MEMORANDUM 15 January 2006
(revised 25 February & 1 March)

TO: U.S. Fish & Wildlife Service, Arcata Office
FROM: George H. Ward & Neal E. Armstrong,
University of Texas at Austin

SUBJECT: Hydrological features of Lower Klamath River and tributaries

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1. The study watershed

The focus of this investigation is the reach of the Klamath River bounded above by Iron Gate Dam and below by the USGS gauge near Klamath (11530500). While our objectives address various aspects of water quality of this reach, analysis and interpretation of the data require information on the prevailing hydroclimate. Therefore, as a preliminary to evaluation of the water-quality measurements from this reach, data were compiled and analyzed on its hydrology. The most useful streamflow gauges are tabulated in Table 1, and shown in Figure 1. The first

Table 1 - Principal USGS gauges presently active in Lower Klamath

Number	*Name*	*Useable record begins:*	*Drainage Area (sq mis)*
11516530	Klamath River below Iron Gate Dam	1960	4,630
11517500	Shasta River near Yreka	1944	793
11519500	Scott River near Fort Jones	1941	653
11520500	Klamath River near Seiad Valley	1951	6,940
11522500	Salmon River at Somes Bar	1927	751
11523000	Klamath River at Orleans	1927	8,475
11525500*	Trinity River at Lewiston	1911	719
11527000	Trinity River near Burnt Ranch	1956	1,439
11530000	Trinity River at Hoopa	1931	2,853
11530500	Klamath River near Klamath	1950**	12,100

* Longest continuous record, however gauge proved anomalous and was not used.
** Data missing for 30 Oct 95 - 30 Sep 97

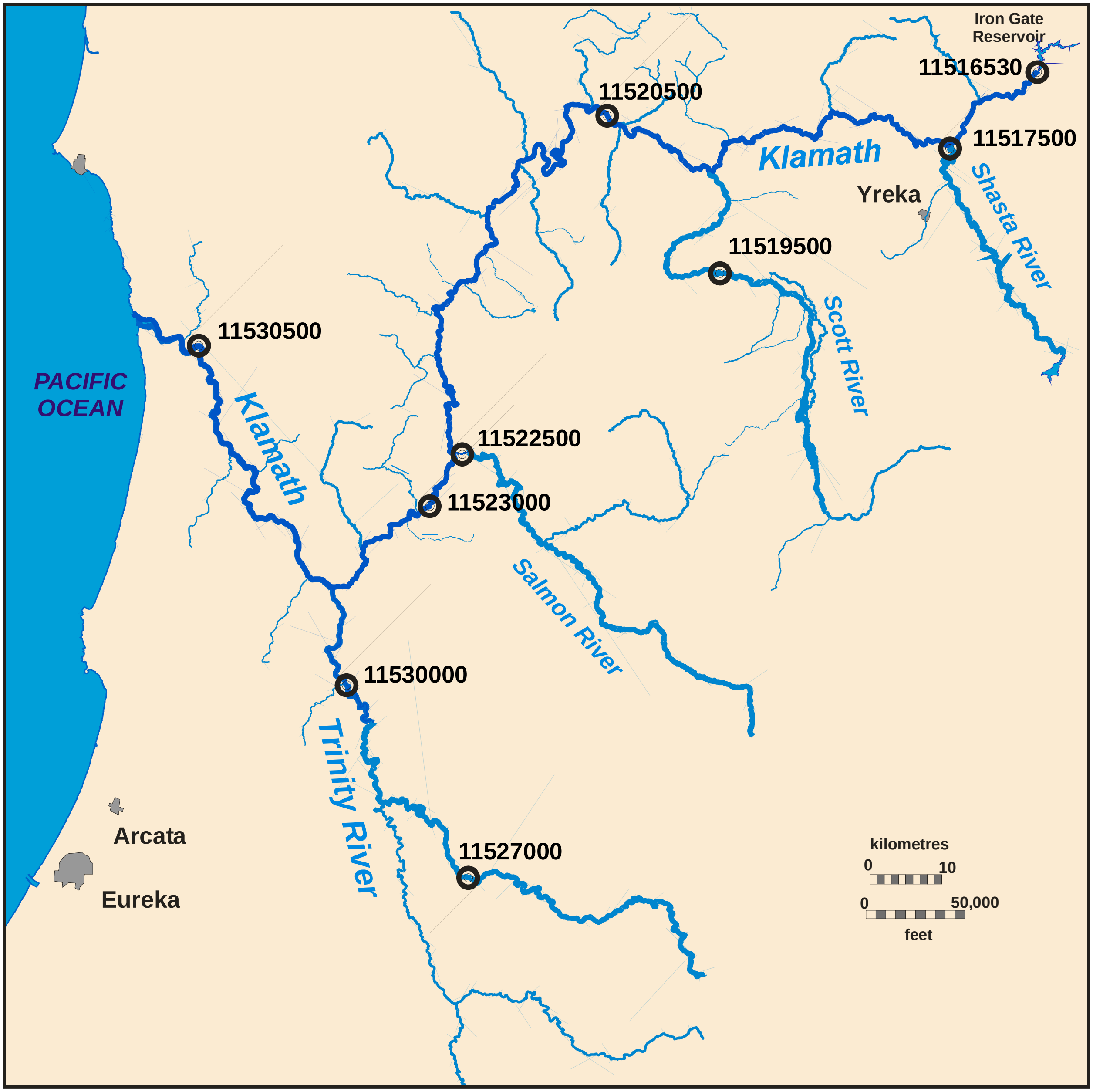

Figure 1 - Study reach of the Klamath and major tributaries, showing principal USGS streamflow gauges.

criterion for utility is that the gauge is continued to be operated by USGS, so that data are available for the periods of FWS data collection. (Many gauges in the basin have been discontinued by USGS.) A second criterion is that the period of record is sufficient for long-term hydroclimatological analyses, several decades at minimum. The earliest year in which a continuous record to the present is available is given for each gauge in Table 1: for most of these,

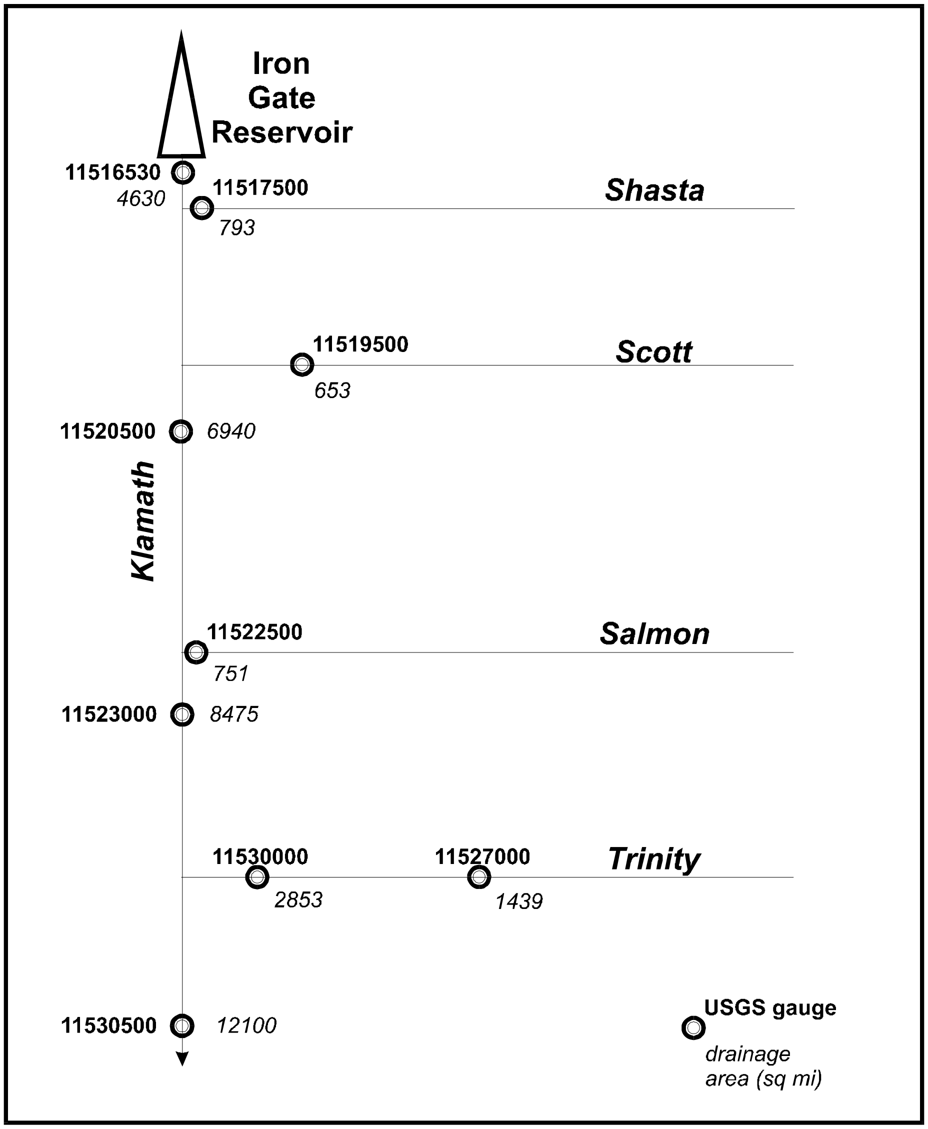

Figure 2 - Stem diagram of study reach.

we have at least five decades available. Figure 2 displays a stem diagram showing the main stem of the Klamath and the four principal tributaries.

2. Geographical and seasonal hydroclimate

To a first approximation, the major determinants of Northern California hydroclimate, and of the Klamath Basin in particular, are the position of the midlatitude westerlies and the physiography

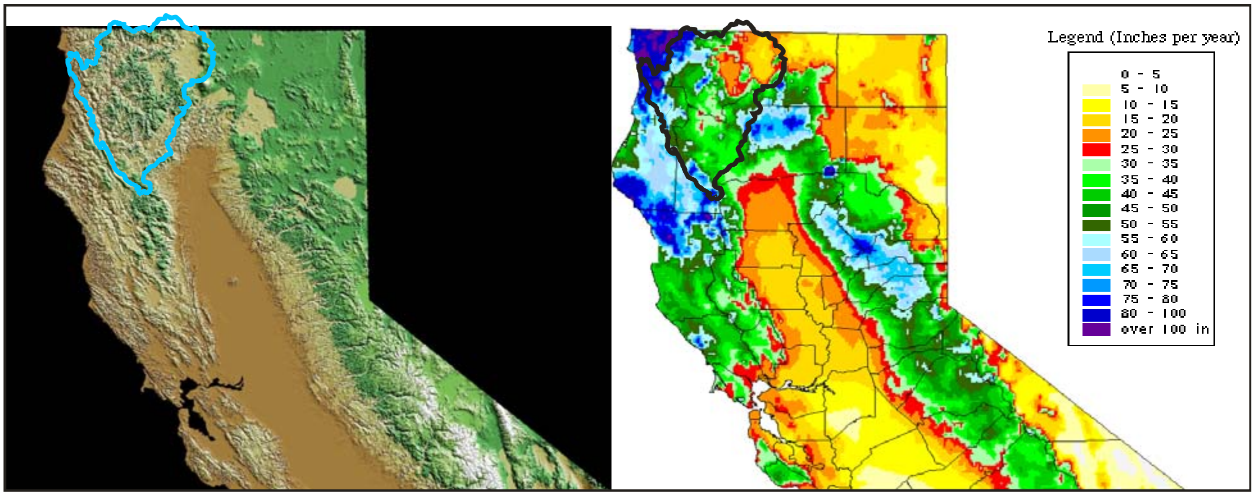

Figure 3 - Northern California topography and precipitation, showing approximate watershed of Klamath below Iron Gate

(a) Physiography. From DEM shaded relief map of U.S. Geological Survey: http://wwwflag.wr.usgs.gov/USGSFlag/Data/maps/

(b) 1961-90 annual precipitation. Copyright 1995, Spatial Climate Analysis Service, Oregon State University: http://www.ocs.oregonstate.edu/prism/

of the land surface. Precipitation is induced or enhanced when the moisture-laden westerlies are forced up by the elevation of the land. In the lee of the coastal ranges, the airstreams have lost much of their moisture in the ascent, and precipitation is diminished, especially if the airstreams descend so that they are heated and dried by adiabatic compression. Synoptic-scale disturbances carried in the westerlies are modulated by this orographic interaction. The relation between orography and precipitation is clearly displayed in the images of Figure 3. For the Klamath this is exemplified by the falloff of runoff (i.e., watershed yield) with increasing elevation, see Figure 4. Here runoff is computed as the ratio of mean annual streamflow to drainage area at each gauge of Table 1, except for those mainstem gauges downstream from Iron Gate, which are computed as $\Delta Q/\Delta A$, Δ denoting the differences between that gauge and the next upstream. (The resulting runoff is therefore due to the drainage area between that gauge and the next upstream.) Elevation is taken as the gauge datum (a systematic underestimate).

The main seasonal signal in precipitation, hence streamflow, is due to the annual strengthening and latitudinal descent of the westerlies during winter, in which cyclones are steered into the

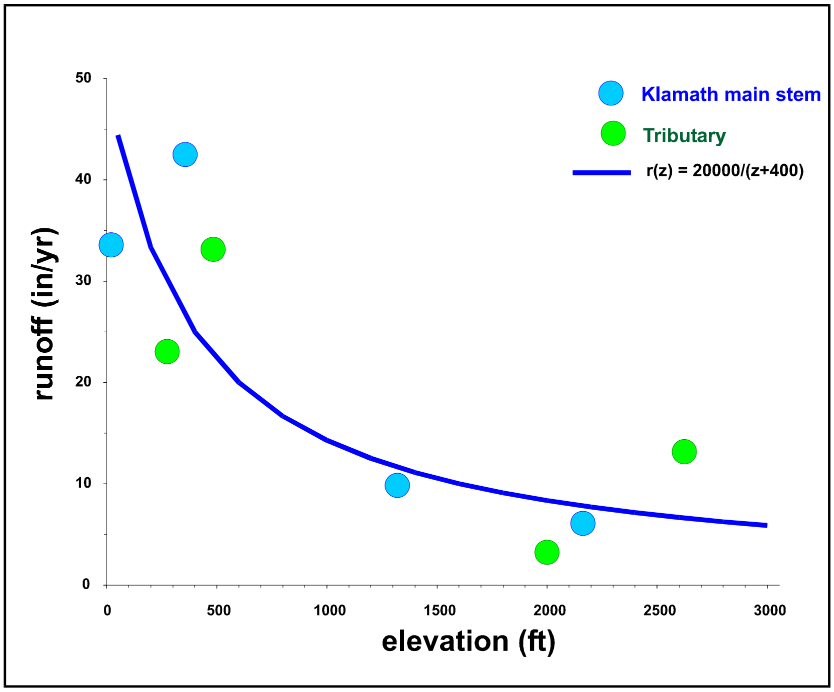

Figure 4 - Average watershed runoff for 1961-2004, for gauges of Table 1 (see text).

Pacific Northwest region. The resulting runoff (and, hence, streamflow) reflects this basic seasonality, as evidenced in the annual variation of monthly streamflow statistics shown in Figures 5 -7. In these figures, the period of record for each gauge extends from the year given in Table 1 through 2005 (2004 for October, November and December). Note the change of scale in Figure 7. The consistency of the annual signal is perhaps better displayed by normalizing the monthly mean values to the long-term annual mean, as shown in Figure 8. In this figure, the averaging period is the same for all gauges, *viz*. 1961-2005 (2004 for October, November and December). From these graphs, several observations may be made:

(i) In the upper portion of the study reach (Fig. 5), main-stem flow is dominated by the releases from Iron Gate.

(ii) From Iron Gate to Klamath, the flow in the Klamath increases by about a factor of four in low flows and by an order of magnitude in high flows.

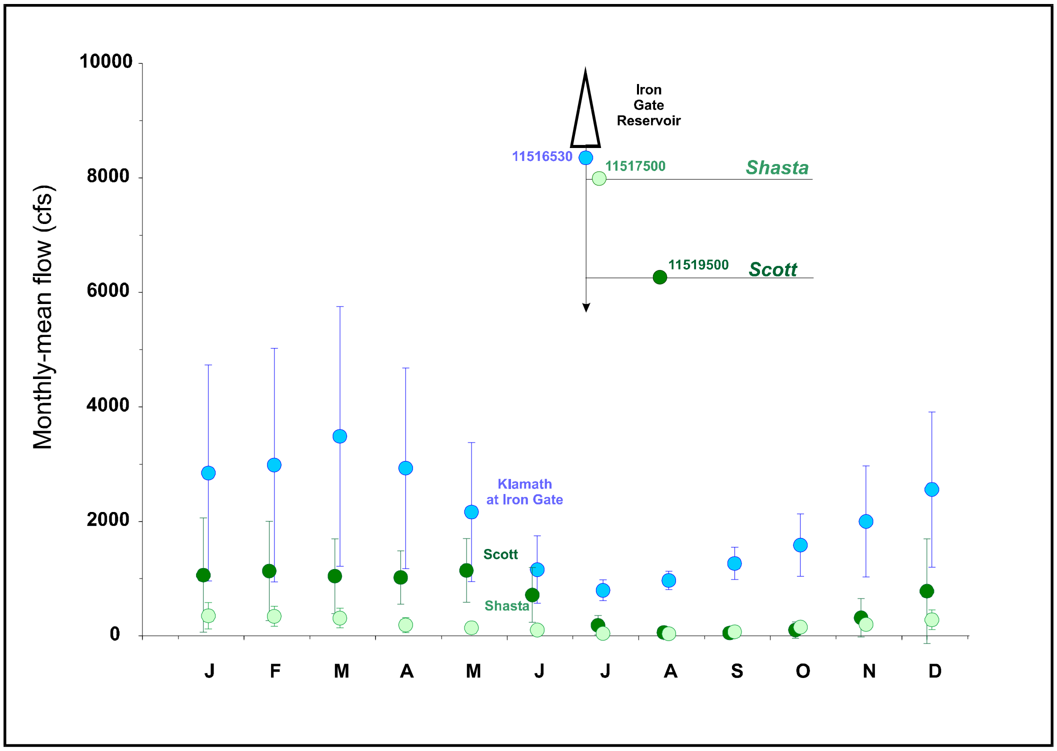

Figure 5 - Period-of-record means and standard deviations of monthly flows at indicated gauges, cf. Fig. 2.

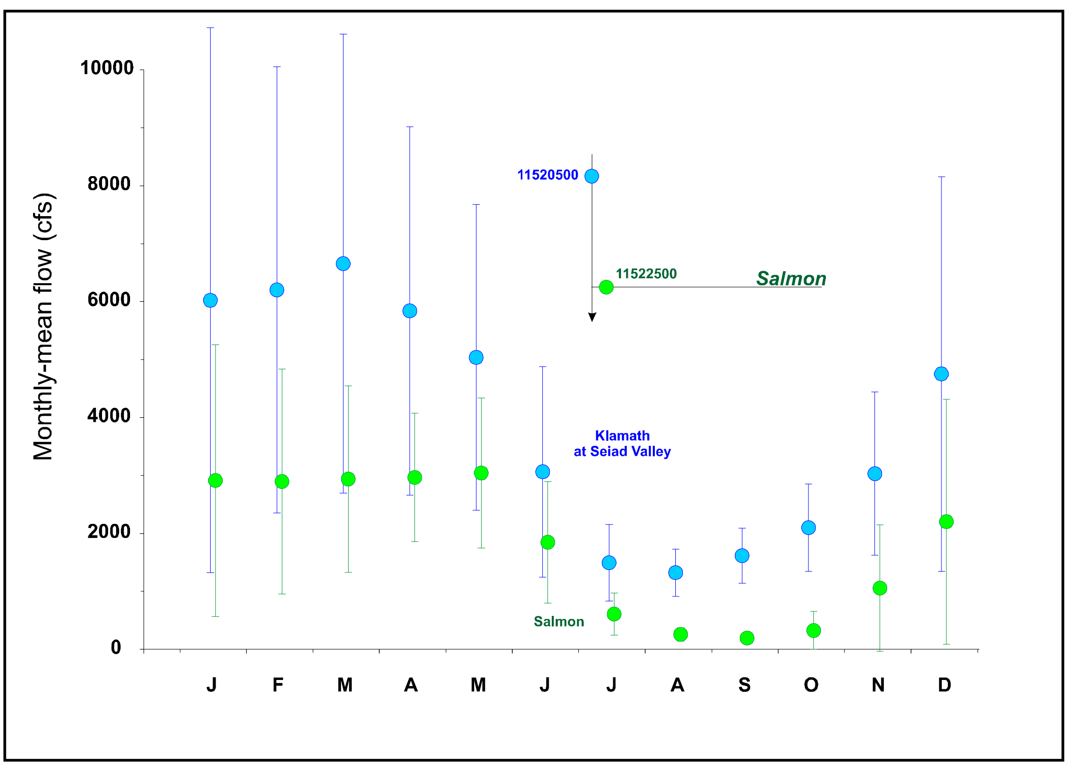

Figure 6 - Period-of-record means and standard deviations of monthly flows at indicated gauges, continued, cf. Fig. 2.

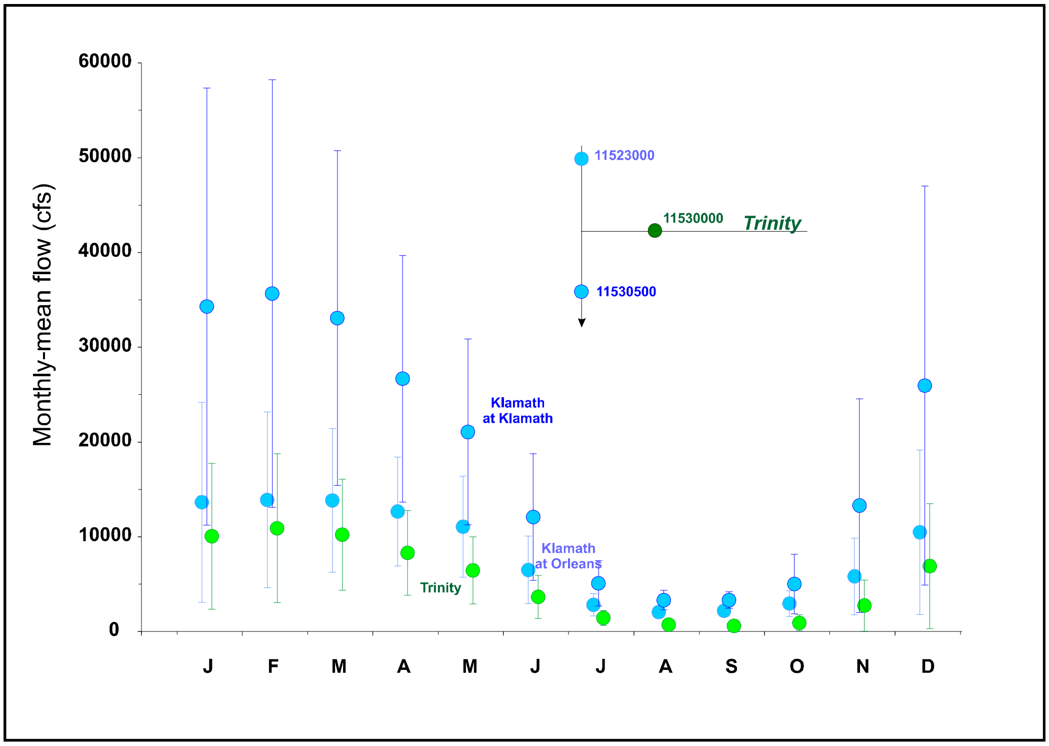

Figure 7 - Period-of-record means and standard deviations of monthly flows at indicated gauges, continued, cf. Fig. 2.

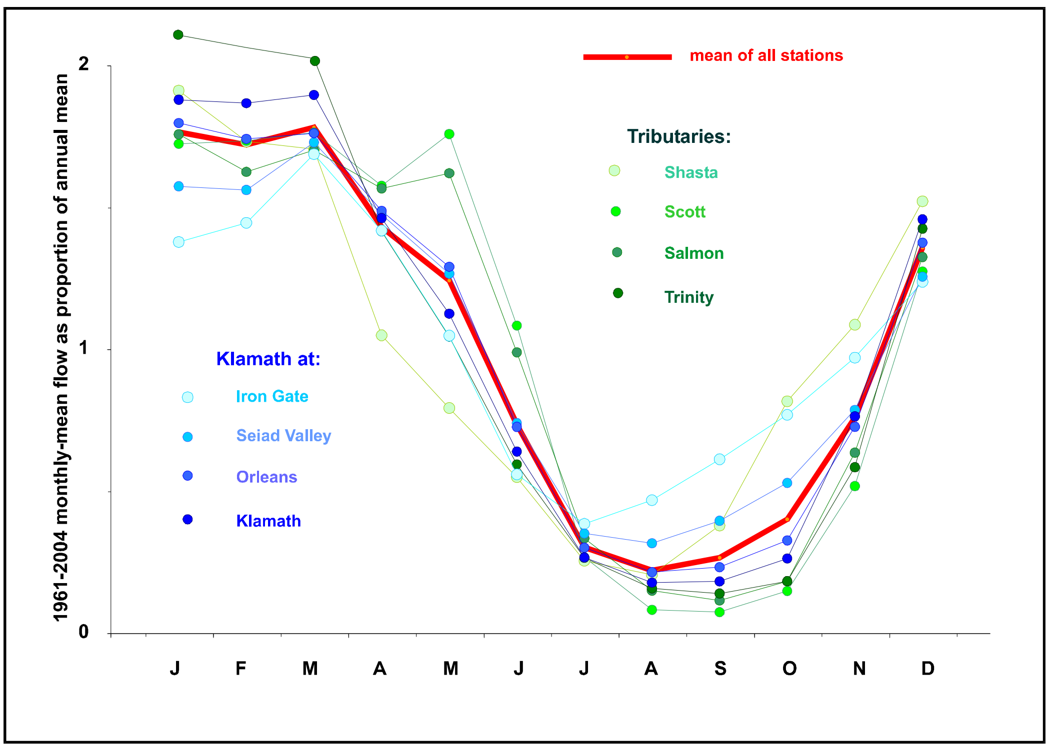

Figure 8 - Annual variation of 1961-2005 monthly mean streamflow at the gauges of Figs. 5 - 7 normalized to annual flow

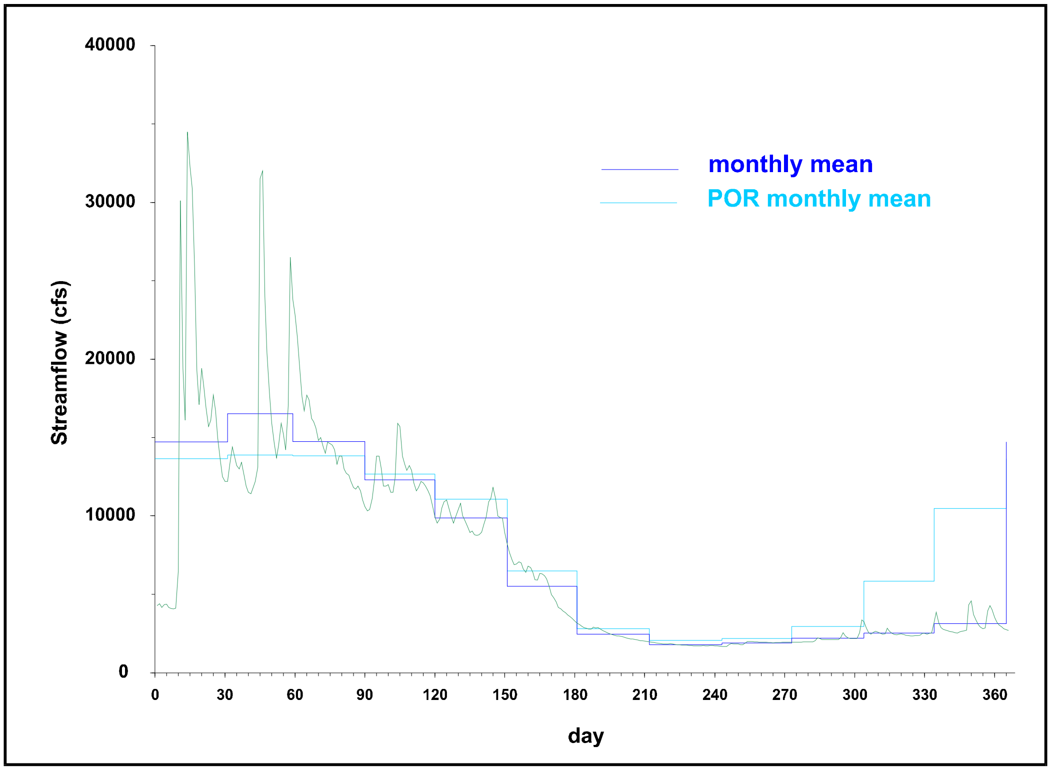

Figure 9 - Daily streamflows in Klamath at Orleans (11523000) in 2000, superposed on monthly means for 2000 and 1928-2005, cf. Fig. 7

(iii) The typical annual variation is increasing flows through the fall, high flows in winter (January through March), declining flows in spring, and low flows in summer (July through October).

(iv) There is considerable interannual variation in this pattern.

The annual pattern (iii) is clearly the result of the exposure of the basin to synoptic-scale storms. In summer, with the retreat of the westerlies into higher latitudes, the Pacific storms are muted in frequency and intensity, and much of the time may be altogether absent. This is mainly responsible for the relatively steady (and low) flows during summer. Only the larger storm systems produce substantial excursions in streamflow, but these are still evident in the daily flow hydrographs, especially during the winter months. An example is shown in Figure 9, for the year 2000 at the Klamath gauge at Orleans, in which daily flows are superposed on monthly means for this same year, as well as the period-of-record means. Clearly, there is considerable day-to-day variation about the monthly means.

3. Interannual variation

The exact wintertime position and strength of the midlatitude westerlies, and the frequency and intensity of synoptic storms exhibit considerable variation from one year to the next. This in turn induces a similar variation in annual flow, as summarized in Table 2 and illustrated in Figures 10-12, the record minimum and maximum differing by about a factor of five at each of the gauges. In these figures, the horizontal line about which the annual flows vary is the period-of-record mean. Note the changing vertical scale from Figure 10 to Figure 12. An important feature of these figures is the coherence in variation in all of the gauges as one progresses from Iron Gate downstream, which demonstrates the large-scale climatological controls on the basin hydrology.

It is noteworthy to observe that a calendar-year annual average may not be the optimal depiction for the interannual variation in hydrology, because the calendar year divides the seasonal freshet of the Klamath. There is a persistence in the position and intensity of the large-scale atmospheric circulation systems that extends over the full winter season: in other words, a "wet-year" or "dry-year" characterization would generally apply to the entire seasonal freshet from

Table 2 - Annual flows in Klamath and tributaries

Gauge	*Name*	*years in record*	*mean flow (cfs)*				
			average	*minimum*	*year*	*maximum*	*year*
Klamath main stem							
11516530	Iron Gate	45	2076	647	1992	3760	1983
11520500	Seiad Valley	54	3935	1170	1992	7478	1983
11523000	Orleans	78	8178	3094	1994	16976	1983
11530500	Klamath	53	17899	7447	1991	40054	1983
Tributaries							
11517500	Shasta near Yreka	61	188	84	1992	375	1983
11519500	Scott near Fort Jones	64	638	150	1994	1387	1983
11522500	Salmon at Somes Bar	78	1775	664	2001	3573	1983
11530000	Trinity at Hoopa	74	5248	1707	1977	12735	1983

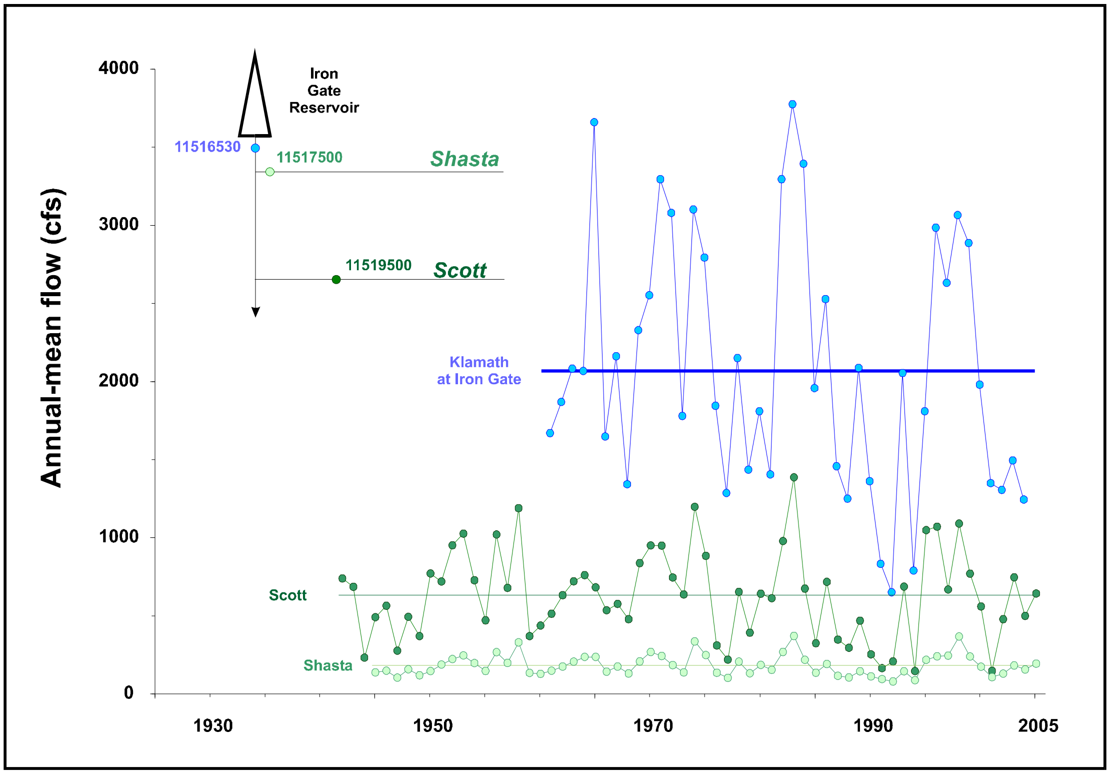

Figure 10 - Time series of annual-mean flows for period of record, Iron Gate reach

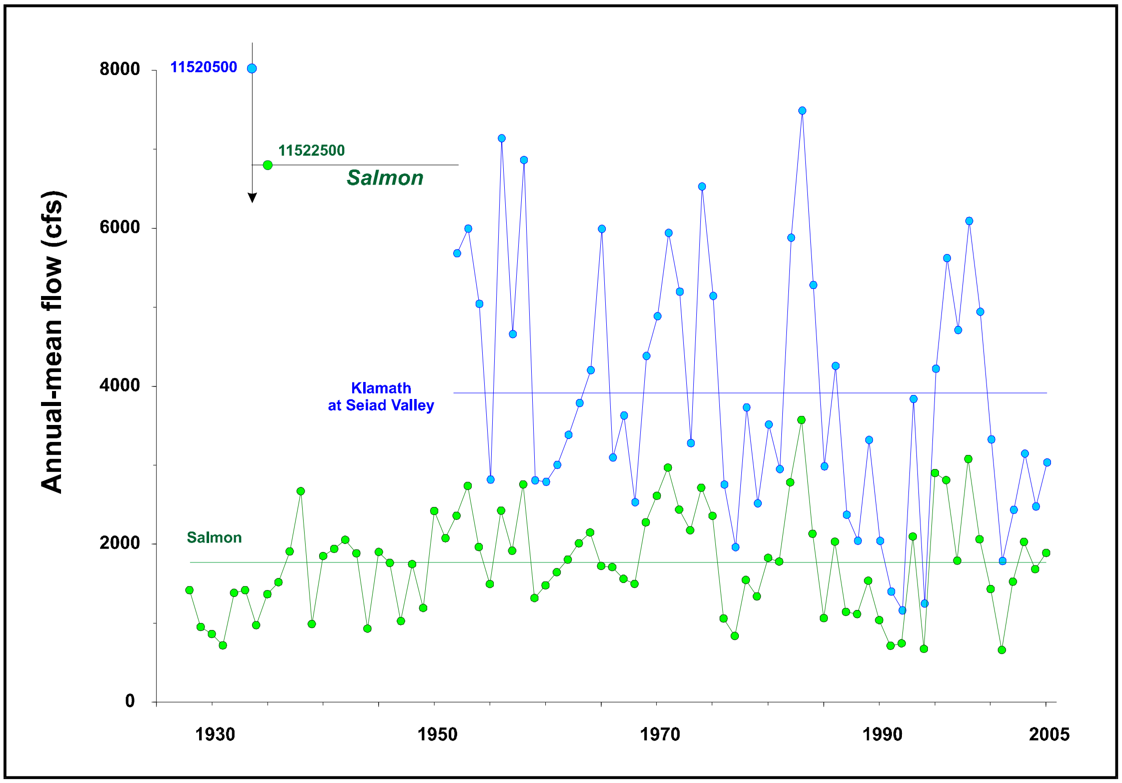

Figure 11 - Time series of annual-mean flows for period of record, Salmon reach

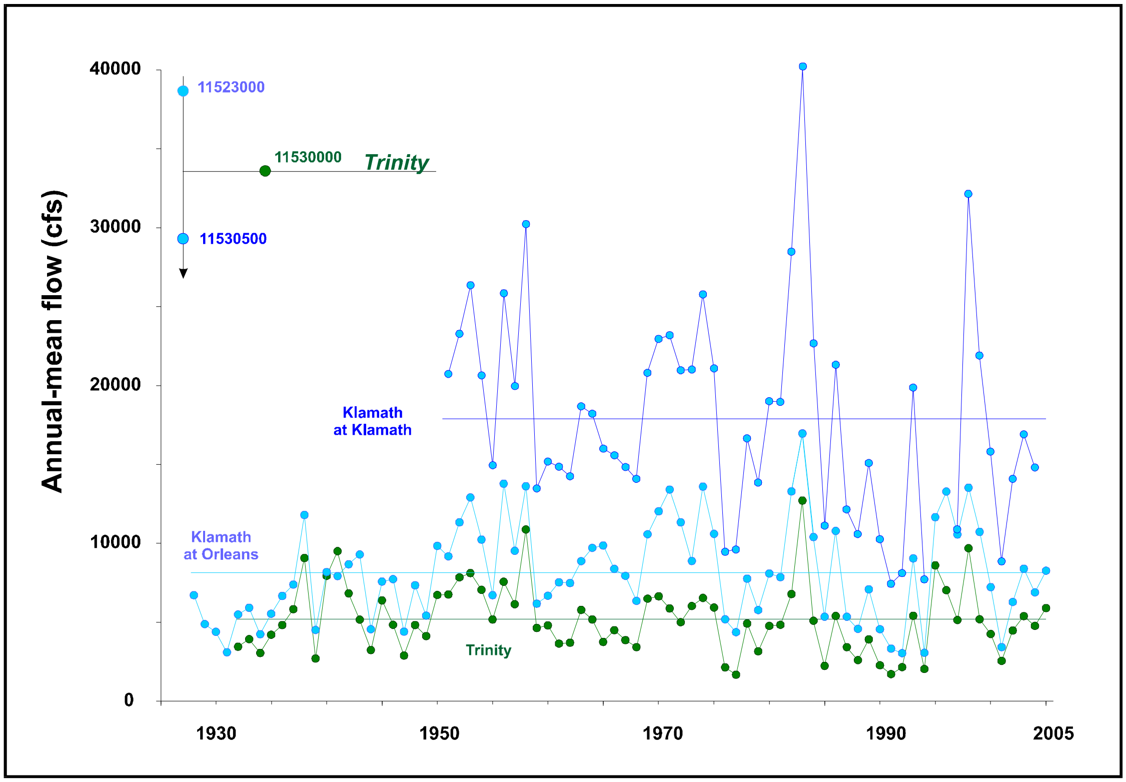

Figure 12 - Time series of annual-mean flows for period of record, Trinity reach

early fall through late spring. A more meaningful annual period would be the "water year", defined from October of the previous year through September. Table 3 summarizes the differences between representing annual flows as calendar year (CY) or water year (WY) means. In general, the WY means have a greater variation, with higher peaks and lower valleys. The range of the *difference*, given in Table 3 as a proportion of the (CY) annual mean, is seen to vary as much as from 150% below the CY mean to 60% above, with a root-mean-square (rms) departure of 10-30%. The least difference between the two averages is exhibited by the Klamath gauge below Iron Gate, which is principally affected by the operation of the dam, and increases down the basin due to the increasing climatological controls on runoff. If the purpose of this analysis were detailed hydrological behavior, much more concern would be given the delineation and statistics of the seasonal freshet (which in some years starts before the beginning of the water year). On the other hand, many other phenomena of importance in the Klamath, such as salmonid migration or agricultural practices, have an intrinsic calendar-year variation, for which

Table 3 - Comparison of CY and WY statistics

Gauge	*name*	*CY-WY period of record*				*CY-WY 1961-2004*			
		range/mean		*rms (cfs)*	*rms/ mean*	*range/mean*		*rms (cfs)*	*rms/ mean*
Klamath main stem									
11516530	Iron Gate	-0.236	0.188	162	0.078	-0.236	0.188	162	0.078
11520500	Seiad Valley	-0.258	0.289	410	0.104	-0.258	0.289	426	0.108
11523000	Orleans	-0.415	0.407	1267	0.155	-0.415	0.407	1418	0.173
11530500	Klamath	-1.485	0.608	5095	0.285	-1.485	0.608	5445	0.304
Tributaries									
11517500	Shasta near Yreka	-0.385	0.394	21	0.115	-0.385	0.394	22	0.119
11519500	Scott near Ft Jones	-0.599	0.502	140	0.220	-0.599	0.502	144	0.227
11522500	Salmon at Somes Bar	-0.580	0.517	352	0.198	-0.580	0.517	376	0.212
11530000	Trinity at Hoopa	-0.467	0.448	992	0.189	-0.467	0.386	933	0.178

the corresponding CY hydrology may be more pertinent. For the water-quality objectives of this study, however, the finer time variation of monthly or even daily flows is our major concern, so we merely note in passing the distinction between CY and WY.

The interannual variation in the monthly means is indicated by the standard-deviation bands of Figures 5-8, and exemplified by Figure 9, but is even more pronounced than Figure 9 would suggest. In fact, the year 2000 was craftily selected for this figure from the 78 years of data available at this gauge, because in this year the individual monthly means are closest to the period-of-record monthly means. (Even in this case, the November and December means depart from the long-term monthly mean values.) In general, an "average" year, in which the monthly means approximate their long-term values, is rare. Most importantly, there tend to be runs of below-average and above-average flows, which are evidenced in the annual time series of Figures 10-12 but better diagnosed by examination of the monthly flows. Figure 13 shows the cumulative departure of the monthly flow from the mean

$$\sum_{i=1}^{N} (Q_i - \overline{Q})$$

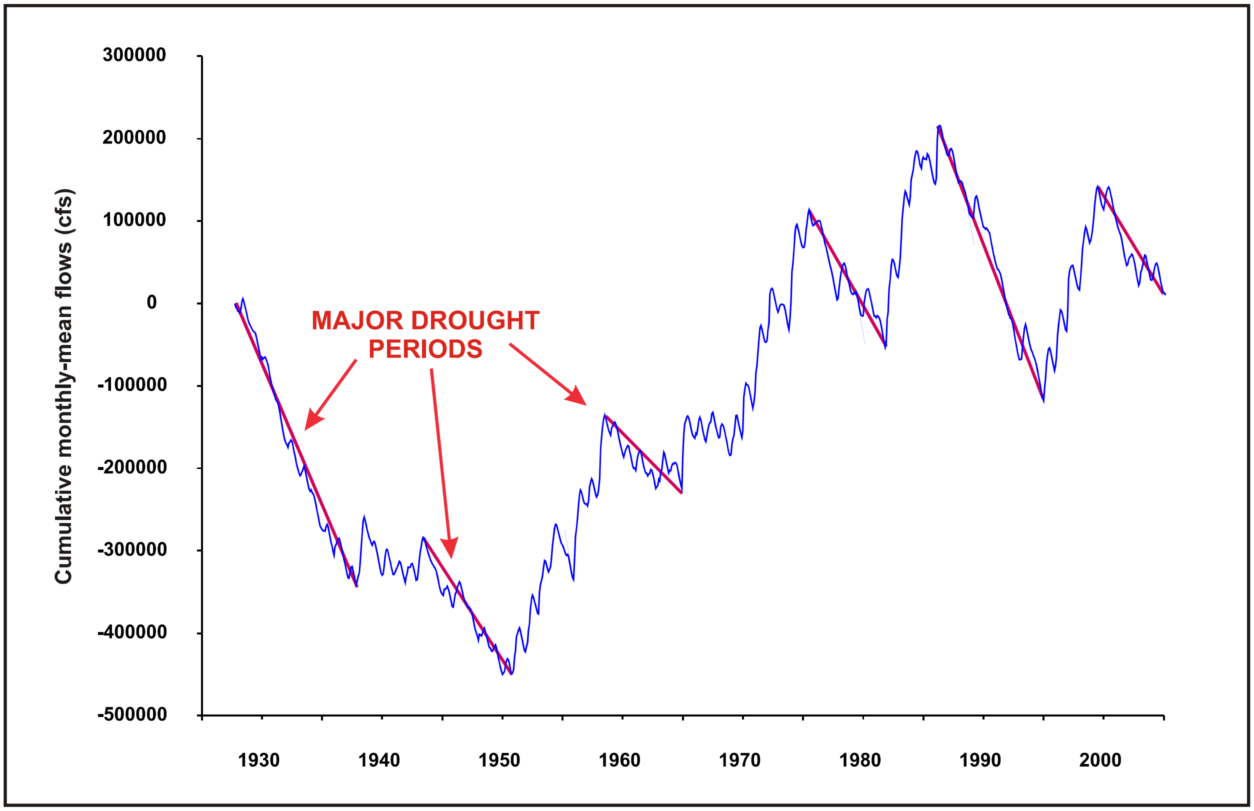

Figure 13 - Cumulative monthly flow diagram, Klamath at Orleans (vertical units arbitrary)

for the *N*th month in the time series, in which $\overline{Q}$ denotes the period-of-record monthly mean flow. Such a diagram facilitates the identification and comparison of drought periods (as well as inflow surfeit periods). For present purposes, a drought is considered to be a period of at least 7 years of below-average flow, exhibited in a cumulative-flow diagram as a period of decline in the cumulative. Historical droughts so diagnosed are indicated by the straight-line fits in Figure 13. The duration of a drought is the time base of the line, i.e. the period over which the average decline in cumulative flow is sustained, and the intensity of the drought is measured by the (negative) slope of the line. At this gauge, the frequency of major droughts has been roughly one every 13 years. We note that the period of water-quality data collection (since 2000) has been one of below-average flows, but the drought of 1986-95 is the most intense in recent years. Historically, one has to go back to the decade of the 1930's to find a drought of similar intensity.

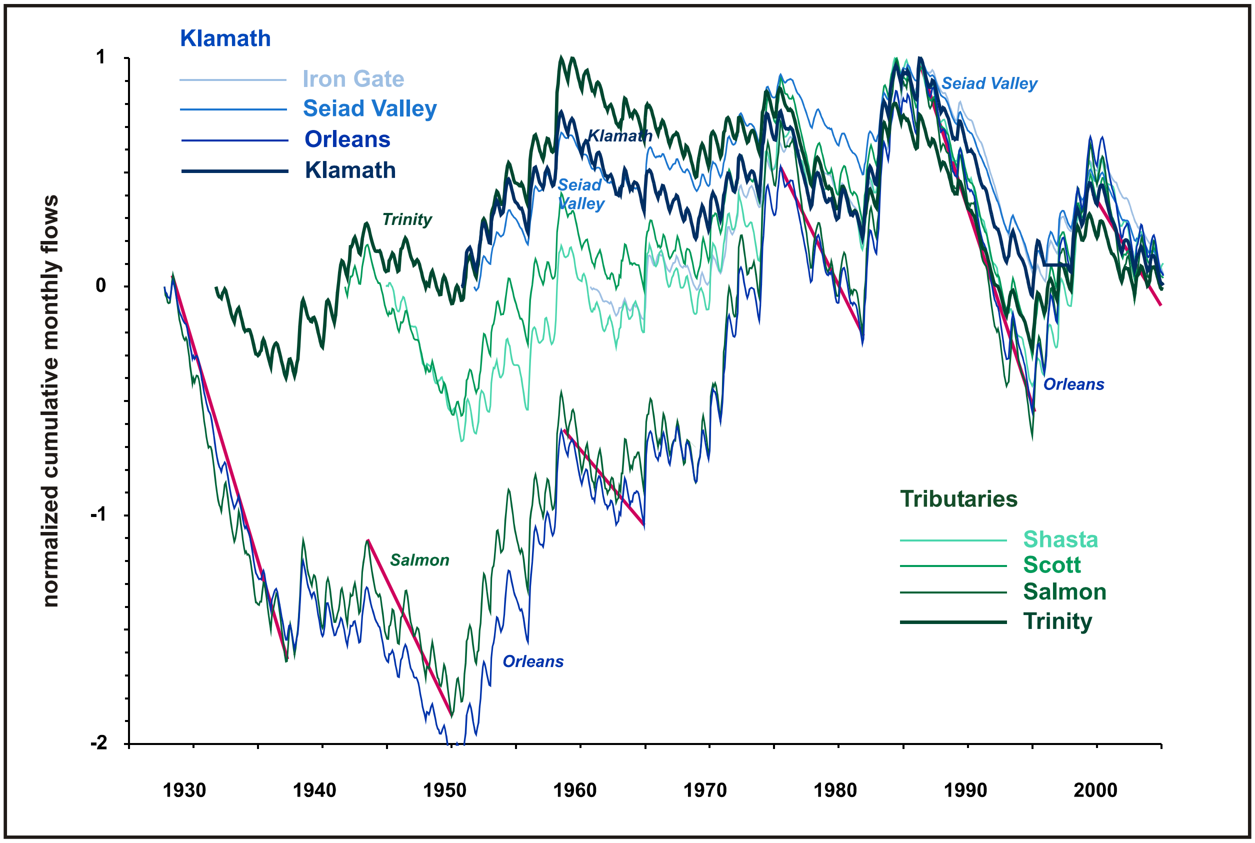

Figure 14 - Normalized cumulative monthly flow diagrams, all gauges

To compare the historical time series at each of the gauges of Table 1, the cumulative flow diagrams have been normalized to the high-flow events of the mid-1980's (see, e.g., Table 2), and are shown together in Figure 14. The consistency among the gauges is remarkable. There are three clusters of diagrams: (i) the upper reaches and tributaries, *viz*. Iron Gate, Seiad Valley, the Scott and the Shasta; (ii) the mid-reach gauges of the Klamath at Orleans and the Salmon (despite their different watershed areas), and (iii) the lower gauges at Klamath and the Trinity. The cumulative-flow diagram of the last, differs substantially from the others in that the intensity of droughts is considerably less, due no doubt to the increased rainfall on the coastal ranges. All of these curves agree in the intensity and duration of the drought of the 1990's. For the period after 2000 during the Fish and Wildlife water-quality monitoring, the drought was of greater intensity in the upper and middle reaches of the study basin than in the lower reach, though this period was one of subnormal flows at all gauges.

4. Storm hydrographs and intra-annual variation

Runoff is an integrated response to precipitation, due to the time lag in travel through the surface drainage system. An idealized storm event is a brief burst of precipitation, so concentrated in time as to approximate a mathematical "delta" function. Because of the time lag and associated averaging, the streamflow "response" is a quickly rising then slowly receding function of time, the storm hydrograph, as sketched in Figure 15. The "response" terminology is advisedly appropriated from signal processing theory, since the response of streamflow to the input of rainfall can be illuminated by the theoretical techniques of that discipline (one immediate example being the extraction of a "unit hydrograph"). In the Klamath this time integration is further enhanced by storage in soil and in surficial aquifers, and by storage at the surface in solid phases of water. This means that the streamflow signal response is even more drawn out, the small quickflow spikes being smoothed out, and only the major storms appearing as impulse-response hydrographs with long recessions, e.g. Figures 11 and 12.

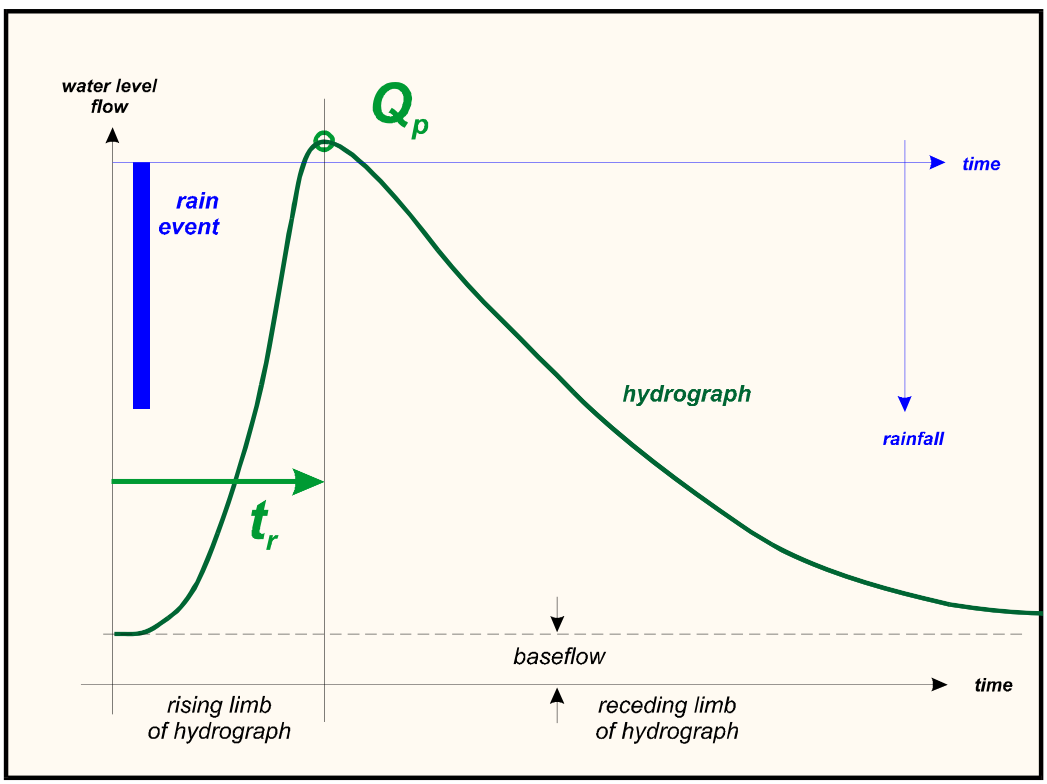

Figure 15 - Idealized impulse-response storm hydrograph

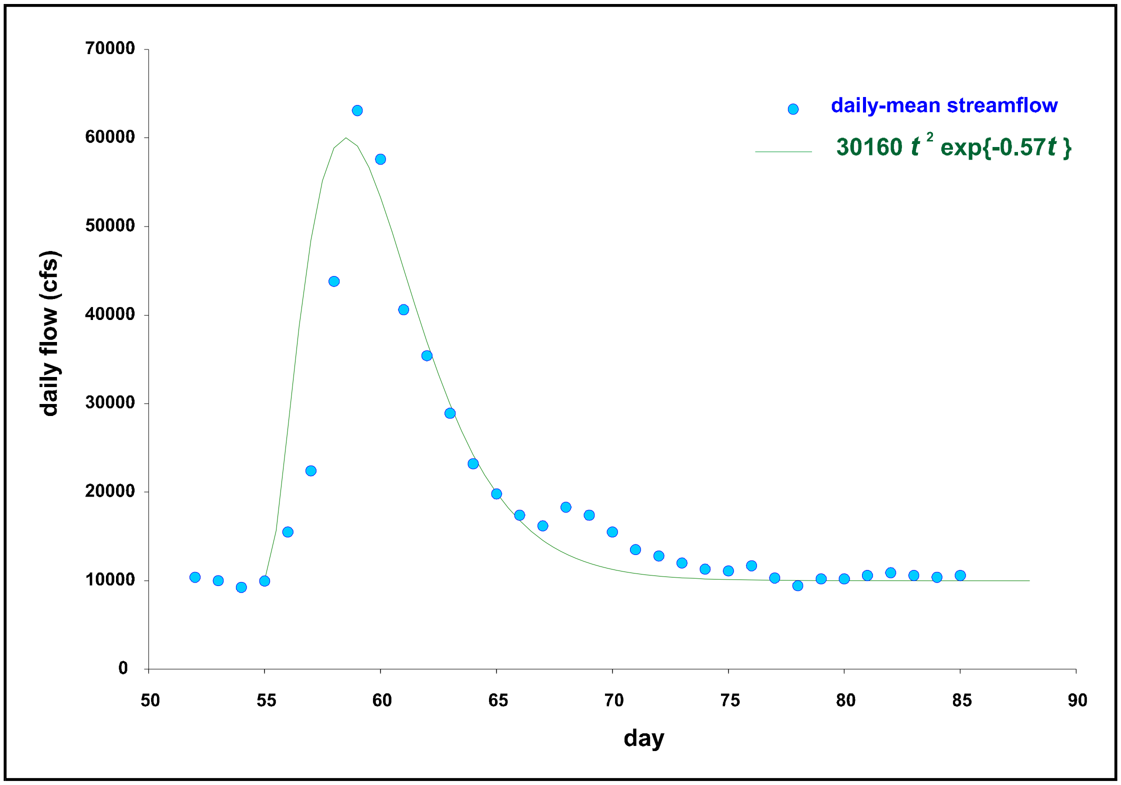

Figure 16 - Storm hydrograph of February 1940, Klamath at Orleans (11523000)

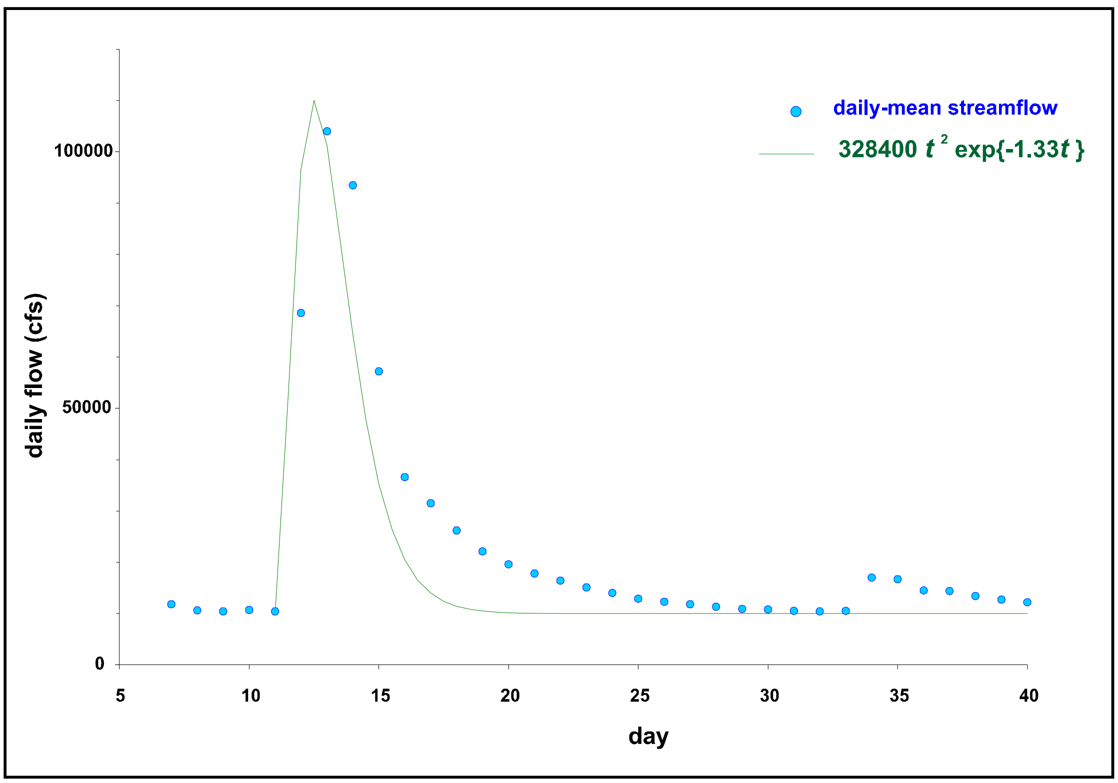

Figure 17 - Storm hydrograph of January 1980, Klamath at Orleans (11523000)

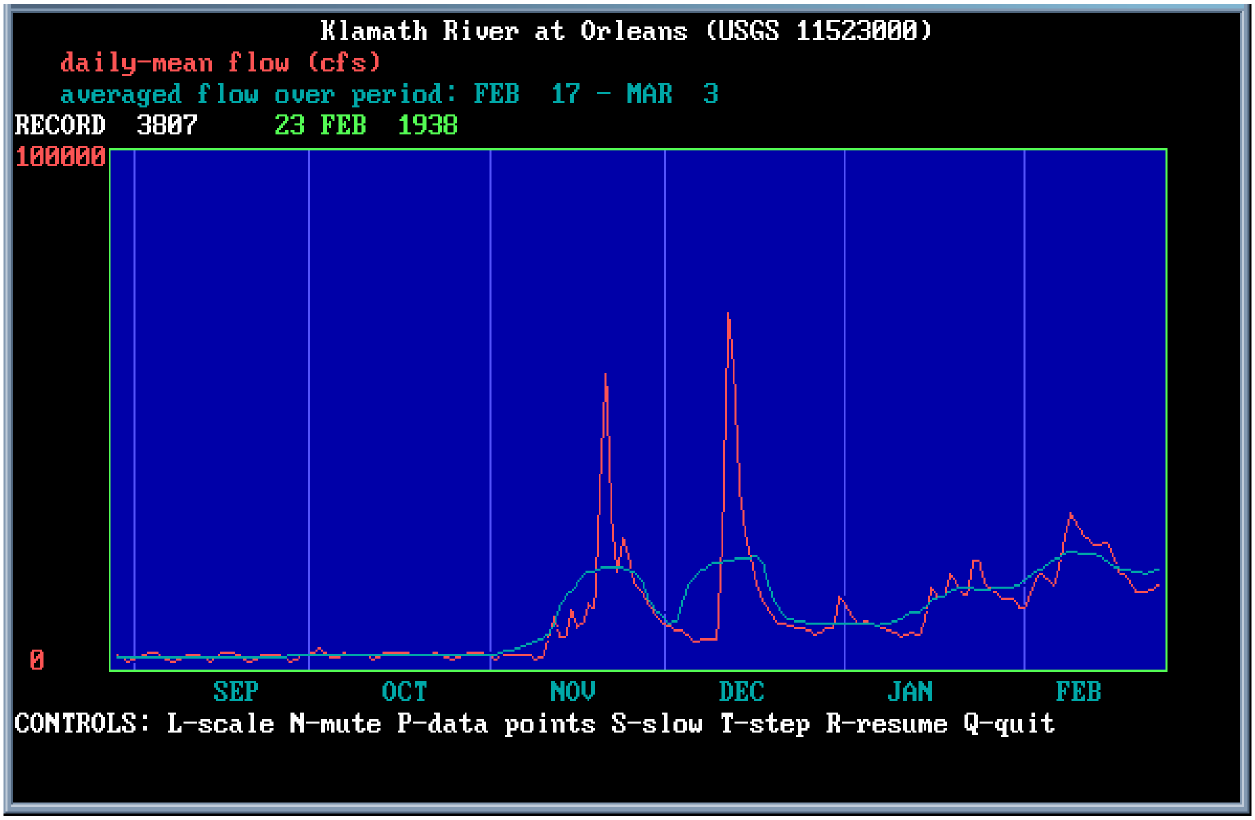

Figure 18 - HYDRAWL display screen

These and other features of the streamflow in the Klamath watershed are better disclosed by graphical display of the complete time series of daily data. However, many pages of graphs, such as Figures 16 and 17, would be required to achieve this presentation. Instead, an animated screen display of the Klamath streamflow is provided with this report, named (in deference to the region of origin of these authors) HYDRAWL, a screen-capture of which is shown in Figure 18. This is activated separately by opening the executable, in the digital file containing this report. (A direct hyperlink to the executable refuses to operate properly.)

Operation is generally straightforward, the user supplying the necessary inputs at the prompts. In addition to the daily flows, a sliding average flow is also displayed, showing the mean flow over a "window" in time defined by two parameters: duration and lag. Duration is the length (or "width") of the window in days, and lag is the time, also in days, of the end of the window (i.e., the latest date in the series defining the window) after the current date (i.e., the data point being displayed). This is the most general means of specifying an averaging window, but most combinations of duration and lag will not be of practical use. If window *duration* N (say) is an odd number, then specifying *lag* to be

$$\frac{1}{2}(N-1)+1$$

results in an average centered on the display date. Specifying *lag* = 0 results in a mean over the preceding N -1 days plus the current display date. For the Klamath gauges, a 15-day centered average is suggested (*duration* = 15, *lag* = 8). Once the display begins, it is controlled by single characters entered on the keyboard. Mnemonics are given at the bottom of the screen. "S" slows the rate of screen display (for well-heeled users with fast computers), "T" freezes the display, and repeated entries of "T" advances the display by a single data point. "R" resumes the normal display. "L" re-scales the vertical axis to accommodate the full range of data presently displayed.

Inspection of the time series of daily flows at the Klamath gauges indicates that the winter freshet is typically composed of a sequence of major storm hydrographs, whose time of recession is 2 - 4 weeks, which supports the selection of a one-month averaging period for most of the analyses reported here. The recession of the winter inflows is sustained well into June most years, a consequence of the storage in the watershed. Under low-flow conditions, a seven-day periodicity in the flows on the Klamath emerges, e.g. Figure 19, prior to the imposition of Iron Gate Reservoir (in 1962), due to hydropower operations. Most importantly, the considerable variation in seasonal flows becomes apparent in the animated display.

5. Water-quality data collection

The purpose of this compilation and analysis of Klamath hydrology is to support companion evaluations of water-quality monitoring conducted by the Fish & Wildlife Service. We have been provided grab-sample data for the period 2001-2005. Hydrological data are needed to address questions relating to mass budgets, to be addressed separately, and to facilitate interpretation of the water quality behavior evidenced in the measurements. Within the present

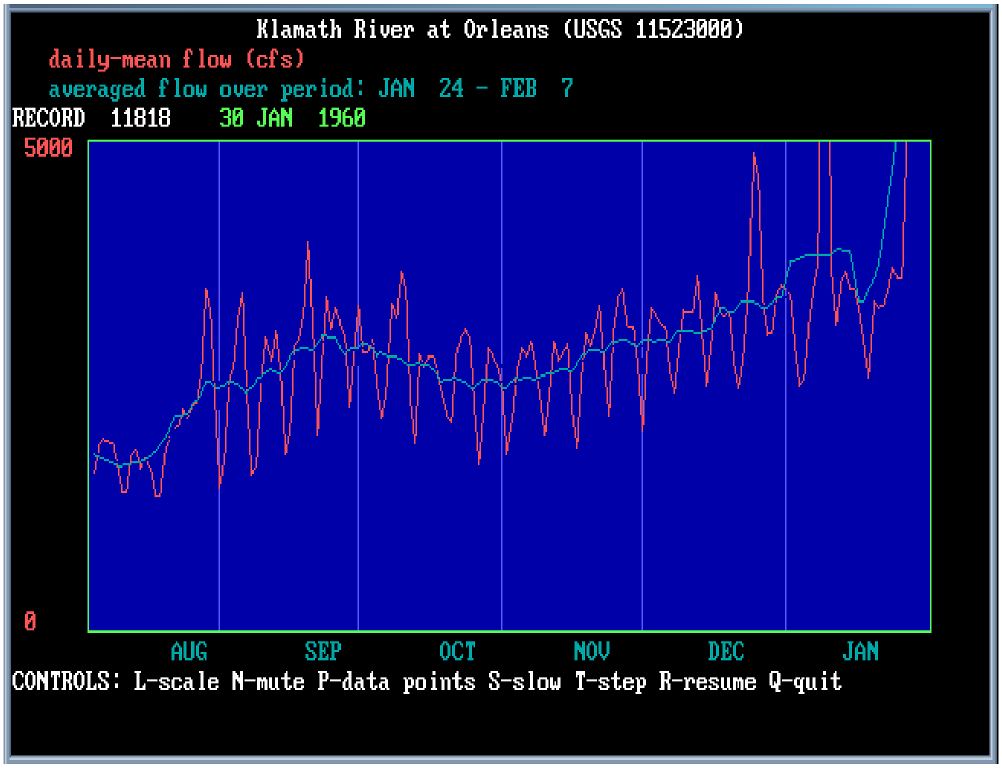

Figure 19 - 7-day periodicity in flows of Klamath at Orleans

context, we note the magnitude of flows attending the sampling events, the excursions in flows that could potentially influence water quality, and the representativeness of the sampling events relative to the normal hydroclimatology of the river. These features are presented graphically, in a series of information-dense time-series plots for the period 2001-2004, *viz*. Figures 20 *et seq*., that proceed down the river system from Iron Gate to Klamath following the stem diagram of Fig. 2. Each of these figures displays the annual daily flows at one of the principal gauges, along with the 1951-2005-mean daily flow, and the daily exceedance, defined to be the fraction of 1951-2005 flows on that day that is exceeded by the daily flow. Superposed on this plot are the dates of the Arcata Fish & Wildlife sampling runs at the stations located at or near that gauge. Thus, on a single graph are displayed the flow conditions encountered on each sampling run and how comparable those flow conditions are to the normal flows in the river on that date. (Evaluations on aggregate timescales are given separately in the following section.) Although the flow axes are consistent for each of the gauges, the axes change from gauge to gauge, to better display the range of hydrological variation.

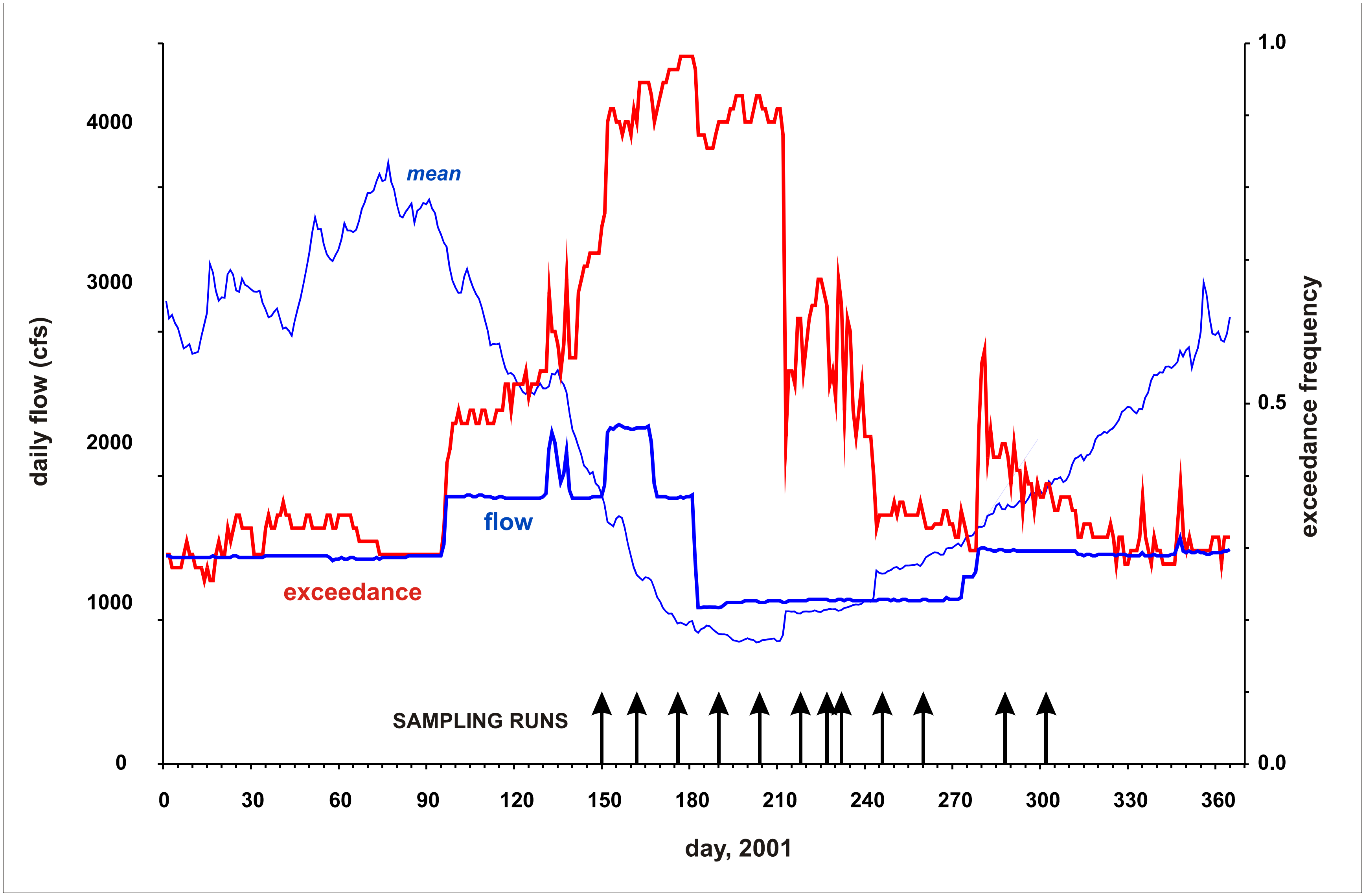

Figure 20 - Daily flow variation 2001 with 1951-2005 mean, Klamath at Iron Gate (USGS 11516530)

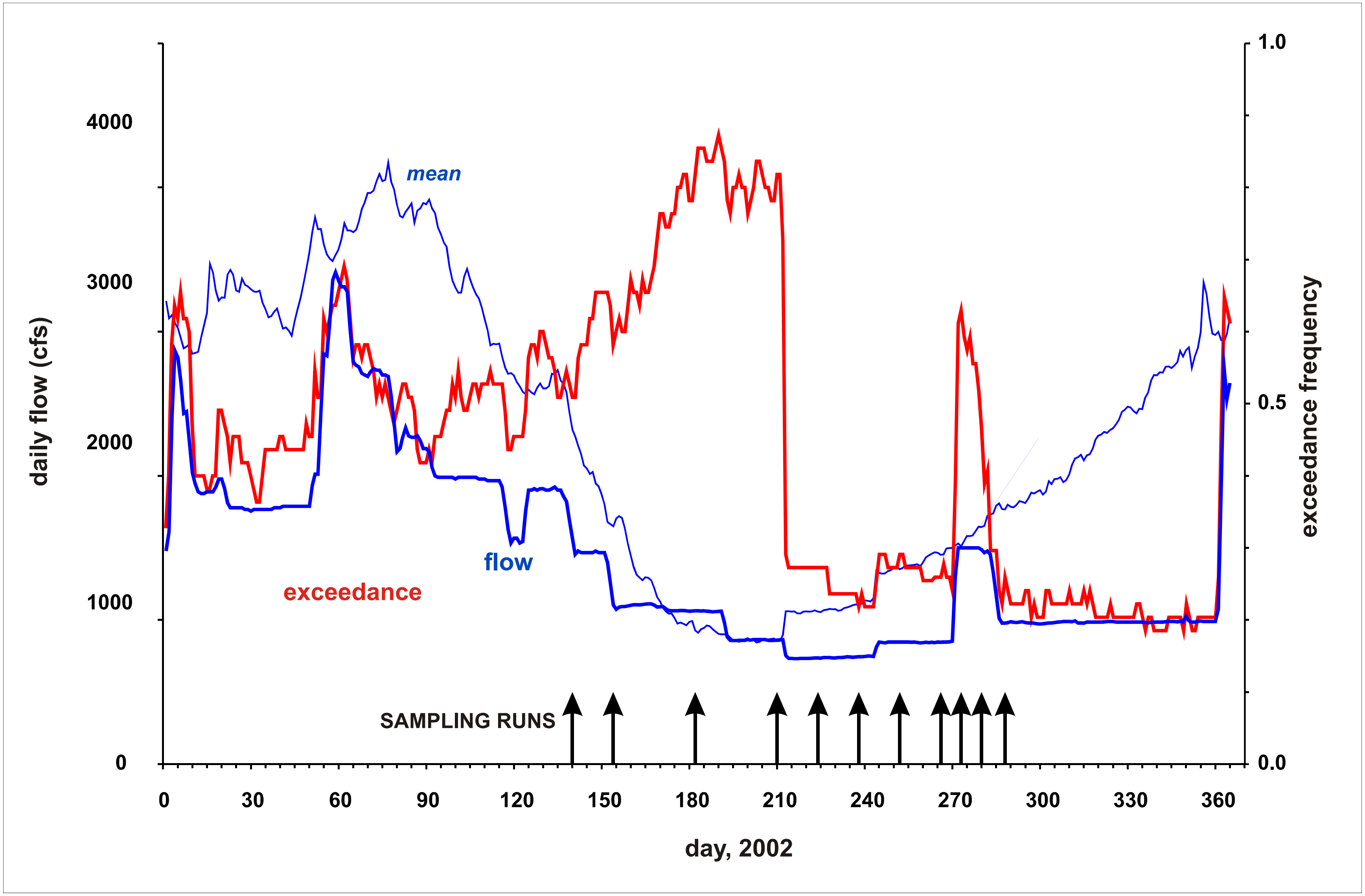

Figure 21 - Daily flow variation 2002 with 1951-2005 mean, Klamath at Iron Gate (USGS 11516530)

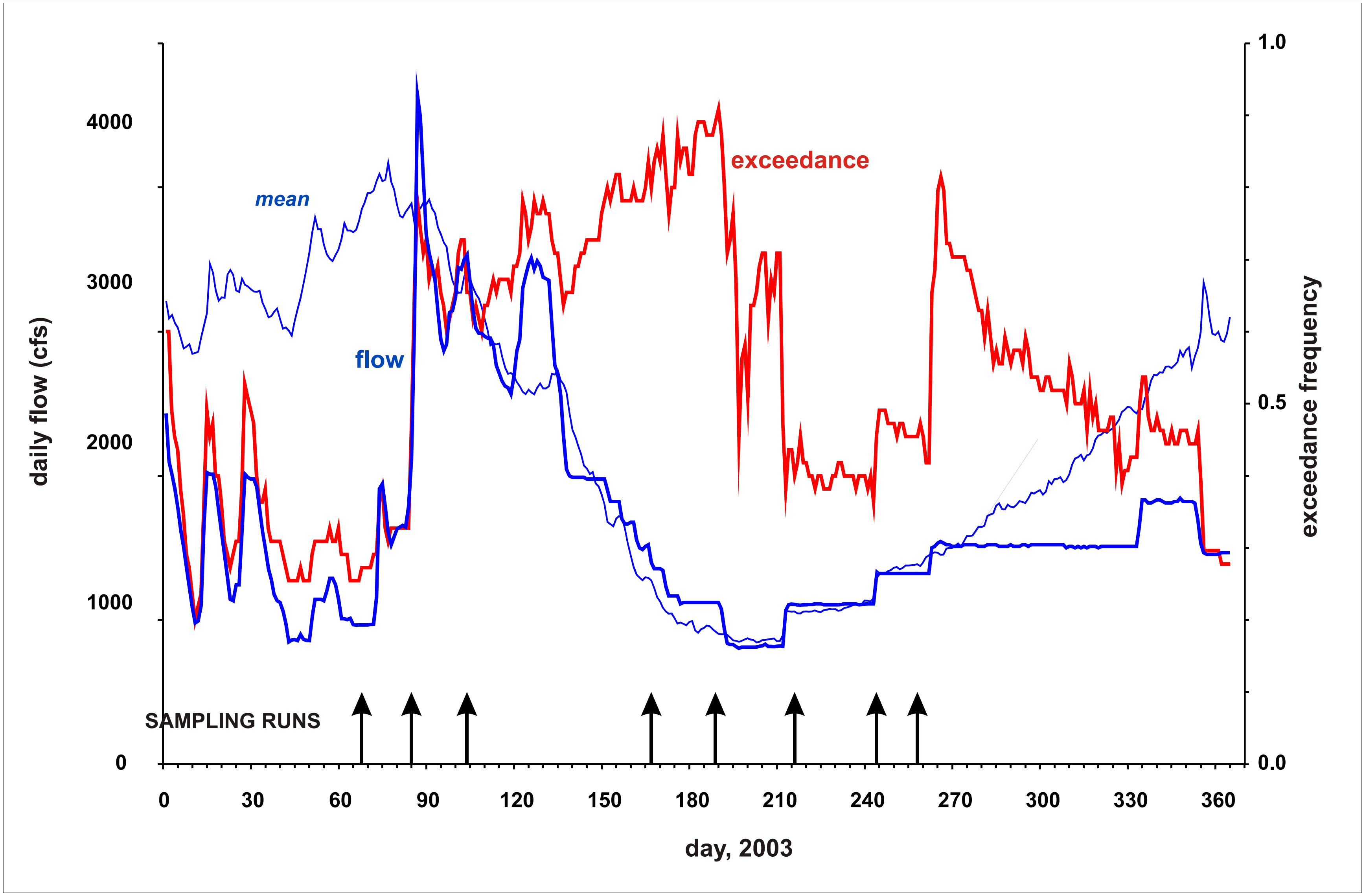

Figure 22 - Daily flow variation 2003 with 1951-2005 mean, Klamath at Iron Gate (USGS 11516530)

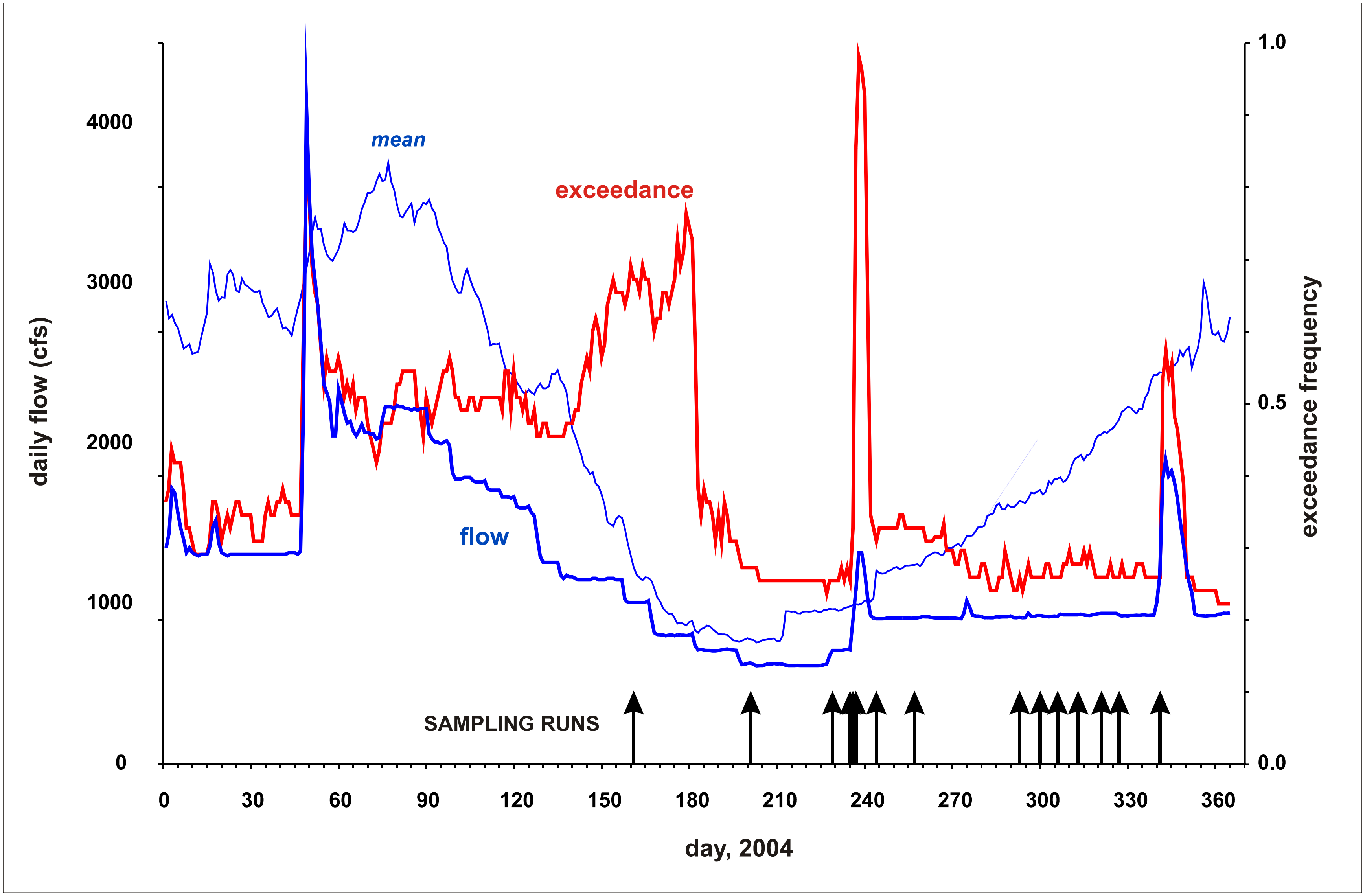

Figure 23 - Daily flow variation 2004 with 1951-2005 mean, Klamath at Iron Gate (USGS 11516530)

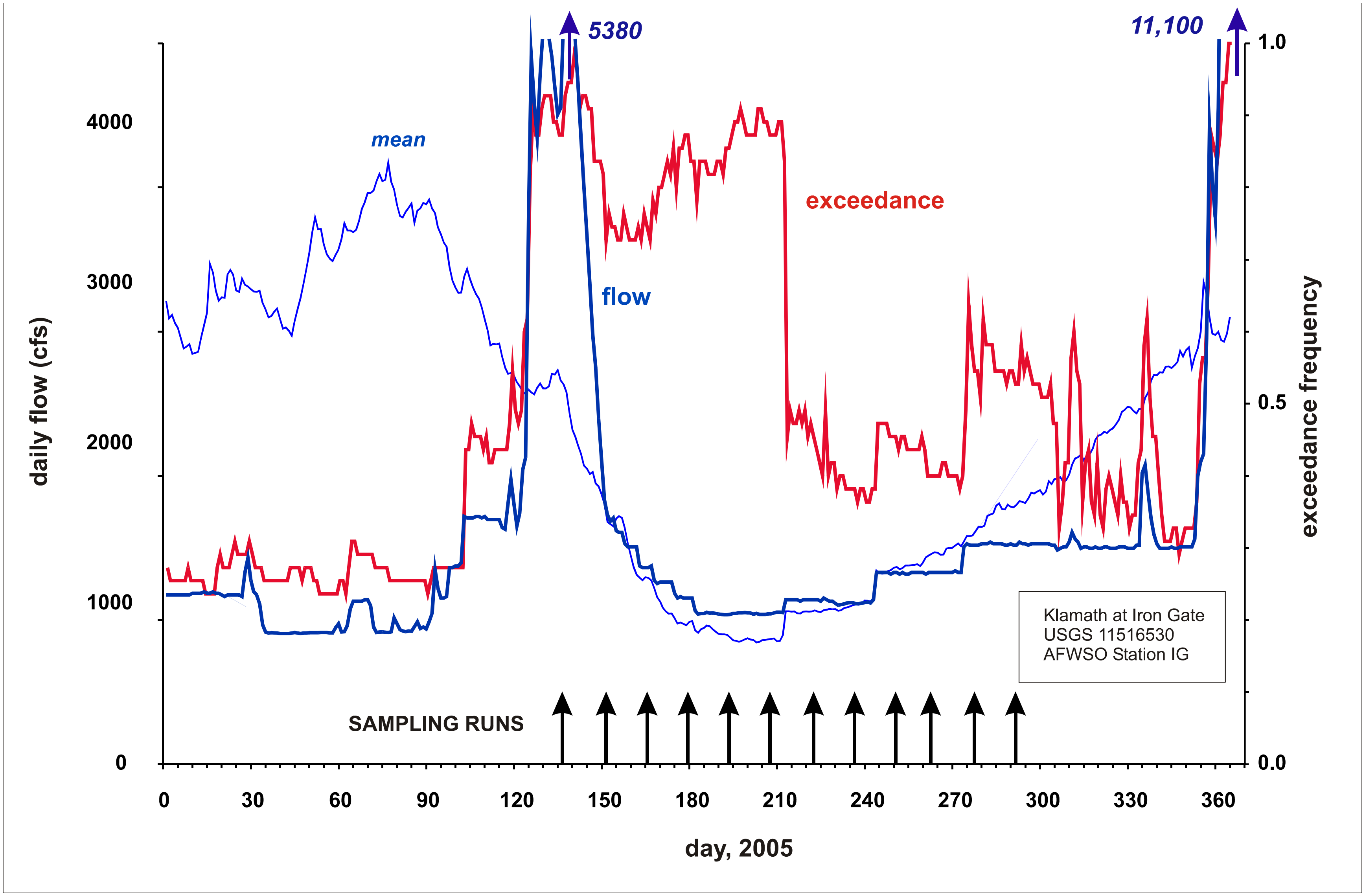

Figure 24 - Daily flow variation 2005 with 1951-2005 mean, Klamath at Iron Gate (USGS 11516530)

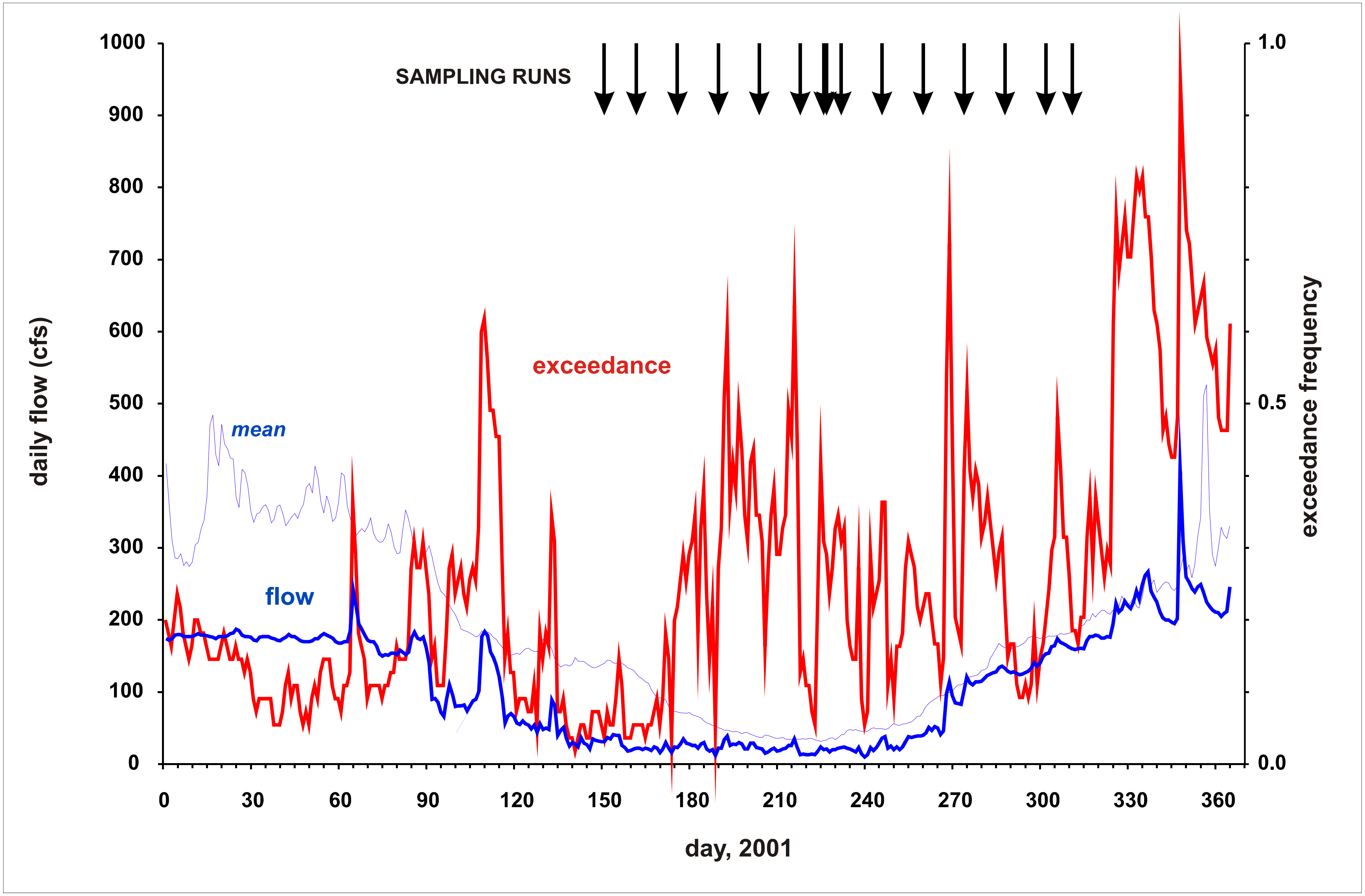

Figure 25 - Daily flow variation 2001 with 1951-2005 mean, Shasta near Yreka (USGS 11517500)

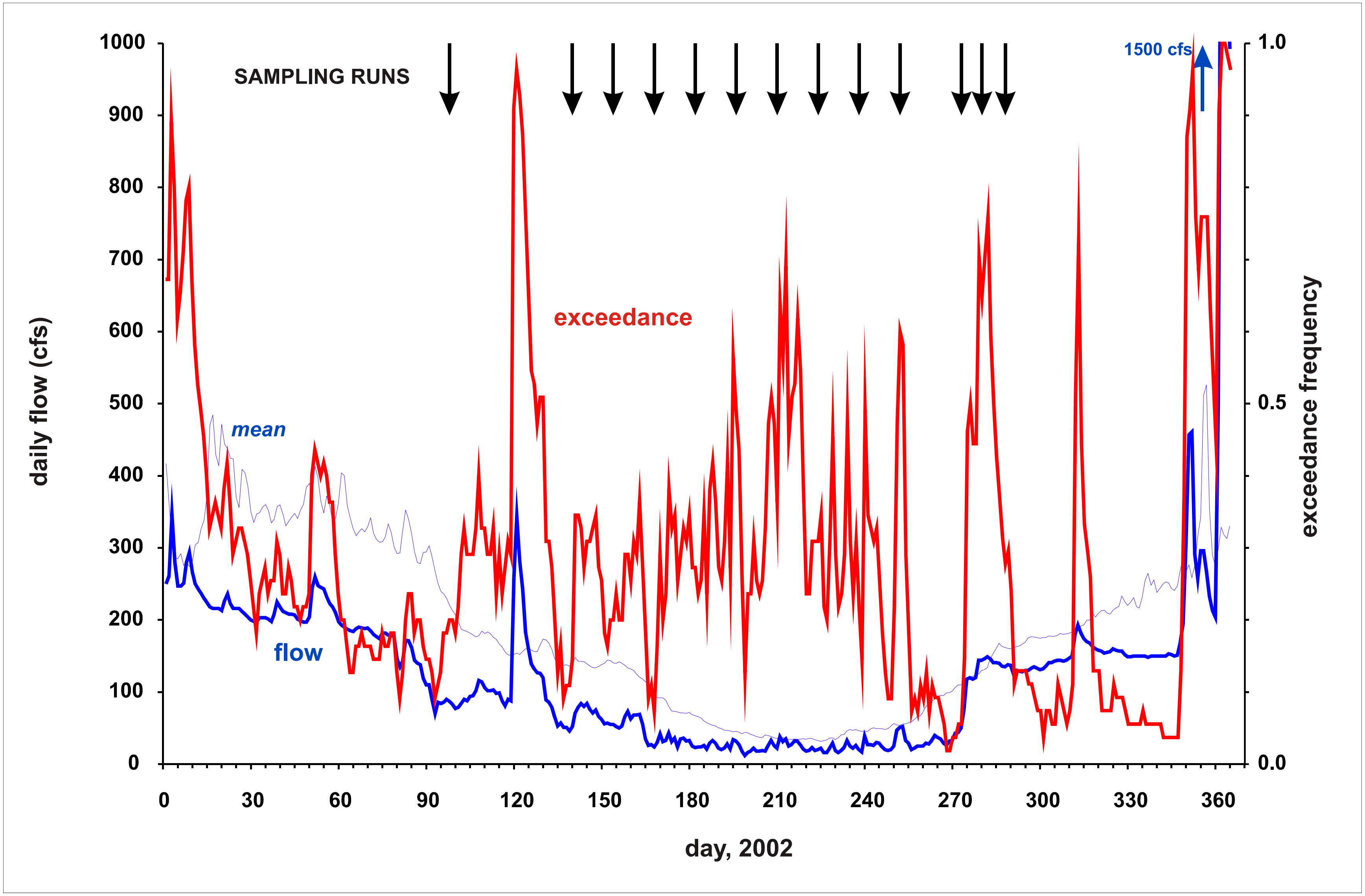

Figure 26 - Daily flow variation 2002 with 1951-2005 mean, Shasta near Yreka (USGS 11517500)

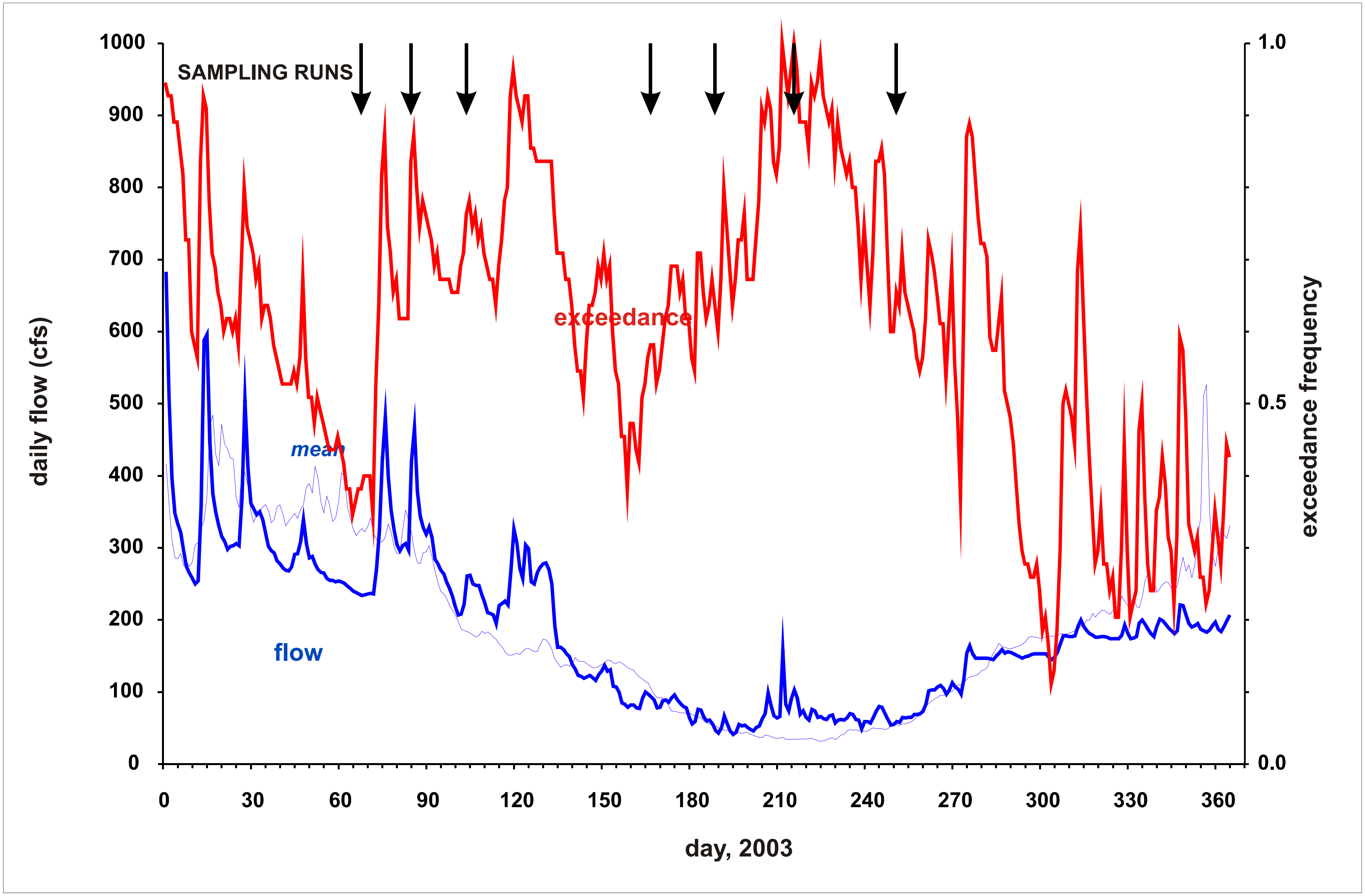

Figure 27 - Daily flow variation 2003 with 1951-2005 mean, Shasta near Yreka (USGS 11517500)

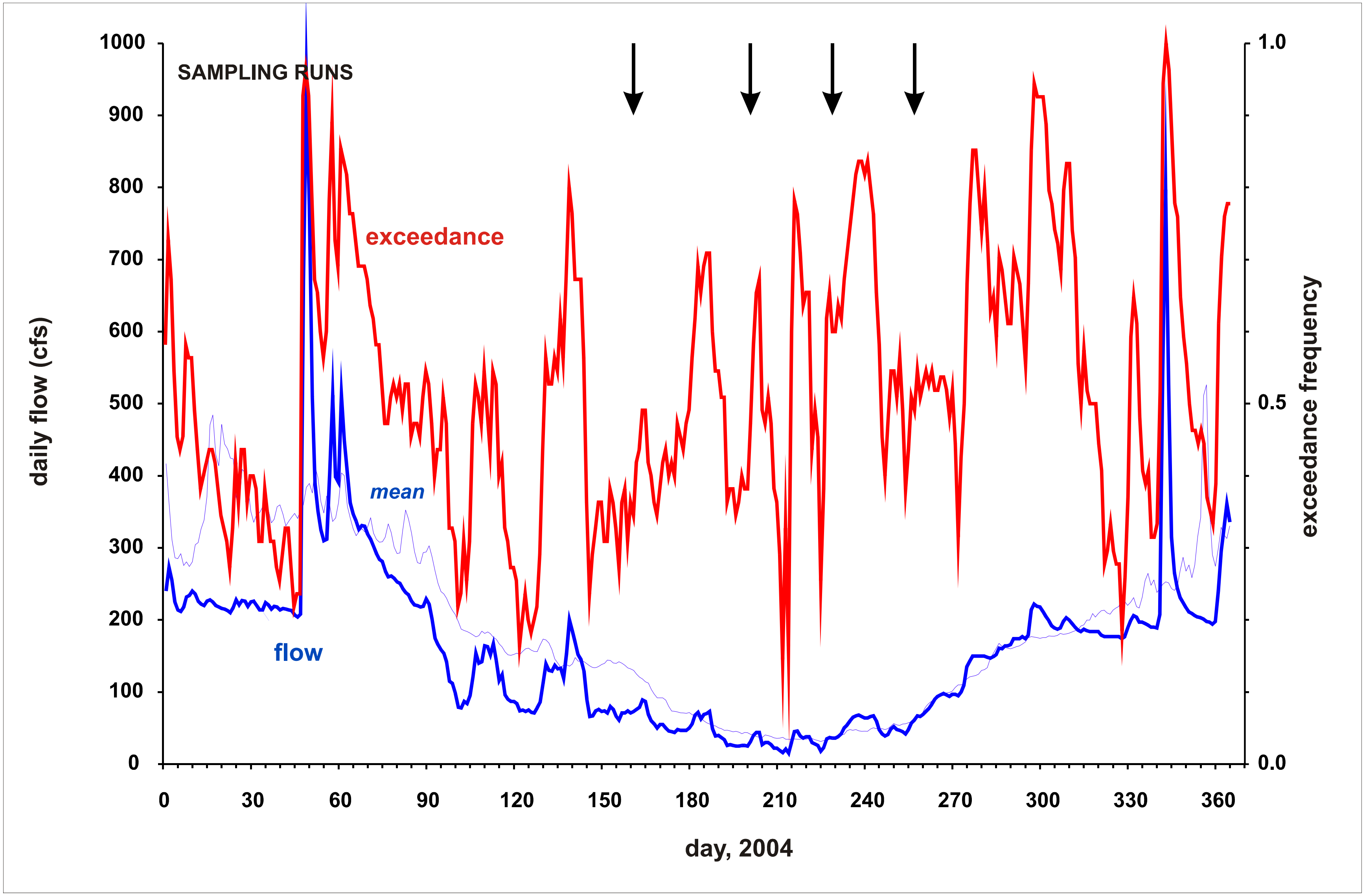

Figure 28 - Daily flow variation 2004 with 1951-2005 mean, Shasta near Yreka (USGS 11517500)

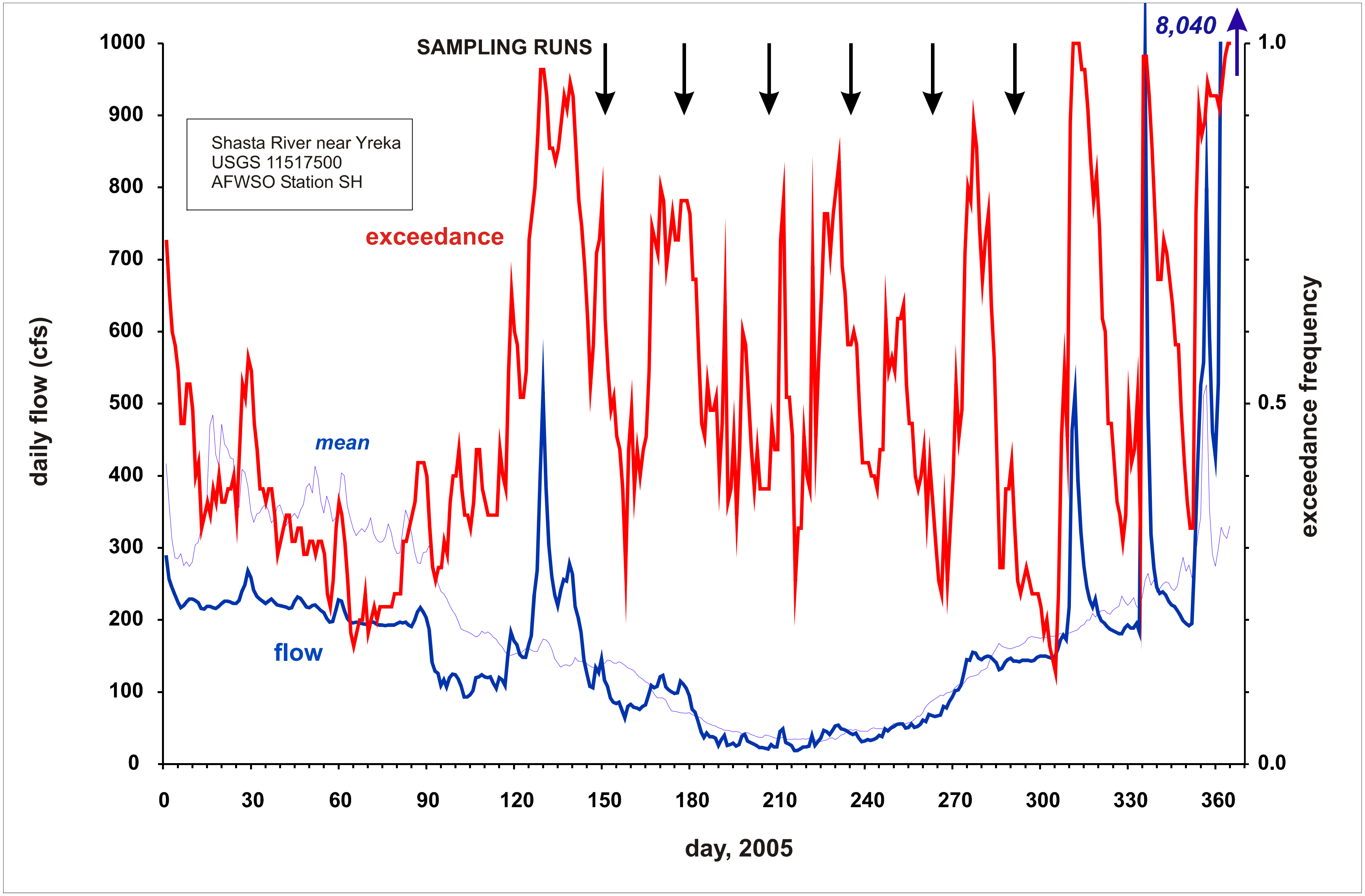

Figure 29 - Daily flow variation 2005 with 1951-2005 mean, Shasta near Yreka (USGS 11517500)

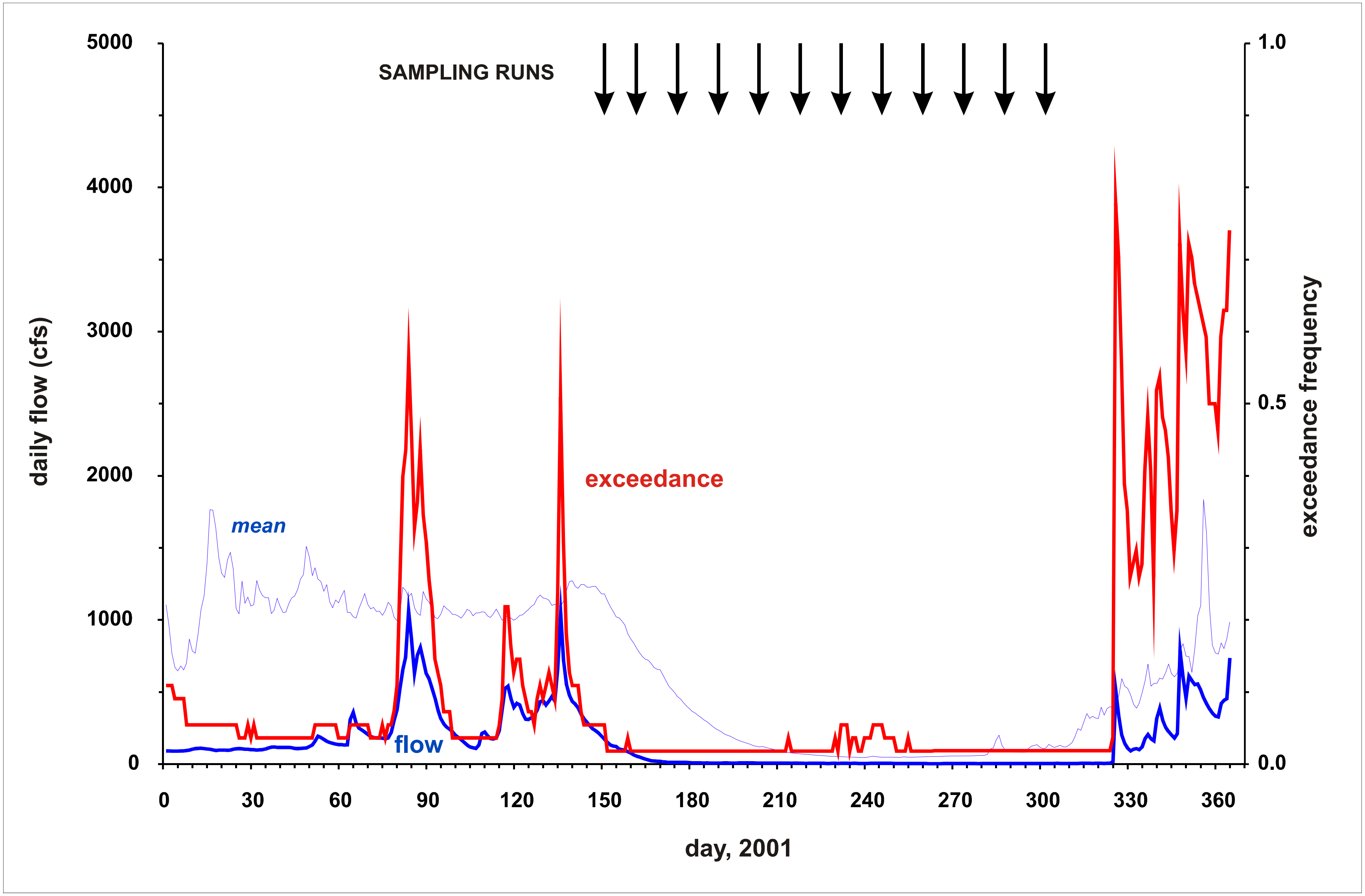

Figure 30 - Daily flow variation 2001 with 1951-2005 mean, Scott near Fort Jones (USGS 11519500)

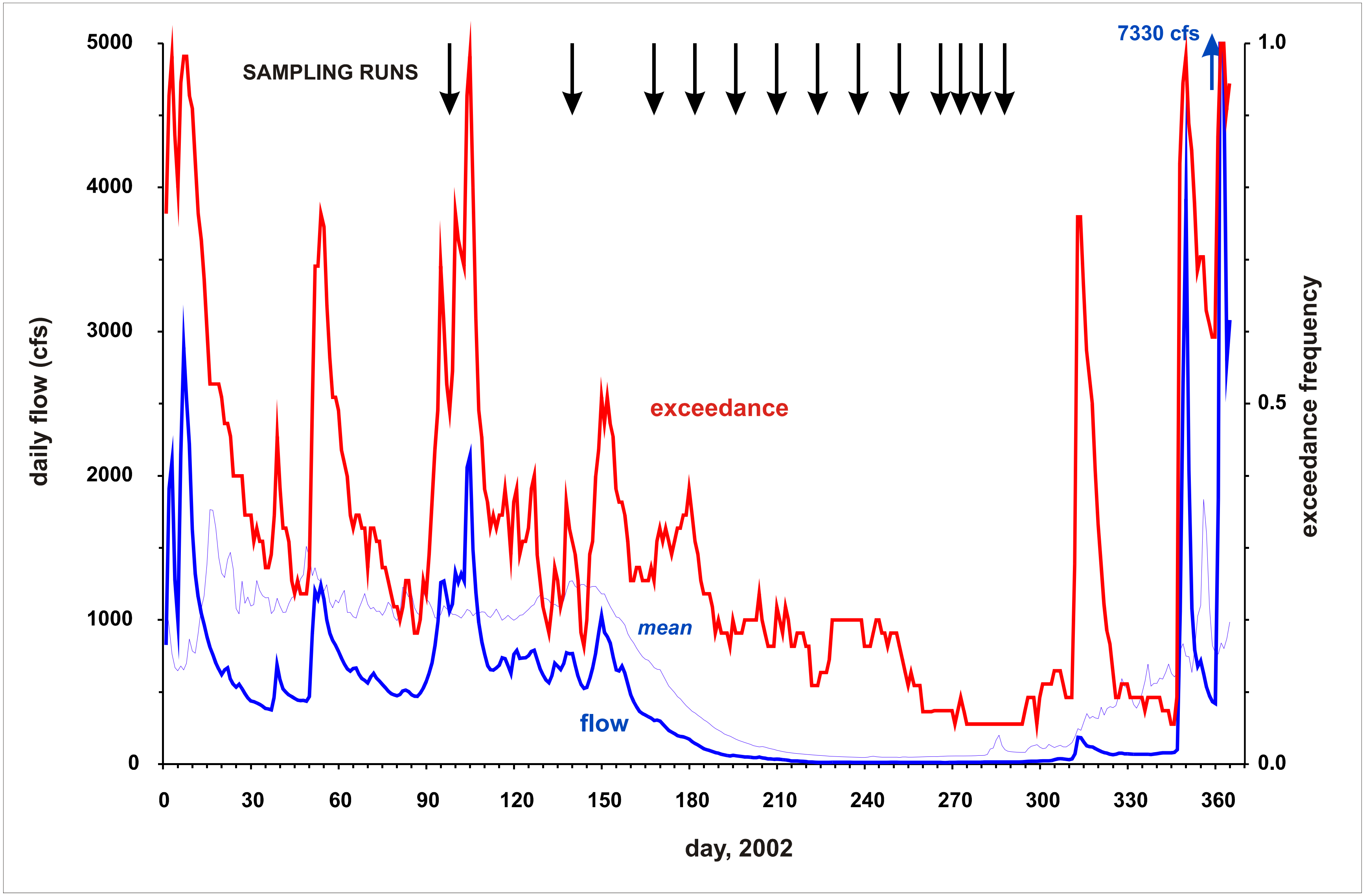

Figure 31 - Daily flow variation 2002 with 1951-2005 mean, Scott near Fort Jones (USGS 11519500)

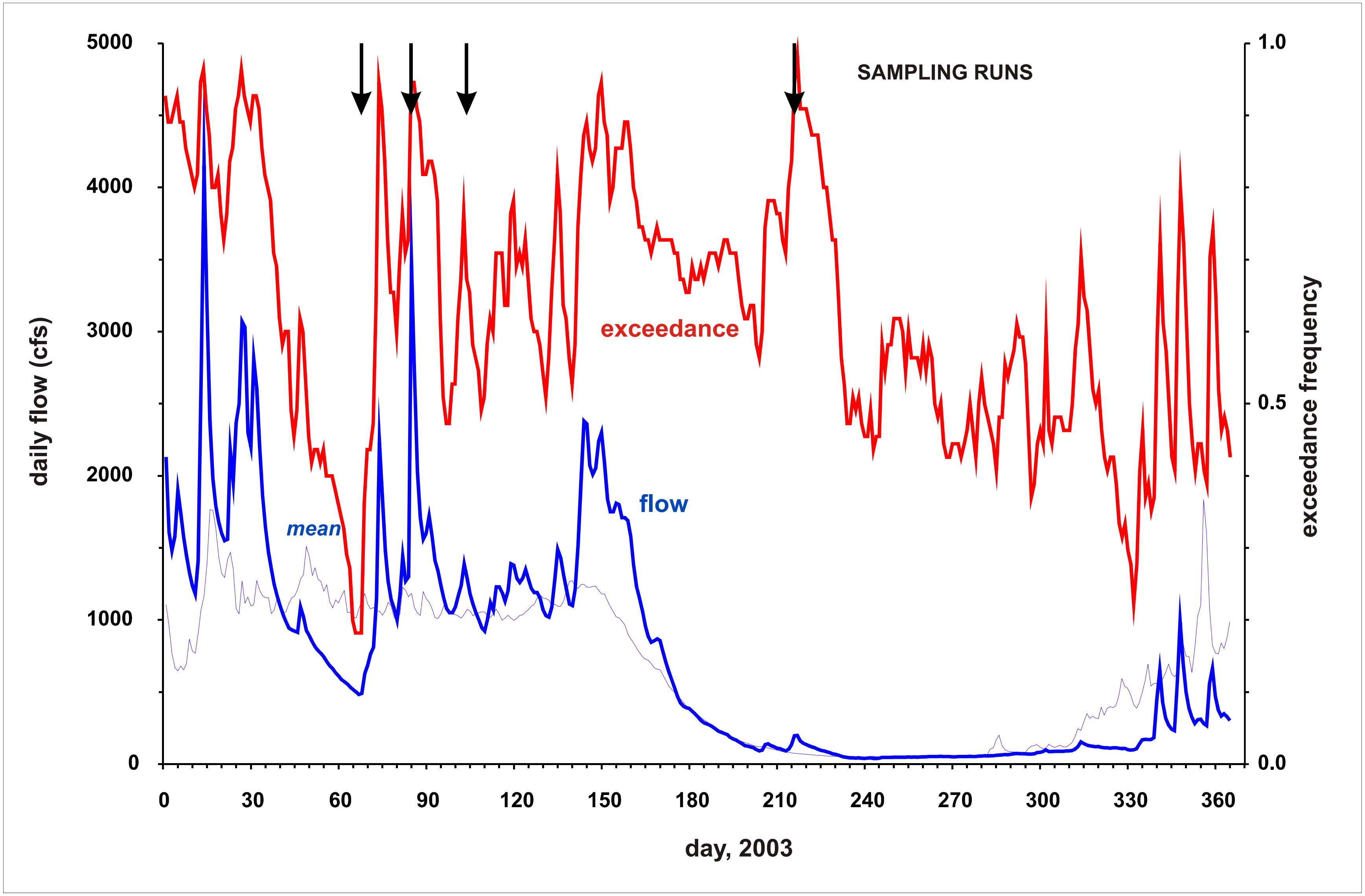

Figure 32 - Daily flow variation 2003 with 1951-2005 mean, Scott near Fort Jones (USGS 11519500)

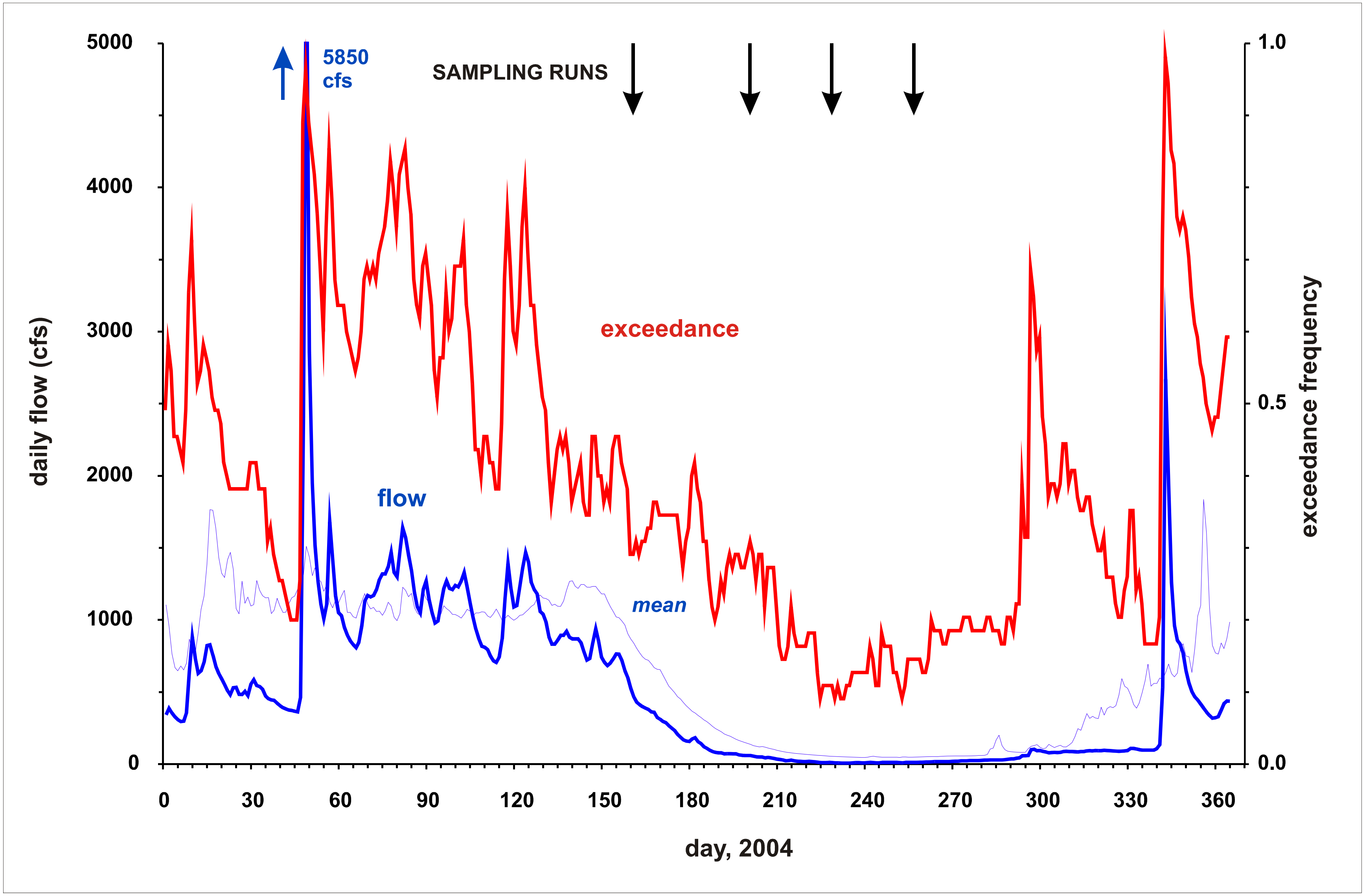

Figure 33 - Daily flow variation 2004 with 1951-2005 mean, Scott near Fort Jones (USGS 11519500)

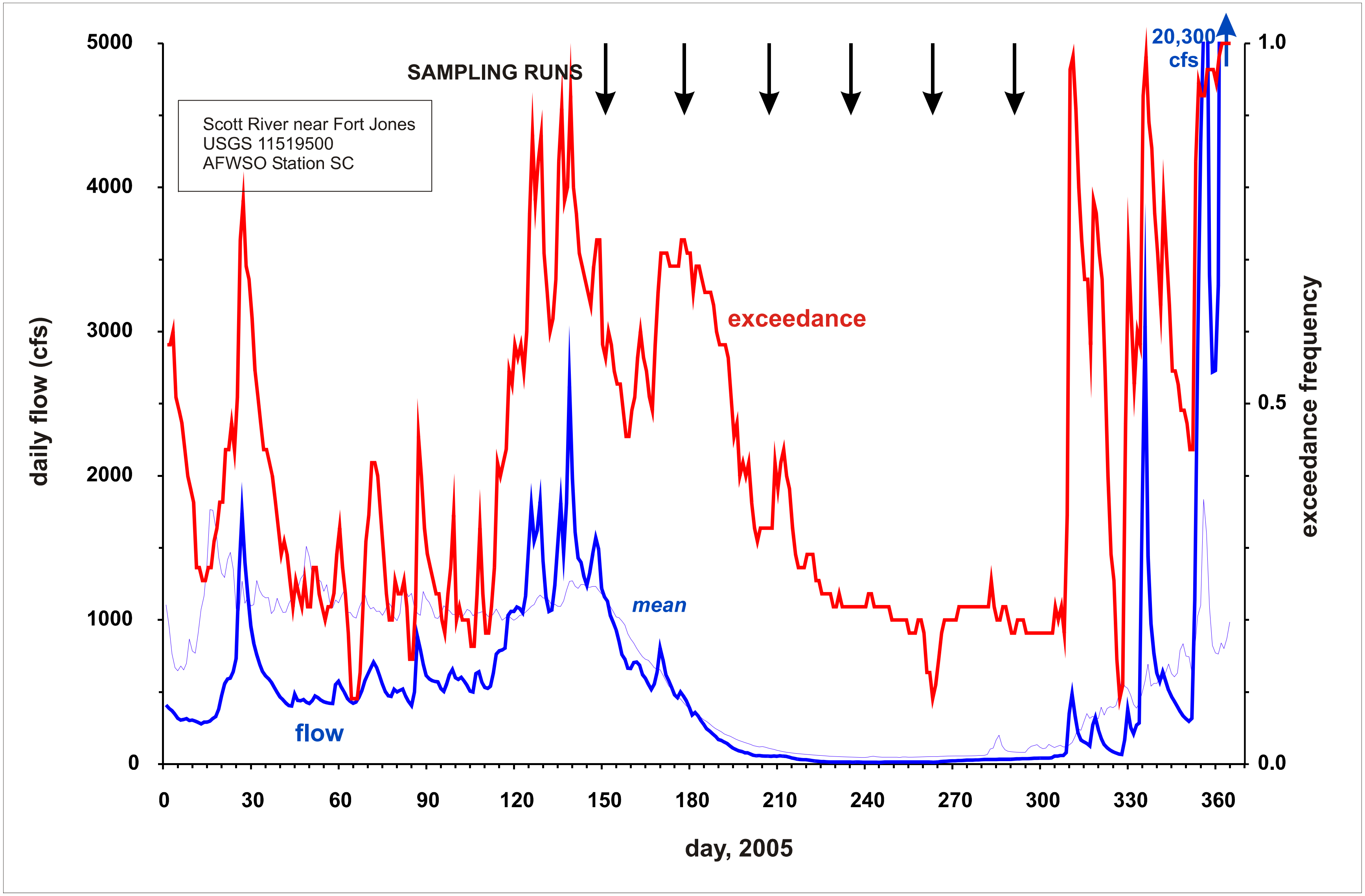

Figure 34 - Daily flow variation 2005 with 1951-2005 mean, Scott near Fort Jones (USGS 11519500)

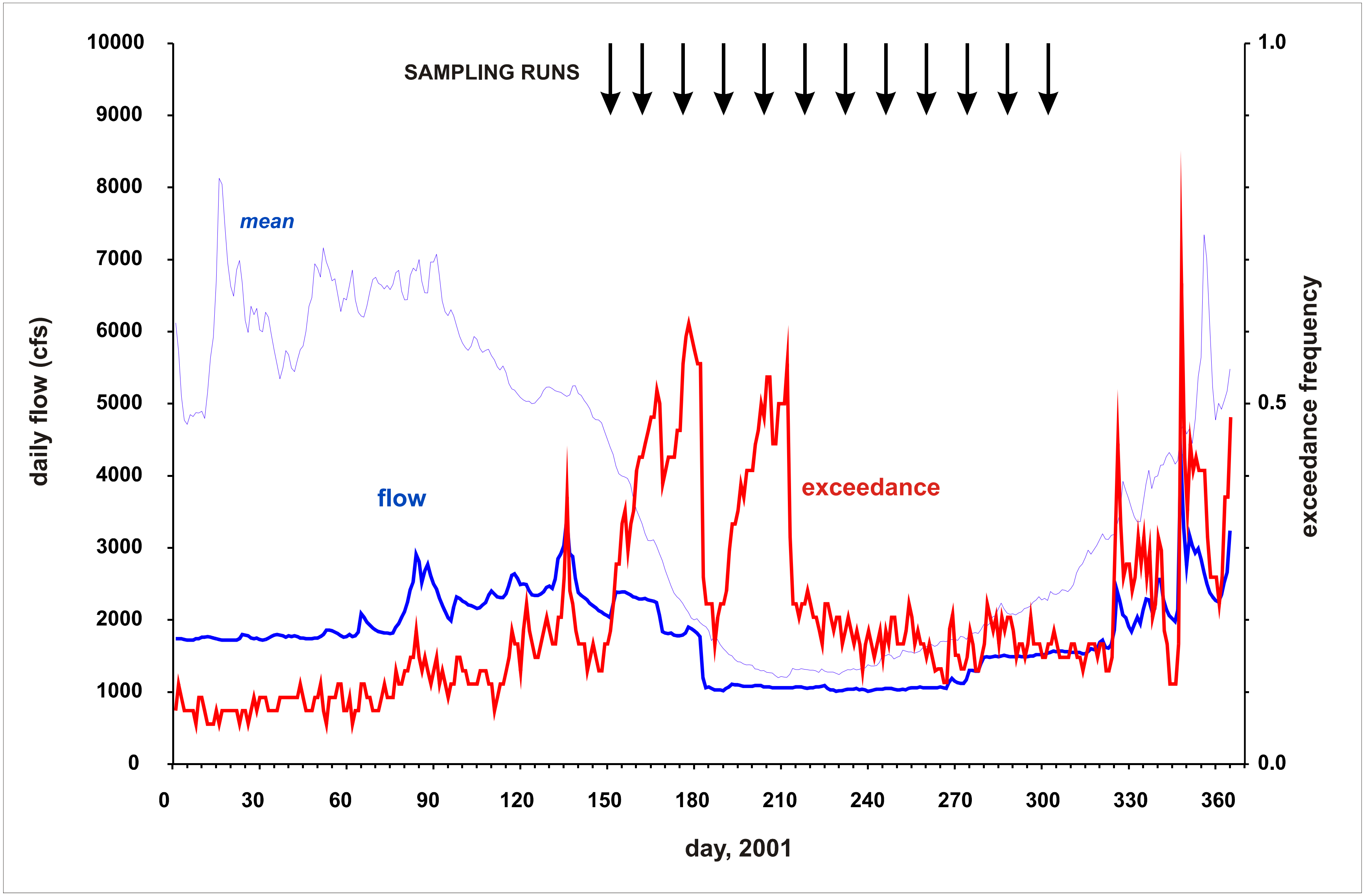

Figure 35 - Daily flow variation 2001 with 1951-2005 mean, Klamath near Seiad Valley (USGS 11520500)

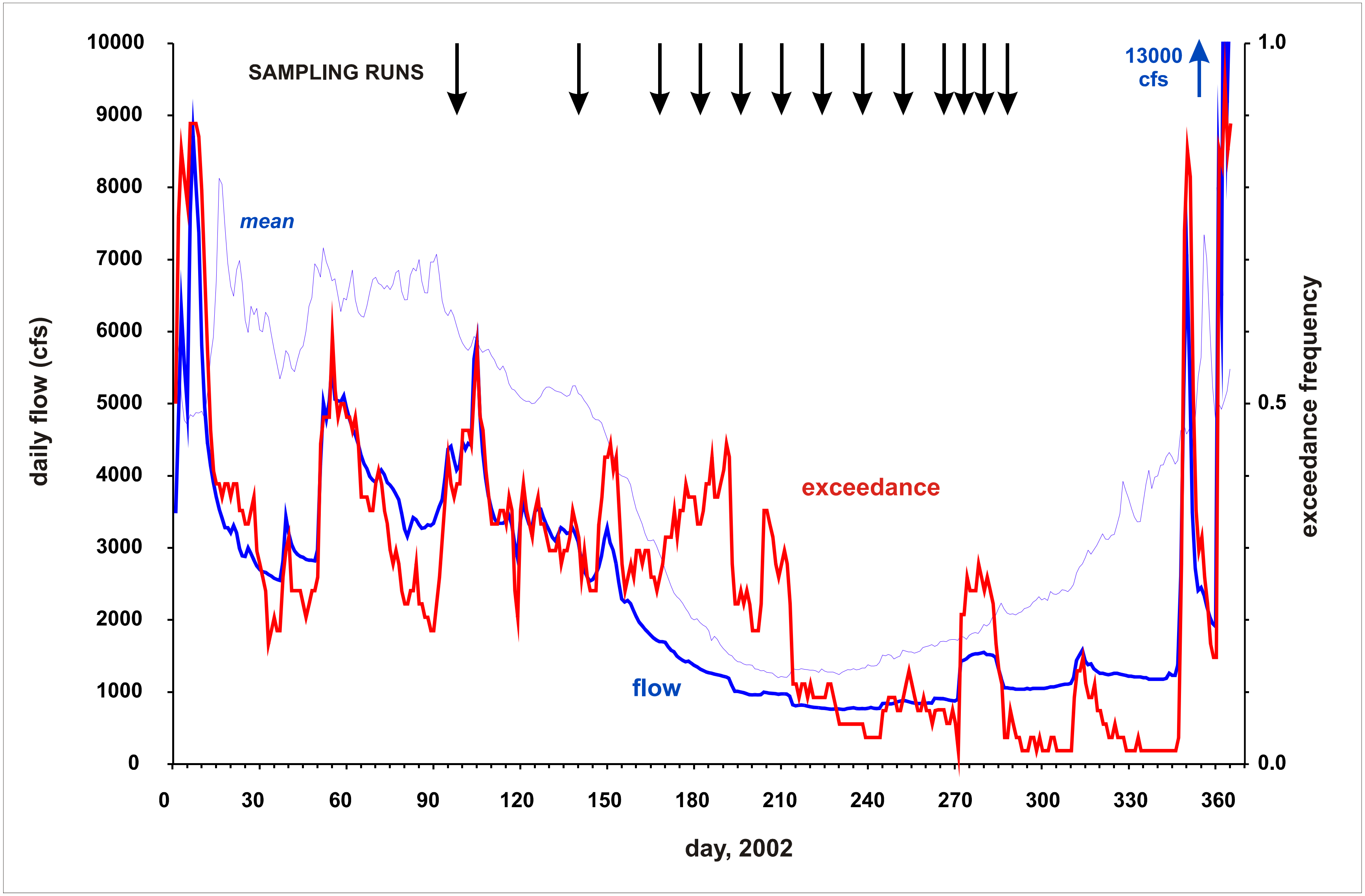

Figure 36 - Daily flow variation 2002 with 1951-2005 mean, Klamath near Seiad Valley (USGS 11520500)

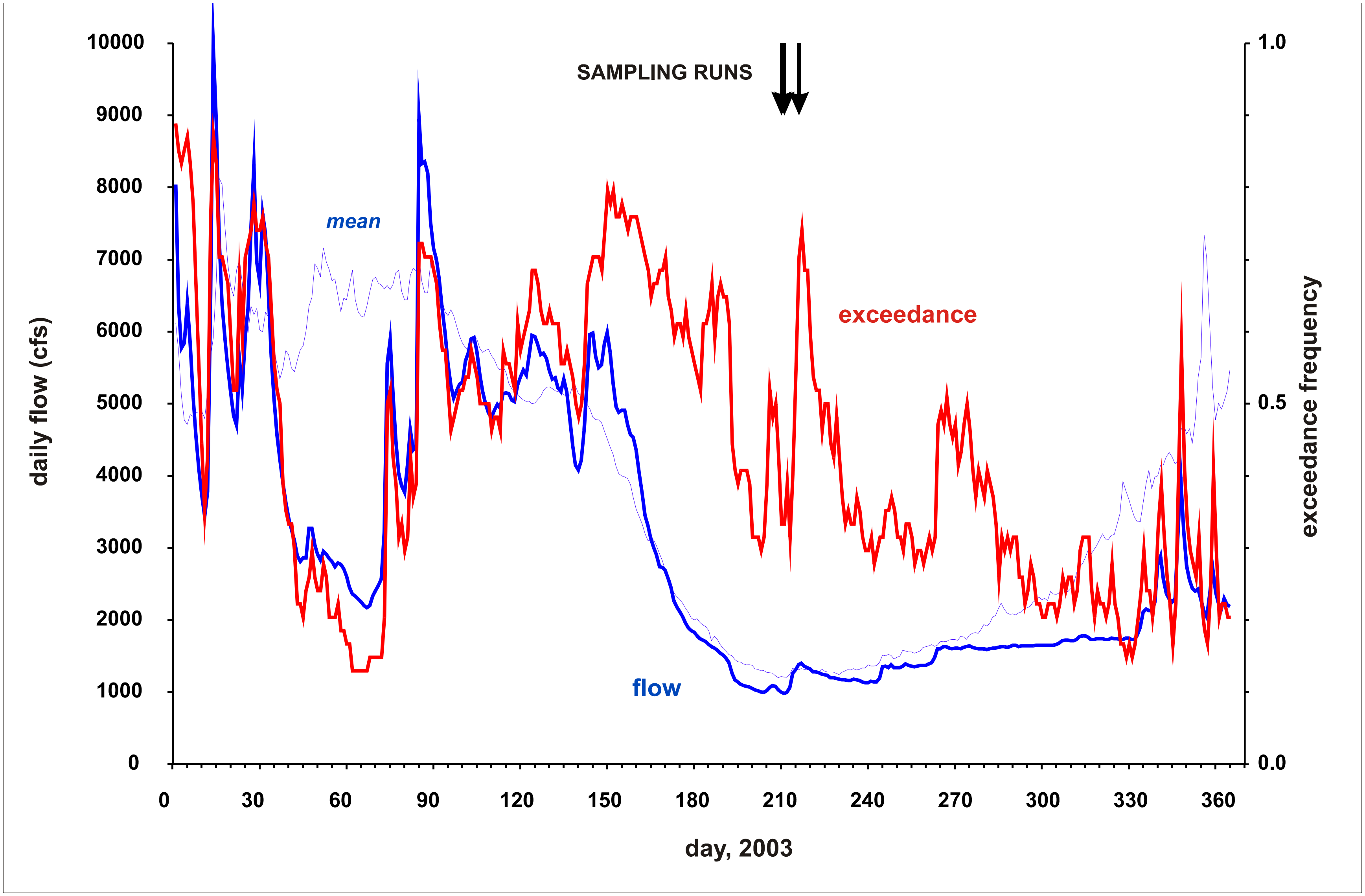

Figure 37 - Daily flow variation 2003 with 1951-2005 mean, Klamath near Seiad Valley (USGS 11520500)

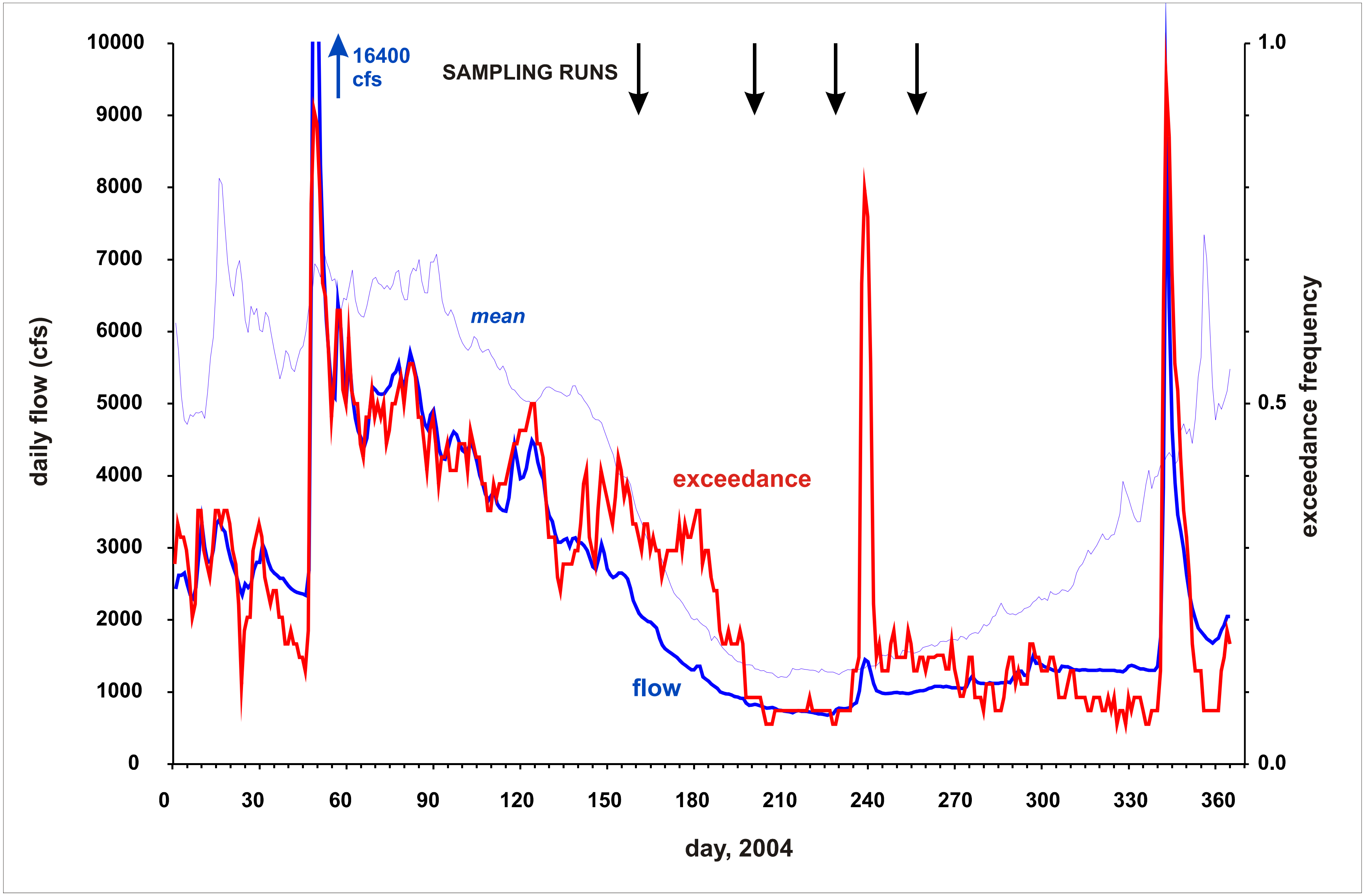

Figure 38 - Daily flow variation 2004 with 1951-2005 mean, Klamath near Seiad Valley (USGS 11520500)

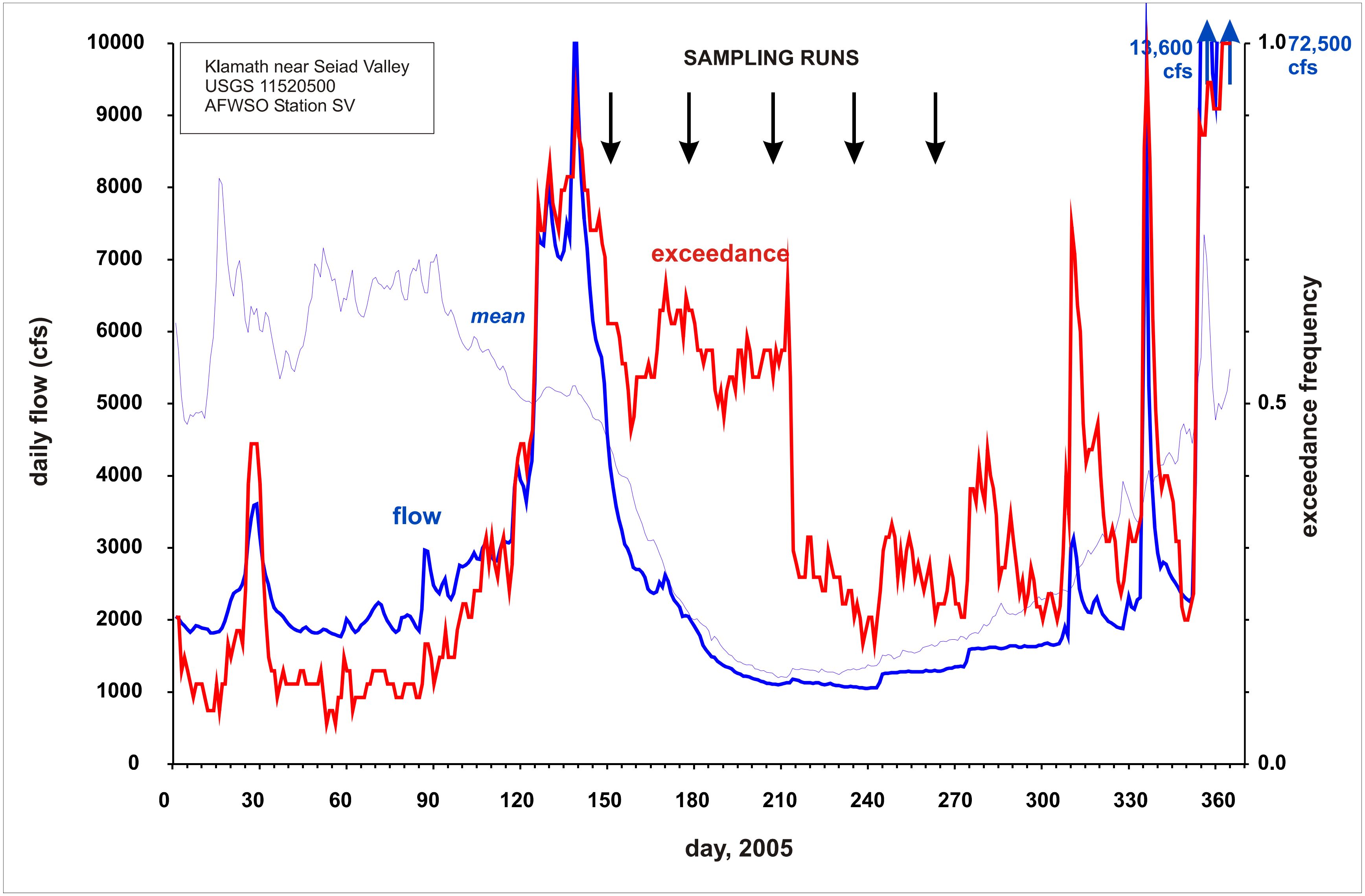

Figure 39 - Daily flow variation 2005 with 1951-2005 mean, Klamath near Seiad Valley (USGS 11520500)

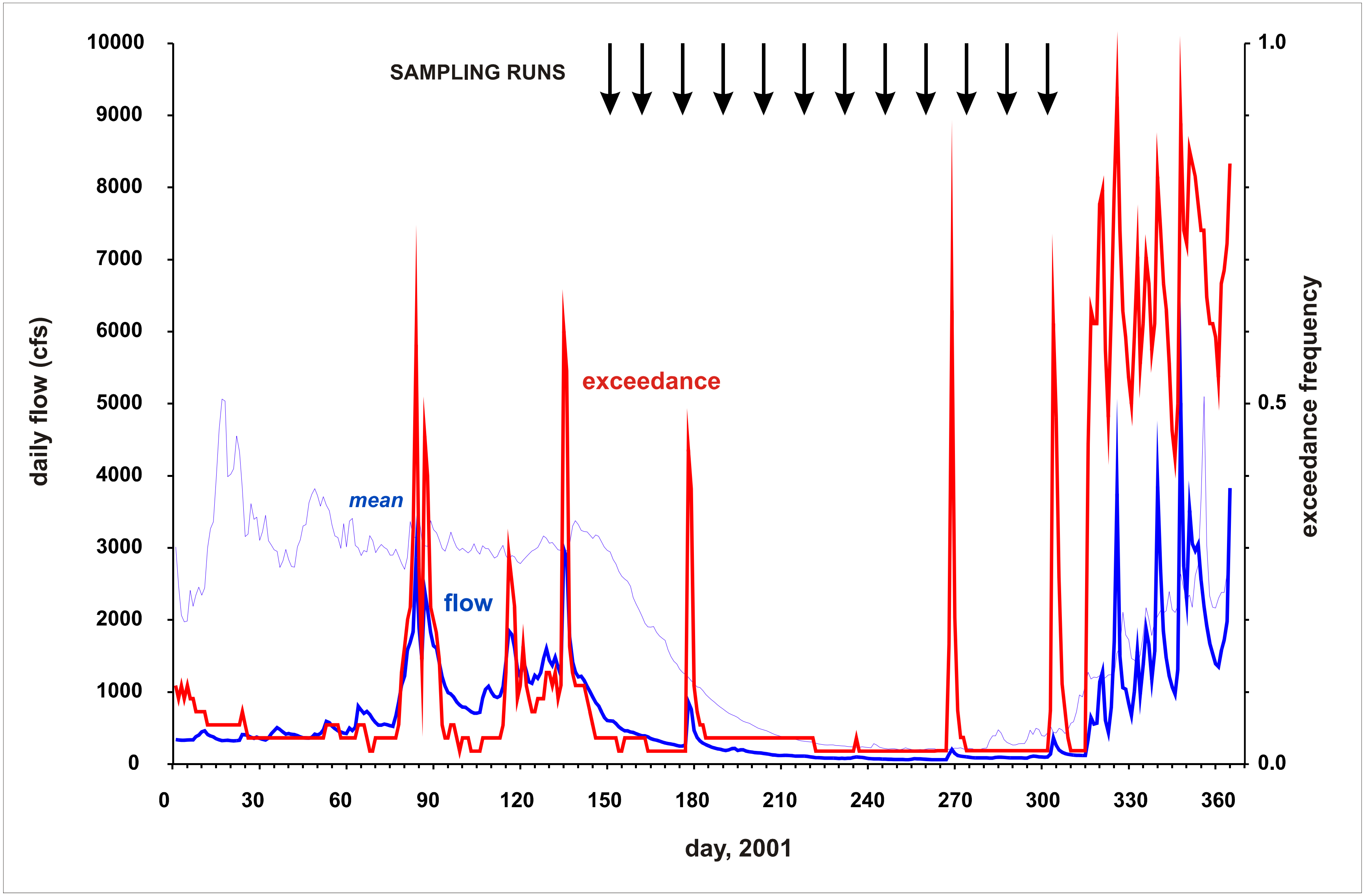

Figure 40 - Daily flow variation 2001 with 1951-2005 mean, Salmon at Somes Bar (USGS 11522500)

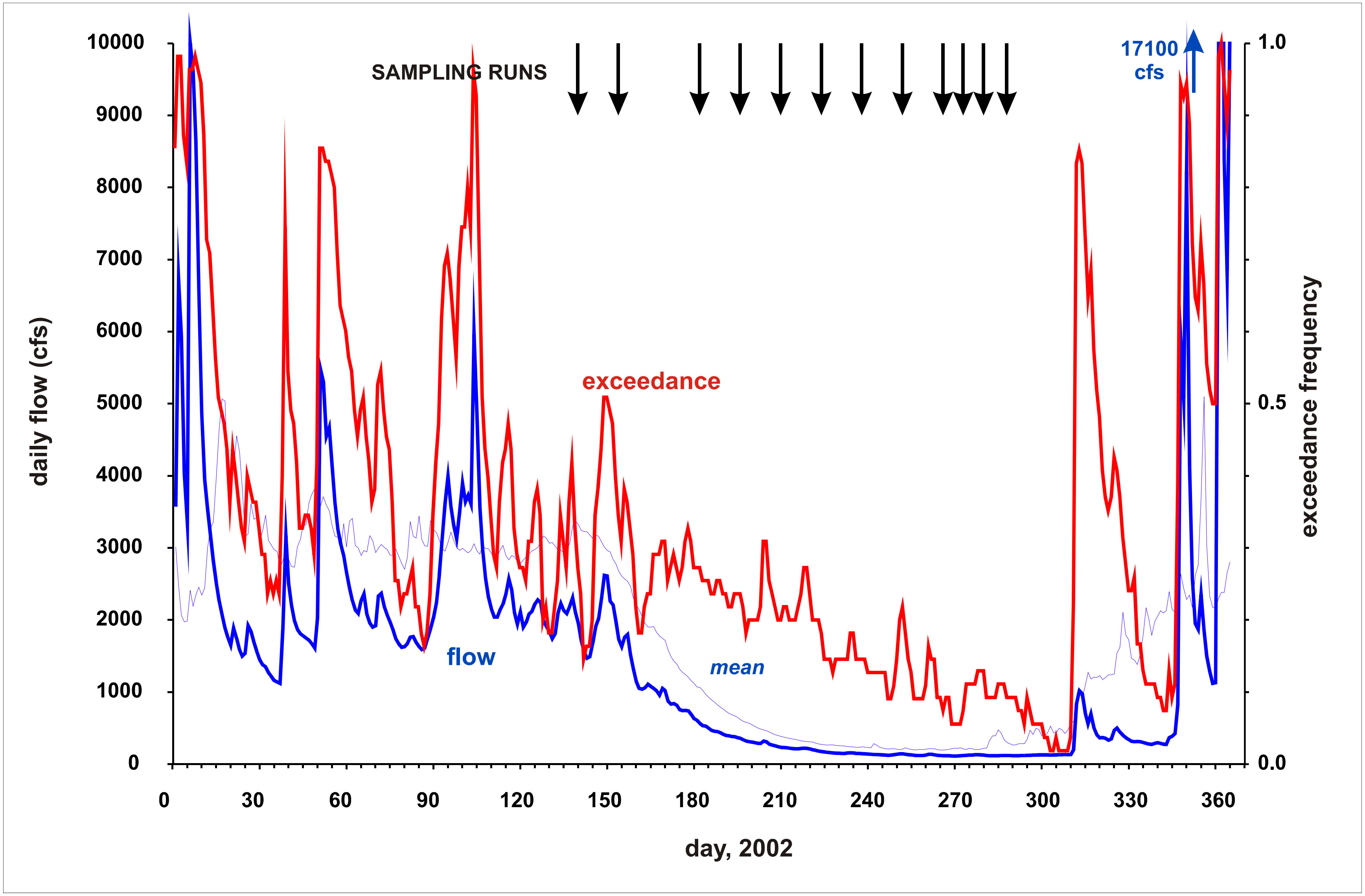

Figure 41 - Daily flow variation 2002 with 1951-2005 mean, Salmon at Somes Bar (USGS 11522500)

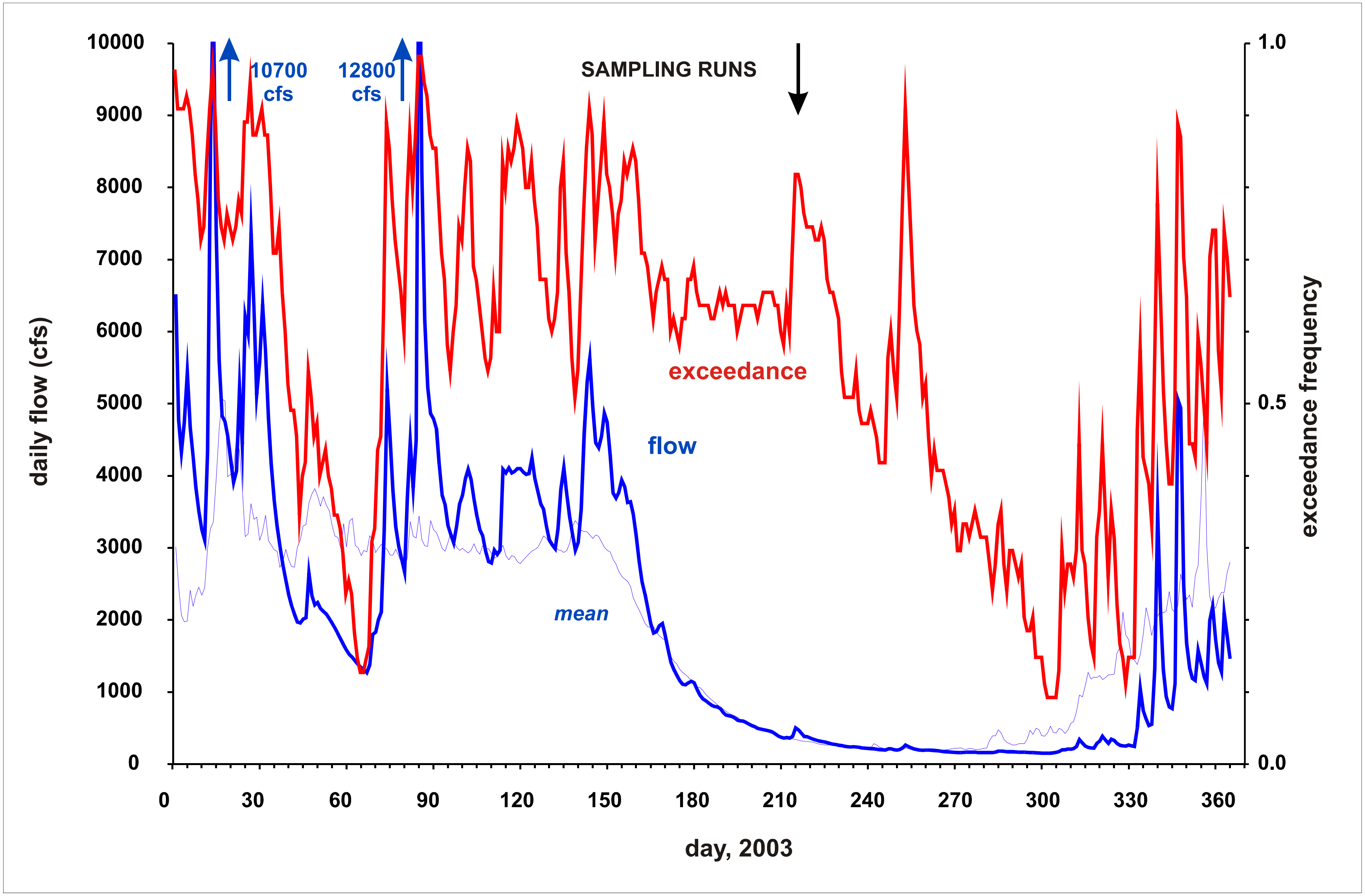

Figure 42 - Daily flow variation 2003 with 1951-2005 mean, Salmon at Somes Bar (USGS 11522500)

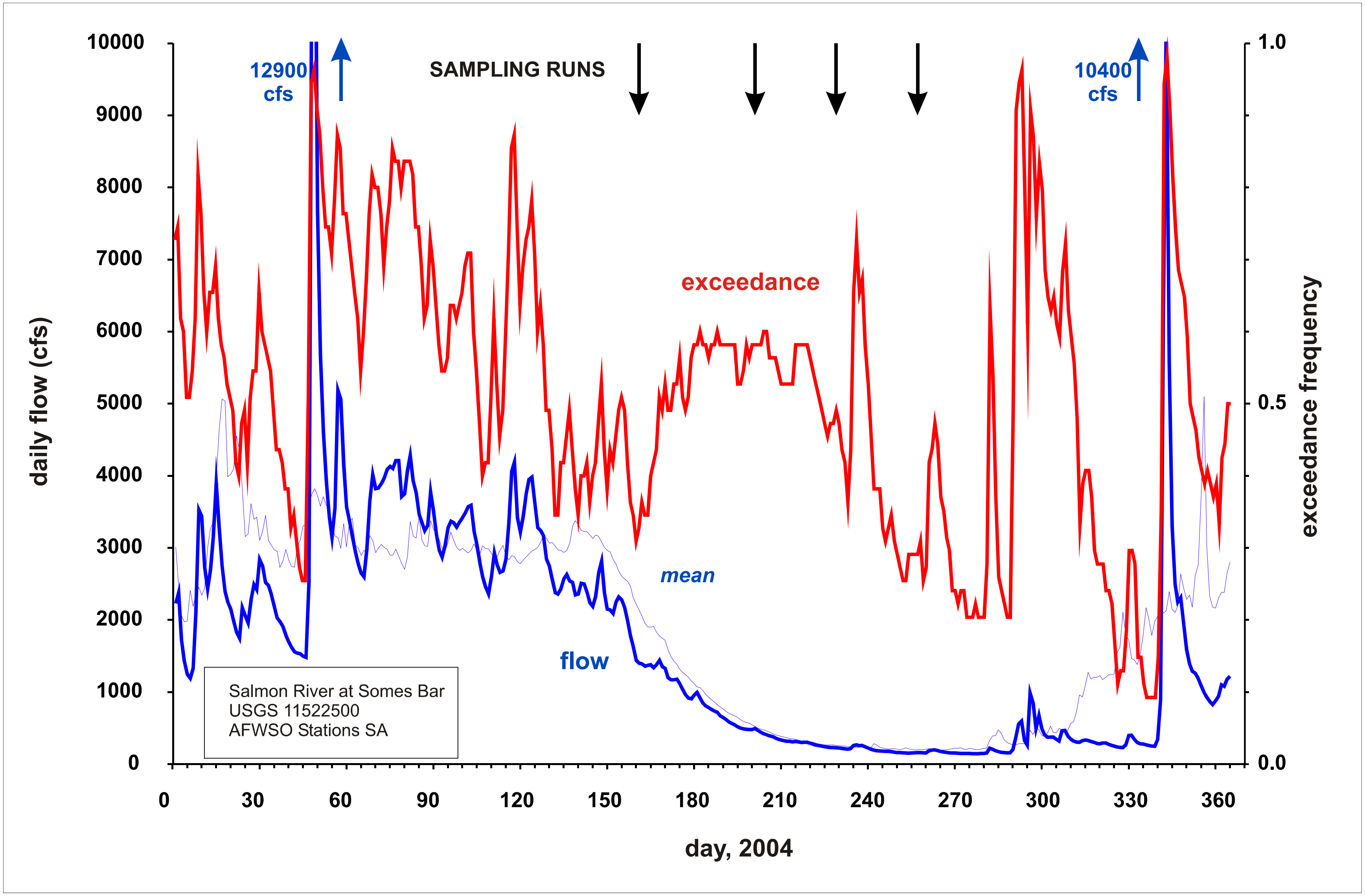

Figure 43 - Daily flow variation 2004 with 1951-2005 mean, Salmon at Somes Bar (USGS 11522500)

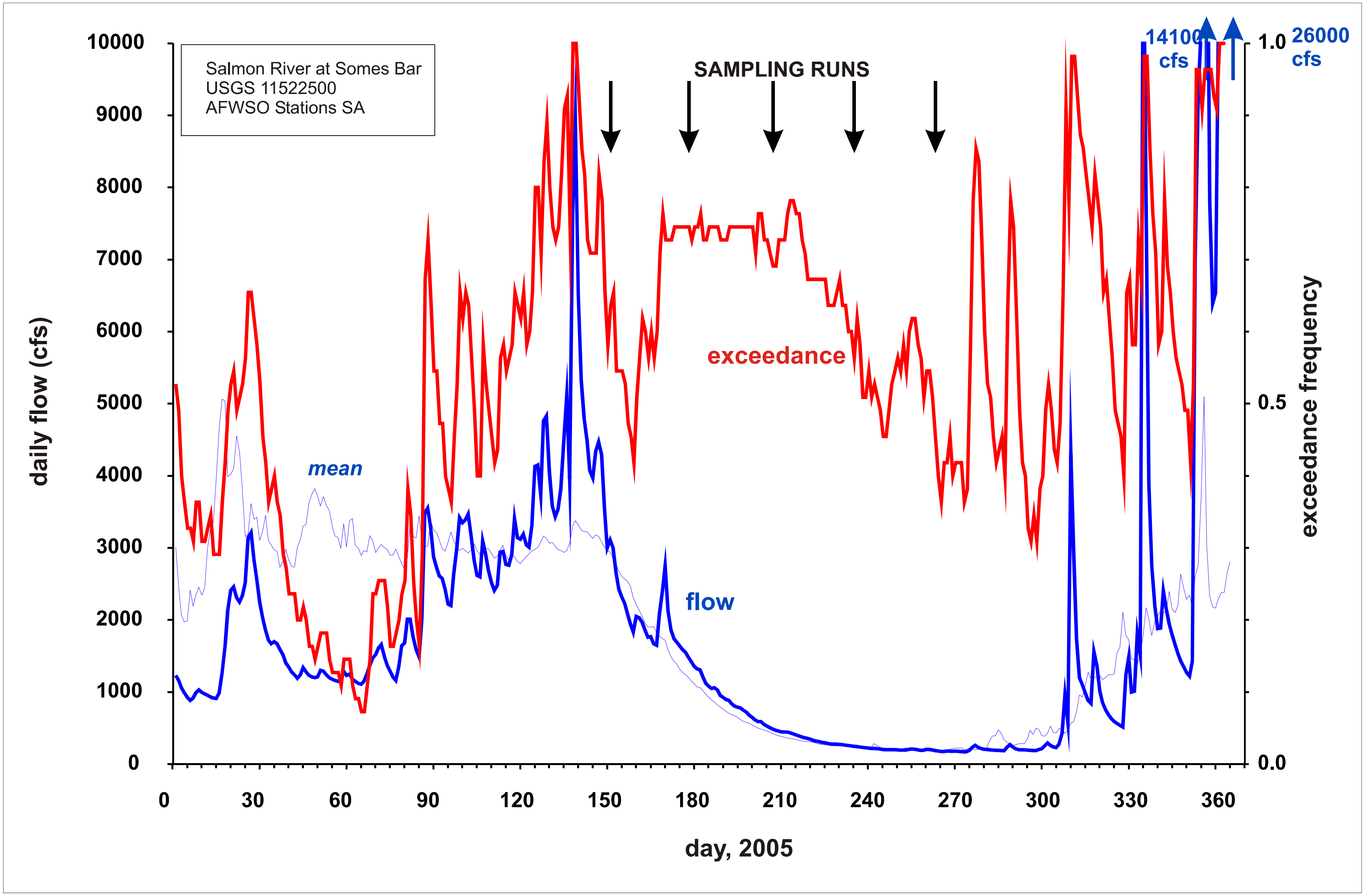

Figure 44 - Daily flow variation 2005 with 1951-2005 mean, Salmon at Somes Bar (USGS 11522500)

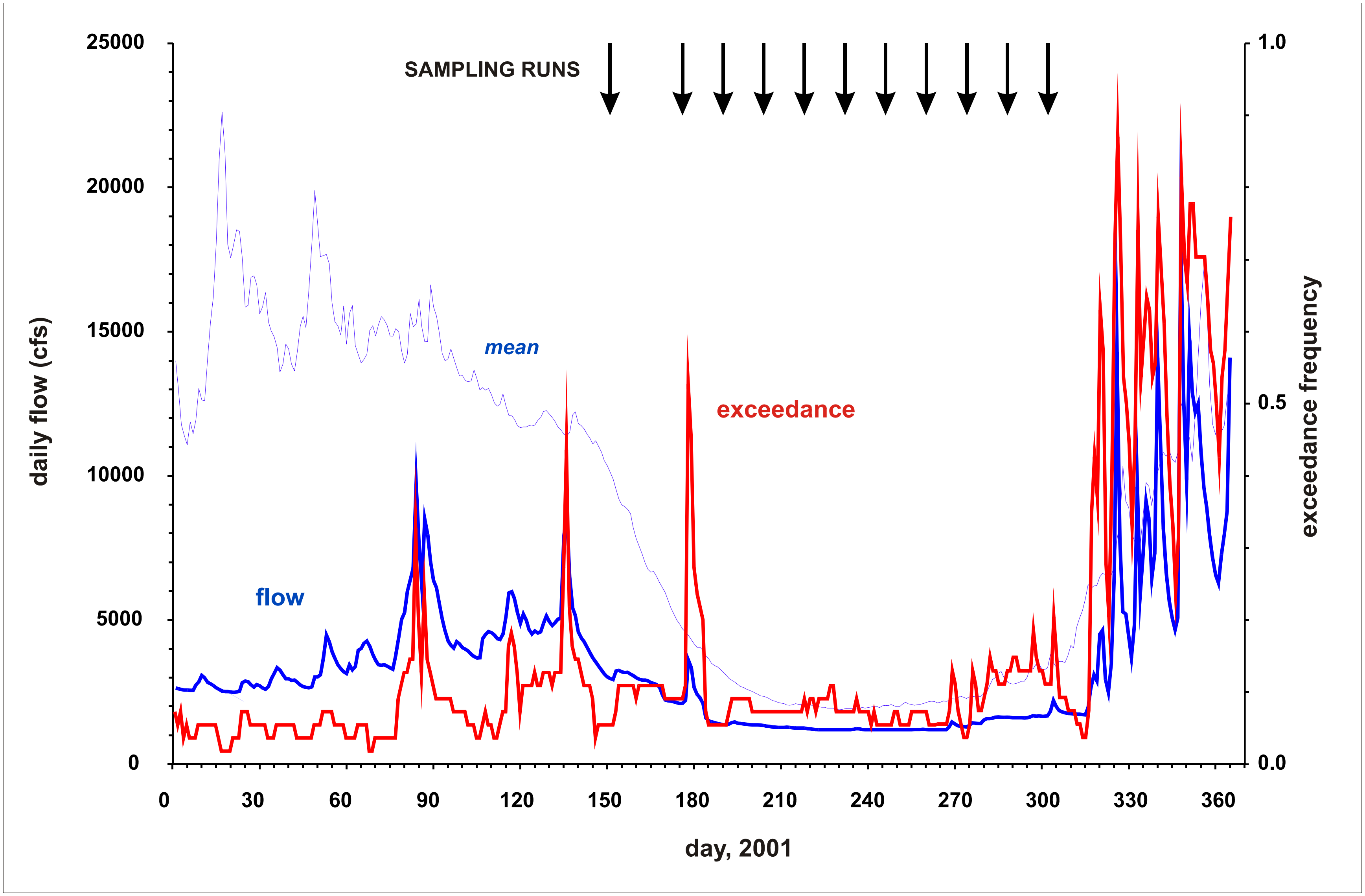

Figure 45 - Daily flow variation 2001 with 1951-2005 mean, Klamath at Orleans (USGS 11523000)

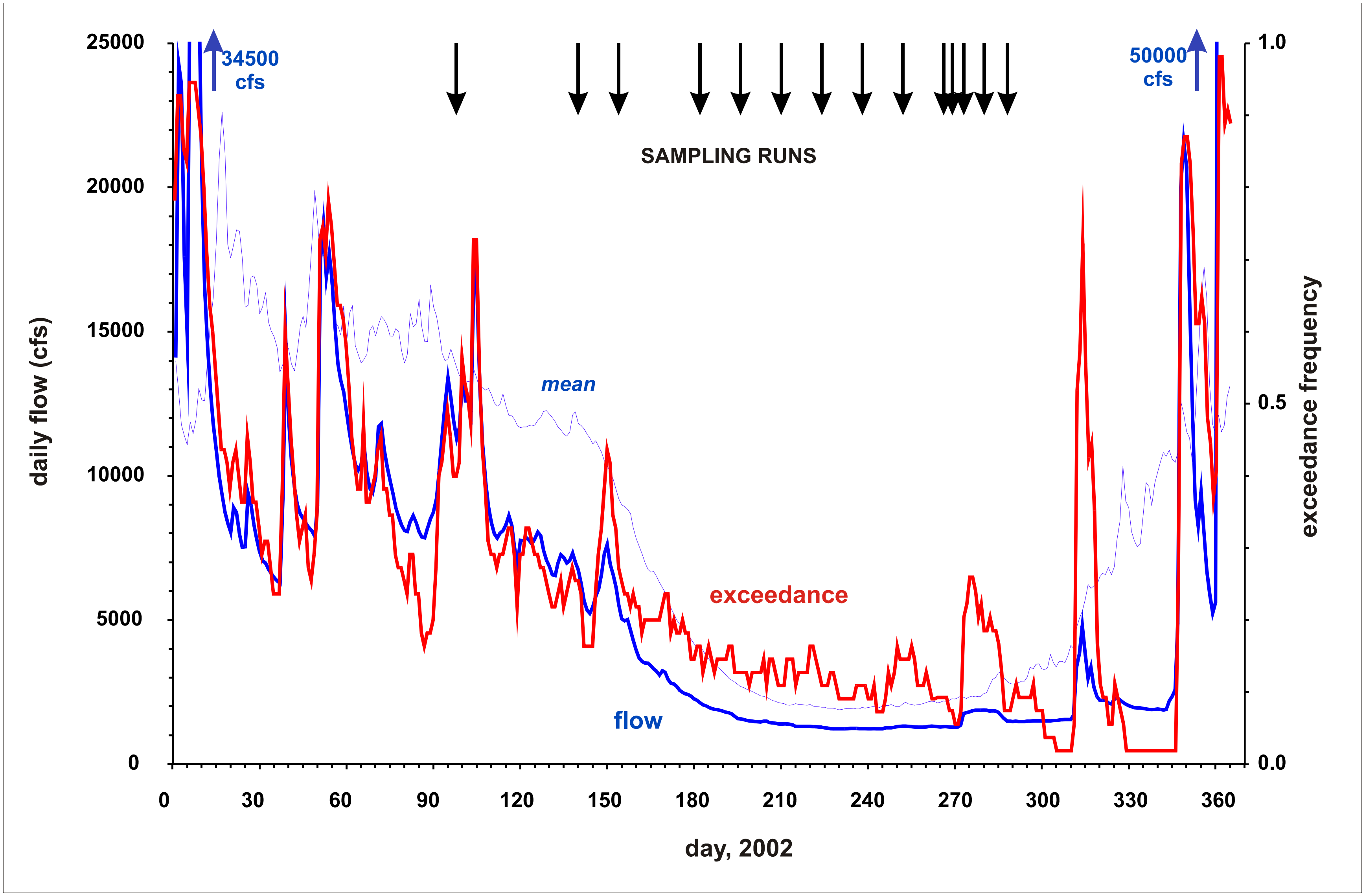

Figure 46 - Daily flow variation 2002 with 1951-2005 mean, Klamath at Orleans (USGS 11523000)

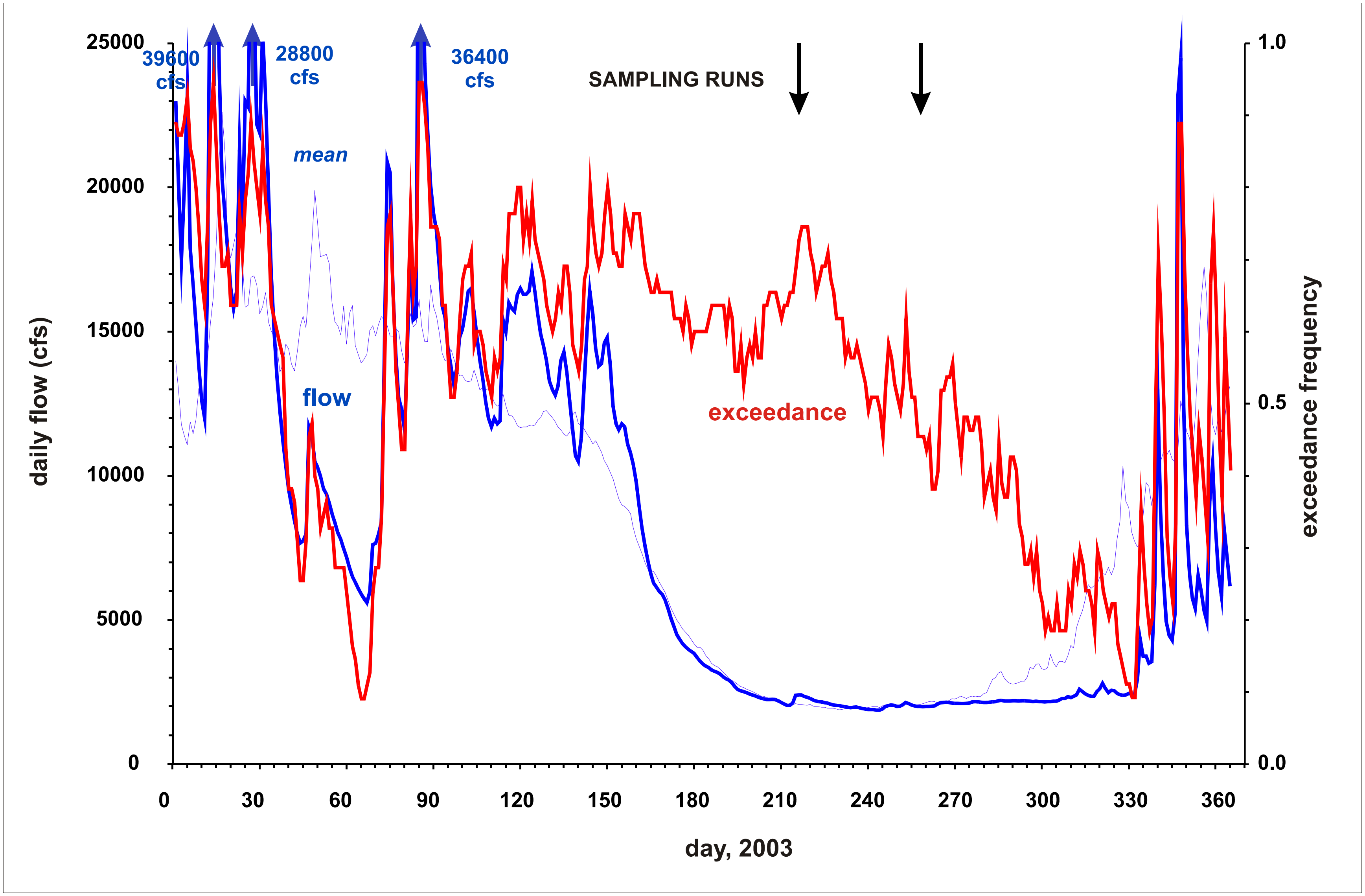

Figure 47 - Daily flow variation 2003 with 1951-2005 mean, Klamath at Orleans (USGS 11523000)

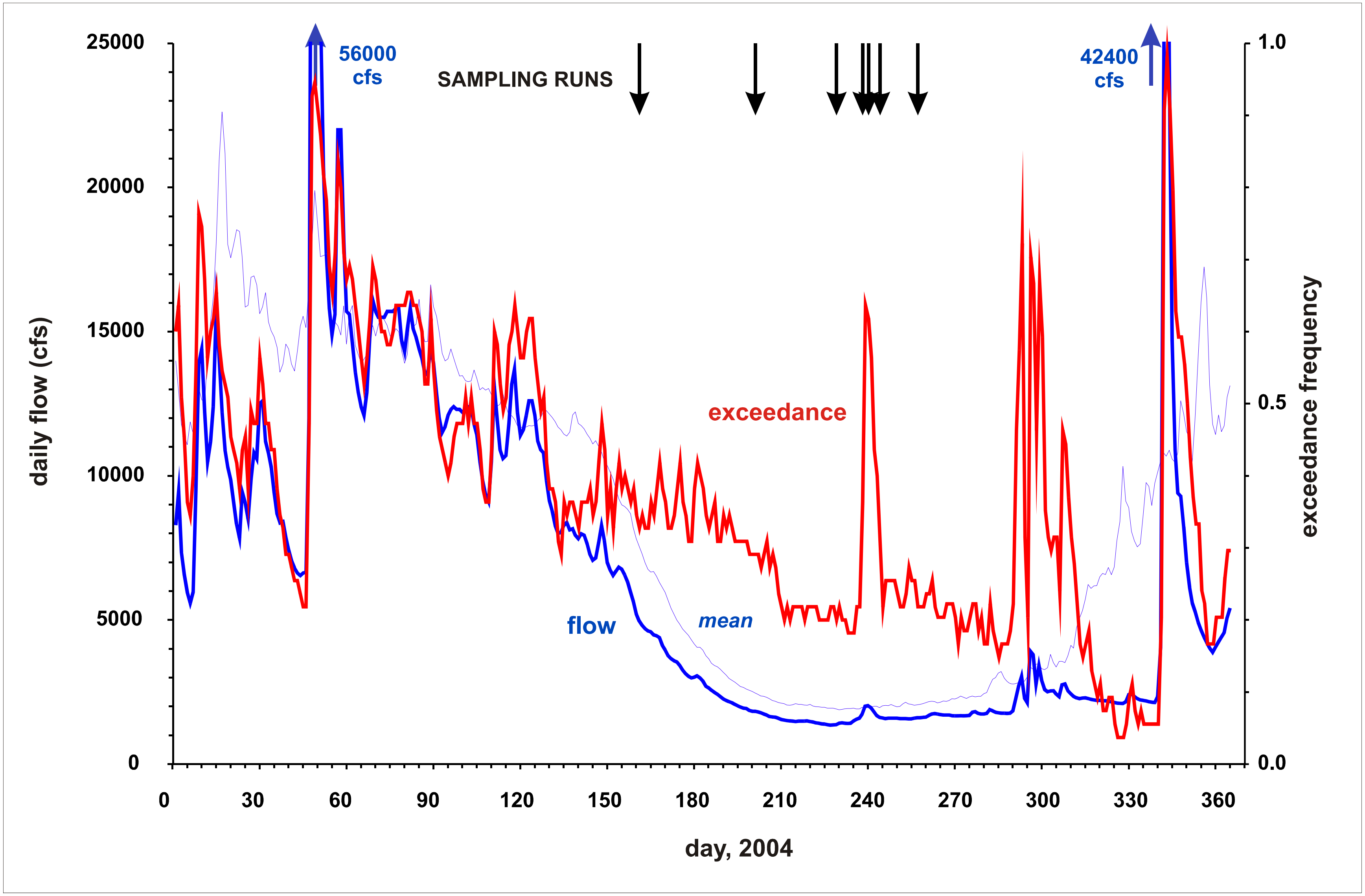

Figure 48 - Daily flow variation 2004 with 1951-2005 mean, Klamath at Orleans (USGS 11523000)

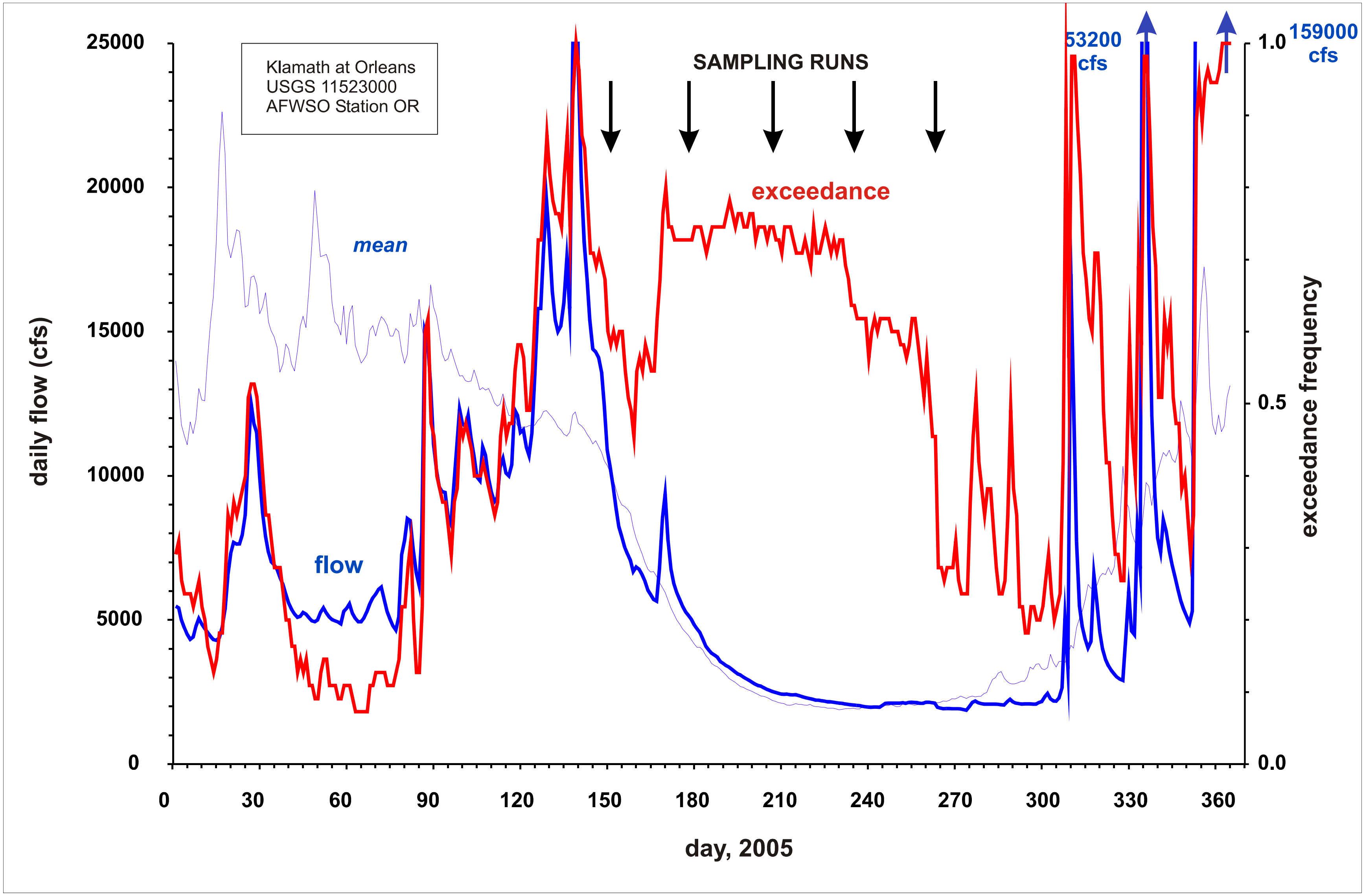

Figure 49 - Daily flow variation 2005 with 1951-2005 mean, Klamath at Orleans (USGS 11523000)

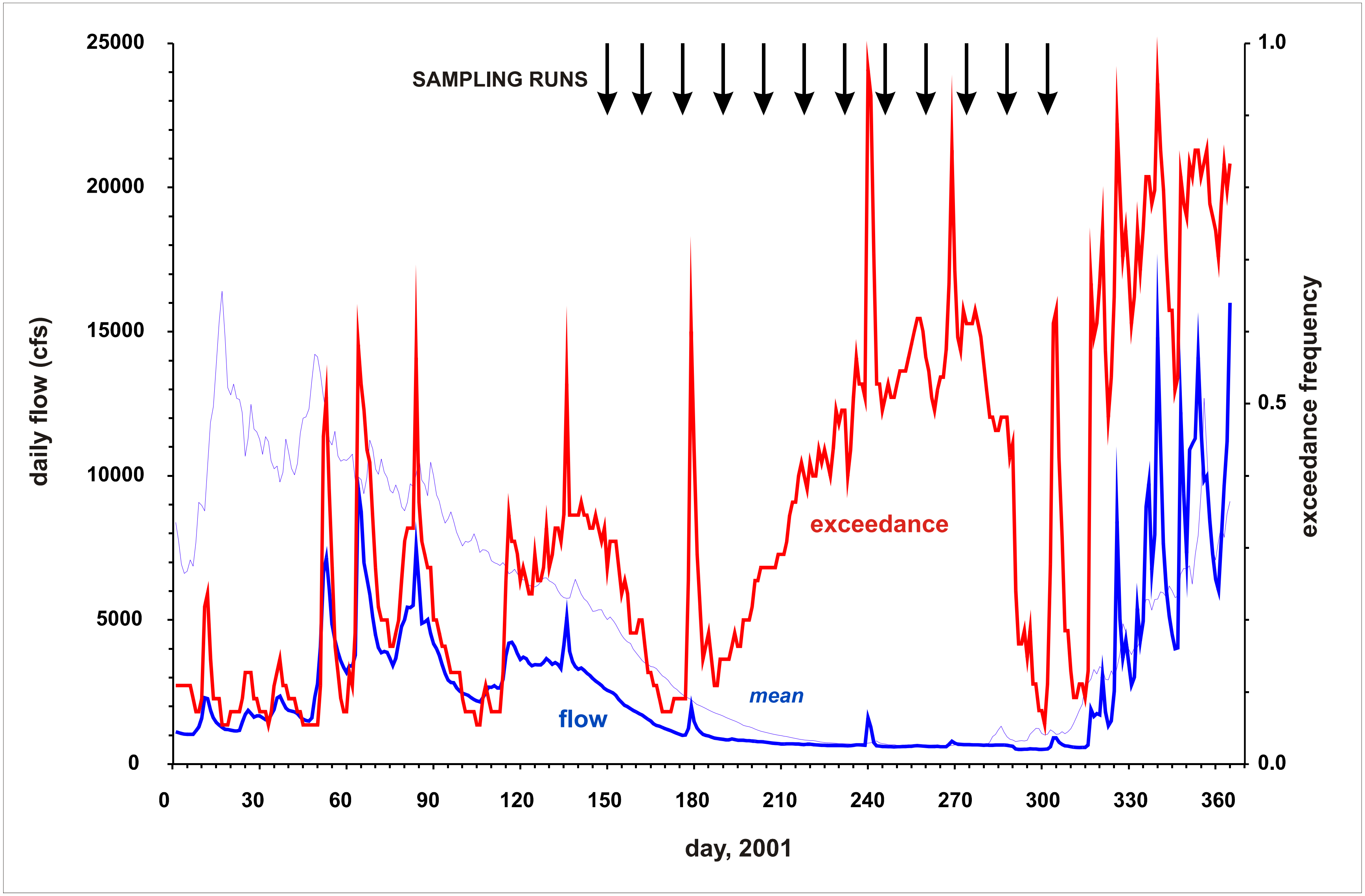

Figure 50 - Daily flow variation 2001 with 1951-2005 mean, Trinity at Hoopa (USGS 11530000)

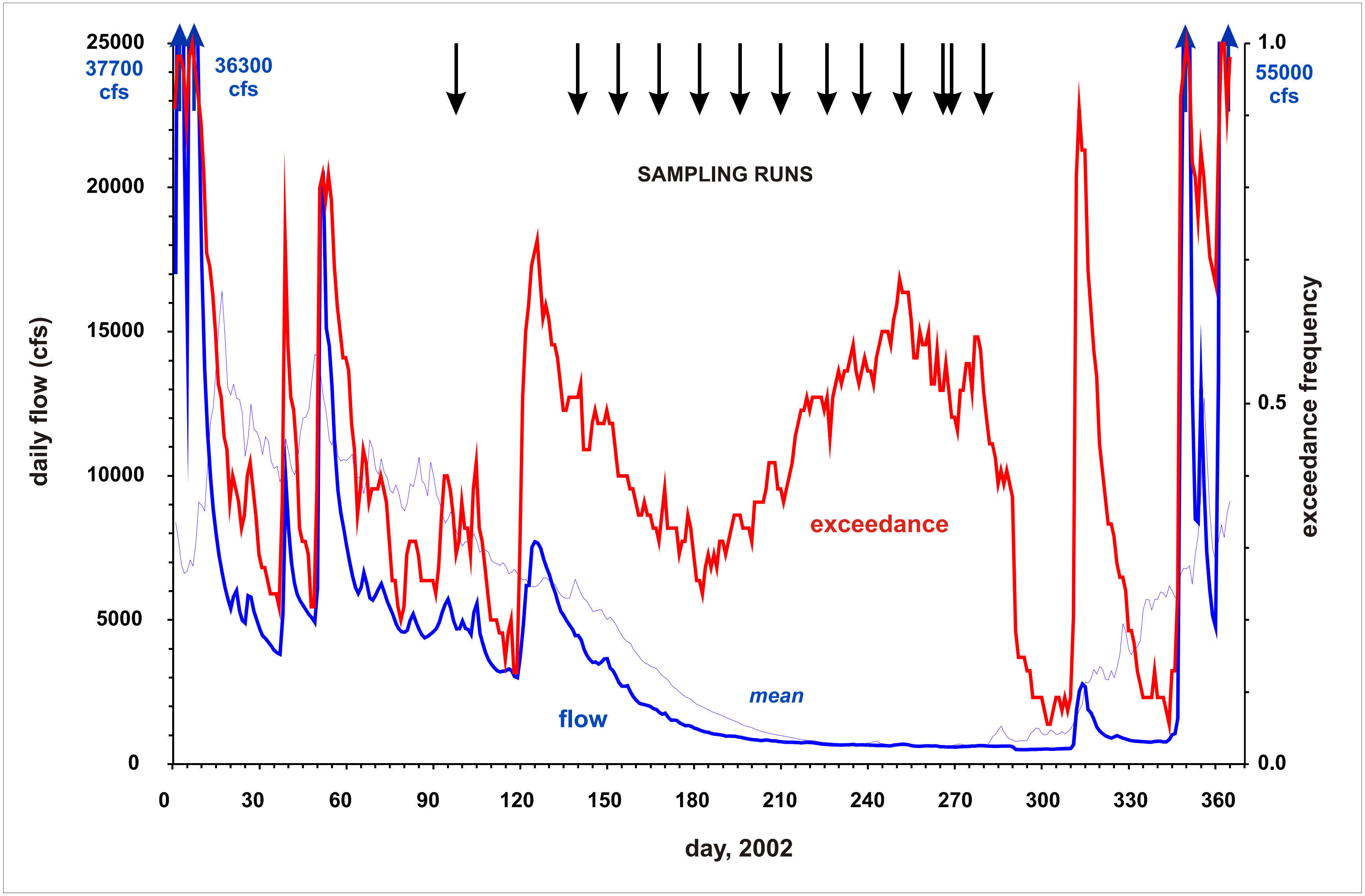

Figure 51 - Daily flow variation 2002 with 1951-2005 mean, Trinity at Hoopa (USGS 11530000)

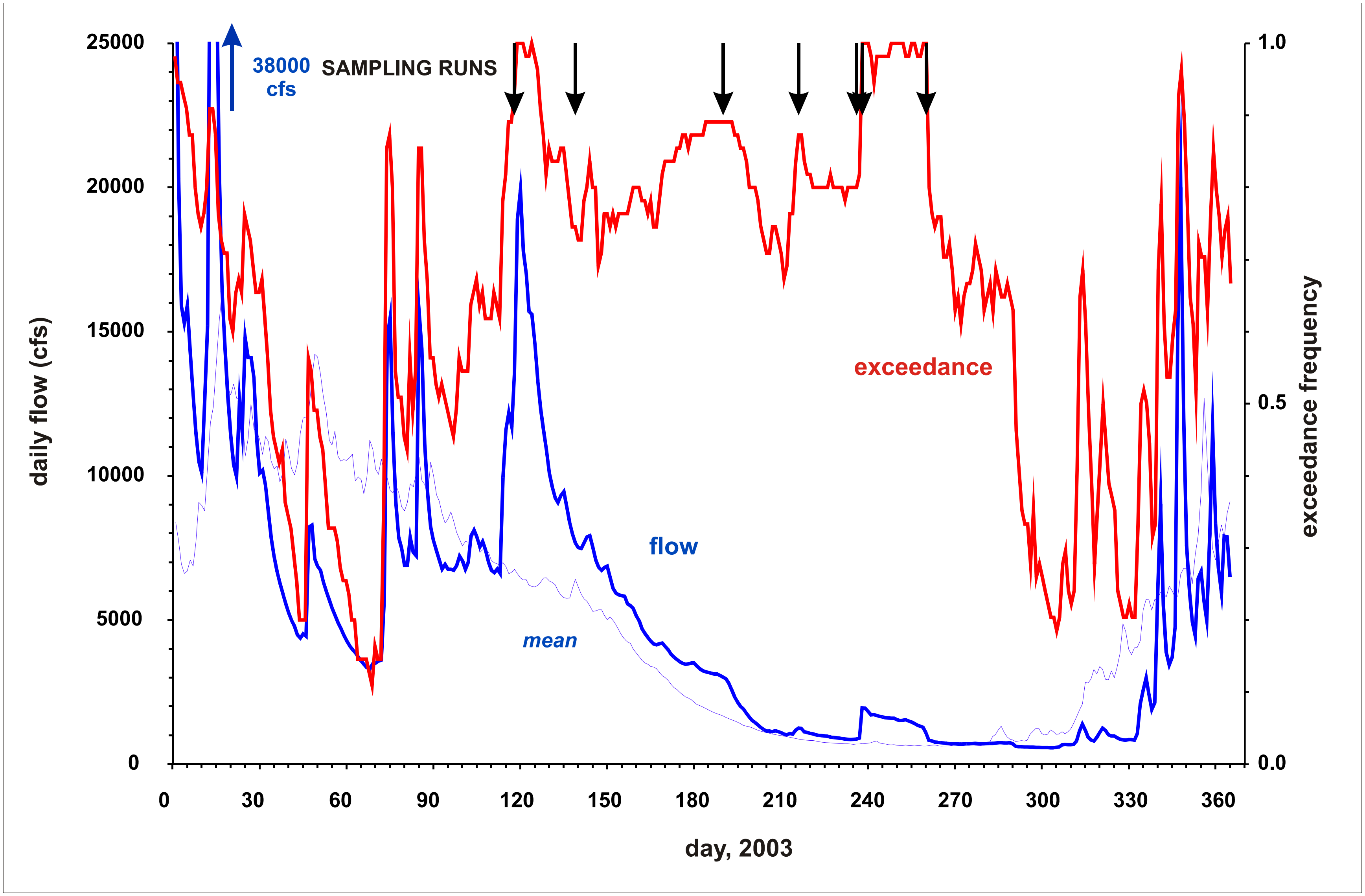

Figure 52 - Daily flow variation 2003 with 1951-2005 mean, Trinity at Hoopa (USGS 11530000)

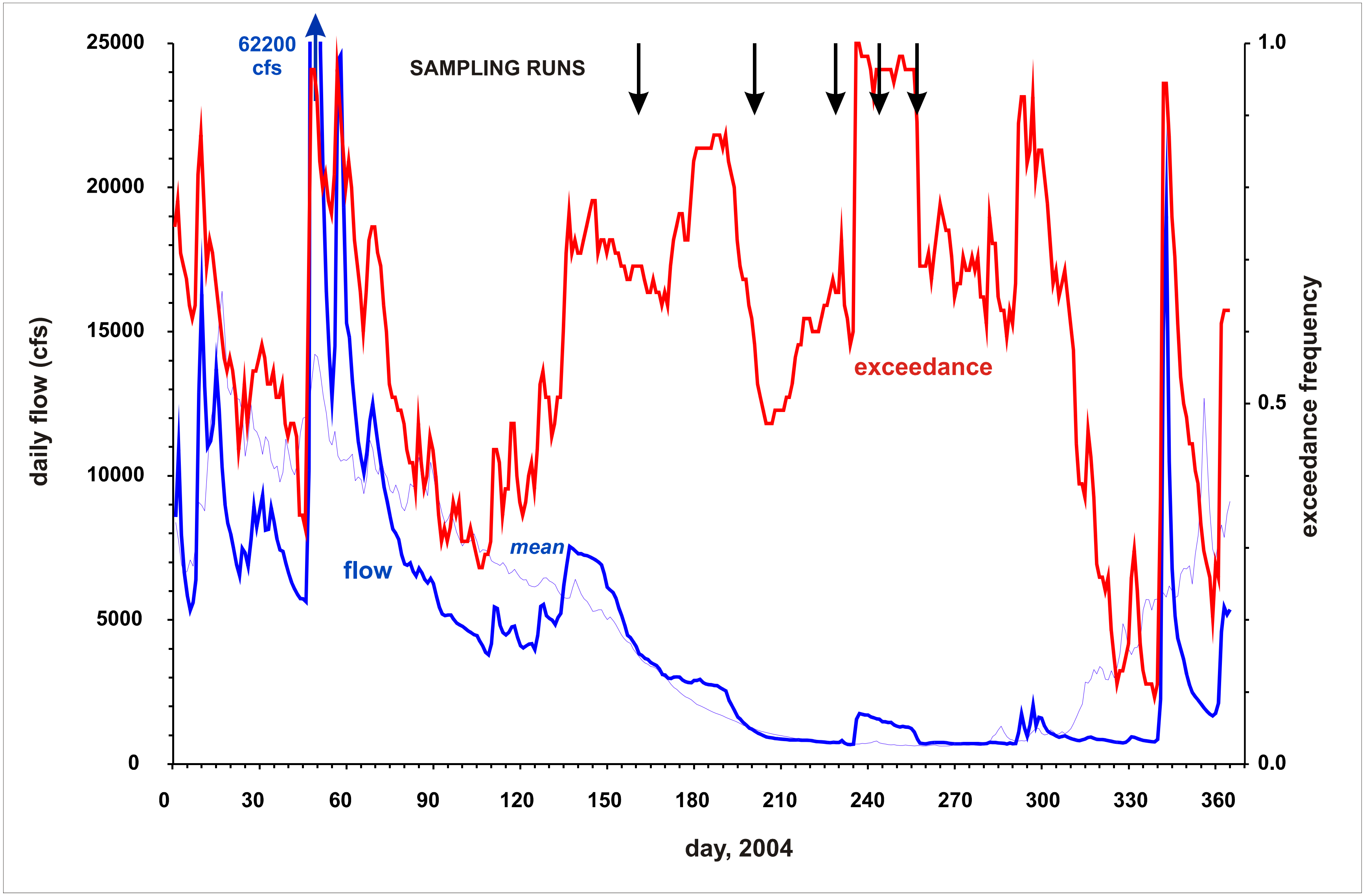

Figure 53 - Daily flow variation 2004 with 1951-2005 mean, Trinity at Hoopa (USGS 11530000)

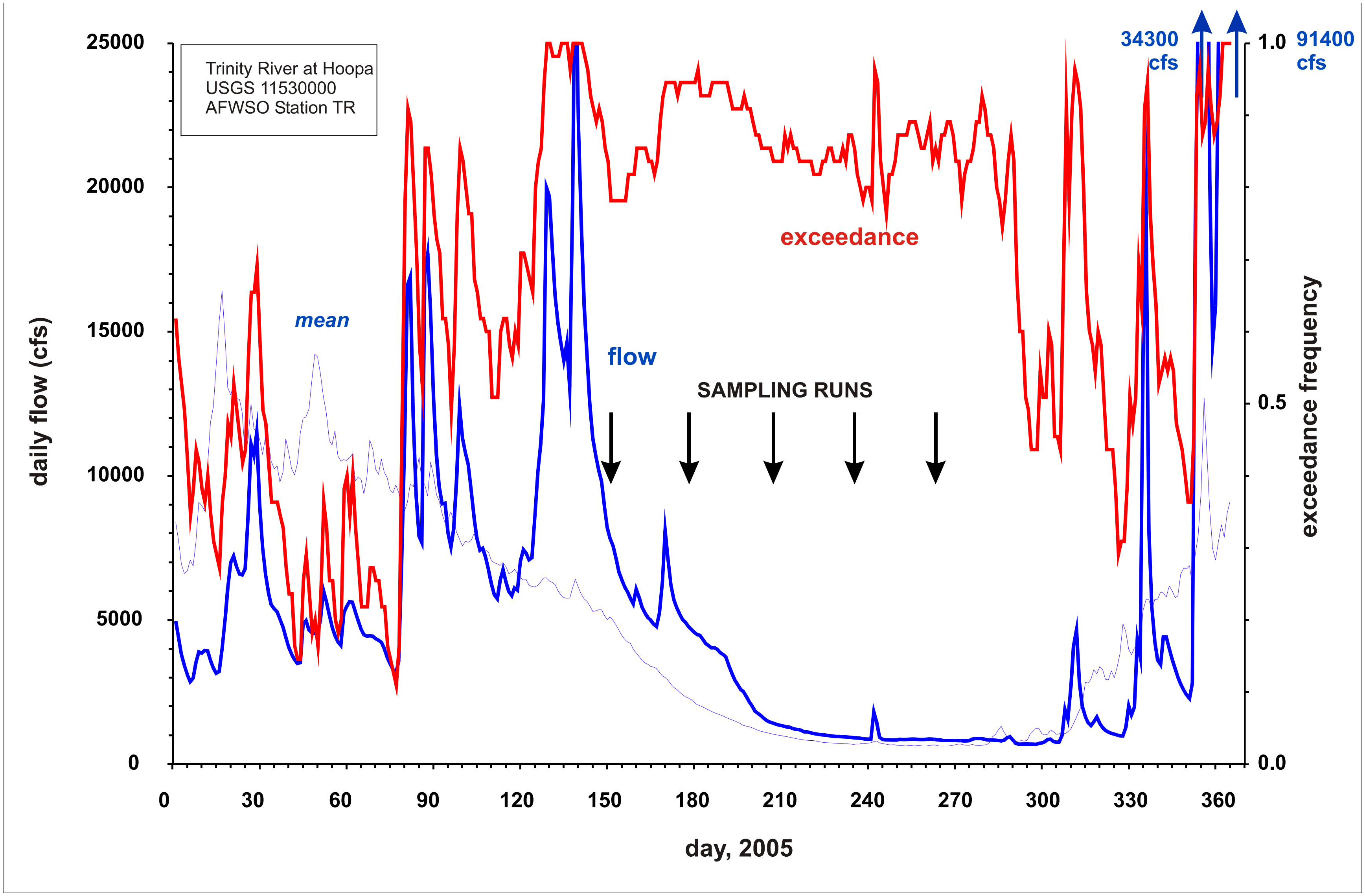

Figure 54 - Daily flow variation 2005 with 1951-2005 mean, Trinity at Hoopa (USGS 11530000)

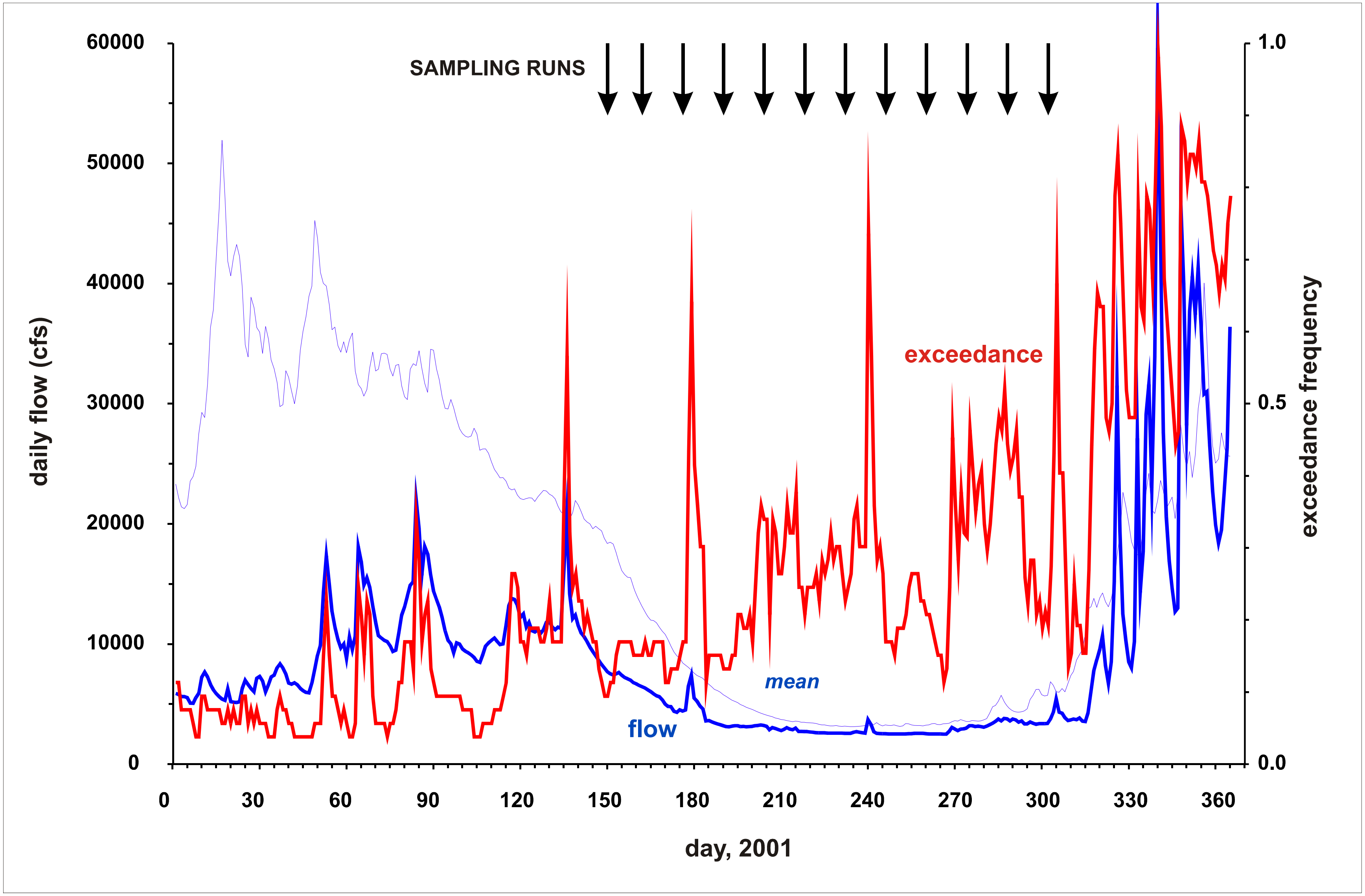

Figure 55 - Daily flow variation 2001 with 1951-2005 mean, Klamath near Klamath (USGS 11530500)

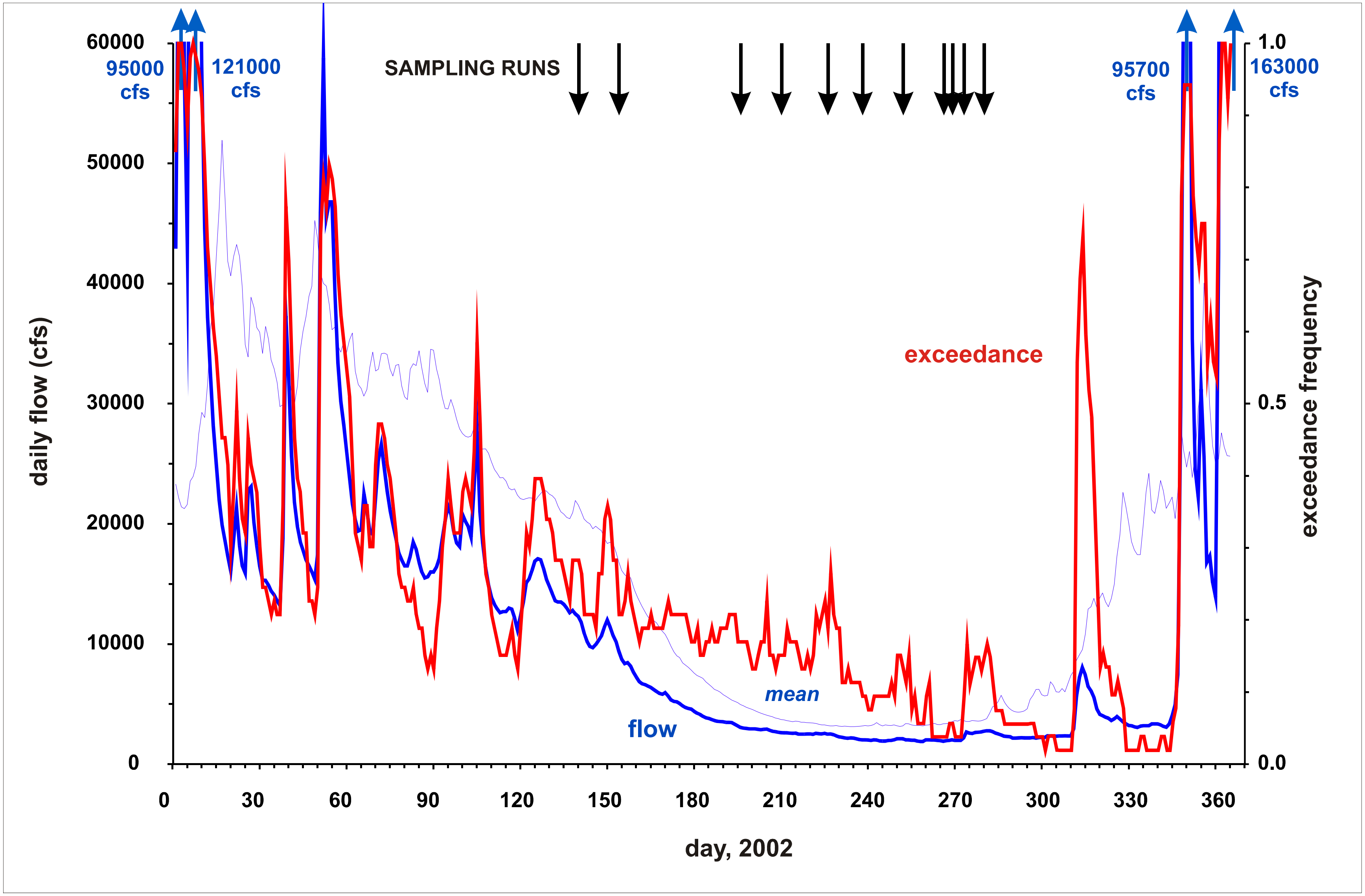

Figure 56 - Daily flow variation 2002 with 1951-2005 mean, Klamath near Klamath (USGS 11530500)

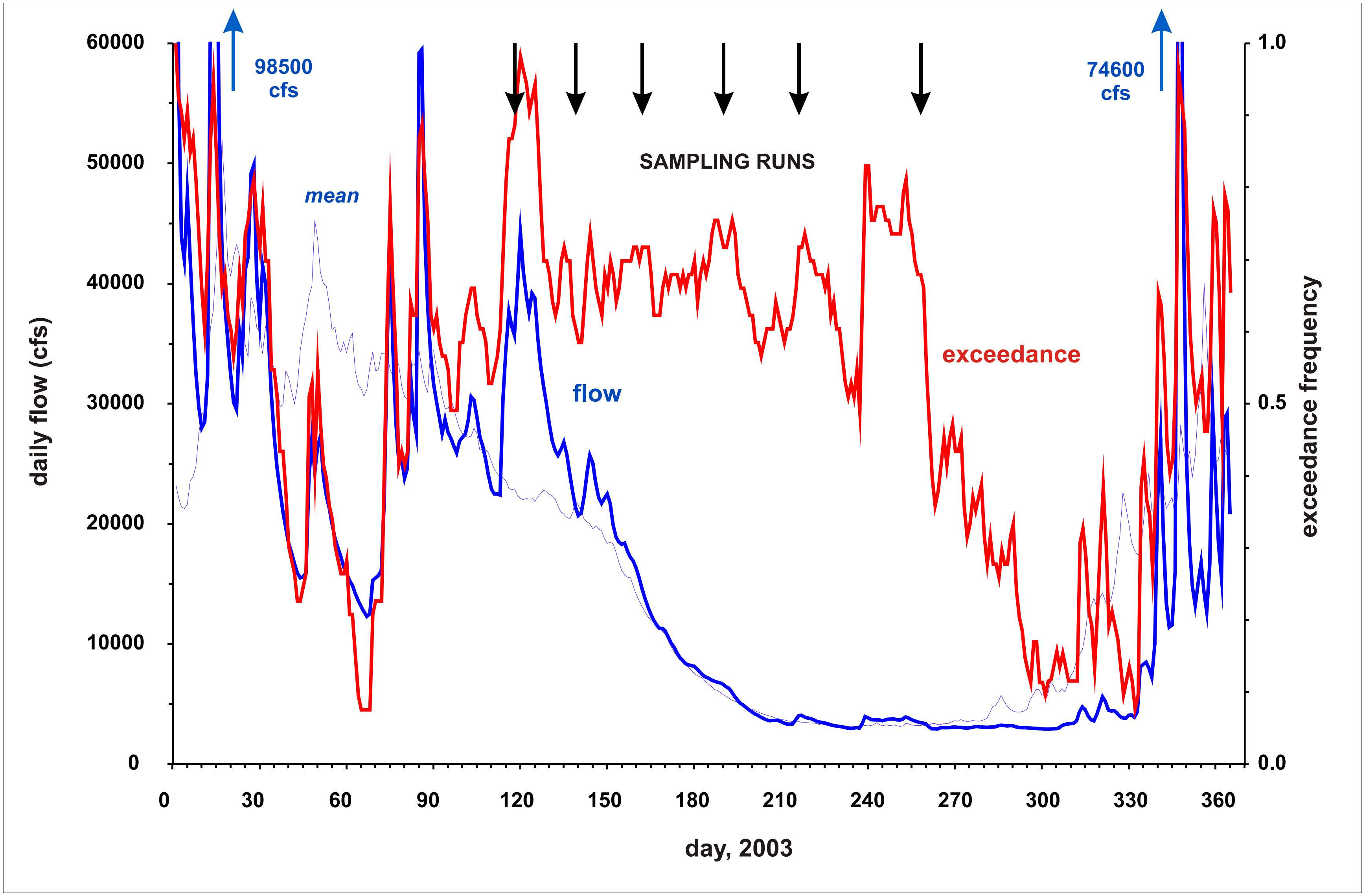

Figure 57 - Daily flow variation 2003 with 1951-2005 mean, Klamath near Klamath (USGS 11530500)

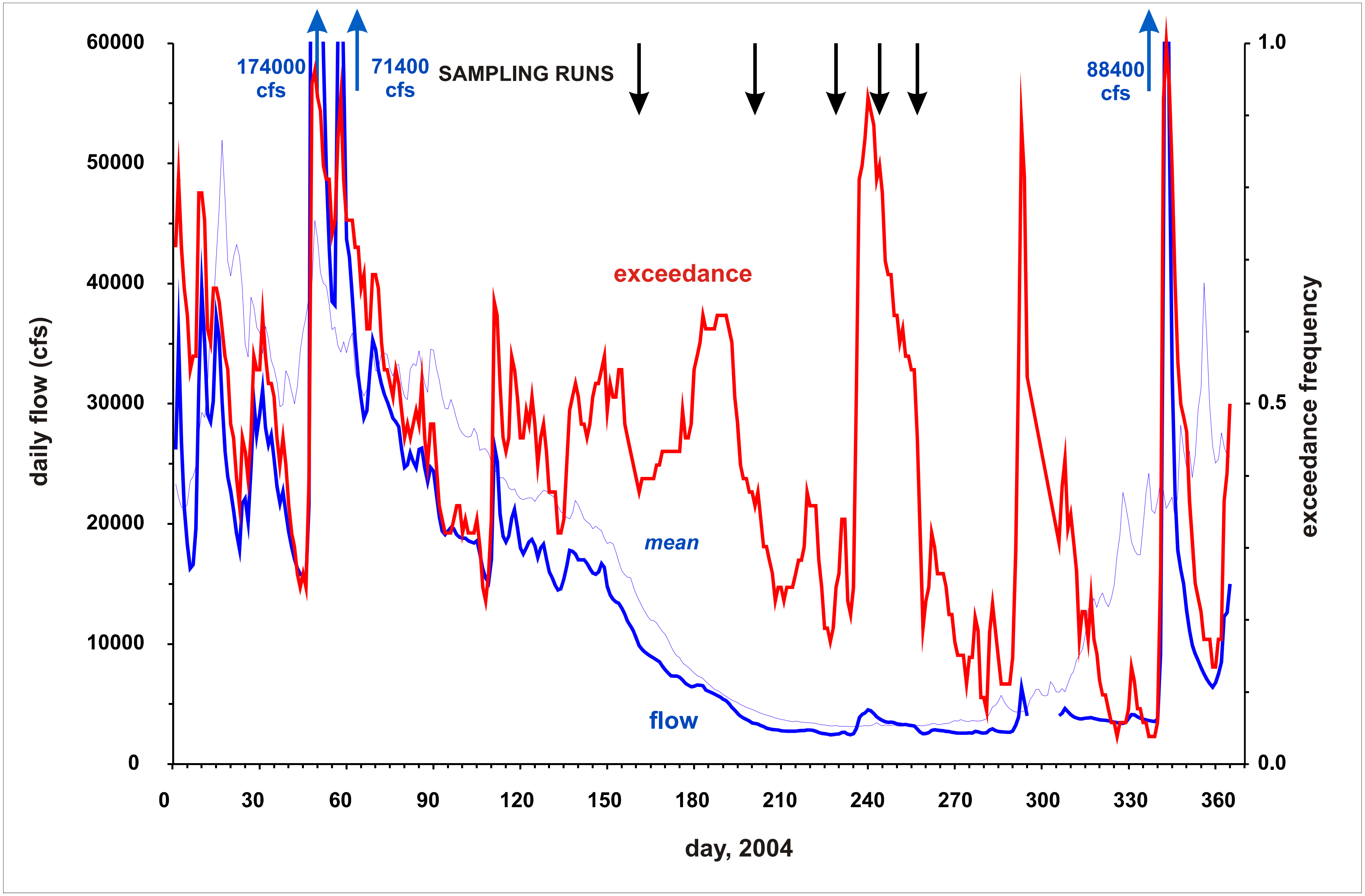

Figure 58 - Daily flow variation 2004 with 1951-2005 mean, Klamath near Klamath (USGS 11530500)

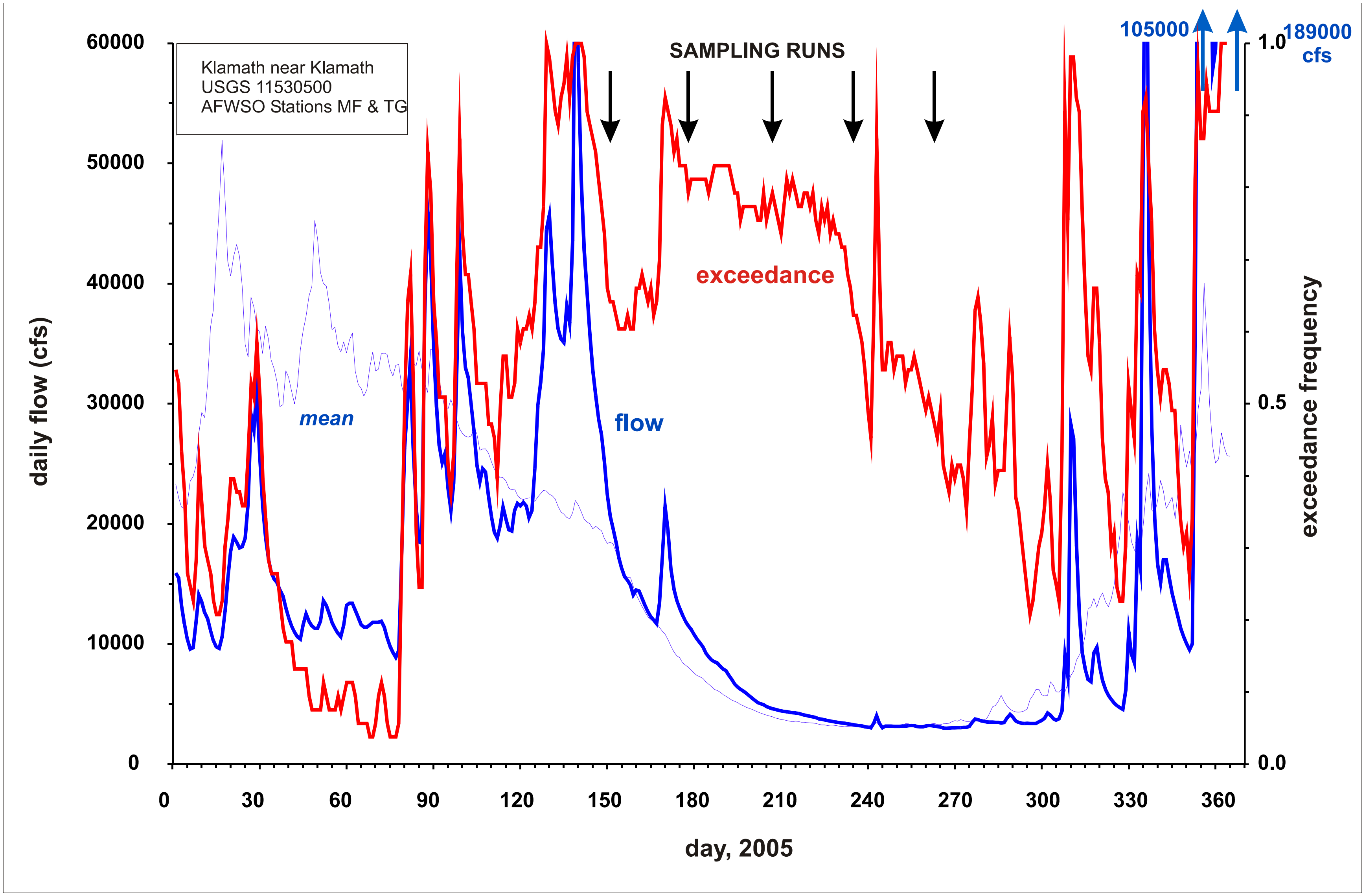

Figure 59 - Daily flow variation 2005 with 1951-2005 mean, Klamath near Klamath (USGS 11530500)

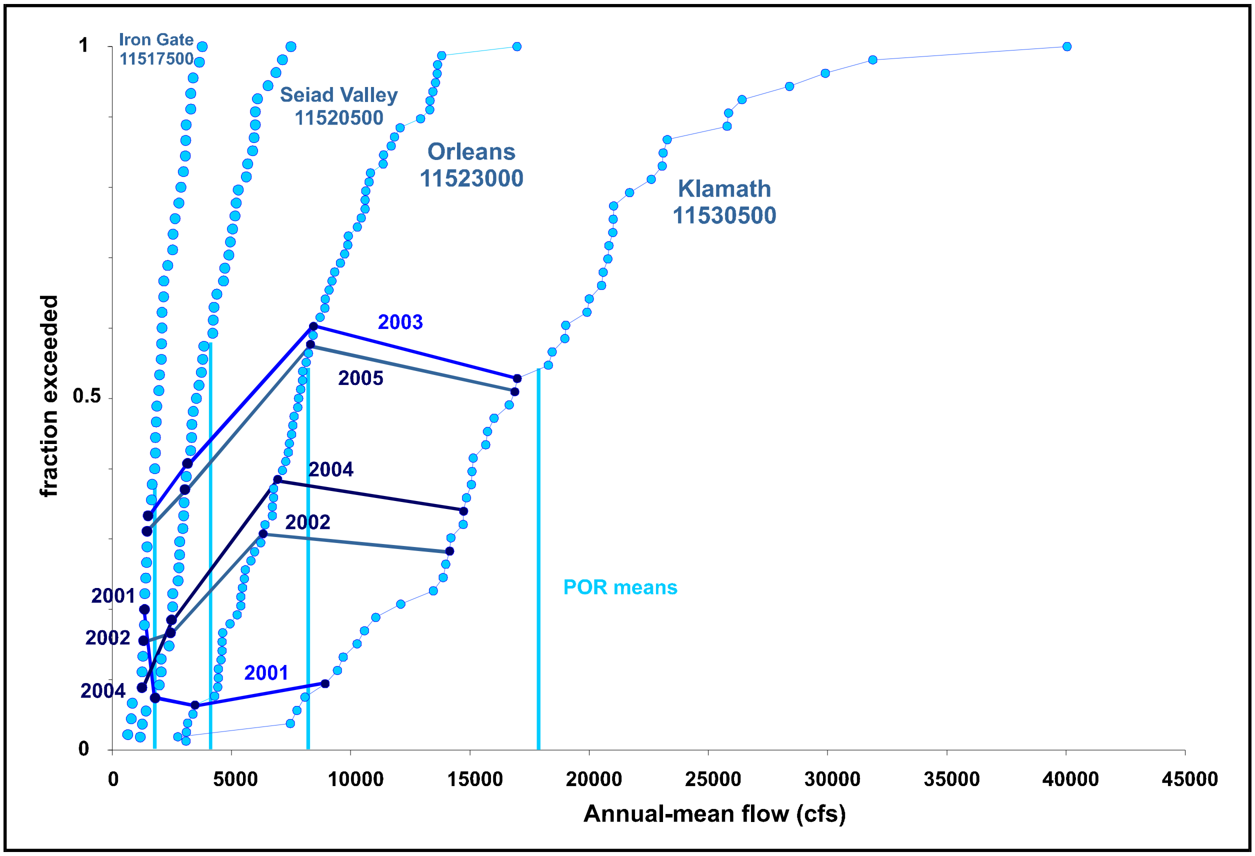

Figure 60 - Annual-mean flow ogives for Klamath main-stem stations, 2001-2005

6. Summary of 2001-2005 hydrology

As noted in Section 3 above, the 2001-2005 period of data collection has been characterized by generally below-average flows. (Indeed, one could remark that the Klamath has been in a state of relative drought for the past two decades, apart from the 1995-2000 period of above-average flow, *cf*. Fig. 14.) An alternative display of this is the cumulative frequency diagram ("ogive"). Figure 60 collects the annual-flow ogives for the mainstem stations on the Klamath, on which are marked each of the years in the data-collection period 2001-2005. For all except two gauges in two years, the annual-mean flows are less than median (which is, in turn, less than the mean), most considerably so, 2001 approximating the POR lower-decile flows for all gauges except Iron Gate. On an annual-flow basis, therefore, the sampling period was atypical, but this may be advantageous, since the lower flows probably represent conditions of higher biological stress.

Given the considerable intra-annual variation and the relatively short travel times in the Klamath, the annual-mean flows of Fig. 60 do not provide a definitive assessment of how representative was hydrology during the field sampling runs. A time scale intermediate between the daily exceedance frequencies of Figs. 20 *et seq*. and the annual ogives of Fig. 60 is needed. For this purpose, the monthly ogives are assembled for the primary water-sampling months of June - October, in Figs. 61-65. The mean flows and individual exceedance frequencies (now in percentage) are abstracted in Table 5. From these figures and the table, the following conclusions can be drawn:

(1) The lowest-flow periods are evidenced by 2002, with most of the summer monthly flows less than the decile, while 2001 was nearly as low, with some of the flows only between the decile and quartile

(2) 2004 would be characterized as low as 2001 and 2002, except for the enhanced runoff from the lower watershed.

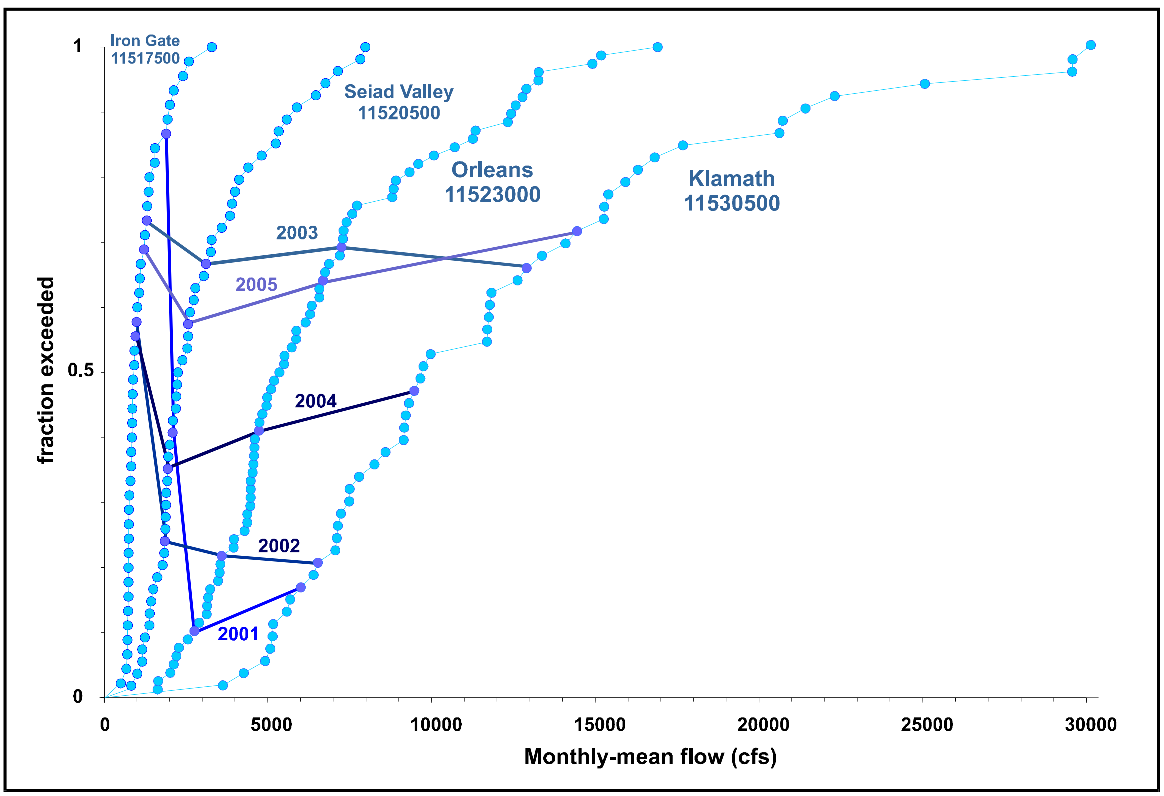

Figure 61 - June monthly-mean flow ogives for Klamath main-stem stations, 2001-2005

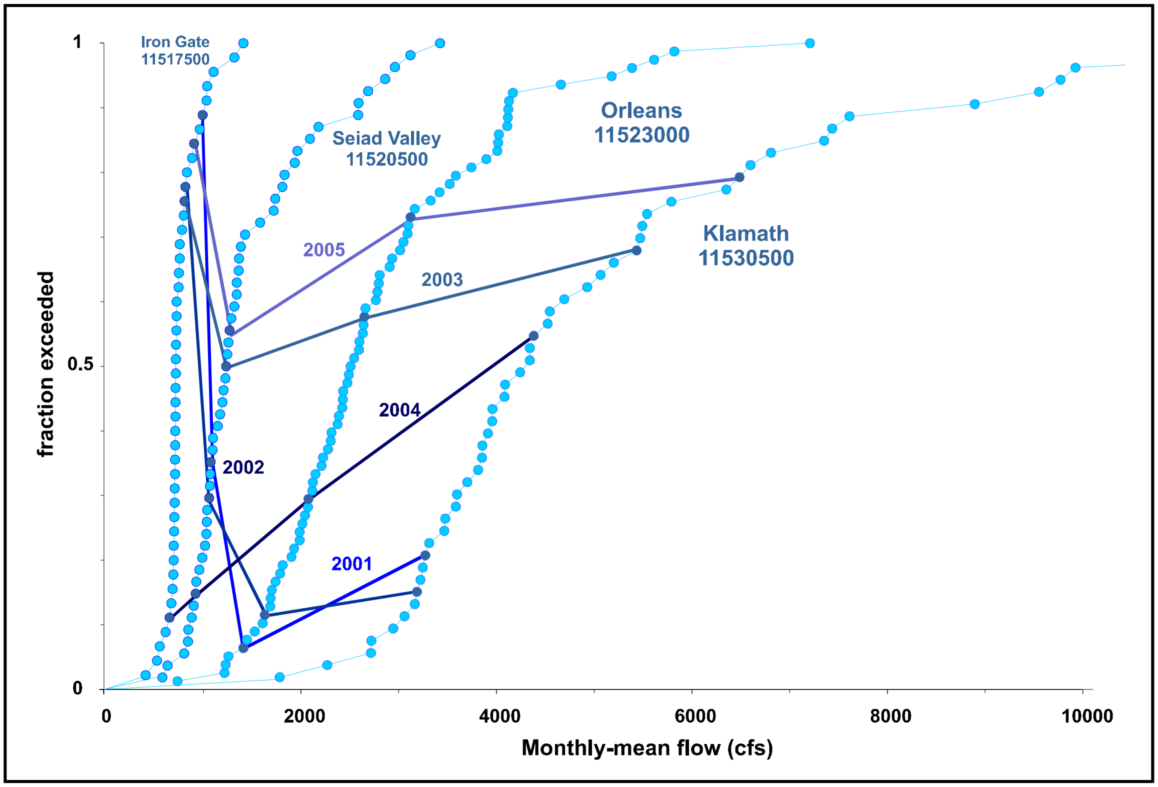

Figure 62 - July monthly-mean flow ogives for Klamath main-stem stations, 2001-2005

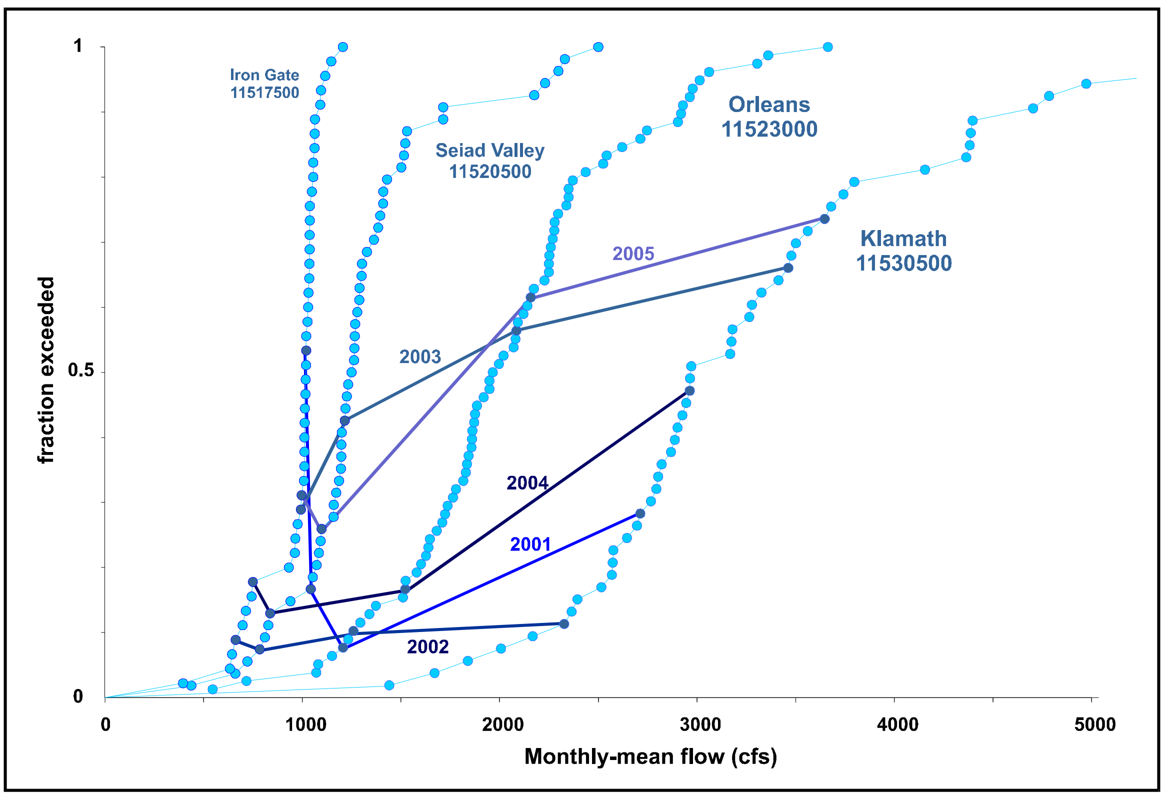

Figure 63 - August monthly-mean flow ogives for Klamath main-stem stations, 2001-2005

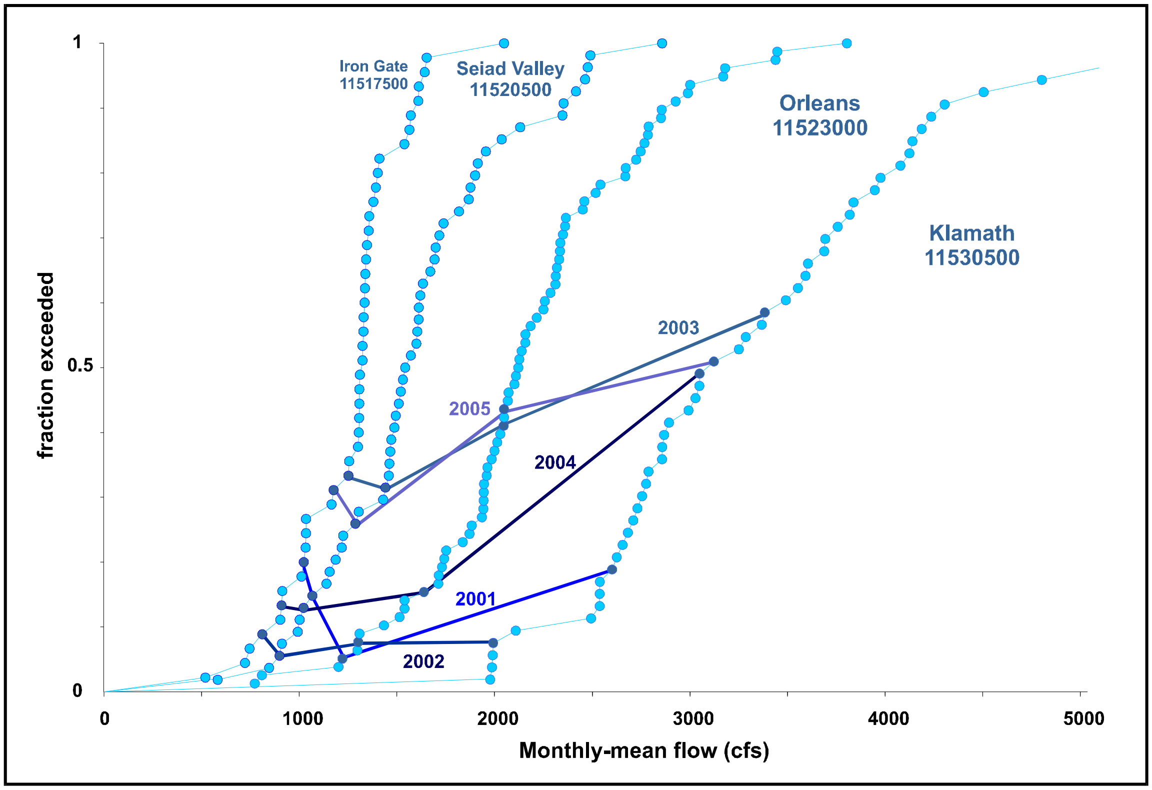

Figure 64 - September monthly-mean flow ogives for Klamath main-stem stations, 2001-2005

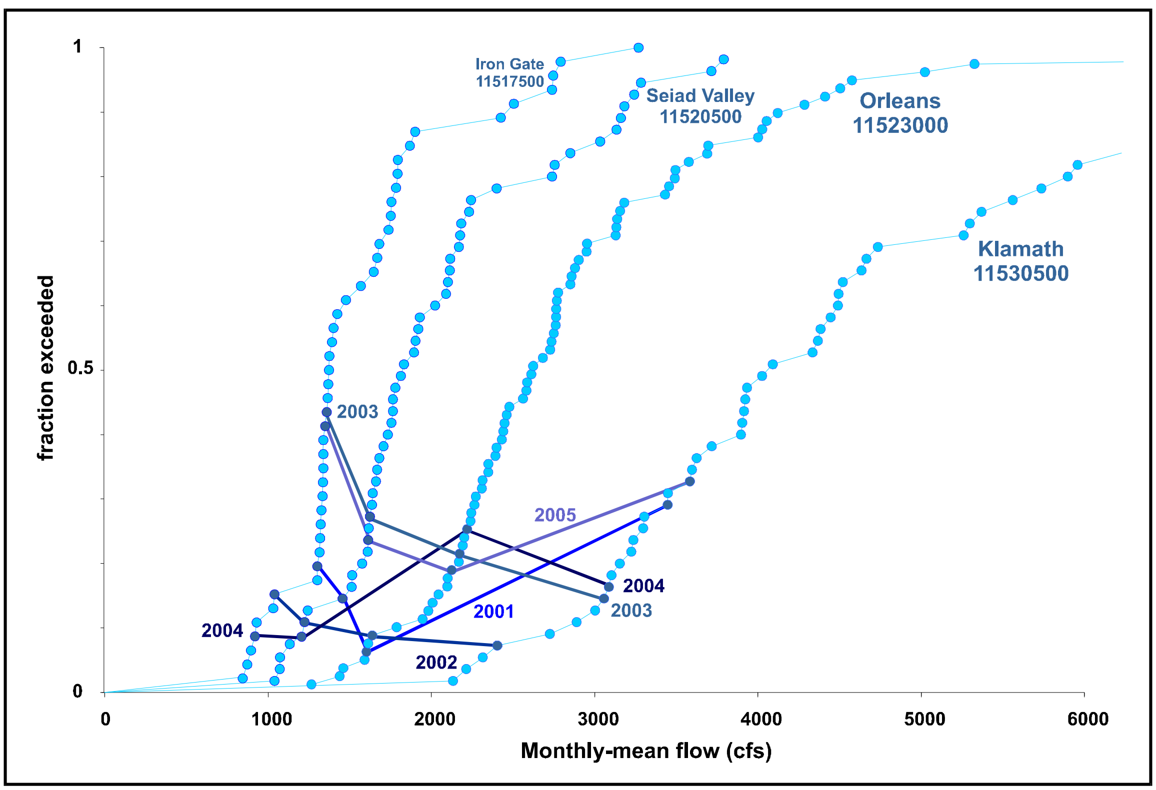

Figure 65 - October monthly-mean flow ogives for Klamath main-stem stations, 2001-2005

Table 4
Monthly-mean flows for sampling periods, June - October, 2001-2005,
Mainstem gauges on the Klamath

	Iron Gate 11516530		Seiad Valley 11520500		Orleans 11523000		Klamath 11530500	
	flow (cfs)	*exceeding (%)*	*flow (cfs)*	*exceeding (%)*	*flow (cfs)*	*exceeding (%)*	*flow (cfs)*	*exceeding (%)*
2001								
June	1897	87	2094	41	2756	10	6006	17
July	1012	89	1095	35	1429	6	3271	21
August	1023	56	1046	17	1209	8	2713	28
September	1026	20	1070	15	1224	5	2601	19
October	1308	20	1463	15	1603	6	3447	29
2002								
June	993	58	1853	24	3593	22	6528	21
July	837	78	1080	30	1647	12	3187	15
August	666	9	787	7	1263	10	2327	11
September	813	9	902	6	1305	8	1993	8
October	1047	15	1229	11	1638	9	2405	7
2003								
June	1304	73	3261	69	7248	69	12902	66
July	827	76	1253	50	2666	58	5201	66
August	996	29	1218	43	2088	56	3463	66
September	1254	33	1444	31	2049	41	3383	58
October	1366	43	1630	27	2172	22	3057	15
2004								
June	953	56	1946	35	4727	41	9473	47
July	674	11	941	15	2095	29	4382	55
August	752	18	840	13	1525	17	2964	47
September	913	13	1025	13	1641	15	3049	49
October	926	9	1217	9	2219	25	3087	16
2005								
June	1222	69	2569	57	6684	64	14443	72
July	925	84	1288	56	3140	73	6487	79
August	999	31	1100	26	2161	62	3647	74
September	1179	31	1290	26	2051	44	3123	51
October	1357	41	1620	24	2124	19	3584	33

(3) 2003 is the closest approximation to a "normal" year, with most of the monthly flows vacillating about median. The flows in 2005, like 2004, were skewed toward higher runoff contributions in the lower watershed.

(4) The above generalizations do not apply so much to the Iron Gate gauge, because of the artificial distortion due to controlled releases through the dam.

(5) In all five data-collection years, the onset of the fall freshet was retarded into November. (With the qualification that in 2005, the freshet is manifested in the last couple of days of October, see Figs. 24, 29, 34, 39, 44, 49, 54, 59, and HYDRAWL.)

(6) One consequence of (5) is that *every* October during the 2001-05 period was below median, most substantially so, see Fig. 65.

In addition to the historical comparisons of Table 4, it is also of interest to analyze the separate sources making up the Klamath flow in the principal reaches of the mainstem, for which purpose a water budget is useful. For each reach between the principal gauges on the Klamath, the downstream-upstream difference in flows is the contribution to the mainstem flow from that intervening drainage area. This contribution can be subdivided into gauged (the sum of the gauged flows on the tributaries) and ungauged (the sum of flow from the ungauged tributaries, the peripheral drainage adjacent to the main stem, and that which drains into the main stem from the reach downstream from each tributary gauge to the mouth). For each of the sampling years 2001-2005, a water budget is given in Table 5. The corresponding runoffs, i.e. watershed yields (the ratio of flow to drainage area), are presented graphically in Figure 66. In this figure, for each principal reach, the large numbers (e.g., 20.7 in the Orleans-to-Klamath reach in 2001) are the total runoff from the intervening drainage area, which is further subdivided into the ungauged contribution (50.0 in the Orleans reach 2001) and the gauged tributary contribution (12.3 in the Orleans reach 2001). A similar diagram is given in Figure 67, except applying to the June-October period instead of the entire year.

Table 5 - Water budgets for Klamath main stem, 2001 - 2005

gauge	*number*	*Mean flows (cfs)*												
		J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*year*
							Calendar year 2001							
Klamath Iron Gate	11516530	1292	1297	1289	1598	1726	1897	1012	1023	1026	1308	1312	1320	1341
Tributaries:														
Shasta near Yreka	11517500	178	175	171	102	44	26	24	19	47	129	186	235	111
Scott near Ft Jones	11519500	99	127	386	276	401	50	8	6	4	4	60	384	151
Total		277	301	557	378	445	75	32	25	51	133	246	619	262
Nongauged		172	181	273	324	282	121	51	-2	-7	22	175	617	184
Total intervening		450	482	830	701	726	196	82	23	44	155	422	1236	446
Klamath Seiad Valley	11520500	1741	1779	2119	2299	2452	2094	1095	1046	1070	1463	1734	2555	1787
Tributaries:														
Salmon at Somes Bar	11522500	362	434	1071	1074	1282	408	186	92	80	102	737	2143	667
Nongauged		576	937	1731	1215	967	254	148	71	74	37	1387	4577	1001
Total intervening		938	1371	2803	2290	2250	662	334	163	154	139	2124	6720	1669
Klamath at Orleans	11523000	2679	3150	4921	4589	4702	2756	1429	1209	1224	1603	3858	9275	3456
Tributaries:														
Trinity at Hoopa	11530000	1418	2837	5004	2968	3367	1569	831	717	633	611	2179	8909	2593
Nongauged		1959	2752	3582	3128	3129	1681	1011	787	744	1234	3001	11042	2846
Total intervening		3378	5589	8586	6096	6496	3250	1842	1504	1377	1845	5180	19950	5439
Klamath at Klamath	11530500	6057	8739	13507	10685	11198	6006	3271	2713	2601	3447	9038	29226	8895

(continued)

Table 5 - Water budgets for Klamath main stem, 2001 - 2005, continued

gauge	*number*	*Mean flows (cfs)*												
		J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*year*
							Calendar year 2002							
Klamath Iron Gate	11516530	1794	1855	2360	1748	1520	993	837	666	813	1047	887	1064	1296
Tributaries:														
Shasta near Yreka	11517500	237	215	170	98	106	44	24	24	32	132	157	358	133
Scott near Ft Jones	11519500	1077	644	570	1018	707	395	64	15	12	17	81	1165	480
Total		1313	859	740	1116	813	439	88	39	43	149	238	1524	613
Nongauged		1176	814	731	1084	801	421	155	83	46	34	132	804	522
Total intervening		2489	1673	1471	2200	1614	860	243	122	89	183	370	2328	1135
Klamath Seiad Valley	11520500	4283	3528	3831	3948	3134	1853	1080	787	902	1229	1257	3392	2431
Tributaries:														
Salmon at Somes Bar	11522500	3453	2509	1966	3010	2027	1127	359	171	125	122	408	3085	1526
Nongauged		6426	4893	3760	3696	1743	613	207	304	278	286	662	5241	2333
Total intervening		9879	7402	5726	6706	3770	1740	567	475	403	409	1070	8326	3859
Klamath at Orleans	11523000	14162	10930	9557	10654	6904	3593	1647	1263	1305	1638	2328	11718	6290
Tributaries:														
Trinity at Hoopa	11530000	13090	8006	5476	4261	5166	1972	924	696	631	573	1133	12003	4493
Nongauged		12142	7303	4699	2132	1061	963	617	368	57	193	596	9396	3287
Total intervening		25232	15309	10175	6393	6227	2935	1541	1065	688	766	1729	21399	7780
Klamath at Klamath	11530500	39394	26239	19732	17047	13131	6528	3187	2327	1993	2405	4057	33117	14070

(continued)

Table 5 - Water budgets for Klamath main stem, 2001 - 2005, continued

gauge	*number*	*Mean flows (cfs)*												
		J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*year*
Calendar year 2003														
Klamath Iron Gate	11516530	1457	1042	1592	2746	2356	1304	827	996	1254	1366	1364	1523	1487
Tributaries:														
Shasta near Yreka	11517500	367	289	306	245	195	89	62	68	82	150	178	193	185
Scott near Ft Jones	11519500	2051	1106	1200	1199	1502	1047	181	88	49	67	111	379	747
Total		2418	1396	1506	1444	1696	1136	243	156	131	218	289	572	932
Nongauged		2195	1132	1183	1234	1306	821	183	66	59	46	88	360	721
Total intervening		4613	2527	2688	2677	3002	1957	426	222	190	263	377	932	1653
Klamath Seiad Valley	11520500	6070	3569	4280	5423	5358	3261	1253	1218	1444	1630	1740	2455	3140
Tributaries:														
Salmon at Somes Bar	11522500	5294	2553	3471	3594	3954	2247	609	300	195	164	295	1658	2028
Nongauged		9656	4689	5982	5696	4817	1739	805	570	410	379	476	3578	3234
Total intervening		14950	7242	9453	9290	8771	3986	1413	870	605	543	771	5236	5262
Klamath at Orleans	11523000	21019	10811	13733	14713	14129	7248	2666	2088	2049	2172	2511	7691	8402
Tributaries:														
Trinity at Hoopa	11530000	15892	6094	7179	8717	9849	4477	2070	1151	1159	660	940	6609	5411
Nongauged		7621	5403	5126	5723	3519	1177	464	224	174	225	708	6908	3100
Total intervening		23513	11496	12305	14440	13368	5654	2534	1375	1334	885	1648	13516	8511
Klamath at Klamath	11530500	44532	22307	26039	29153	27497	12902	5201	3463	3383	3057	4159	21208	16913

(continued)

Table 5 - Water budgets for Klamath main stem, 2001 - 2005, continued

gauge	*number*	*Mean flows (cfs)*												
		J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*year*
							Calendar year 2004							
Klamath Iron Gate	11516530	1375	1914	2164	1831	1306	953	674	752	913	926	932	1163	1239
Tributaries:														
Shasta near Yreka	11517500	226	334	300	135	109	63	39	42	68	167	187	263	161
Scott near Ft Jones	11519500	546	1083	1178	1056	982	430	78	14	14	46	91	548	503
Total		772	1416	1478	1191	1091	493	117	56	82	214	278	811	664
Nongauged		619	1364	1464	1123	981	500	149	32	30	77	103	518	577
Total intervening		1391	2781	2942	2314	2072	993	266	88	112	291	382	1330	1242
Klamath Seiad Valley	11520500	2766	4695	5106	4145	3378	1946	941	840	1025	1217	1314	2493	2481
Tributaries:														
Salmon at Somes Bar	11522500	2352	3627	3622	3142	2778	1482	565	257	167	314	320	1738	1691
Nongauged		5047	7385	6030	4489	2936	1299	588	428	450	688	678	3255	2759
Total intervening		7398	11012	9652	7632	5714	2781	1154	685	616	1002	998	4992	4450
Klamath at Orleans	11523000	10165	15707	14758	11777	9092	4727	2095	1525	1641	2219	2312	7485	6931
Tributaries:														
Trinity at Hoopa	11530000	9062	15516	9576	4802	5905	3816	1782	982	1032	976	869	3794	4808
Nongauged		7058	11899	6243	2958	1761	930	505	456	376	-107	646	3501	2990
Total intervening		16119	27414	15819	7760	7666	4746	2287	1438	1408	869	1515	7295	7798
Klamath at Klamath	11530500	26284	43121	30577	19537	16758	9473	4382	2964	3049	3087	3828	14780	14729

(continued)

Table 5 - Water budgets for Klamath main stem, 2001 - 2005, continued

gauge	*number*	*Mean flows (cfs)*												
		J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*year*
							Calendar year 2005							
Klamath at Iron Gate	11516530	1059	821	871	1363	3561	1222	925	999	1179	1357	1343	2640	1450
Tributaries:														
Shasta near Yreka	11517500	231	219	200	123	216	94	34	36	63	145	226	775	198
Scott near Ft Jones	11519500	554	492	549	649	1453	656	134	22	16	35	184	2937	644
Total		786	712	749	772	1668	750	168	58	80	180	410	3712	841
Nongauged		433	423	476	757	1377	596	196	43	31	83	399	3999	739
Total intervening		1218	1135	1225	1529	3045	1346	363	101	111	263	809	7712	1581
Klamath nSeiad Valley	11520500	2277	1956	2096	2892	6606	2569	1288	1100	1290	1620	2152	10351	3031
Tributaries:														
Salmon at Somes Bar	11522500	1652	1352	1688	2845	4345	1942	764	296	193	215	1121	6178	1889
Nongauged		2647	2316	3172	4678	5068	2174	1088	764	569	290	1831	15491	3358
Total intervening		4299	3668	4861	7523	9414	4116	1852	1060	762	504	2953	21669	5247
Klamath at Orleans	11523000	6576	5624	6957	10415	16019	6684	3140	2161	2051	2124	5105	32020	8278
Tributaries:														
Trinity at Hoopa	11530000	5563	4794	7587	7996	13435	5706	2657	1056	846	802	1827	18534	5926
Nongauged		3886	2340	3847	6659	5561	2053	690	431	225	658	2586	2543	2622
Total intervening		9449	7133	11435	14655	18997	7759	3347	1487	1071	1460	4412	21077	8548
Klamath at Klamath	11530500	16025	12757	18392	25070	35016	14443	6487	3647	3123	3584	9517	53097	16826

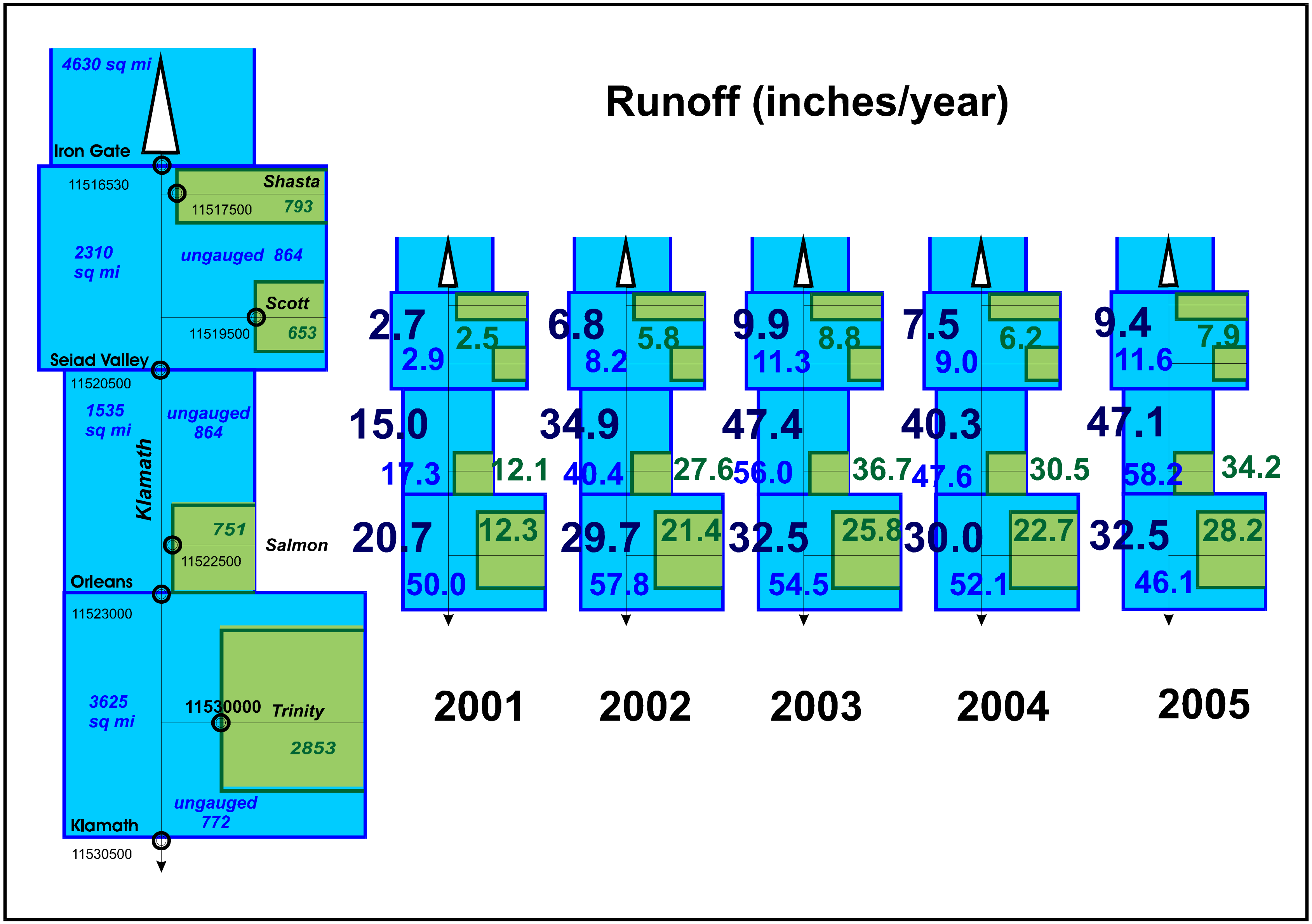

Figure 66 - Annual runoff (inches/year) superposed on stem diagram

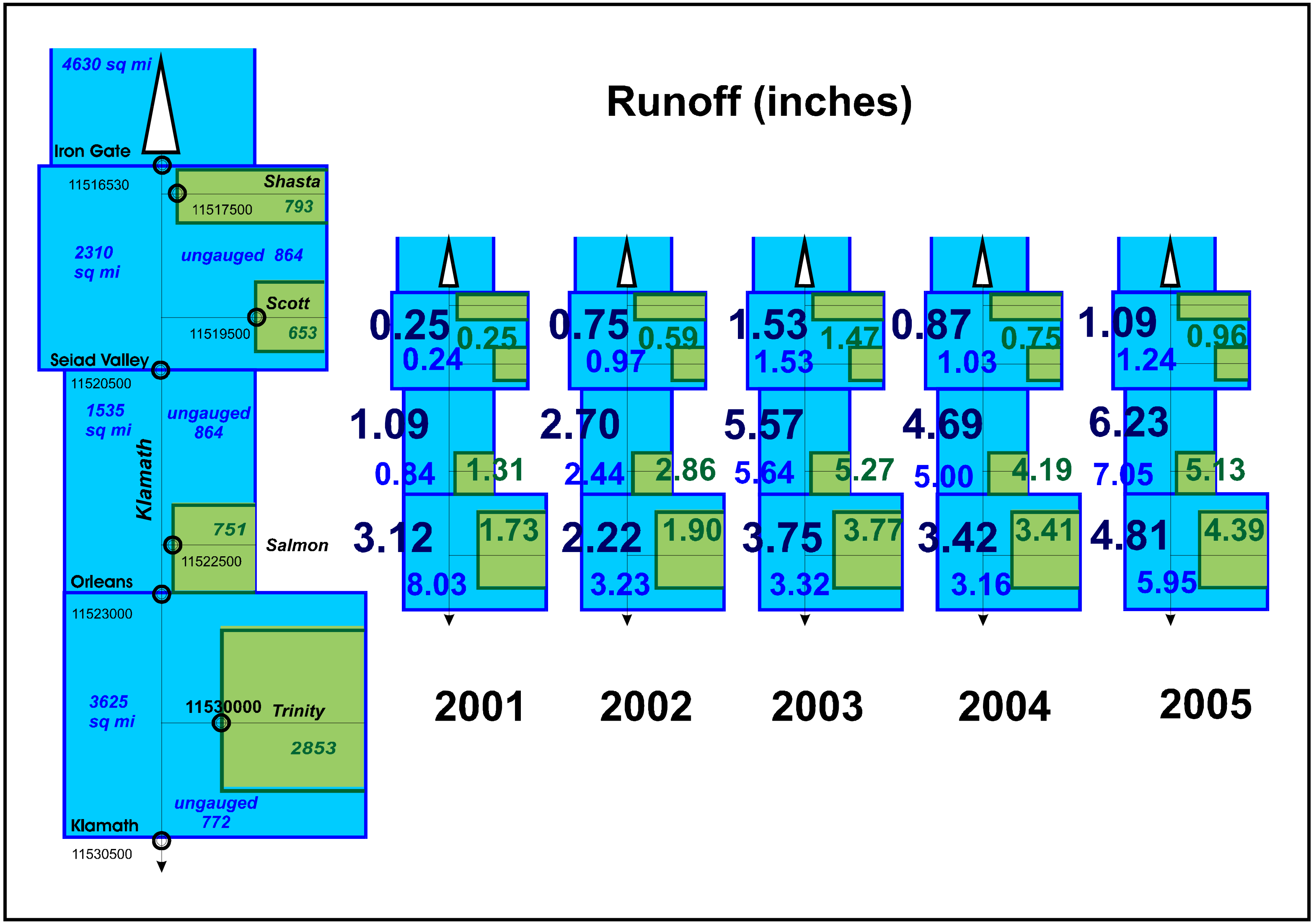

Figure 67 - Runoff (inches) for the data collection period June - October, superposed on stem diagram