PRECIPITATION EXTREMES AT THE CENTRAL SIERRA SNOW LABORATORY, CALIFORNIA

by

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Information on precipitation timing and amount is critical to water supply management and flood forecasting. Traditional approaches to estimating and predicting these and other hydrological parameters are typically most effective in the near-average range of conditions. It is the extreme situations, however, that are often most critical. To improve capabilities for predicting extreme conditions, more information is needed on the amount and frequency of precipitation extremes.

This paper presents summary and inferential statistics and return periods for precipitation amount and duration at the Central Sierra Snow Laboratory near Lake Tahoe, California. Rain is not differentiated from snow or from mixed rain and snow. This paper addresses the following questions: (1) What is the likelihood of days with precipitation, (2) What is the amount of precipitation in sequences of days with precipitation, and (3) What are the return periods for precipitation amounts during various time periods?

METHODS

Study Site, Data Record, and Instrumentation

The Central Sierra Snow Laboratory (CSSL) was chosen for this study because of its long record of meteorological measurement and its location at a forested site typical of much of the Sierra Nevada's western slope. CSSL (39°19'26" N, 120°22' W) is 1 km east of Soda Springs, California, in the true fir zone near the crest of the Sierra Nevada.

The predominant westerly air flow in winter brings maritime air masses that deposit large amounts of precipitation, mostly in the form of snow. Precipitation occurred during 44% of the days in 10 recent winters. Average annual snowfall at CSSL is about 10 m and the mean annual maximum snow depth is 290 cm. Smith (1982) characterized precipitation at CSSL from 1899 through 1974 as highly variable. Mean surface wind speeds are low (< 0.5 m s^{-1}) in the 40 x 50 m clearing where precipitation is measured. Mean winter air temperature (-2.6°C) is relatively high (Smith, 1982). Midwinter snow melt and rain typically occur once or twice annually at the 2100 m elevation of CSSL.

Precipitation measurements used were recorded at or near CSSL at four sites from 1899 to 1988. Over 95% of the measurements were made at three sites; the fourth site was active only in the late 1920's. These sites are located within 5 km of each other over an elevation range of 82 m (Smith, 1982). Double mass plots of the precipitation records from these stations and from other sites in the American River basin that were not relocated show a straight line relation and suggest that combining the data from the four sites will not introduce significant errors (Smith, 1982) in calculating descriptive statistics. Therefore, data from all four sites were combined for this study.

In recent decades precipitation timing and amount at each site have been monitored by an Alter-shielded, weighing recording gauge (Belfort[2]) located atop a 9-m tower in the center of a clearing. Although the gauge has been shielded only since the 1940's, its location in forest openings in the nearby sites reduced the detrimental effects of wind on gauge catch efficiency. Daily precipitation totals were manually computed from a strip chart trace for each day of each year, summer precipitation included. In winters 1986-87 and 1987-88 two gauges were in place; during the other years a single gauge was installed. The 95% confidence interval around the mean weekly differences of 32 replicated readings of measurable precipitation was ± 0.35 cm. The difference as a percentage of the mean of the replicated measurements averaged 15% over the 32 pairs.

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2 Trade names are stated solely for information. No endorsement by the U.S. Department of Agriculture is implied.

Analytical Procedure

Two types of time periods were examined: (1) "events"--consecutive days with recorded precipitation of at least 1.3 mm, and (2) "intervals"--any period of 1 to 10 consecutive days within a hydrologic year. Descriptive statistics were computed for event duration and frequency per year, and for precipitation amount for events of varying duration. Interpretation of the descriptive statistics assumed the following: (1) precipitation amount was independent of the number of events, (2) precipitation amount per event was distributed normally, and (3) distribution of event durations over the 89 years of record followed a Poisson distribution. Return periods were calculated for precipitation amounts over intervals of varying lengths. To determinate return periods, the method of moments was used to estimate the parameters of a log-Pearson type III distribution (Kite, 1977).

RESULTS

Event Duration and Amount

Over the 89-year record, almost 50% of the 2781 events were 1 day long (Table 1). Twenty-five percent were 2 days long, with a decreasing percentage of longer events down to 0.5% for events 9 days or longer. On average, approximately 14 1-day events occurred annually during the 89-year period of record; the chance of 14 or fewer 1-day events occurring was 0.519 (Table 2). Similarly, the chance of more than two 5-day events occurring in any year was 0.118 (1-0.882) (Table 2).

Table 1. Descriptive statistics for precipitation amounts during 1- to 20-day events (consecutive days all receiving precipitation), Central Sierra Snow Laboratory, 1899-1988.

Event duration (Days)	Statistic					
	Number of events	Mean (cm)	Median (cm)	Standard error (cm)	Maximum (cm)	Minimum (cm)
1	1290	1.1	0.7	0.03	18.2	0.2
2	697	2.9	2.4	0.08	13.9	0.3
3	362	5.5	4.6	0.20	32.6	0.7
4	198	7.5	6.4	0.33	27.0	1.3
5	106	11.0	9.7	0.60	41.7	1.9
6	67	13.7	12.5	0.85	41.8	4.1
7	40	18.1	17.3	1.18	40.1	6.7
8	18	18.7	20.8	1.94	31.1	6.3
9	13	25.3	23.7	3.23	52.2	9.3
10	17	26.5	26.0	4.20	78.3	8.1
11	7	33.5	27.8	6.60	69.0	18.8
12	6	38.0	38.1	3.71	49.5	26.2
13	5	38.9	37.3	10.11	76.0	18.4
14	4	32.4	36.7	5.07	38.9	17.3
16	1	39.8	39.8	---	39.8	39.8
17	1	38.7	38.7	---	38.7	38.7
20	1	28.8	28.8	---	28.8	28.8

Mean precipitation amounts increased steadily as events increased in duration through 12 days, and steadied at 38-40 cm for most of the longer events (Table 1). Maximum recorded precipitation was more variable, and dropped abruptly from 76 cm, for the 13-day events, to 38-40 cm for most of the longer events (Table 1). Variation in precipitation amount increased as event duration increased (Figure 1). Sixty percent of the 1-day events received $\leq$ 0.8 cm of precipitation (Figure 2). The precipitation range increased to 0-2.9 cm for 60% of the 2-day events, and to 0-10 cm for 60% of the 5-day events (Figure 2).

Interval Return Periods

Precipitation amounts varied from 14.3 cm ($\pm$ 0.9 cm at the 95% confidence level) for the 10-year return period/1-day interval, to 69.7 cm ($\pm$ 16.7 cm at the 95% confidence level) for the 100-year return period/10-day interval (Table 3). Increases in precipitation amounts tapered off as interval lengths increased, and expected precipitation only doubled between 2- and 10-day intervals (Table 3). Precipitation amounts for the 100-year return period were about 50% greater than for the 10-year RPs.

Table 2. Estimated cumulative probability of occurrence (less than or equal to) of annual precipitation events (consecutive day all receiving precipitation) of varying duration, Central Sierra Snow Laboratory, 1899-1988.

Events each year	Event duration (days)											
	1	2	3	4	5	6	7	8	9	10	11	12
0	.0	.0	.017	.109	.304	.472	.638	.819	.864	.827	.924	.935
1	.0	.004	.087	.350	.666	.827	.925	.983	.990	.984	.997	.998
2	.0	.016	.228	.617	.882	.960	.989	.999	*	*	*	*
3	.0	.048	.420	.815	.967	.993	.999	*	*	*	*	*
4	.001	.110	.615	.925	.999	*	*	*	*	*	*	*
5	.004	.207	.774	.974	.999	*	*	*	*	*	*	*
6	.011	.335	.882	.992	*	*	*	*	*	*	*	*
7	.024	.477	.945	.998	*	*	*	*	*	*	*	*
8	.049	.616	.977	*	*	*	*	*	*	*	*	*
9	.088	.738	.991	*	*	*	*	*	*	*	*	*
10	.145	.832	.997	*	*	*	*	*	*	*	*	*
11	.221	.900	.999	*	*	*	*	*	*	*	*	*
12	.312	.944	*	*	*	*	*	*	*	*	*	*
13	.414	.971	*	*	*	*	*	*	*	*	*	*
14	.519	.985	*	*	*	*	*	*	*	*	*	*
15	.620	.993	*	*	*	*	*	*	*	*	*	*
16	.712	.997	*	*	*	*	*	*	*	*	*	*
17	.791	.999	*	*	*	*	*	*	*	*	*	*
18	.854	*	*	*	*	*	*	*	*	*	*	*
19	.902	*	*	*	*	*	*	*	*	*	*	*
20	.937	*	*	*	*	*	*	*	*	*	*	*

* Cumulative probability is greater than 0.999.

Table 3. Precipitation amounts (cm) and 95% confidence interval lengths by return period and length of interval (1 to 10 consecutive days with or without precipitation), CSSL, 1899-1988.

Days in Interval	Return Period (Years)			
	10	20	50	100
1	14.3 ± 0.9	16.6 ± 1.3	19.9 ± 2.1	22.4 ± 5.5
2	21.5 ± 1.6	25.8 ± 2.5	32.0 ± 6.9	37.2 ± 11.4
3	26.8 ± 2.0	32.0 ± 5.5	39.5 ± 7.7	45.6 ± 12.3
4	30.2 ± 2.1	35.7 ± 5.6	43.3 ± 7.6	49.4 ± 12.1
5	33.3 ± 2.2	39.2 ± 5.8	47.2 ± 7.9	53.5 ± 12.5
6	36.0 ± 2.5	42.5 ± 6.2	51.4 ± 11.1	58.6 ± 13.5
7	37.9 ± 2.5	44.6 ± 6.3	53.8 ± 11.2	61.0 ± 13.6
8	40.8 ± 2.7	47.4 ± 6.5	57.1 ± 11.5	64.8 ± 16.5
9	42.2 ± 5.3	49.6 ± 6.7	59.6 ± 11.7	67.5 ± 16.8
10	44.1 ± 5.4	51.6 ± 6.7	61.8 ± 11.7	69.7 ± 16.7

DISCUSSION AND SUMMARY

Using the log-Pearson type III distribution as the basis of the recurrent interval computations is debatable (Wallis and Wood, 1985). Kite (1977) suggested that the log-Pearson type III distribution is unsuitable when the skew coefficient is less than zero. Because this skew is typical when individual days within an event are generally not extreme occurrences, return periods were not calculated for events.

Because summer precipitation is infrequent at CSSL, usually brief, and brings a small amount of precipitation (often below the 1.3 mm threshold amount used to define events), including the summer data does not alter the analysis appreciably. We believe the results are conservative in terms of winter precipitation amount and event duration.

The information on precipitation duration and amount presented here should be expanded to other sites and combined with similar analyses of air temperature to develop joint probabilities for large precipitation amounts and high air temperature. These conditions are precursors to flood flows in the central Sierra Nevada, and knowing the probability of their occurrence would help in a variety of prediction and engineering tasks.

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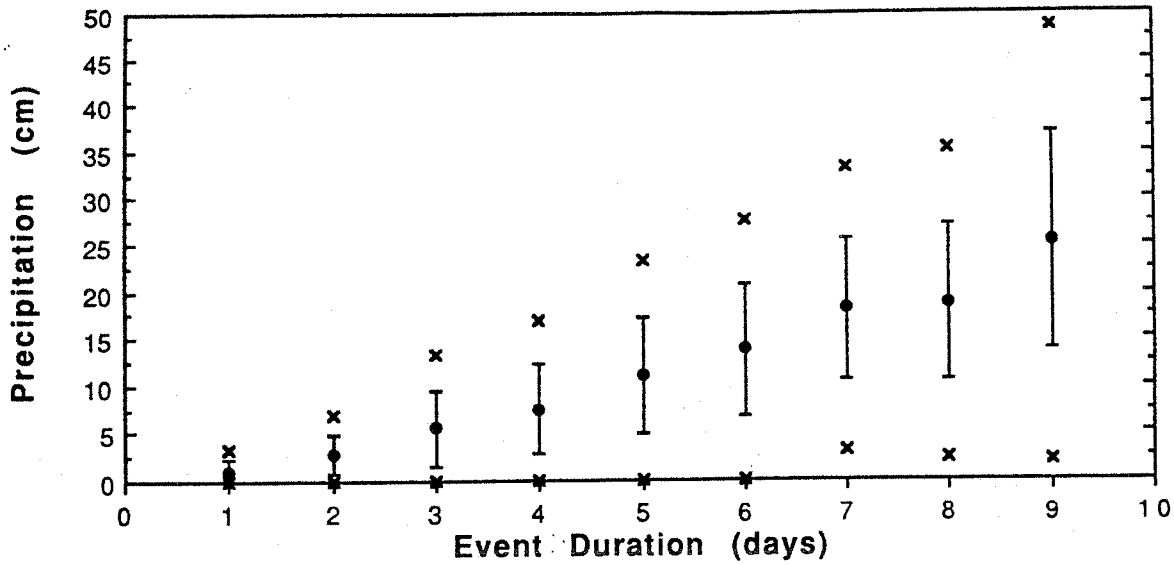
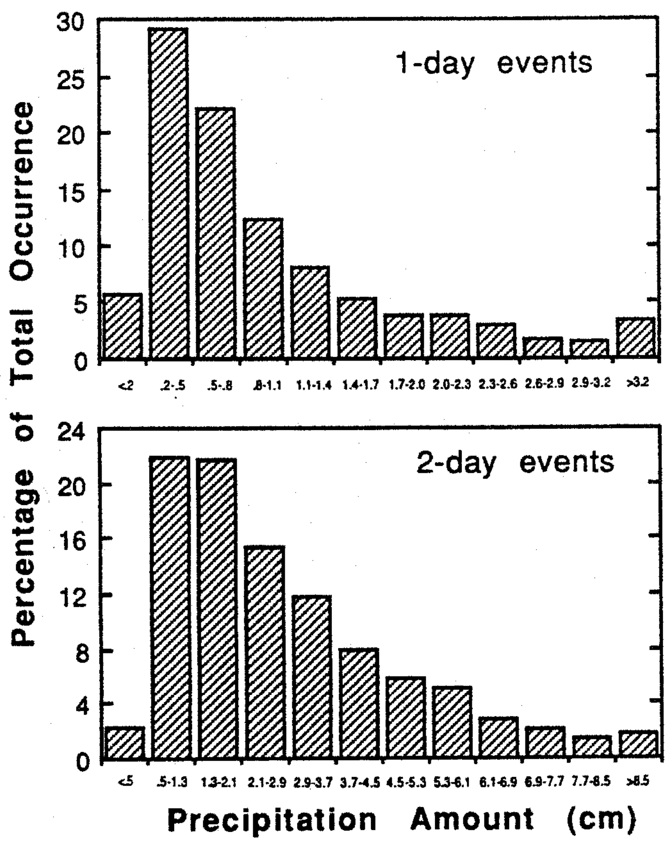


Fig. 1. Amount of precipitation (mean [●], 1 standard deviation [bar], and two standard deviations [x]) by event duration, Central Sierra Snow Laboratory, 1899-1988. Events are consecutive days with precipitation.



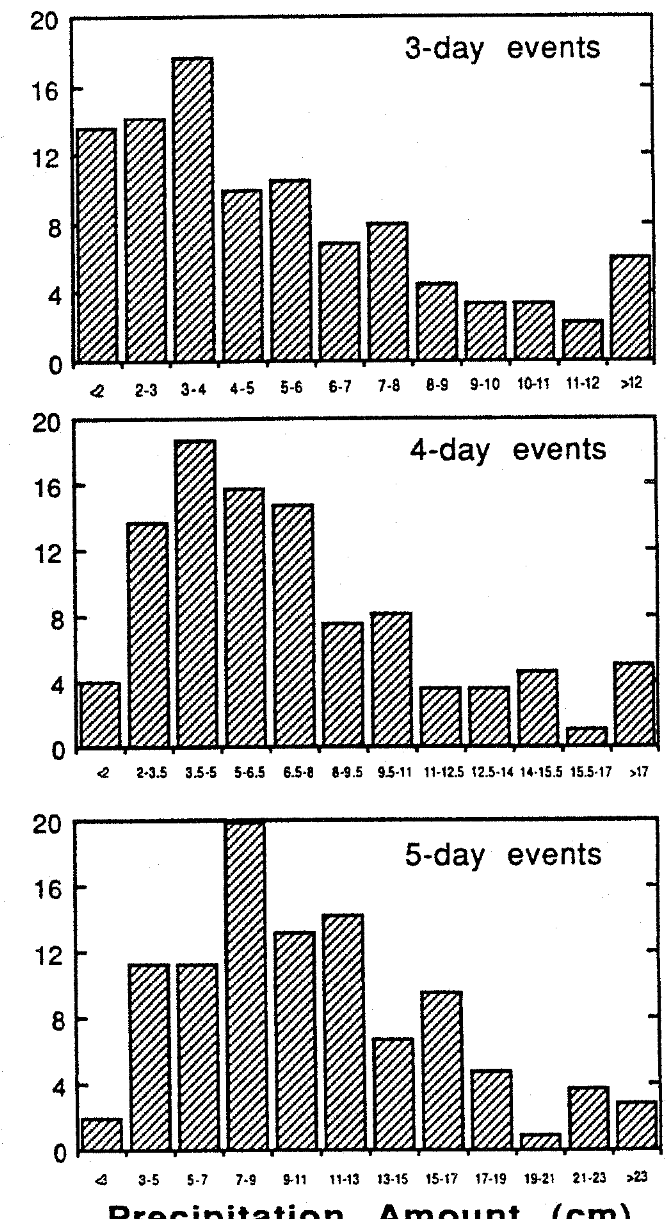


Fig. 2. Histograms of recorded precipitation amount for events (consecutive days with precipitation) 1 day, 2 days, 3 days, 4 days, and 5 days long, Central Sierra Snow Laboratory, 1899-1988, showing increasing variability and precipitation amounts as event duration lengthens.