PERSISTENCE OF SOIL MOISTURE CHANGES RESULTING FROM ARTIFICIALLY EXTENDED SNOWMELT

806-86

By

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INTRODUCTION

The snowpack in the Sierra Nevada and more northern ranges is effectively an enormous water storage system. An estimated 51 percent of surface runoff in California is derived from the snowpack zone (Anderson, 1963). Since both the amount of water stored and the timing of its release are critical to California's water supply, methods of augmenting winter snowpack and delaying melt have been discussed for at least 70 years (Church, 1912; Kattelmann, 1982). Cloud seeding was begun by public utilities in the 1950's, and proponents have claimed a 32% increase in precipitation from cold westerly storms in the Lake Almanor watershed (Mooney and Lunn, 1969) and a 6% increase in runoff from the Kings River watershed (Henderson, 1966). Additionally, it has been suggested that cutting the upper elevation forests in small openings or narrow strips would both concentrate the snow in the cut areas and delay melt (Church, 1912; Anderson, 1956). Research in California, Colorado, and Alberta indicate that snow redistribution following forest harvest is a common phenomenon (Anderson and Gleason, 1959; Troendle and Leaf, 1980; Swanson and Golding, 1982). In the Sierra Nevada, such forest management practices have resulted in an estimated 16-day difference in the end of snowmelt between small openings and large open areas (Anderson, 1963).

The often unstated assumption in these efforts is that the additional increment of snow due to either redistribution (following forest harvest) or cloud seeding will be transformed into additional runoff. For optimal use, this increase in streamflow should occur late on the recession limb of the snowmelt hydrograph, after reservoir operators have ceased to spill excess winter runoff.

To test this assumption, the period of snowmelt on four 960 m^2 circular plots was artificially extended by the surficial application of approximately 2.5 cm of water per day for 10 to 12 days (2.5 cm of water is a conservative estimate of daily spring snowmelt in sites similar to the study area in central Sierra Nevada). The resultant changes in pore pressure, soil moisture potential, and soil water content in these plots and adjacent control areas were monitored throughout summer and early autumn 1985. The proportion of augmented water leaving the 50-ha watershed was monitored using a sodium bromide tracer. This paper reports only the preliminary results of changes in pore water pressure and soil water content.

METHODS

The study site was Onion Creek 1, a forested research watershed in the central Sierra Nevada ranging in elevation from 1870 to 2200 m. Four treated and three control plots were located roughly parallel to the creek about 80 m apart on a northeast slope. Of the four treated plots, two were intensively sampled. In these two plots eight sets of tensiometers were installed, typically at three depths (approximately 110, 80 and 30 cm): two sets were located where snowmelt was being simulated, three sets were at the bottom of the slope within 3 m of the stream, and three sets were at a midslope location. In the presumed absence of any impeding soil horizon, a single open standpipe piezometer was installed at approximately 1 m depth adjacent to each nest of tensiometers. Soil moisture resistance (gypsum) blocks were also installed in groups of three in the two intensively sampled plots at two depths (approximately 50 and 95 cm) at both upslope and near stream locations. In the two other treated plots, a piezometer and two tensiometers were installed at each of three locations.

Two control plots were placed at a similar slope position immediately upstream of the two intensively sampled plots, with the third control plot adjacent to one of the less intensively instrumented irrigated plots. The control plots also had sets of tensiometers at three depths--for practical reasons limited to two sets upslope, one set midslope, and two sets near the stream (downslope). Each tensiometer nest had an associated piezometer. Sets of soil moisture blocks were also installed in the two control areas adjacent to the

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intensively sampled plots at the same depths and slope locations. Tensiometers and piezometers were read daily until mid-June, then three times a week. Resistance blocks were measured weekly until late July, then twice a week. Bentonite was placed around the instruments in order to prevent vertical percolation of water.

The network of tensiometers served as a relatively sensitive measure of increased soil matric suction from saturation (0 kPa) through field capacity (-33 kPa) then to the limit of the instrument (typically -60 kPa). The soil moisture resistance blocks were intended to monitor the drying curve from the -60 kPa limit of the tensiometers to permanent wilting point, or -1500 kPa.

Given similar soils in the treated and control plots, the shape of the drying curve for the tensiometers and soil moisture blocks should be nearly identical. If the simulated snowmelt did have a persistent effect, the drying curves in the treated areas should be offset in time from those in the control areas. Since the time interval between readings was not consistent, it was necessary to evaluate the presence and magnitude of a time lag between treated and control plots by comparing the Pearson product moment correlation with no time lag with the correlations at time lag t. If the maximum correlation at time lag t (t being either positive or negative) was larger than the correlation at time lag 0 and outside the 95% confidence interval for the correlation at time lag 0, the time lag was accepted as significant. When data from several instruments were available for a given depth and slope location, average values were used.

Water was sprinkled on the test plots to simulate extended snowmelt; therefore, the experiment began on 31 May 1985 when about 10% snow cover remained. 2.5 cm of water was then applied daily using 360° impact sprinklers over a 12-hour period for each of 12 days in plot 1 and 11 days in plot 2.

RESULTS

Basic soil and topographic data pointed out the diversity within the experimental area. While conditions between the two intensively-sampled plots (plots 1 and 2) and their adjacent control areas (controls 1 and 2, respectively) were as homogeneous as possible, differences between the two sites were considerable. Plot 2 had coarser and stonier soils than plot 1 with minimal development of soil horizons and a higher hydraulic conductivity. The slope at plot 2 was steeper than at plot 1, and the sprinklers used to simulate snowmelt were higher upslope. Hence, the results are presented first on a plot basis, then aggregated into "treated vs. control."

As might be expected, water levels in the piezometers located within the perimeter of the sprinkled area ("upslope") increased by 170 to 400 mm within three days after sprinkling began (fig. 1). These higher water levels generally were maintained until sprinkling ceased, then dropped precipitously. The two piezometers located just two meters downslope of the sprinkled area in plot 1 ("midslope") showed a similar response, while the midslope and downslope piezometers in plot 2 continued to indicate no positive pore water pressures for the duration of the sprinkling. That water levels in two downslope sites in plot 1

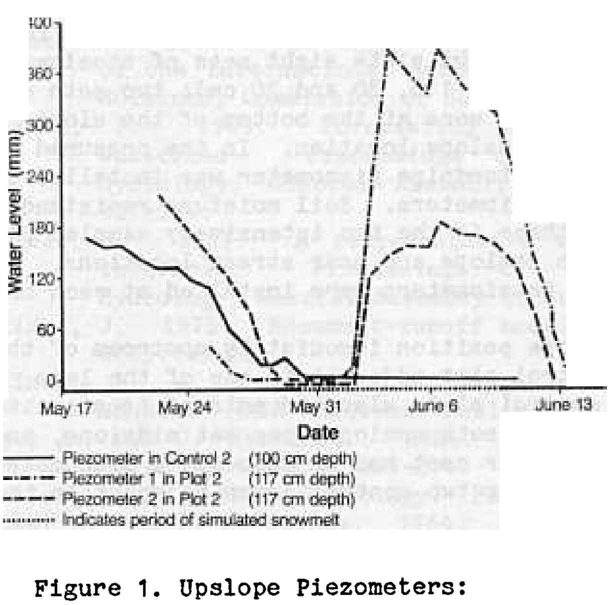

Figure 1. Upslope Piezometers:
Plot 2-Control 2

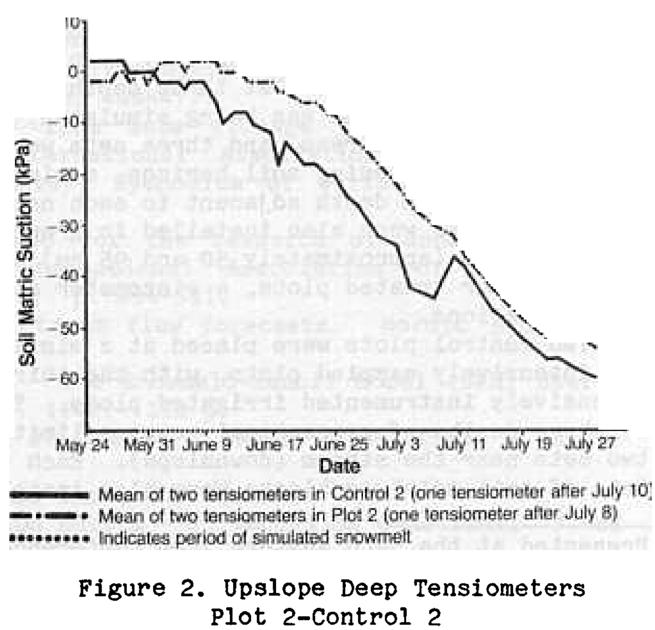

Figure 2. Upslope Deep Tensiometers
Plot 2-Control 2

Table 1. Maximum Correlations and Estimated Lag in Days

		Upslope			Downslope		
		Deep	Mid-depth	Shallow	Deep	Mid-depth	Shallow
Tensiometers							
Plot 1-control 1	r	--	.996	.950	.992	.997	.993
	lag	--	13	22	14	6	6
Plot 2-control 2	r	.983	.97	.978	.978	.983	.995
	lag	9	10	8	-3	0	12
Soil Moisture Blocks							
Plot 1-control 1	r	.996	--	.993	.999	--	.990
	lag	22	--	22	17	--	17
Plot 2-control 2	r	.999	--	.992	.997		.985
	lag	0	--	11	0		11

declined much less rapidly than the adjacent control piezometers suggests that the simulated snowmelt upslope was affecting the water table near the stream.

Many of the tensiometers in the treated plots also indicated a response to the sprinkling. Again, this response depended on the location and depth of the instruments. In the upslope area, all correlations between treated and control tensiometers improved when the control tensiometers were lagged by 6 to 14 measurement periods (about 8 to 22 days). These lagged correlations differed significantly from the correlations at time lag 0 (table 1). The mean values are shown for the two deep tensiometers in the upslope areas of plot 2 and control 2 (fig. 2).

Results from the downslope tensiometers point out the differences between sites. In the plot 1-control 1 comparisons, maximum correlations for deep, mid-depth and shallow tensiometers were obtained with 14-, 6-, and 6-day lags, respectively. These correlations were all outside of the 95% confidence interval for the correlation with no time lag. For the downslope sites in plot 2-control 2, the deep tensiometers indicated that the soil dried out slightly more rapidly in the treated area than in the control area, the mid-depth tensiometers showed no significant differences, and the shallow tensiometers showed a slower rate of drying in plot 2 than control 2 (table 1). When the downslope data from the two treated plots were combined and compared with the two control plots, all correlations fell within the 95% confidence interval of the correlation with no time lag. Correlations for the unaggregated tensiometer data with no time lag ranged from 0.86 to 0.98.

The gypsum block data supported the overall trend of the piezometer and tensiometer data, but differed in the time lag needed to maximize treated-control correlations (table 1). Unlagged correlations ranged from 0.67 to 0.99, but a correlation of 0.99 was obtained for all comparisons when a lag of 0 to 22 days was introduced (table 1). While it is difficult to relate these changes in electrical resistance to a precise change in soil water content, the data are consistent in recording a pattern of change in resistance at each site and hence a decrease in soil wetness.

DISCUSSION

The three types of instruments--piezometers, tensiometers, and gypsum blocks--were all installed in May 1985, but their responses to the simulated snowmelt tended to occur over different time spans. Water levels showed the maximum response to sprinkling within 3 days and by late June water levels in most of the piezometers were zero. Because the soil was near saturation when sprinkling began, the tensiometers in the treated plots showed only a small response during the period of sprinkling and the difference between treated and control tensiometers was often more marked in July. Similarly, most of the increase in the resistance of the gypsum blocks occurred in early August, nearly two months after the simulated snowmelt treatment. Taken together, these sets of instruments suggest that a treatment effect occurred and persisted through mid-August. Such effect was particularly true in plot 1, where the effect of sprinkling in the upslope area apparently extended downslope for 10 to 15 m to the stream channel. In this downslope area the treatment effect seemed attenuated, but with some indication that this attenuation was less at 1 m depth than for the upper part of the soil profile (table 1). Indeed, the treatment effect observed in the top 50 cm of soil may be due to the sustained high water content below this layer.

Somewhat greater difficulty arises in reconciling the results from plot 2-control 2. In the upslope area, the piezometers and deep tensiometers demonstrated a response to the simulated snowmelt, but this apparently was less persistent than in plot 1. The steeper slope and coarser soils likely resulted in more rapid drainage. Given these factors and the distance of the sprinklers from the stream, it should not be surprising that sprinkling had no apparent effect on soil water conditions at the downslope piezometers, tensiometers, and gypsum blocks. The only exceptions were the shallow gypsum blocks and shallow tensiometers; and lacking other evidence, this condition is tentatively ascribed to site differences rather than the treatment itself.

In summary, the preliminary results from this study strongly suggest that a shift in the date of final snowmelt creates a soil moisture differential which may persist through most of summer, despite the transpiration demands of the surrounding forest trees. Since summer baseflow in a first-order watershed such as Onion Creek 1 is dependent upon groundwater levels and soil moisture content, any temporal shift in the drying curve results in a marginally higher rate of delivery to the stream, and a physical basis for claiming that snowpack augmentation or redistribution can increase summer streamflows.

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