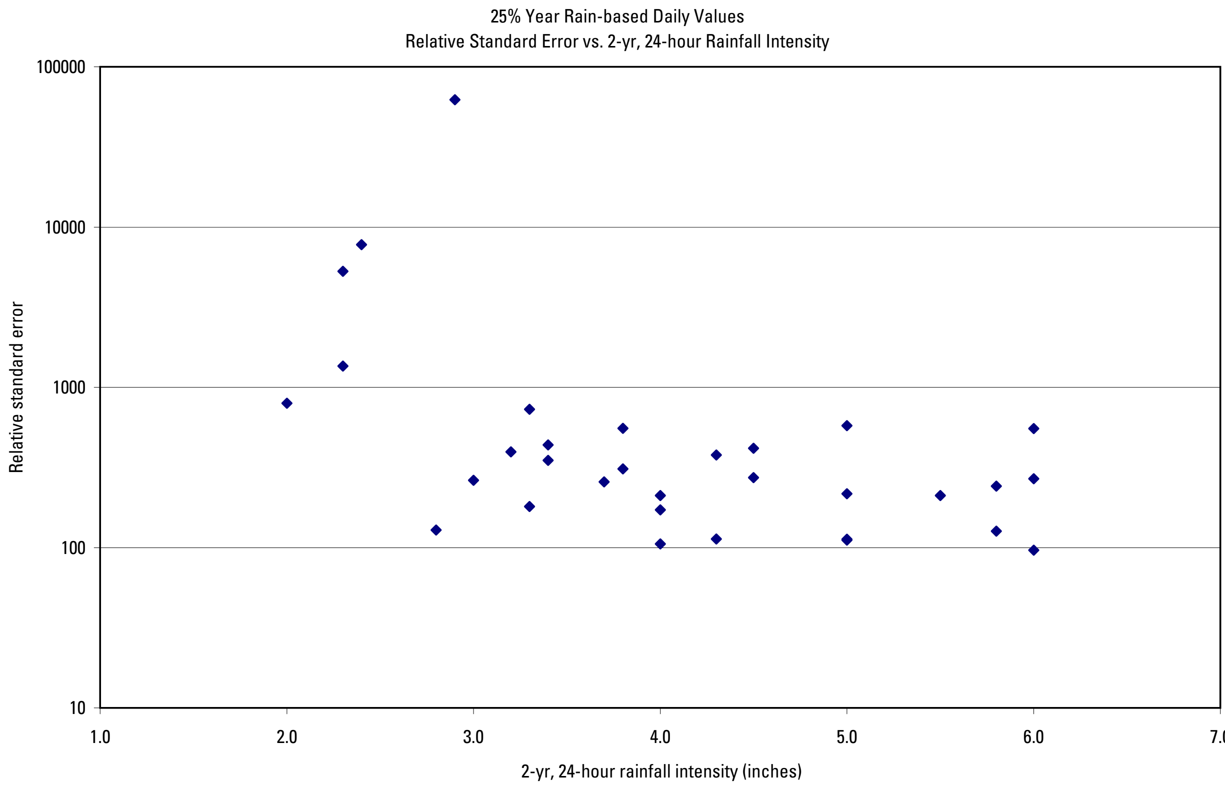


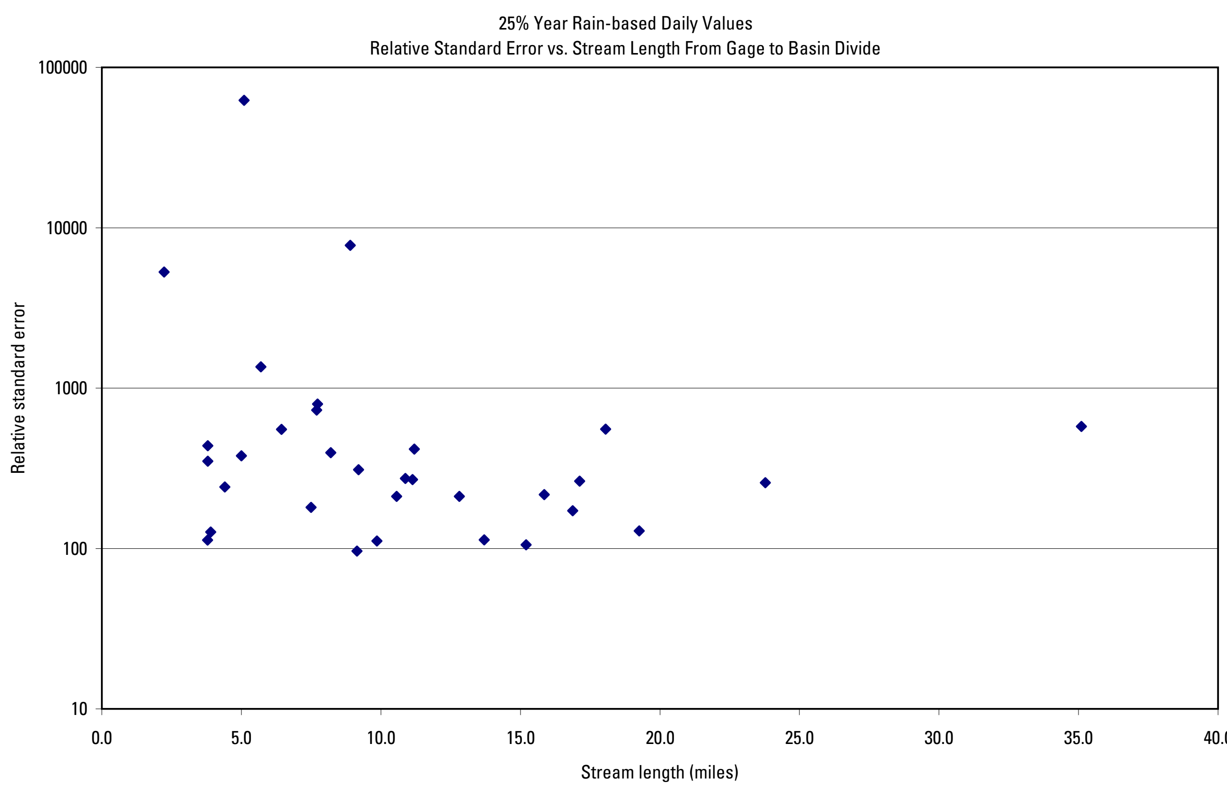
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



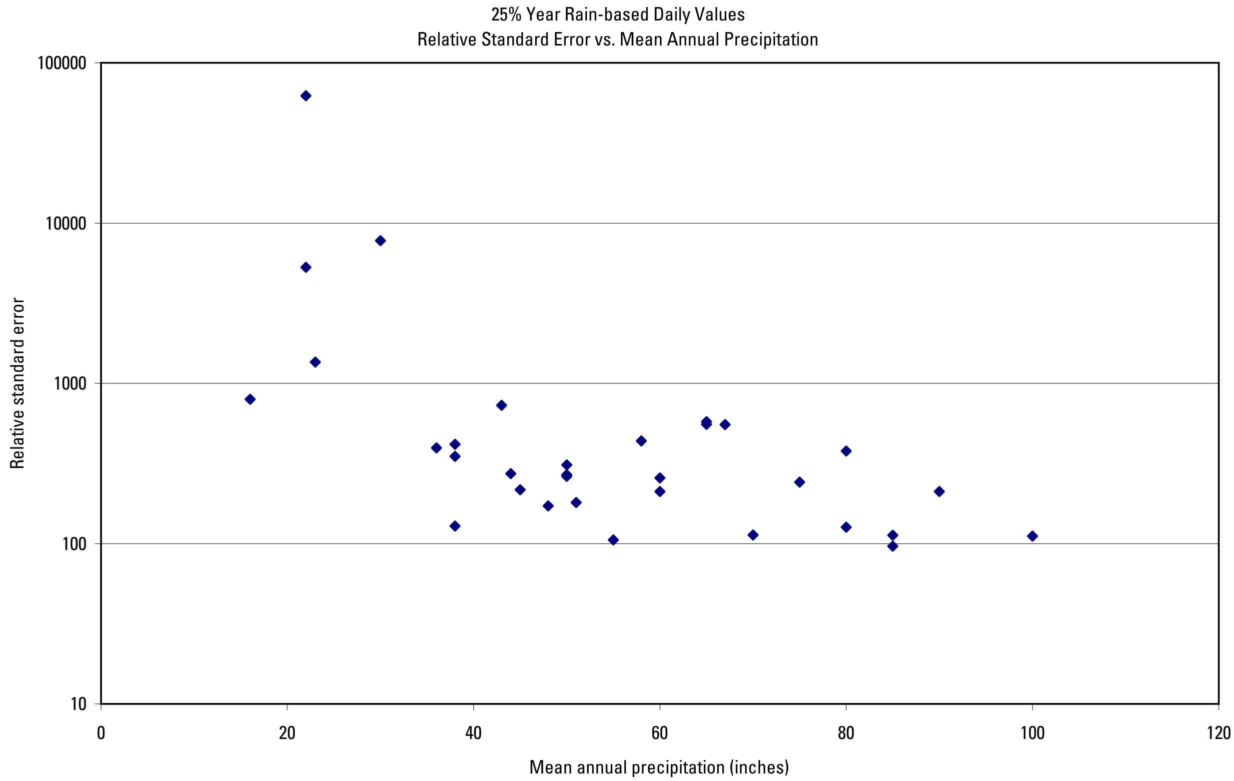


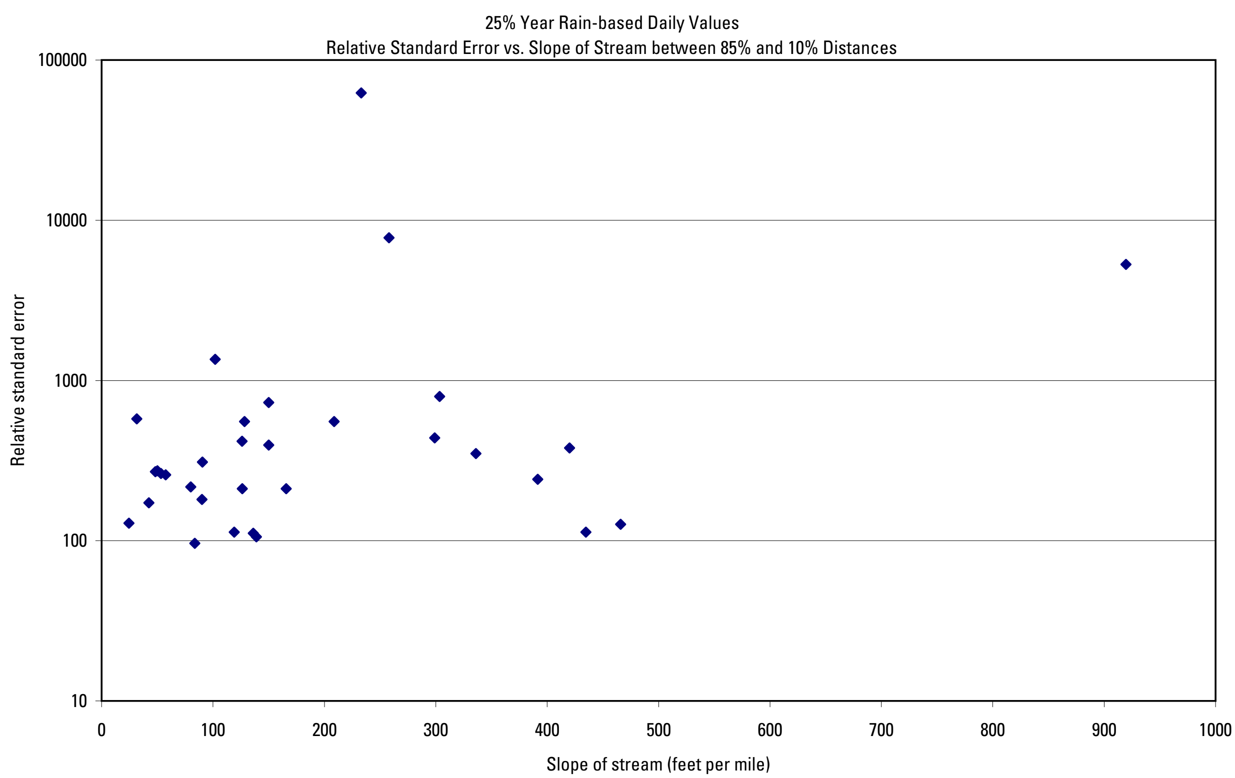
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



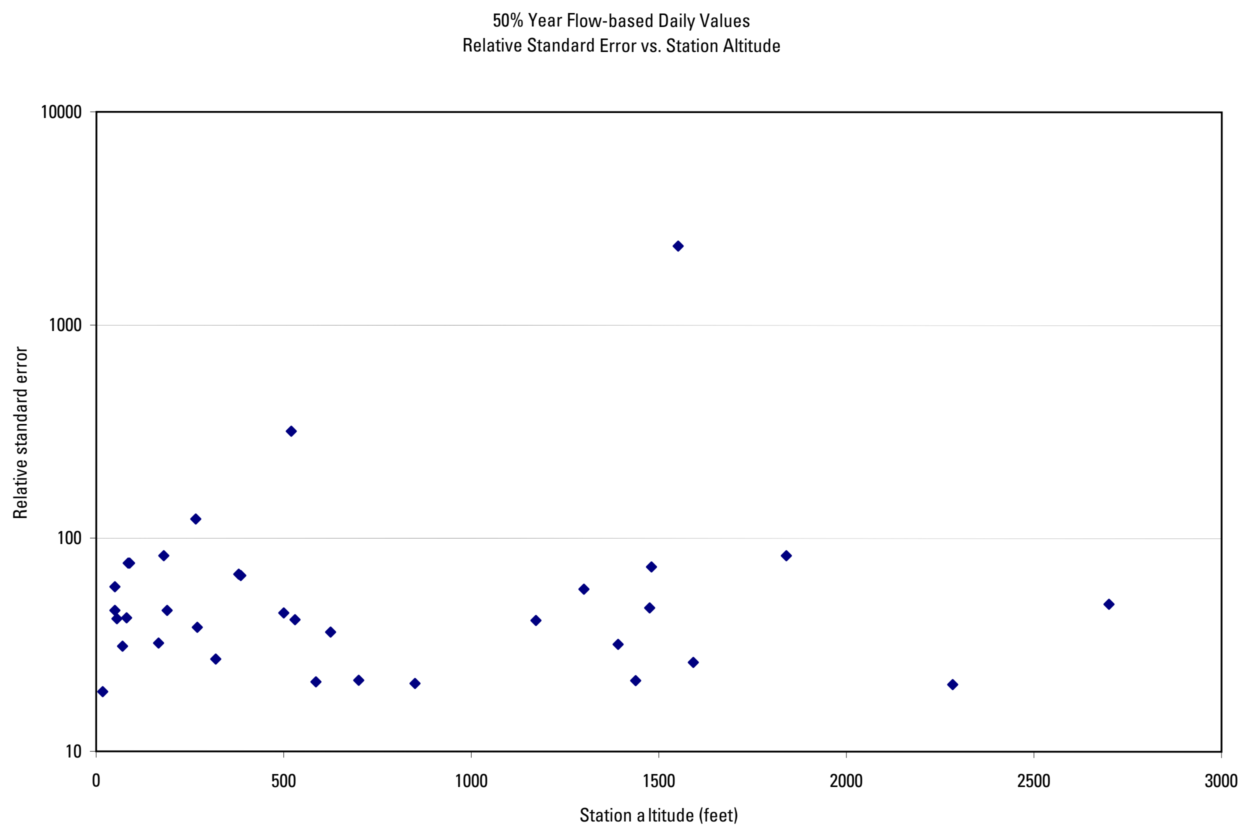


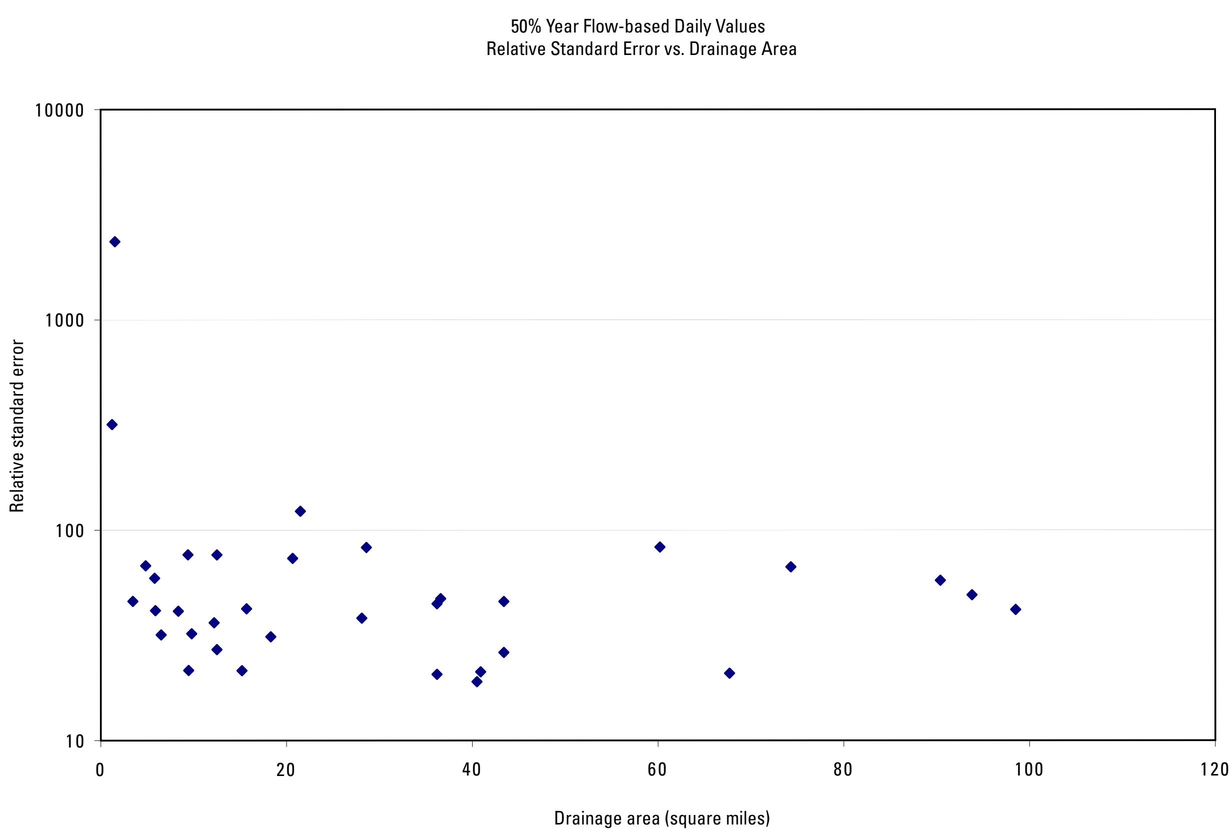
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued





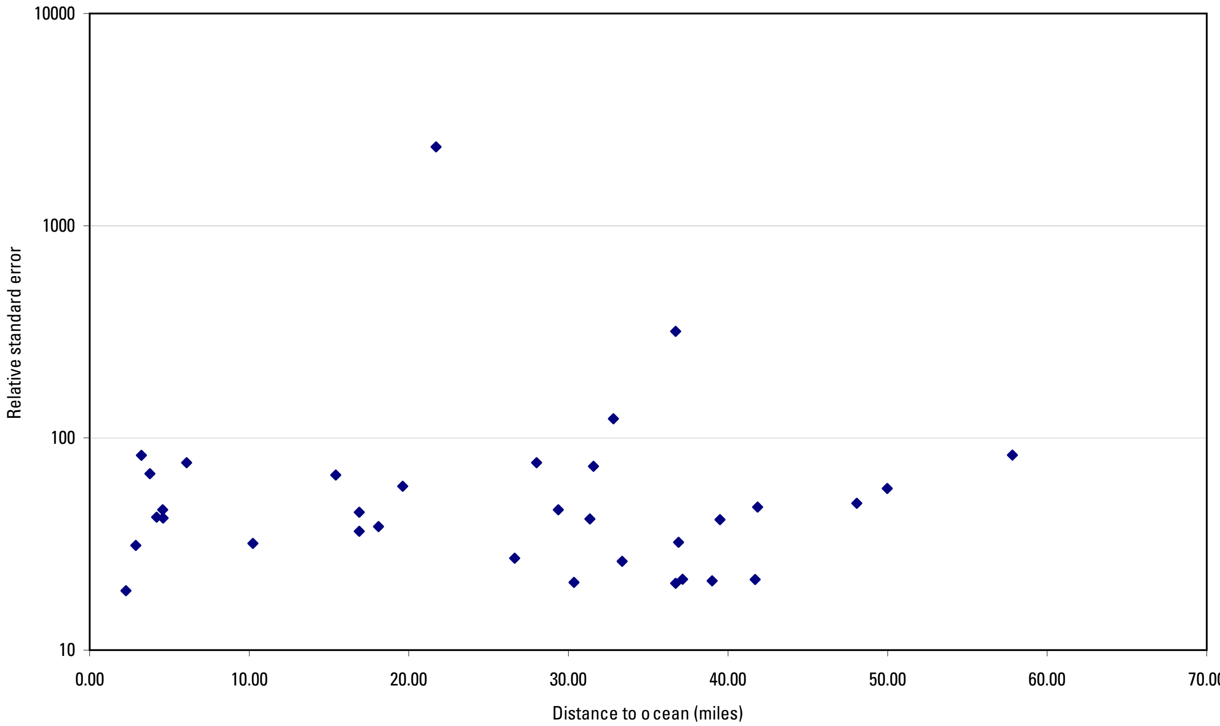
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



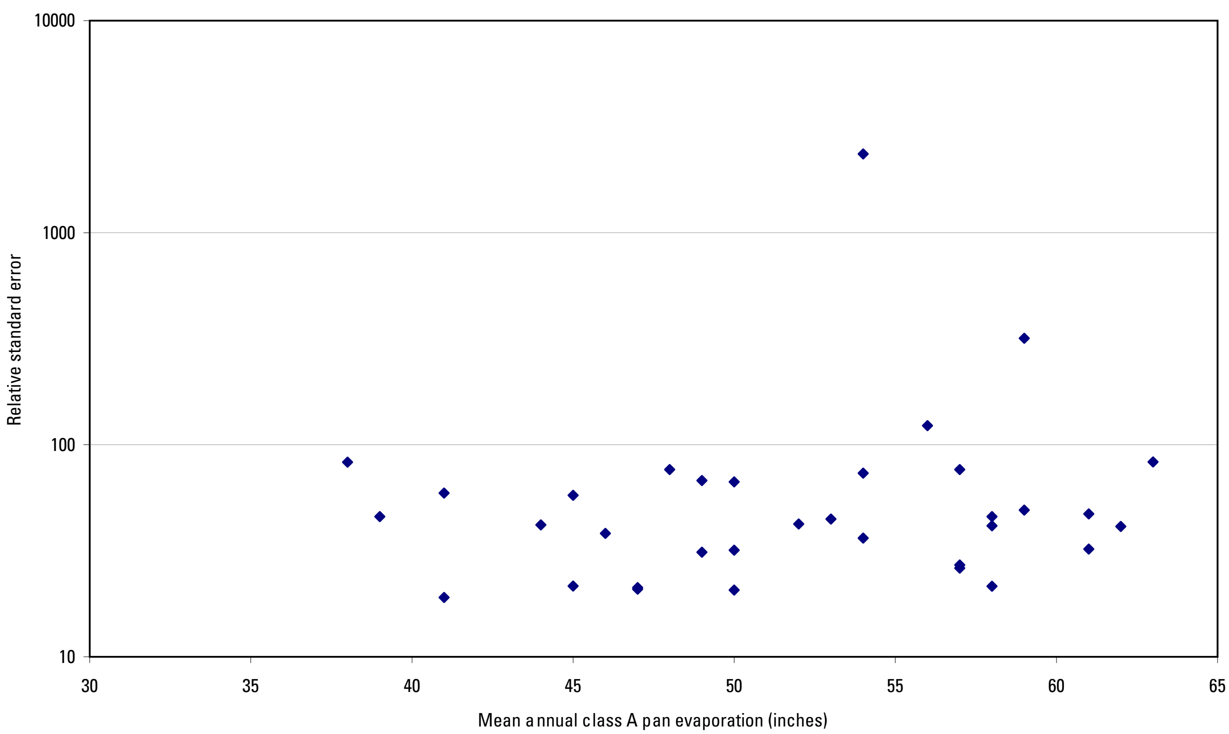


Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued

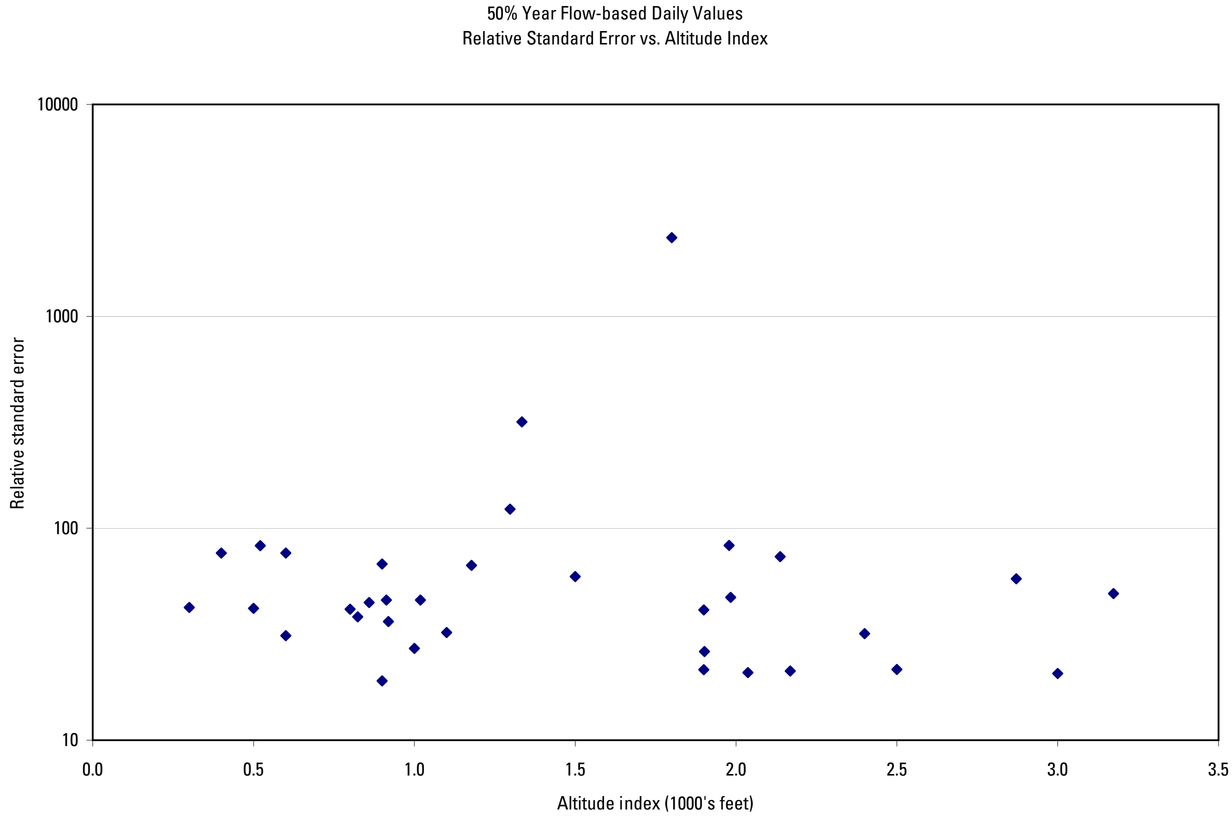
50% Year Flow-based Daily Values
Relative Standard Error vs. Distance to Ocean

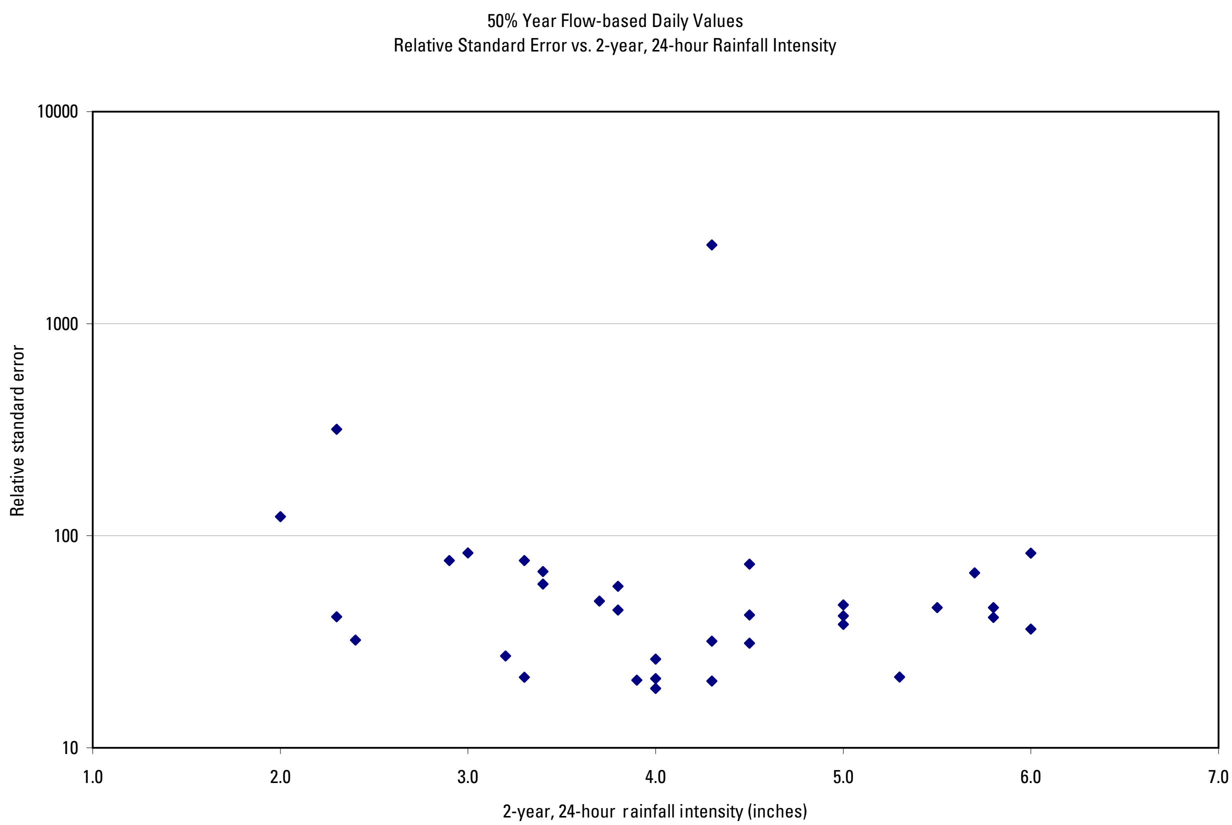


50% Year Flow-based Daily Values
Relative Standard Error vs. Mean Annual Class A Pan Evaporation (inches)

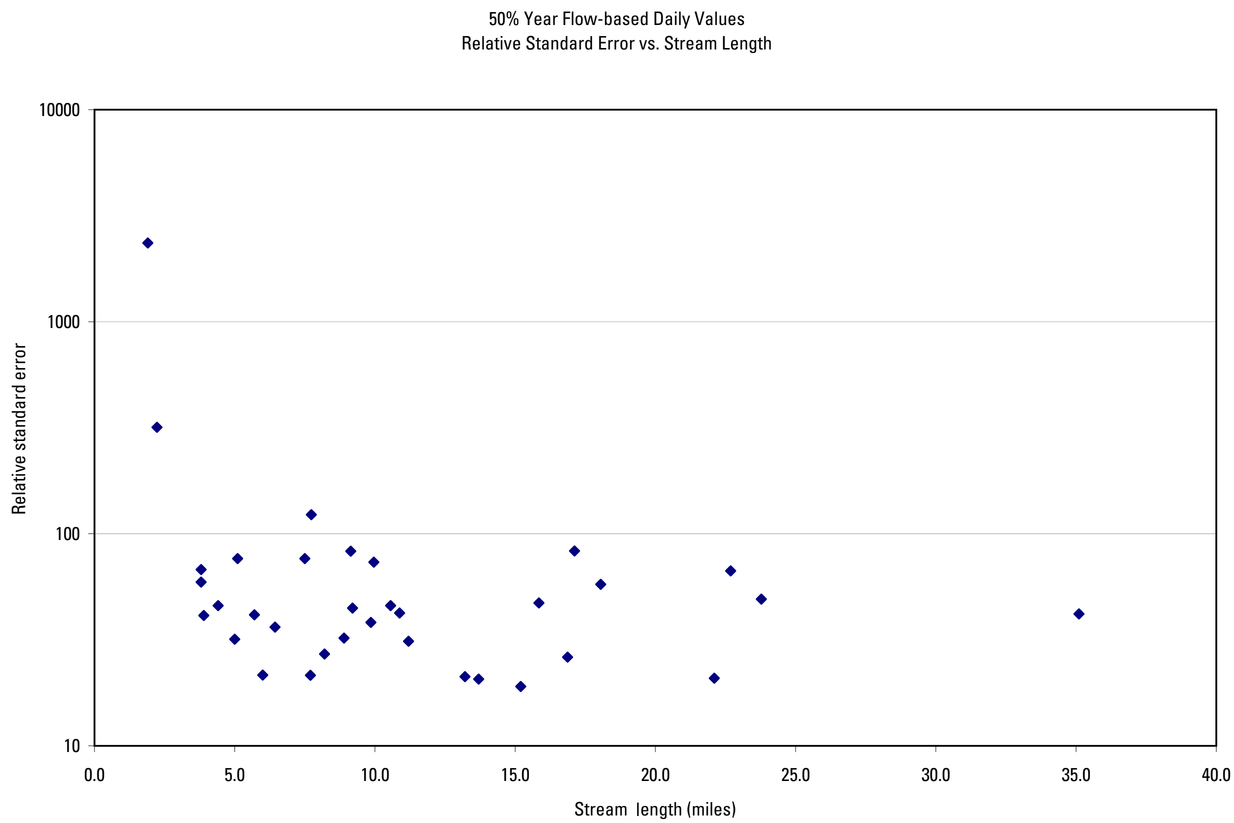


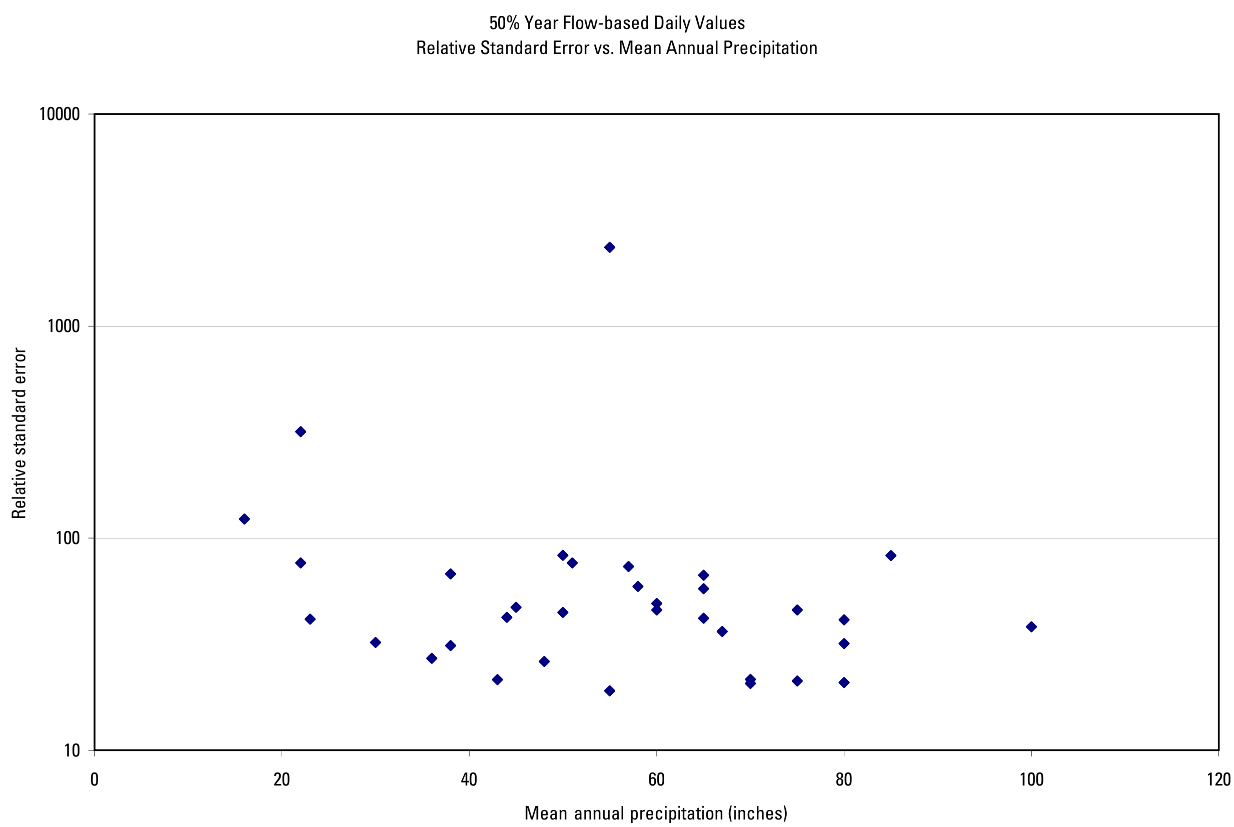
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



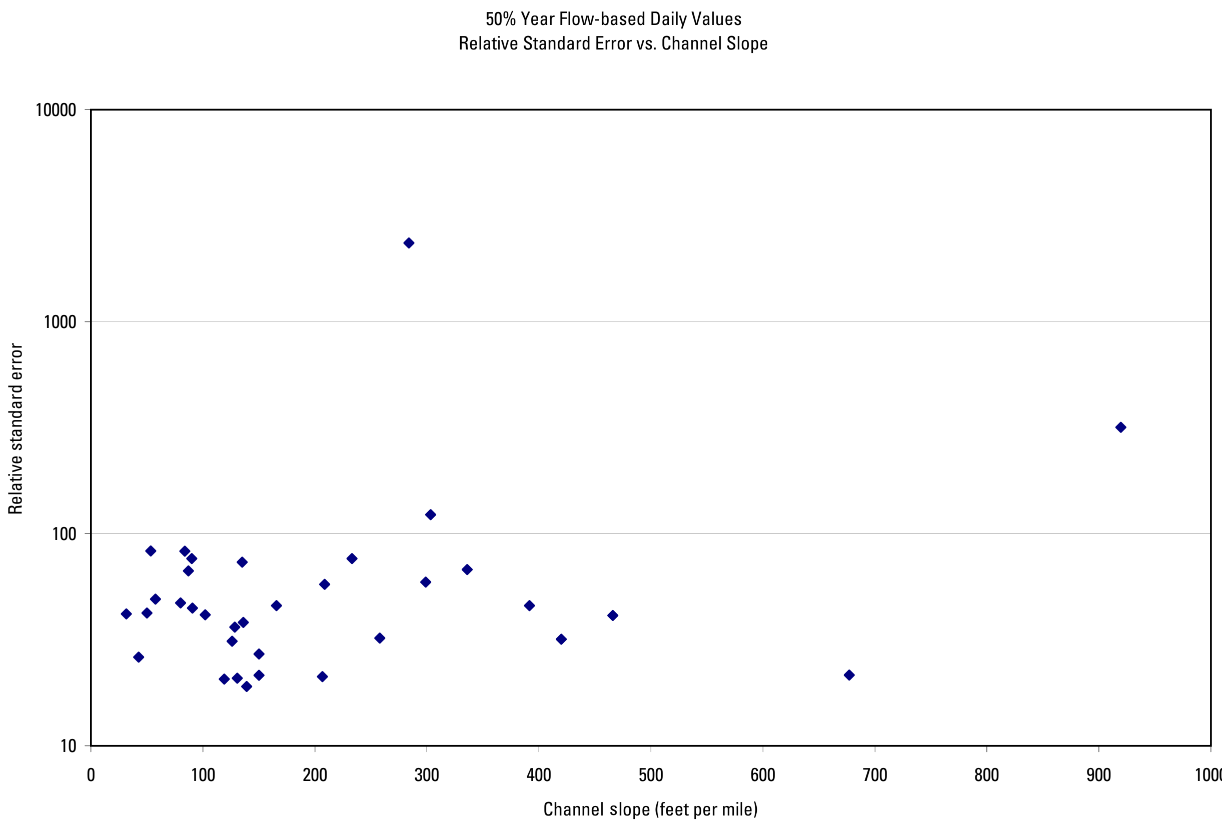


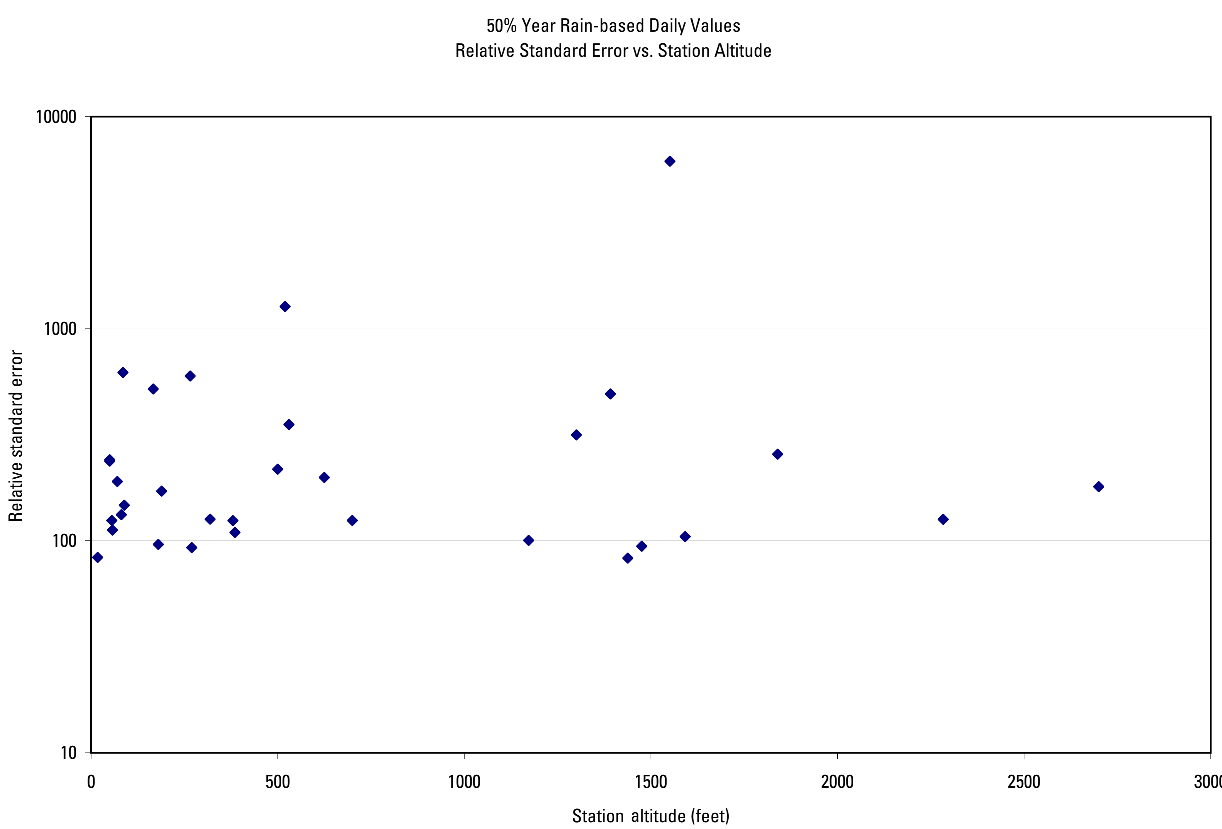
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



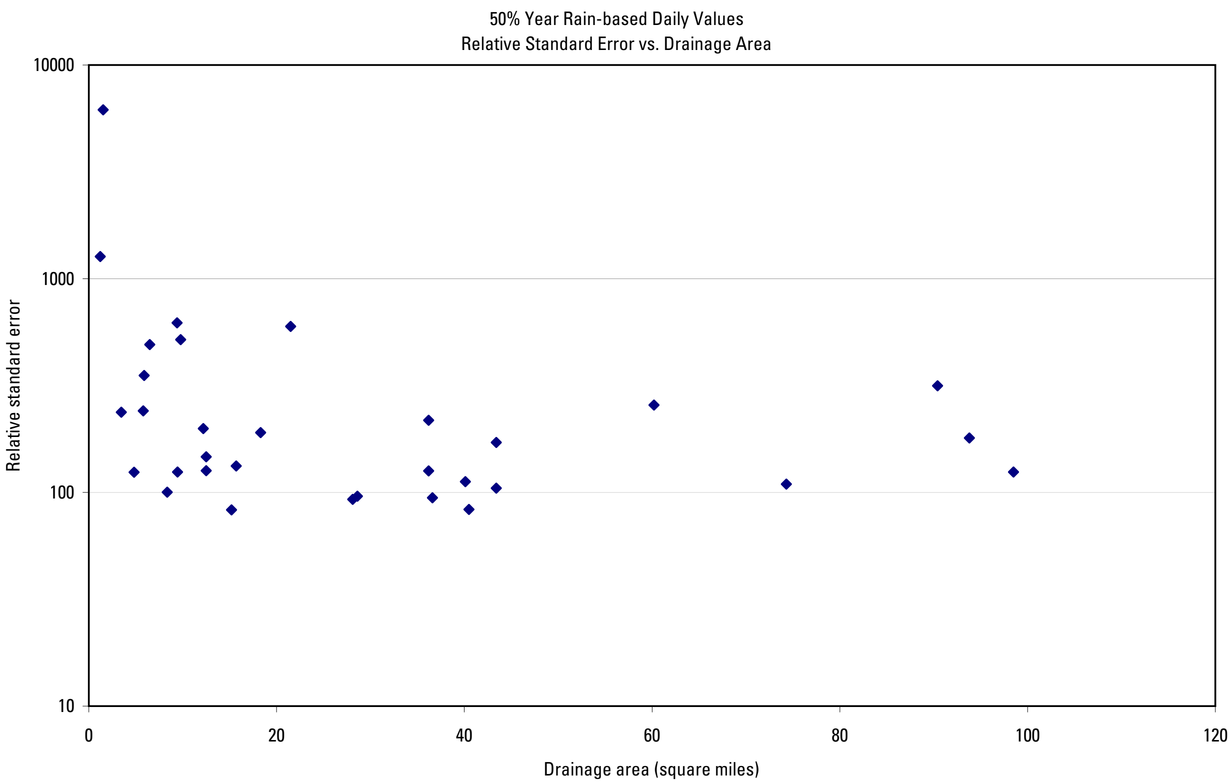


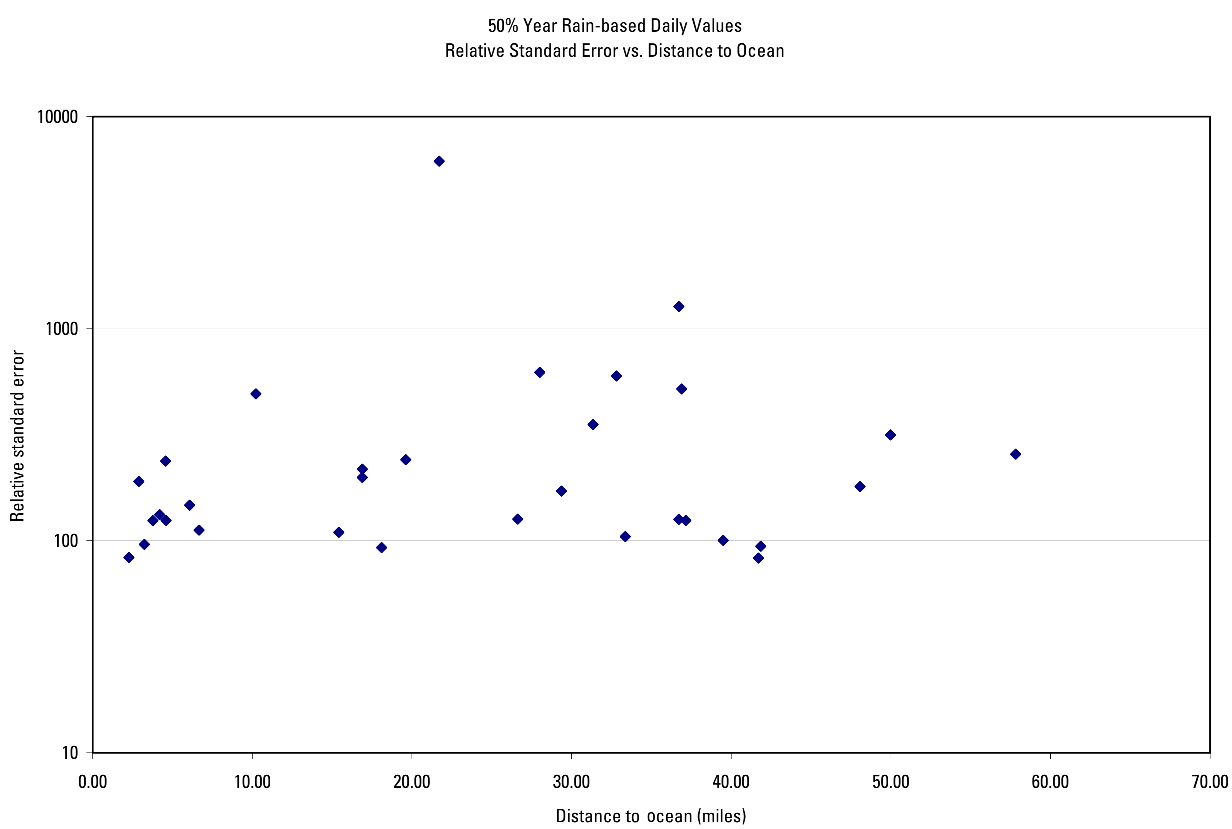
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued



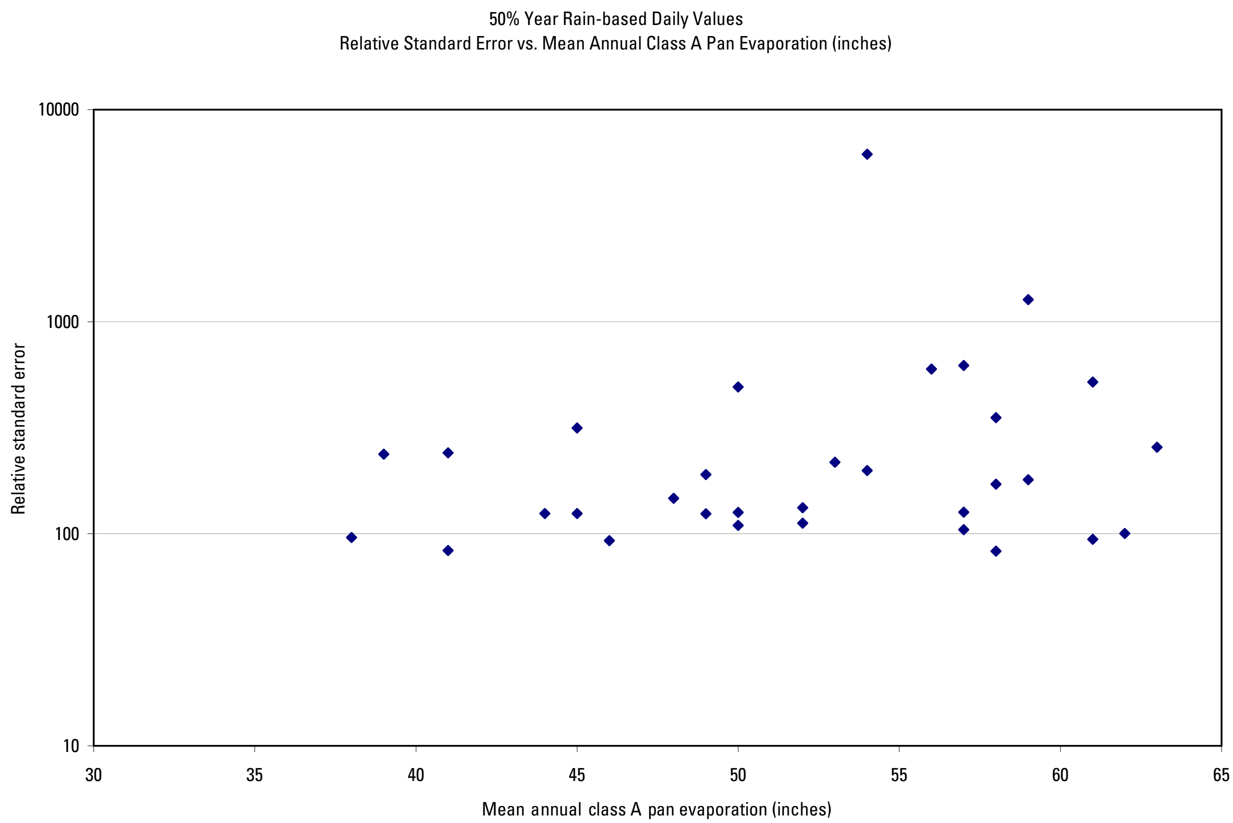


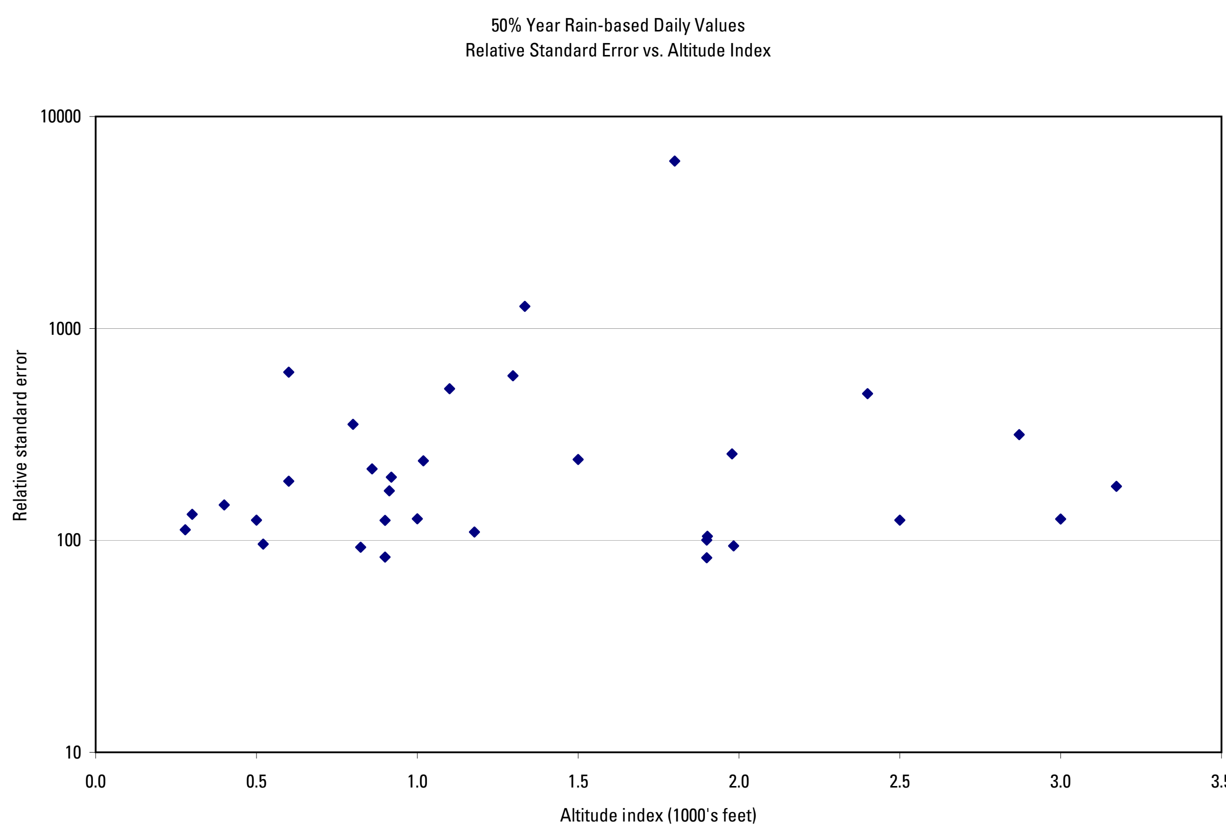
Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued





Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued





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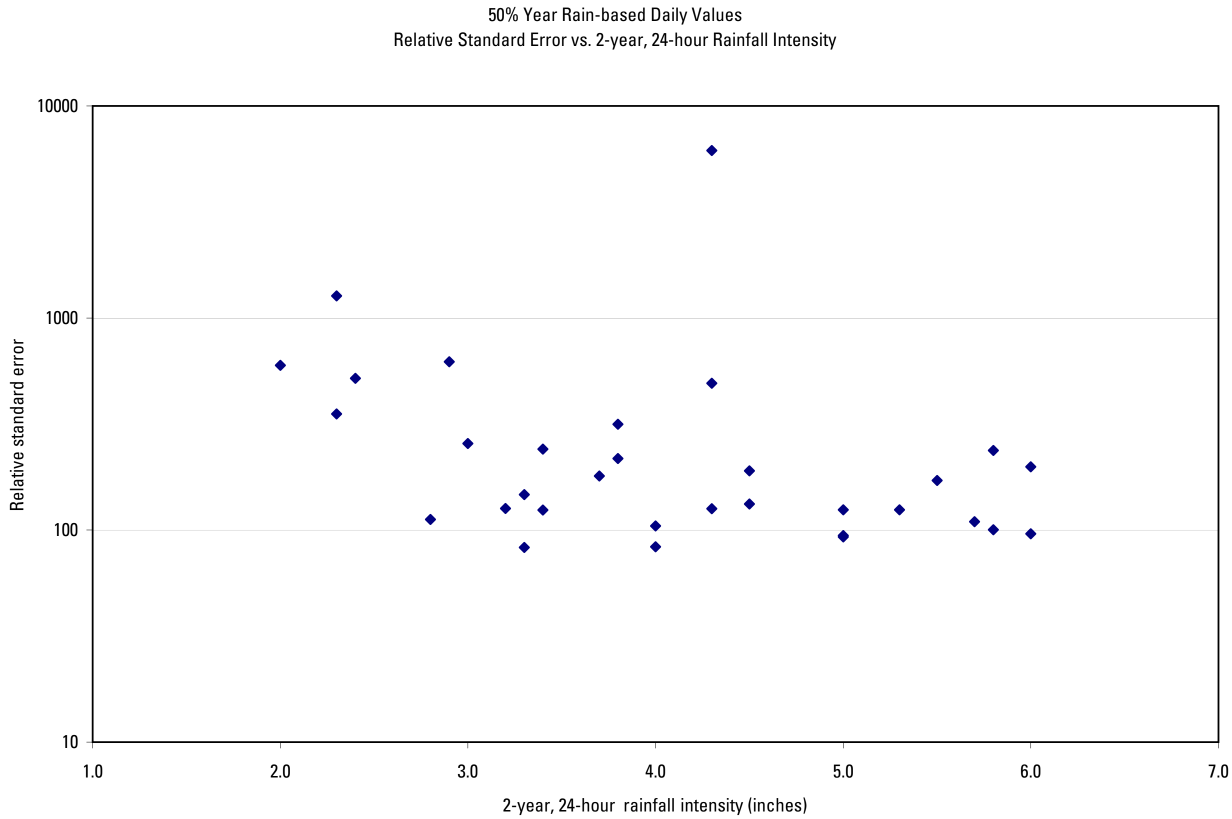

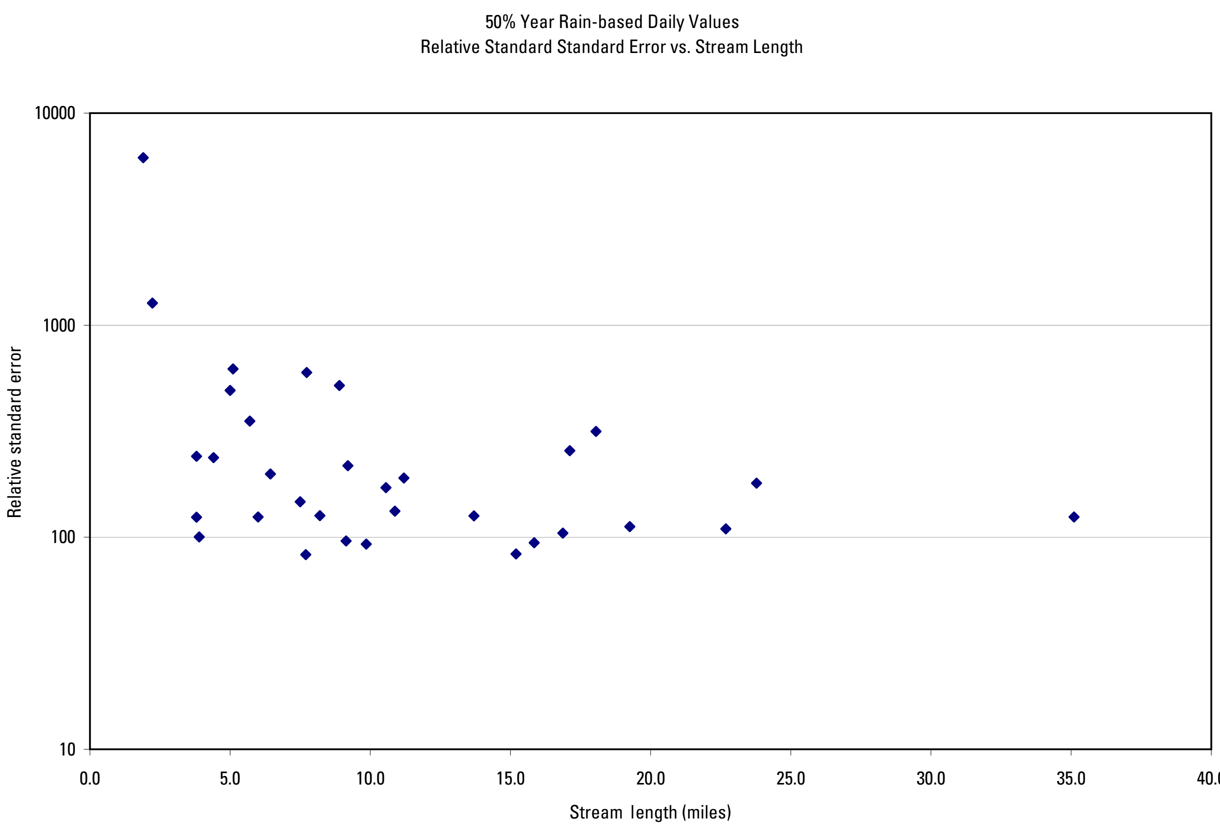

Appendix 3. Computed relative standard errors plotted versus basin characteristics for all stations' 25- and 50-percentile December 15 to March 31 mean-daily-flow estimates.—Continued