PRECIPITATION INTENSITY DURING RAIN-ON-SNOW

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ABSTRACT

Mid-winter rainfall onto established snowpacks has the potential to generate high stream flows and flooding. Rain-on-snow can also increase the potential for snow avalanche. Precipitation intensity is a vital piece of information when forecasting and assessing stream flow and snow stability during rain-on-snow. Precipitation intensity during 120 rain-on-snow storms from the past 21 winters at the Central Sierra Snow Laboratory in the Sierra Nevada of California were analyzed. These data were used to generate both storm and seasonal recurrence intervals for varying mid-winter rainfall intensities. Mid-winter rainfall intensities were found to range between less than 1 mm/hr to over 27 mm/hr with a mean of 2 mm/hr. Mean maximum rainfall intensity was found to be 5 mm/hr for approximately 5 hours. An average annual maximum rainfall rate of 8 mm/hr has a recurrence interval of approximately 3 years.

INTRODUCTION

High intensity "warm" precipitation has been observed as a precursor to mid-winter flood flows and increased avalanche activity in the Sierra Nevada and Cascade mountain ranges. The Central Sierra Snow Laboratory (CSSL, elevation 2100 m), 2 km west of Donner Pass, California receives rain-on-snow annually. Of the 20 largest precipitation events recorded at the CSSL since 1946, more than half have *not* been associated with record snowfall. All of these events have occurred during the winter and have fallen as rain-on-snow. The largest precipitation events in the central Sierra Nevada are rain-on-snow events. Rain/snow levels of at least 2500 m are common during many mid-winter rain storms; rain-on-snow has been observed at 3600 m in the southern Sierra Nevada during the spring. More than 215 mm of rainfall was measured at 3000 m elevation on Mammoth Mountain (southern Sierra Nevada) with precipitation intensities of up to 10 mm/hr. Flooding was widespread throughout the range during this event.

	mean	std dev	max	min
rainfall (mm)	57.3	76.1	390.8	0.8
duration (hr)	32.0	31.7	158.0	1.0
intensity (mm/hr)	1.6	1.1	5.0	<0.1
max intensity (mm/hr)	5.1	5.9	27.0	0.5
max intensity duration (hr)	4.9	5.4	24.0	1.0

Table 1. Statistics for 120 rain-on-snow storms, winters 1978-1998, Central Sierra Snow Laboratory.

Research has shown that the largest floods produced by the major river systems of California have occurred during rain-on-snow. The presence of expansive snow cover greatly increases stream flow potential; rain-on-snow produces greater runoff than either rainfall or snowmelt alone. At the Alpine Meadows Ski Area—a few kilometers north of Lake Tahoe—over half of the last 75 winter rain storms have resulted in avalanche activity within the ski area's boundary. In addition, 76% of the documented landslides in the Sierra Nevada during winters 1982 and 1983, and 85% of observed landslides in western Oregon have been attributed to rain-on-snow.

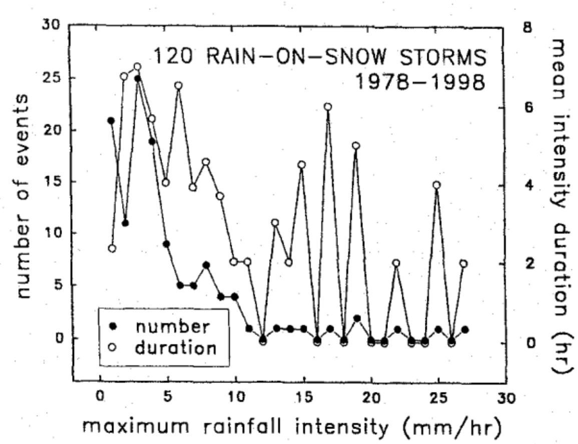

Figure 1. Mean intensity duration and number of events for differing maximum rainfall intensities.

In addition to rainfall amount, rainfall intensity is a critical factor when forecasting or assessing the flood, landslide, and snow avalanche potential during mid-winter rain storms. Previous research at the CSSL has

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shown rainfall intensity having a positive correlation with water percolation rates through a snowpack, independent of snow depth. Great snowpack outflow can saturate underlying soils and increase stream flow. There is also evidence suggesting snowpacks not having previously outflowed some amount of liquid water being more susceptible to avalanching. Percolating rain water decreases shear strength through bond destruction and lubrication of subsurface shear planes. Small amounts of rain can increase strength between bonds due to capillary forces, however as water contents increase, these attractions weaken quickly.

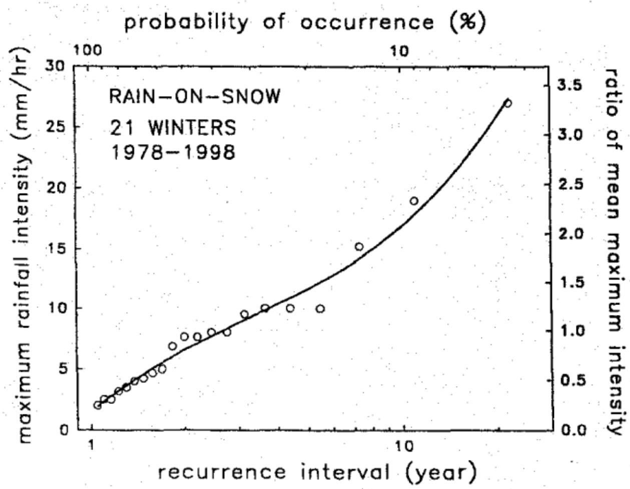

Figure 2. Recurrence interval for each season's maximum rainfall intensity.

DATA SET AND ANALYSIS

While the measurement of precipitation is relatively straight forward, discriminating precipitation type—snowfall or rainfall or a mix of the two—during any one event can be difficult. At the CSSL, fluctuating rain/snow levels during storms is common, as is snowfall coincident with air temperatures up to 3° C, and on occasion (supercooled) rainfall as low as -2° C. Direct observation is still the best way to differentiate between rainfall and snowfall.

For the past 21 winters (1978-1998), precipitation type has been observed and documented at the CSSL. Records were scoured and 120 rainfall events identified. All of the precipitation fell as rain. These events were identified independent of total rainfall amount: they ranged from a minimum of less than 1 mm to a maximum of just over 390 mm. The mean was 57 mm, standard deviation 76 mm. All storms identified were rain-on-snow, that is, the rainfall of each event fell onto snowpacks permanently on the ground for that season. Table 1 describes the general statistics of the data set; Figure 1 plots each storm set sharing a common maximum rainfall intensity (to the nearest millimeter) against the mean intensity duration for that set. Figure 1 also slates the number of events for each maximum intensity. Generally, both the number of events and mean intensity duration decrease as maximum intensity rates increase. In separate analysis, when plotted, each storm's total rainfall is found to increase as duration and mean intensity increases.

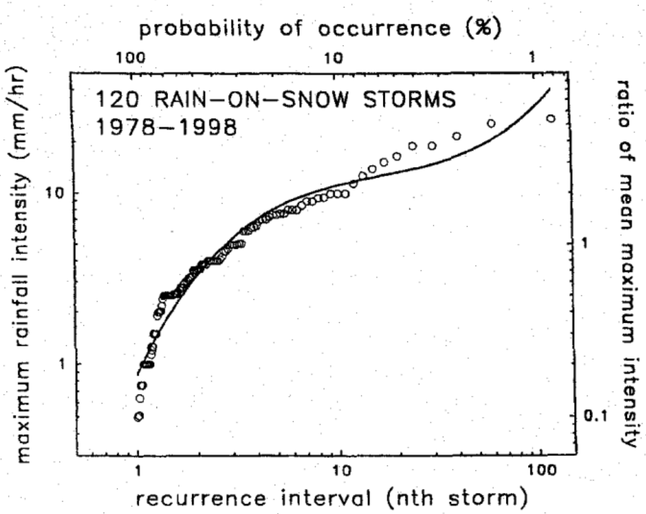

Figure 3. Recurrence interval for each storm's maximum rainfall intensity.

To generate rainfall-intensity frequency curves, maximum intensities were considered random events, the premise being that maximum rainfall intensities observed during a period of time will constitute a sample of an indefinitely large population in time. Two analyses were done. The first (Figure 2) considers the maximum rainfall intensity of each winter season. Figure 2 ($n = 21$) shows that the mean annual maximum rainfall intensity (8 mm/hr) has a recurrence interval of approximately 3 years. Figure 3 considers each individual rain storm a maximum event ($n = 120$). With a mean storm maximum intensity of 5 mm/hr, on average this rainfall rate will be equaled or exceeded approximately every third rain storm.

CONCLUSIONS

Analyses of the past 21 winters at the CSSL suggest a mean seasonal peak rainfall intensity occurring, on average, once every three seasons. Data from 120 rain storms at the CSSL propose that peak rainfall intensity occurs every third storm. At an average of almost six rain storms per winter, these results differ. This is primarily due to the vast difference in size of the data sets. 95 of the 120 (79%) rain-on-snow events at the CSSL had peak precipitation intensities less than 8 mm/hr, the mean annual maximum. Previous research at the CSSL indicates the mean annual maximum rain-on-snow storm (a combination of rain and snowfall, n = 46) of 151 mm having a recurrence interval of 2.6 years. This, in combination with the fact that mean intensity tends to increase as total rainfall increases, agrees well with the 21 point data set above. Past data analyses also show the frequency of mid-winter rain at the CSSL increasing.

To help facilitate the forecasting of flood flows, land-mass failures, and snow avalanche hazard during rain-on-snow, rainfall amounts and rates from other sites should be combined with soil moisture, stream flow, and snow stratigraphy data.

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