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HYDROLOGIC IMPACTS OF A LARGE-SCALE MOUNTAIN PINE BEETLE (*DENDROCTONUS PONDEROSAE* HOPKINS) EPIDEMIC[1]

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ABSTRACT: The Jack Creek watershed, a 133 km^2 (51.5 mi^2) drainage in southwestern Montana, was impacted by a mountain pine beetle (*Dendroctonus ponderosae* Hopkins) epidemic in 1975-1977 which killed an estimated 35 percent of its total timber. Ana'yses of USGS streamflow data for four years prior to and five years after mortality suggest a 15 percent post-epidemic increase in annual water yield, a two- to three-week advance in the annual hydrograph, a 10 percent increase in low flows and little increase of peak runoff.
(KEY TERMS: water yield; southwestern Montana; mountain pine beetle; lodgepole pine.)

INTRODUCTION

Forested ecosystems are affected regularly by catastrophic events such as wildfire or decimation by insects or disease. Most watershed research has focused on the impacts of forest management activities and has been limited to small areas. This is not due to lack of interest in abrupt natural changes in hydrologic systems but rather to the lack of opportunity to make observations before and after large areal disturbances. Indeed, Harr (1981) has commented on our need for large-scale studies and observations.

One of these rare opportunities is present in Jack Creek in southwestern Montana. The mountain pine beetle has always been present in this drainage, but tree mortality has been limited. Between 1975 and 1977, a massive pine beetle outbreak occurred in the drainage. By 1978, mortality ranged from 50 percent to 60 percent of commercial timber (greater than 18 cm D.B.H.) to 35 percent of the total growing stock. The results of small watershed research lead us to expect water yield increase following such a disturbance. We might also expect the timing of snowmelt runoff and the magnitude of peak discharges to change. This paper attempts to reveal if changes have occurred in Jack Creek hydrology and if those changes support the few observations that have been made on the hydrologic impacts of large-scale vegetation disturbance.

THE WATERSHED

Jack Creek is a third-order tributary of the Madison River (Figure 1). Its headwaters form along the Madison Range Divide. Part of the drainage borders the Spanish Peaks Primitive Area, and portions were recently included in the new Lee Metcalf Wilderness. Highest elevations in the drainage are over 3000 meters.

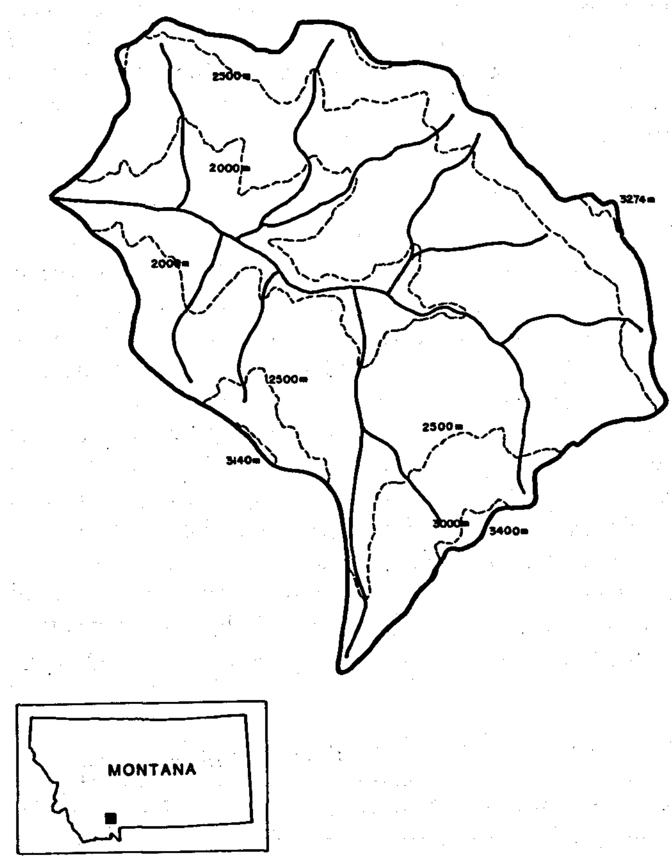

Figure 1. Jack Creek Watershed.

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Like much of Montana, the drainage has been in "checkerboard" ownership, about evenly divided between the Burlington Northern Corporation and the Beaverhead National Forest. There are some small private holdings and developed recreation sites, but the drainage has had little disturbance by forest management activity.

The highest elevations exhibit true alpine ecosystems. The subalpine timber zone (about 85 percent of the drainage) is composed of lodgepole pine/subalpine fir at higher elevations, lodgepole pine/Douglas-fir at lower elevations and lodgepole pine/Engelmann spruce in the riparian zones and frost pockets. Lodgepole pine is always a major component of the stands. The USDA Forest Service estimates that 75 percent of the commercial timber in the drainage is lodgepole pine and that 80 percent of this was dead by 1978. The mortality was uniform in the drainage, and accounted for 35 percent of timber in all age classes.

In September 1973, the U.S. Geological Survey (USGS) began gaging Jack Creek for daily discharge data. The gage is located on the Beaverhead National Forest about 14.2 km east of Ennis, Montana, at an elevation of 1707 m. The drainage area above the gage is 133 km^2 (51.5 mi^2). Stream records are considered "good" by the USGS. This means that about 95 percent of the daily discharge values are within 10 percent of the true value. There is no regulation or diversion above the station.

HYDROLOGIC ANALYSES

Monthly and total water yields for 1974-1982 appear in Table 1. It is futile to try to compare monthly and total water yields directly because we have no reliable precipitation information. As with many forested watersheds in Montana, precipitation inputs must be estimated from valley observations often made a considerable distance away. In this case, the nearest climatological station is at Ennis, Montana, 14.2 km from the watershed at 1500 m. Average annual precipitation at Ennis for the corresponding period of hydrologic record was 347 mm. Lowest precipitation occurred in water years 1974 (234 mm) and 1979 (256 mm). Lowest water yields occurred in water years 1977 and 1979 and highest water yields in water years 1974 and 1982. This poor correlation limits the use of Ennis data for estimating precipitation in the Jack Creek watershed.

DOUBLE-MASS ANALYSIS

The double-mass plot is used routinely to check the consistency of many kinds of hydrologic data by comparing data from a single station with those of a pattern composed of the data from several other stations in the area. Double-mass analysis was conducted according to USGS procedures (Searcy and Hardison, 1960).

Four USGS gaged watersheds were chosen to provide average area runoff for the analysis. These watersheds were:

1. Willow Creek (USGS No. 06035000; 217 km^2).
2. Madison River (USGS No. 06041000; 5662 km^2).
3. Ruby River (USGS No. 06019500; 1393 km^2).
4. Gallatin River (USGS No. 06043500; 2137 km^2).

Runoff data for the double-mass plot (Figure 2) appear in Table 2. All watersheds are within a 100-km radius of Jack Creek, which helps ensure climatic uniformity. The consistency of discharge data for these watersheds was not determined. Pine beetle outbreaks in this part of Montana have been widespread, but the Willow Creek and Ruby River drainages are not heavily timbered, and the Gallatin and Madison drainages are probably large and diverse enough to mask any impacts from similar disturbances.

Despite the brief period of record, a distinct "break" appears in the relationship. Note that the "break" occurred after water year 1977, a phenomenon consistent with the observations of the timing of the mountain pine beetle epidemic and tree mortality.

The lack of long-term monitoring precludes assigning any statistical significance to the break using analysis of covariance. Nevertheless, reduced evapotranspiration should result in increased water yield. The pre-epidemic relationship has a slope of about 1.15. The post-epidemic relationship has a slope of about 1.3. While this is an improper use of the double-mass plot, the change of slope indicates about a 15 percent increase in average annual water yield attributable to the mortality of the watershed's lodgepole pine component. This increase is nearly identical to the one reported by Love (1955), and

TABLE 1. Jack Creek Monthly and Total Water Yields – Water Years 1974-1982 (mm).

Water Year	October	November	December	January	February	March	April	May	June	July	August	September	Total
1974	12	9	9	8	6	8	21	52	148	52	26	15	365
1975	12	9	9	8	7	6	7	21	98	77	29	17	300
1976	17	12	11	9	8	8	14	96	90	50	25	18	358
1977	14	10	10	8	7	7	17	34	59	24	15	13	218
1978	13	9	9	8	6	10	22	65	104	58	26	21	351
1979	16	12	10	8	7	7	13	57	66	33	17	12	259
1980	11	8	8	6	6	6	23	68	58	34	18	16	262
1981	12	10	9	7	6	7	21	75	98	42	20	13	320
1982	13	10	9	8	7	8	18	78	127	59	29	20	385

substantiated by Bethlahmy (1974, 1975) following an Engelmann spruce beetle epidemic of similar proportion in the White River (Colorado) watershed.

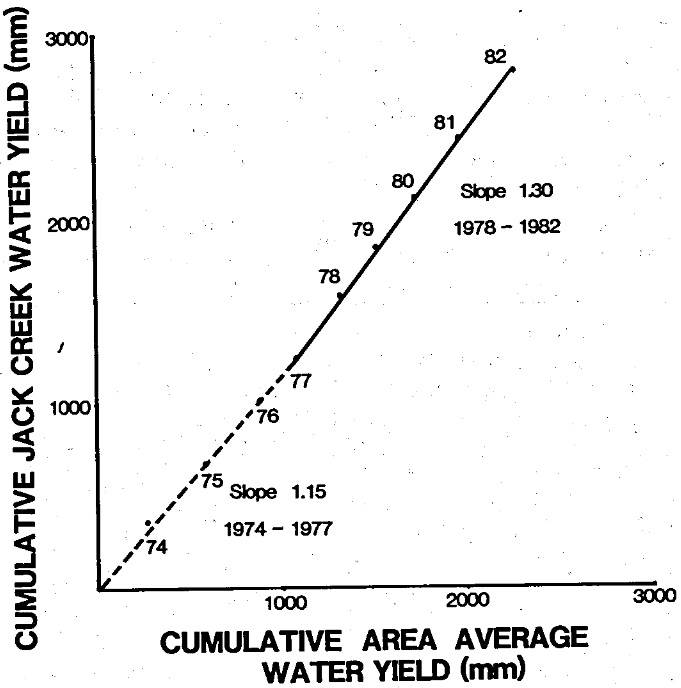

Figure 2. Double-Mass Plot for Jack Creek and Four Larger Southwestern Montana Drainages.

ANNUAL HYDROGRAPH

Pre- and post-epidemic annual hydrographs appear in Figure 3. A water yield of 305 mm (32,960 acre-feet) was chosen because it approximates the mean observed water yields of both the pre- and post-epidemic periods. The monthly water yield distribution of both periods was determined and appears in Table 3. The annual water yield was then partitioned according to these distributions.

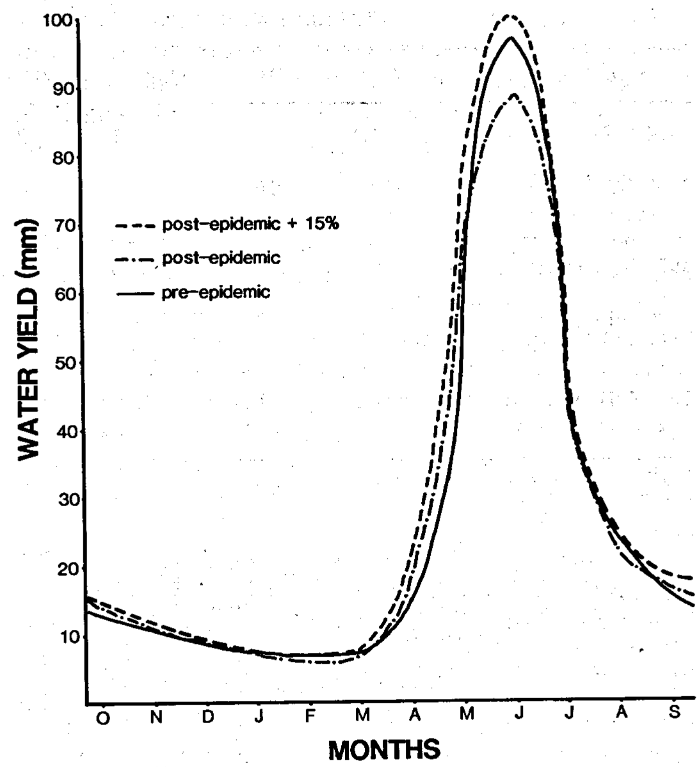

Figure 3. Pre- and Post-Epidemic Annual Hydrographs for Jack Creek.

The results are typical snowmelt-dominated hydrographs and represent a classic example of snowmelt desynchronization. There is no difference between low flow portions of the hydrographs (September through February). Snowmelt timing has been advanced one to two weeks because of reduced soil-moisture recharge requirements and the mortality-induced changes in canopy cover. The June water yield has been reduced by about 10 percent. Since the area under both curves is equivalent to 305 mm of runoff, the snowmelt peak was widened to accommodate the reduced June runoff.

TABLE 2. Runoff Data for the Double-Mass Plot (mm).

Water Year	Willow Creek	Madison River	Ruby River	Gallatin River	Area Average	Cumulative Area Average	Cumulative Jack Creek
1974	168	299	125	462	264	264	365
1975	313	338	162	467	320	584	665
1976	241	346	148	496	308	892	1023
1977	105	254	108	278	186	1078	1241
1978	145	287	142	381	239	1317	1592
1979	123	243	100	309	194	1511	1851
1980	173	260	128	332	223	1734	2113
1981	224	259	117	359	240	1974	2433
1982	261	322	153	discontinued 455 (est.)	298	2272	2818

TABLE 3. Monthly Distribution of Water Yields in the Pre- and Post-Epidemic Periods.

Water Years	October	November	December	January	February	March	April	May	June	July	August	September
1974-1977 (percent)	4.4	3.3	3.1	2.7	2.2	2.4	4.8	16.4	31.8	16.4	7.7	5.1
EXAMPLE (mm) (total = 305 mm)	13	10	9	8	7	7	15	50	97	50	23	16
1978-1982 (percent)	4.1	3.1	2.8	2.4	2.0	2.4	6.1	21.8	28.7	14.3	7.0	5.2
EXAMPLE (mm) (total = 305 mm)	14	10	9	7	6	7	19	66	88	44	21	16
EXAMPLE + 15% (mm) (total = 350 mm)	14	11	10	8	7	8	21	76	101	50	25	18

NOTE: Values rounded to nearest 0.1 percent and whole mm.

If we accept the double-mass analysis suggestion of an actual 15 percent increase in average annual water yield after the epidemic, the post-epidemic hydrograph should increase by 15 percent. The 305 mm example pre-epidemic water yield is now compared to a 350 mm post-epidemic water yield (also on Table 3 and Figure 3). Desynchronization is still observed. Snowmelt runoff timing has been advanced two to three weeks. There is essentially no difference in the June water yields, and the recession limb of the hydrograph has not shifted in time from the pre-disturbance state. Fall and winter low flows have been increased by about 10 percent. These hydrographs are strikingly similar to the pre- and post-logging hydrographs observed during the Fool Creek experiment in Colorado (Troendle, 1983). However, in that 2.89 km^2 watershed, 50 percent of the timber was harvested (vs. a 35 percent reduction of growing stock in Jack Creek), causing an estimated 40 percent increase in annual water yield.

Although the magnitude of average monthly flows may not be related to peak instantaneous discharges or even daily average discharges (Megahan, 1979), the minor difference between pre- and post-epidemic June discharge is at least consistent with Helvey and Tiedemann's (1978) failure to detect peak discharge changes following a Tussock moth defoliation of the Umatilla River drainage in Oregon. The USGS records indicate, however, that highest daily discharges occur in both the last two weeks in May and the first two weeks in June. The post-epidemic hydrograph indicates substantial May water yield increase, so caution must be used before drawing absolute conclusions about impacts on peak discharges.

CONCLUSIONS

The data suggest that the following changes have occurred in the hydrology of Jack Creek after a mountain pine beetle epidemic:

1. Double-mass analysis indicates a change in annual water yield which coincides with the timing of the pine beetle epidemic and subsequent tree mortality. The death of 35 percent of all timber in the drainage has apparently produced an average increase in annual water yield of about 15 percent. The reduction of evapotranspiration and interception loss following mortality and needle-fall is probably similar to that produced by timber harvest of the same magnitude.

2. Annual hydrographs indicate that post-epidemic snowmelt timing has been advanced two to three weeks. Because of desynchronization, even the estimated 15 percent increase in post-epidemic average annual water yield does not produce a great difference in the highest monthly (June) average water yield. This suggests that, in the absence of major site disturbance and soil compaction, timber harvest spread uniformly throughout a large drainage may not increase peak discharges. Harr (1976) argued that even complete clearcutting produces only small increases in peak flow rates in western Oregon, but this has remained a controversial subject in the northern Rocky Mountain region where it is thought that water yield increases may accelerate channel and bank erosion.

OPPORTUNITIES FOR CONTINUED OBSERVATION

Negotiation for a major land "swap" between the Forest Service and Burlington Northern to consolidate ownership in Jack Creek has been completed, and salvage logging will occur in the future. The USGS recently decided to discontinue gagging Jack Creek because of budget limitations. The Montana Department of Natural Resources and Conservation will assume responsibility for the continuation of data collection.

These actions will allow assessment of road construction and harvesting hydrologic impacts in the drainage and future evaluation of the rates of vegetative/hydrologic recovery after this major disturbance.

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