Bulletin of the International Association of Scientific Hydrology, XIII, 4 – 12/1968

THE GENERATION OF SPRING PEAK FLOWS BY SHORT-TERM METEOROLOGICAL EVENTS

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ABSTRACT

Spring peak flows recorded over a 25-year period in Benton Creek, a small forested watershed in northern Idaho, were studied in their relation to meteorological events. More peak flows were generated by rain-on-snow than by clear-weather snowmelt; the two types of peaks differ in magnitude and in other characteristics. Two rather simple techniques were used to calculate the generative capacity of a rainfall-temperature event and the hypothetical outflow of water from a snowpack during rainy and rainfree periods. Similar data on spring peaks on two regional subbasins were considered also.

INTRODUCTION

Short-term meteorological conditions—usually lasting less than a week—may suddenly accelerate streamflow during the rising stage of spring runoff in the northern Rocky Mountains. Heavy rain falling on the snowpack may directly contribute excess water to snowmelt runoff in some years. In other years, a stationary airmass accompanied by continuous warm temperatures may lead to a very high rate of heat transfer to the snowpack and indirectly bring about a rapid acceleration of melt and runoff. These contrasting types of events, because of their timing and intensity, often bring about spring peaks on small drainages.

Detailed investigation of peak flow runoff on mountain streams has been undertaken, but little attention has been given to the concurrent meteorology. Recently, graphical and numerical methods for determining the frequency and magnitude of peak runoff were published in two excellent volumes by Bodhaine and Thomas 1964, and Thomas, Broom, and Cummans 1963. There was need for an ensuing study of ambient rainfall-temperature events in relation to peak runoff, covering their relative frequency of occurrence, their synchronization with maximum conditions, and their generative capacity.

This paper deals with such relationships on small subbasins. Detailed information was obtained from an analysis covering hydrometeorological records collected on a small forested watershed in northern Idaho. Somewhat less extensive records from two regional subbasins are also discussed.

QUALIFICATIONS OF THE STUDY WATERSHED

Scarcity of weather data has been the main deterrent to studies of this kind. For the northern Rocky Mountains, as for other regions of heavy snow accumulation, climatic and streamflow data are scanty. Coverage by rainfall-temperature reporting stations in mountainous terrain is grossly inadequate. However, long-established facilities on Benton Creek within the Priest River Experimental Forest, Priest River, Idaho, are an exception. Here the combination of a permanent gaging site and close proximity to a weather station qualified the watershed for analytical study.

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Benton Creek, in the Selkirk mountain range, drains a steep, west-facing basin of 1.48 square miles. Elevations range from 2,660 feet at the gaging site to 5,510 feet at the summit of Gisborne Mountain. The terrain is almost completely forested by the major timber types (fig. 1). Only 8 percent of the timber cover has been removed, and most of this was removed before 1941.

Streamflow records have been kept on Benton Creek since 1938. Since the original cover of timber might have affected water yield, peak flows of 1938 to 1941 were not used in the analysis. At the Headquarters station (elevation 2,350 feet) 1.4 miles west of the gaging site, rainfall or snowfall and temperature observations have been made almost daily since 1912.

Certain peak flow characteristics of Benton Creek typify the average small snow-fed stream of the middle and lower elevational zone. Spring peaks, according to record, have occurred as early as March 30 and as late as May 29; 76 percent occurred in May. For the 25 years of record, the annual yield of water averaged 16 area inches. A resumé of yearlong runoff characteristics during the first 16 years of record was reported by Stage (1957).

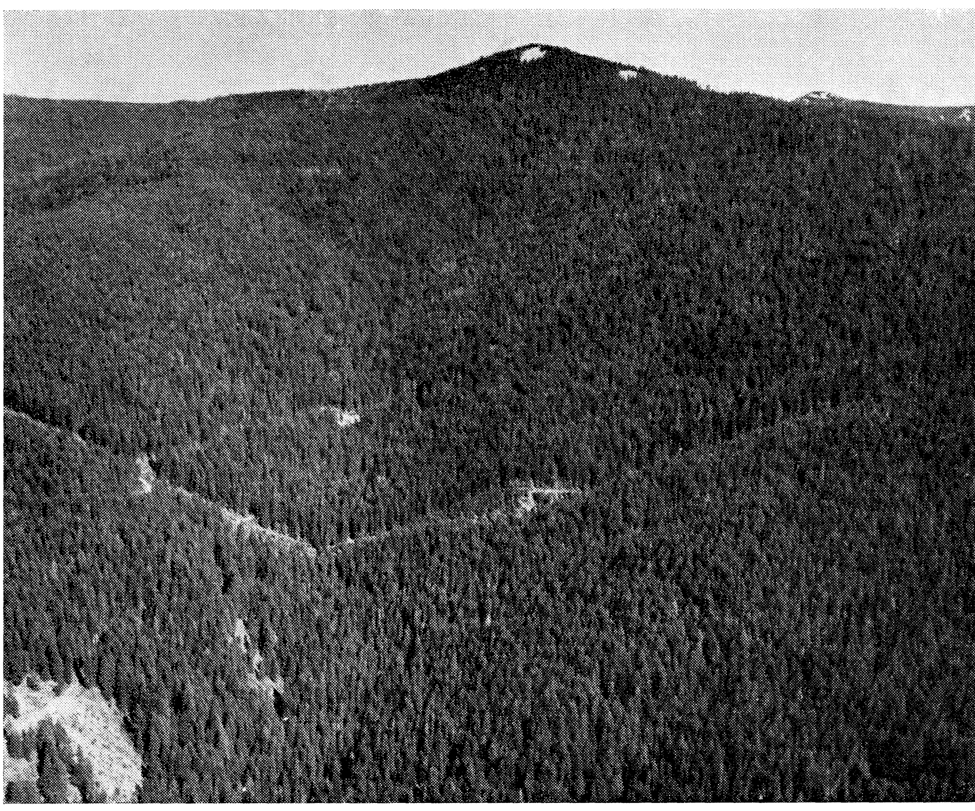

Fig. 1 — Panoramic view of Benton Creek, Priest River Experimental Forest, above gaging site.

Analytical procedures

Analytical procedures included study of peak runoff, classification according to generative influence, study of interdependence of peaks, and determination of an index of outflow potential.

Peak runoff during the snowmelt season was analyzed in an annual series. By the method used (U.S. Soil Conservation Service 1966), only one event per year was taken. The peak was defined as the 24-hour volume of flow from midnight to midnight, expressed in area inches. (Hereafter, the terms "peak runoff" and "peak volume" are used interchangeably.) A period of 1 week or more usually separated the annual maximum spring peak from the second-highest rise in streamflow of the season.

Spring peak volumes were characterized through 1965 according to the generative importance of rainfall. The sum of the rainfall was measured at Headquarters station for a reference period of 6 consecutive days up to and including the day of peak discharges. Station rainfall was used as an index and was not converted to basin rainfall to adjust for orographic influence, nor was it corrected for prevalence of adiabatic conditions in early spring when upper-elevational precipitation may have fallen as snow. A peak volume was arbitrarily defined as being significantly influenced by rainfall if the storm(s) totaled more than 0.50 inch during a 6-day sequence. If less than 0.50 inch of rain fell, the peak was listed as being generated by snowmelt.

Interdependence of multiple peaks in the same season was given careful consideration in the study of peak magnitude. A late-season spring peak "coasted" downstream, in many instances, riding high on the recession of an earlier rise in streamflow. This contributed to establishment o a high absolute peak volume, but such a peak was rejected in the analysis as a true measure of the generative capacity of a short-term rainfall-temperature event. To isolate the event and eliminate antecedent effects, the generative capacity was derived by subtracting the lowest daily volume within the 6-day sequence from the spring peak volume, expressed in area inches.

An index-station technique was used also to estimate the water available for runoff in Benton Creek for a 6-day sequence. The estimate was derived by adding to daily rainfall an estimate of the daily snowmelt that was contributed at Headquarters station, assuming snow was present, during the 6 days in question. This index of the water flowing from the snowpack at a point location, hypothetically at least, afforded a common base upon which to compare the runoff potential of a rainy sequence with a rainfree sequence. This value, expressed in inches, is referred to herein as the index of outflow potential (IOP). For the analysis, the IOP was derived for three time periods occurring between March 26 and May 31. These dates limit the known range of recorded spring peaks in Benton Creek. The time periods were the 6-day spring peak sequence, the 6-day maximum rainfall sequence, and the 6-day maximum air temperature sequence. The 6-day sequence for maximum rainfall or maximum temperatures may or may not have coincided with the 6-day spring peak sequence.

The daily snowmelt component of the IOP was computed using two generalized equations derived by the U.S. Army, Corps of Engineers (1960), one for surface snowmelt and one for snowmelt from rain percolating through snow. For densely forested basins, temperature indexes of surface snowmelt are fairly reliable for estimating springtime snowmelt at a point location. The simplified formula for deriving snowmelt as a function of air temperature can be expressed as

$$M = 0.04\,(T_{\max} - 42) \qquad (1)$$

where M is the daily snowmelt in inches for a forest site, and $T_{\max}$ is the daily maximum temperature in degrees F. In the analysis, the maximum temperature recorded at Headquarters station for the appropriate day was used.

Daily snowmelt by the transfer of heat from rain percolating through a snowpack is relatively small (U.S. Army, Corps of Engineers 1960) and may be expressed simply in terms of rainfall and free air temperatures:

$$M_p = 0.00695\, P_r (T_a - 32) \qquad (2)$$

where M_p is the daily snowmelt from rain, P_r is the daily rainfall in inches, and T_a is the air temperature in degrees F. Because the time of day when rain fell and the corresponding air temperature were not known, daily mean temperature was the variable used in the above equation.

Data derived from these equations for the spring peak, maximum rainfall, and maximum high-temperature sequences are listed for the 25-year-period in table 1.

TABLE

Sequential data for spring peak flows, maximum rainfall, and maximum

	Date of peak		Spring peak sequence				Maximum rain-	
Year	Month-day (1)	Peak volumes (2)	6-day rainfall (3)	Surface melt-Eq. 1 (4)	Rainfall melt-Eq. 2 (5)	Index of outflow potential (6)	6-day rainfall (7)	Surface melt-Eq. 1 (8)
	—Area inches—		—Inches—					
								RAIN-ON-SNOW
60	3-30	0.428	2.23	1.52	0.10	(2) 3.85	2.35	0.60
48	5-24	.410	1.71	6.20	.28	8.19	1.71	6.20
53	4-29	.369	1.62	4.08	.16	5.86	2.04	4.16
65	4-21	.366	1.88	2.40	.16	4.44	1.88	2.40
61	5- 7	.336	2.64	2.40	.19	5.23	2.64	2.40
45	5-17	.324	2.51	3.88	.31	6.70	2.51	3.88
57	5-21	.314	2.50	5.44	.37	(2) 8.31	2.94	4.32
59	5-20	.237	1.33	3.40	.11	(2) 4.84	1.48	2.84
51	5-12	.231	.57	6.16	.10	(2) 6.83	1.03	4.88
63	5- 9	.191	1.58	3.28	.16	(2) 5.02	2.05	1.88
62	5-29	.183	2.03	6.28	.38	8.69	2.03	6.28
42	5-28	.139	2.29	5.52	.38	8.19	2.30	6.36
41	5-18	.081	3.19	3.52	.39	7.10	3.19	3.52
44	5-24	.057	1.76	4.00	.14	(2) 5.90	1.79	3.88
Mean (n = 14)			1.99	4.15	.23	6.37	2.14	3.83
								SNOWMELT
52	4-27	.565	.00	7.32	.00	7.32	1.19	3.64
56	4-22	.547	.06	6.64	.01	6.71	.77	.80
50	5-13	.511	.07	6.68	.01	6.76	1.02	.96
54	5-19	.443	.00	8.88	.00	8.88	1.36	.88
49	5-11	.436	.00	9.80	.00	9.80	1.52	2.88
43	5-16	.366	.00	7.92	.00	7.92	2.39	.84
55	5-21	.334	.06	5.56	.01	(3) 5.63	2.43	1.04
64	5-21	.314	.14	8.20	.02	(3) 8.36	.99	2.84
46	5- 7	.314	.33	7.36	.04	7.73	1.93	1.84
58	5-12	.246	.41	7.32	.07	7.80	2.73	2.24
57	5- 9	.125	.21	8.08	.04	8.33	1.14	2.08
Mean (n = 11)			.12	7.61	.02	7.75	1.59	1.82
Mean (all years)						6.98		

(1) Number of days shown in columns (15) and (16) when added to date in column (1) give day c
(2) IOP for spring peak sequence greater than IOP for maximum rainfall sequence.
(3) IOP for spring peak sequence slightly greater than IOP for maximum temperature sequence.

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temperature for Benton Creek, 1941-1965, *by descending order of peak volumes*

fall sequence		Maximum temperature sequence				Synchronization with spring peak (1)	
Rainfall melt- Eq. 2 (9)	Index of outflow potential (10)	6-day rainfall (11)	Surface melt- Eq. 1 (12)	Rainfall melt- Eq. 2 (13)	Index of outflow potential (14)	Maximum rainfall (15)	Maximum temperature (16)
Inches						*Days*	
SPRING PEAKS							
0.11	3.06	0.66	7.36	0.10	8.12	+ 1	+41
.28	8.19	.36	8.84	.06	9.26	0	+ 4
.21	6.41	.19	7.44	.04	7.67	− 1	+ 8
.16	4.44	.05	7.56	.01	7.62	0	+39
.19	5.23	.00	8.92	.00	8.92	0	+19
.31	6.70	.19	8.44	.04	8.67	0	−11
.42	7.68	.00	9.04	.00	9.04	+ 2	+10
.13	4.45	.09	6.52	.00	6.51	+ 1	− 5
.12	6.03	.00	7.72	.00	7.72	+ 3	+11
.14	4.07	.00	8.88	.00	8.88	−30	+15
.38	8.69	.06	7.52	.01	7.59	0	−40
.39	9.05	1.28	7.80	.27	9.35	− 1	− 2
.39	7.10	.00	8.24	.00	8.24	0	+ 8
.14	5.81	.00	7.92	.00	7.92	+ 1	− 7
.24	6.21	.20	8.01	0.4	8.25		
SPRING PEAKS							
.11	4.94	.00	8.32	.00	8.32	+ 6	+31
.03	1.60	.00	9.36	.00	9.36	−22	+28
.06	2.04	.02	7.48	.00	7.50	−42	+ 3
.06	2.30	.00	9.08	.00	9.08	−41	+ 1
.17	4.57	.00	10.68	.00	10.68	− 8	+ 3
.12	3.35	.00	7.92	.00	7.92	−46	0
.14	3.61	.00	5.60	.00	5.60	−29	+ 1
.07	3.90	.02	8.28	.00	8.28	−24	− 1
.16	3.93	.12	7.72	.02	7.86	−26	+20
.22	5.19	.01	10.96	.00	10.97	−22	+16
.09	3.31	.00	8.88	.00	8.88	−35	+17
.11	3.52	.02	8.57	.00	8.59		
	5.03				8.40		

ccurrence of maximum rainfall or temperature.

Peaks generated by rain-on-snow and snowmelt

The basic hydrologic processes that operate over the Benton Creek watershed in the period before peak volume is reached need elaboration before the correlation with weather events can be shown. These processes follow the same general pattern from year to year. Early in the melt period (March 15-April 10), a portion of the watershed, particularly at middle and high elevations, may not be completely primed with stored soil moisture. As a result, only a small portion of the snow-covered area may be contributing to runoff, but the contributing area increases as melt progresses and storage deficits are filled. In the analysis it was assumed that in Benton Creek the entire snow-covered area was contributing before the peak volume period was reached.

As melt progresses into May, the snow-covered area usually diminishes rapidly. Area of bare ground increases, and in turn, more of the surface soil begins to dry, thus creating a water deficiency in the soil that must be satisfied by spring rain, which would otherwise contribute to runoff. Obviously then, the smaller the area covered with snow and the drier the surface soil free of snow cover, the less will be the effectiveness of heavy rain or warm, clear weather in producing high peak runoff.

In some years, the rate of snow-cover depletion may be relatively slow because of cool temperatures in early spring. This delay poses a potential flood threat with the advent of heavy rain or warm, clear weather.

The pertinent data about the 25 spring peak events and their relation to maximum rainfall and temperatures are summarized in table 1.

Frequency of occurrence of rain-on-snow and snowmelt peaks

Spring peak events are classified according to the method described earlier. Rain-on-snow contributed to the spring peak in 56 percent of the years studied; the figure for snowmelt alone is 44 percent. Thus, rainfall played a dominant role in generating peak volumes from 1941 to 1965.

Relation to maximum rainfall and maximum temperatures

As shown in column 15 of table 1, the sixth day of the maximum rainfall period coincided quite closely, except in 1963, with the day of actual rain-on-snow peak. Note that in about one-half of the years the two events were synchronized perfectly. Periods of maximum temperatures (column 16) usually occurred well into the recession stage of runoff, at which time the area of snow cover on Benton Creek was minimal. In years when the sequence of maximum temperatures took place before the rain-on-snow peak, either the snowpack was generally light [2] or maximum temperatures were associated with the season's second-highest rise.

Snowmelt-caused peak volumes were not well synchronized with periods of maximum temperature. In 5 of 11 years, peak volume occurred 16 to 31 days before the highest temperature of the season. This means that somewhat lower cumulative temperatures were associated with the triggering of a snowmelt peak, which occurred at a time when the area of snow cover and other watershed conditions were probably optimal.

In the years of snowmelt peaks, the period of maximum seasonal rainfall occurred generally many days before the actual peak (column 15, table 1). The amount of maximum rainfall was generally high; however, it was accompanied by cool temperatures and thus the melt contribution from heat exchange was relatively low, as suggested by the low IOP in column 10 in table 1. In contrast, the contribution made by melt resulting from ambient air temperature was considerable for the years of rain-on-snow peaks. The mean IOP for maximum rainfall averaged 76 percent greater for rain-on-snow peaks than the mean IOP for maximum rainfall in years of snowmelt-caused peaks. Thus, the occurrence of heavy rainfall during the spring season did not necessarily generate the spring peaks in Benton Creek.

[2] Based on snow data from the Benton Springs Cooperative Snow Course located in headwaters of Benton Creek.

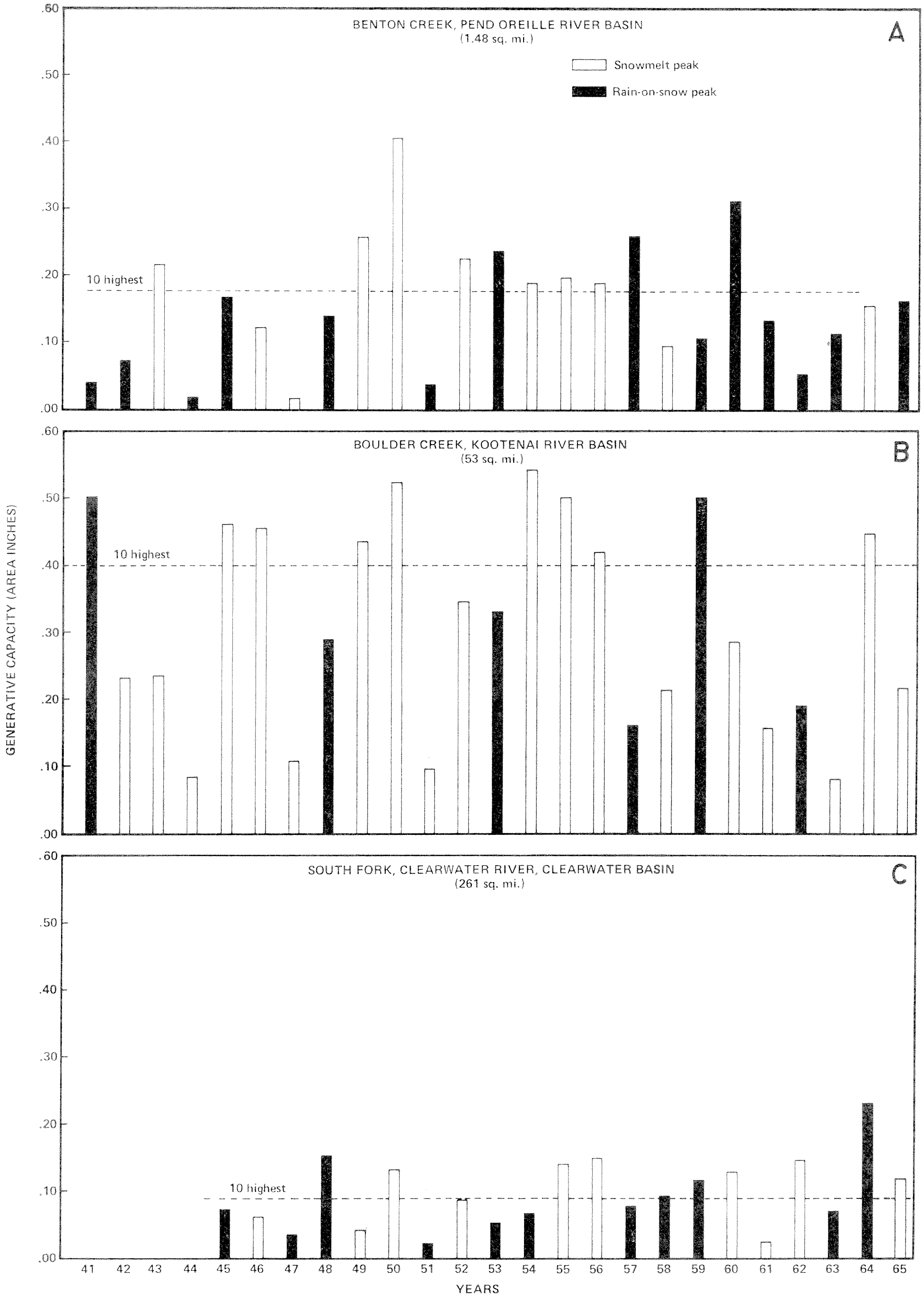

Fig. 2 — Generative capacities by years for A. Benton Creek; B. Boulder Creek; and C. South Fork, Clearwater River.

Relative magnitude of rain-on-snow and snowmelt peaks

We should not assume that rainfall at the time of spring peak will create a more critical peak runoff condition than snowmelt alone. A plot of generative capacities of rain-on-snow and snowmelt alone, calculated from the spring peak as described earlier (fig. 2A), indicates that the highest single peak and six others of the 10 highest generated peaks were associated with a snowmelt event.

The U.S. Army, Corps of Engineers (1960) used generalized melt equations to calculate the peak discharge for the maximum possible flood on the drainage of a large basin, the Salmon River. They found that even when the maximum observed rainstorm (1.2 inches in 2 days) was used in the rain-on-snow formula, calculations yielded a flood crest slightly less than found for snowmelt alone. They attributed this to concurrent meteorological conditions, which affected the computations. When a low-temperature rainfall-producing airmass is considered as operative in the area, less heat must be considered available for snowmelt than under clear-weather snowmelt conditions.

The strong suppressing influence of rainfall on ambient air temperatures and, by implication, on snowmelt, was evident in Benton Creek. The mean surface melt for rain-on-snow peak years was considerably less than that for snowmelt peak years by 3.46 inches (table 1, column 4). This implies that loss of heat energy for melting snow may be only partially compensated for by increased input of rainfall on snow-covered areas. However, this lower rate of outflow from snow-covered areas may be offset by excess runoff from areas *not* covered with snow, thus accounting for the relatively high generative capacities associated with some rain-on-snow conditions.

Six of the 14 rain-on-snow peak years in which IOP for the spring peak sequence was greater than IOP for the maximum rainfall sequence are of special interest (table 1, footnote 2). In those 6 years, rainfall during the spring peak sequences totaled less than that of the maximum rainfall period for the season. Even so, the low rainfall input was more than offset by the estimated melt due to slightly warmer temperatures. Different trends occurred in 2 years when snowmelt peaks prevailed (table 1, footnote 3). Then, a slight deficiency in heat energy may have been compensated for by a slightly greater rainfall input.

The fact that in those 8 years the occurrence of optimum rainfall-air temperature combinations resulted in higher indexes of outflow potential than either the rainfall or temperature maximum sequence is significant. Obviously, several meteorological periods of high generative capacity may occur by chance in any one spring runoff season. It is only when one of these weather events occurs concurrently with the ideal watershed condition—optimal snow cover and soil moisture—that the spring peak is reached.

Meteorological effects on spring peak conditions in two regional subbasins

Application of analysis techniques to regional subbasins was greatly restricted because of insufficient or inadequate climatic data. Rainfall records for one or more stations were available, but temperature readings were generally lacking. Only the analysis of frequency of occurrence and relative magnitude of meteorological events in relation to spring peak conditions was possible.

Criteria in selection of subbasins were (*a*) comparability with Benton Creek as to elevation range and forest cover, (*b*) length of streamflow record, and (*c*) proximity of gaging site to climatic stations. The two smallest drainages that came reasonably close to fulfilling the selection criteria were Boulder Creek (area 53 square miles), located 27 miles northeast of Benton Creek; and the upper South Fork of the Clearwater River (area 261 square miles), located 212 miles south-southeast. Boulder Creek has a greater spread in elevation than Benton Creek, from 2,600 to 6,435 feet; the upper South Fork occurs at a higher elevation, varying from 3,816 to 6,485 feet. Elevation ranges are 3,835 and 2,669 feet, respectively, while Benton Creek has a range of 2,850 feet. Both large subbasins are covered almost entirely by forests of varying age classes.

No single rainfall-reporting station near or within either drainage was maintained throughout the period of record—25 years on Boulder Creek and 21 years on the upper South Fork. Consequently, incomplete records from three stations were combined for each subbasin into the semblance of a continuous seasonal record of rainfall data (3). The source of rainfall information was the U.S. Weather Bureau Monthly Climatological Data. Stream records were obtained from Water Supply Papers and Idaho State water resource summaries published by the U.S. Geological Survey.

Uniformity of streamflow regimes

Timing and magnitude of spring peak volumes was considered, as a sidelight, in a test of uniformity of streamflow regimes on Benton Creek and two larger drainages. In statistical comparisons of the timing of spring peak volumes, coefficients of correlation were found to be very low—that is, −.117 for Benton Creek vs. Boulder Creek and +.526 for Benton Creek vs. South Fork of the Clearwater River. Agreement was very good if ranking of peaks by magnitude was ignored and the time of spring peak on Benton Creek was compared with a corresponding rise and fall on the other stream. The spring peak on Benton Creek, for instance, might be synchronized with the first, second, or fourth highest rise on Boulder Creek. The nonranked comparisons between Benton Creek-Boulder Creek and Benton Creek-South Fork gave high correlation coefficients of +.992 and +.989, respectively. This indicates that rise and fall of streamflow on the widely separated drainages—very dissimilar in area but comparable as to elevation range—responded concurrently to meteorological conditions. Magnitude of response or comparable ranking, on the other hand, varied considerably because of geographical variation in the intensity of the rainfall-temperature event and because of the differences in physical factors peculiar to the individual watersheds. For comparison, a general summary of spring peak volumes and generative capacities of weather events for the three drainages is given in table 2.

Frequency of occurrence of rain-on-snow and snowmelt peaks

Peak volumes on the subbasins were classified as being generated by rain-on-snow or snowmelt alone in the same manner as on Benton Creek. The percent chance of rain-on-snow or snowmelt alone contributing to the spring peak flow was computed as follows:

	Rain-on-snow	*Snowmelt*
Boulder Creek	24	76
South Fork, Clearwater River	52	48
Benton Creek	56	44

Note the preponderance of snowmelt peaks on Boulder Creek.

Some rainfall stations were quite far away from the larger basins; therefore, it was questionable whether the 6-day totals actually represented rainfall intensity in the drainage proper. For example, at Boulder Creek numerous peak volumes were preceded by what appeared to be rainfree or near rainfree sequences. Inspection of rainfall totals at Headquarters station for the same period preceding the peak volume on Boulder Creek strongly indicated, however, that Boulder rainfall stations probably indexed weather in the basin adequately. In fact, in only 2 years, 1957 and 1960, did rainfall totals for the two areas vary about the 0.50-inch mark, so as to affect the classification of peak volumes (table 2, columns 7 and 8).

A similar comparison with South Fork rainfall stations, located over 200 miles from Headquarters station, showed less agreement. In 6 of 7 years rainfall totals at South Fork exceeded 0.50 inch, thus defining the flood as rain-caused (table 2, columns 12 and 13 and footnote 1).

(3) The following weather stations and record years were used: Boulder Creek—Clark Fork, Idaho, 1941-1956; Cabinet Gorge, Idaho, 1957-1960; Troy 18N, Montana, 1961-1965. South Fork of the Clearwater River—Fenn Ranger Station, Idaho, 1945-1950, 1952; Elk City, Idaho, 1951, 1953 (April), 1954 (June), 1958-1965; Dixie, Idaho, 1953 (June), 1954 (April), 1957.

TABLE

Summary of spring peak volumes and generative capacities for three

Benton Creek				Boulder				
Year-month (1)		Spring peak volume (2)	Generative capacity of weather event (3)	Year-month (4)		Spring peak volume (5)	Generative capacity of weather event (6)	6-day rainfall (Boulder stations) (7)
		—*Area inches*—				—*Area inches*—		—*Inches*—
50	5	0.511	0.411	54	5	1.151	0.542	0.00
60	3	.428	.314	50	5	.730	.524	.00
57	5	.314	.261	55	5	.730	.501	.13
49	5	.436	.259	41	5	.651	.501	2.78
53	4	.369	.238	59	4	.744	.500	.81
52	4	.565	.226	45	5	.554	.461	.00
43	5	.366	.216	46	5	.744	.455	.12
55	5	.334	.199	64	5	.814	.446	.02
56	4	.547	.191	49	5	.786	.435	.00
54	5	.443	.191	56	5	.933	.419	.00
45	5	.324	.168	52	4	.630	.346	.00
65	4	.366	.164	53	5	.744	.330	.51
64	5	.314	.157	48	5	.905	.289	2.80
48	5	.410	.140	60	5	.681	.285	.29
61	5	.336	.133	43	5	.639	.235	.18
46	5	.314	.124	42	4	.421	.231	.17
63	5	.191	.115	65	5	.602	.216	.00
59	5	.237	.106	58	5	.564	.213	.05
58	5	.246	.096	62	5	.658	.190	.76
42	5	.139	.075	57	5	.730	.161	.51
62	5	.183	.053	61	5	.772	.156	.00
41	5	.081	.039	47	5	.627	.107	.00
51	5	.213	.038	51	5	.580	.096	.07
44	5	.057	.018	44	5	.256	.083	.14
47	5	.125	.017	63	5	.435	.081	.00

([1]) Only one of the rainfall totals of the comparison exceeded 0.50 inch.

Relative magnitude of rain-on-snow and snowmelt peaks

The highest peaks on Boulder Creek, as on Benton Creek, were generated by snowmelt alone. Eight of the 10 highest peak volumes occurred during rainfree or near-rainfree periods (fig. 2B). The same trend did not hold on the South Fork. The two highest floods, which occurred in 1948 and 1964, were associated with excessive rainfall (fig. 2C); snowmelt alone was responsible for fewer of the highest peaks than on the two northerly drainages.

Findings from the South Fork analysis appear to reject the hypothesis that rain-on-snow

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drainages studied, 1941-1965, *by descending order of generative capacities*

Creek	South Fork, Clearwater River				
6-day rainfall (Head-quarters) (8)	Year-month (9)	Spring peak volume (10)	Generative capacity of weather event (11)	6-day rainfall (South Fork stations) (12)	6-day rainfall (Head-quarters) (13)
—Inches—		*—Area inches—*		*—Inches—*	
0.00	64 6	0.523	0.231	1.90	0.97
.07	48 5	.527	.154	1.04	(1) .27
.07	56 4	.299	.149	.05	.07
3.14	62 4	.285	.145	.35	.06
.79	55 5	.271	.140	.08	.06
.23	50 5	.232	.133	.00	.02
.04	60 4	.217	.127	.00	.00
.02	65 4	.392	.118	.02	.02
.00	59 5	.237	.116	.60	(1) .40
.00	58 4	.185	.092	1.69	2.43
.00	52 4	.234	.087	.04	(1) .52
.69	57 5	.289	.078	1.88	2.50
1.71	45 5	.187	.073	.51	(1) .23
(1) .66	63 5	.202	.070	.82	(1) .10
.17	54 4	.130	.067	.65	(1) .18
.25	46 4	.171	.061	.02	.11
.11	53 4	.190	.053	1.83	2.04
.21	49 5	.284	.042	.22	.05
2.02	47 5	.281	.036	1.66	(1) .48
(1) .28	61 5	.171	.024	.15	.00
.00	51 5	.170	.022	.86	.57
.14					
.10					
.30					
.00					

during the spring snowmelt period *does not* create a more critical peak flow condition. Is the upper South Fork of the Clearwater River unique in this respect? Have the vagaries of weather in the past 25 years spared Benton Creek and Boulder Creek the rainfall concentrations capable of producing a record-breaking rain-on-snow flood? Evidence, for the present at least, does not provide a concise answer to these questions.

Summary

Benton Creek analysis

1. Slightly more than one-half of the spring peak volumes were associated with rain-on-snow events.
2. The timing of maximum spring discharge, for years of rain-on-snow peaks, was more closely synchronized with the ending day of maximum rainfall than it was, for years of snowmelt peaks, with the ending day of maximum temperatures.
3. In some years heavy rainfall, accompanied by relatively high air temperatures, affected the generation of spring peak runoff, whereas in other years heavy rainfall had a strong suppressing effect on air temperature, so that snowmelt contribution to runoff was probably less, and spring peak volumes did not occur.
4. The highest peak runoff of record was a snowmelt event.

Boulder Creek-South Fork, Clearwater River analysis

1. Three-fourths of all the spring peak volumes studied in Boulder Creek were associated with snowmelt alone; in the South Fork, 52 percent of the spring floods were associated with rain-on-snow events.
2. The highest generated peaks in Boulder Creek were associated with clear-weather melt; for a similar period in the South Fork rainfall events had higher generative capacity.

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