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Summer Evapotranspiration Trends As Related to Time after Logging of Forests in Sierra Nevada

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Abstract. The quantity of summer soil moisture lost from logged forest openings was related to the length of time since the creation of the opening, in the subalpine forest zone of the Sierra Nevada west side, near the Central Sierra Snow Laboratory, California, at an elevation of 6000 to 7000 feet. Soil moisture depletion was measured in forest openings which were created in 1959, 1955, 1950, and 1948, and in the forest surrounding these openings. Soil moisture was found to be uniformly near field capacity in all plots in early June. Later soil moisture was lost most rapidly from the forested parts of the plots and at progressively slower rates toward the center of the openings. The rate of moisture loss was greatest in early summer and then decreased as the availability of moisture decreased. Maximum soil moisture depletion occurred in early September, nearly all the available moisture being depleted from the forest. The quantity of residual soil moisture increased toward the center of the openings. At the period of maximum soil moisture depletion, openings 1 year old were found to have 6.9 inches more soil moisture per 4 feet of soil than the surrounding forest had, which is an expression of the quantity of moisture saved as a result of the logging operation. In openings 5 years old, the saving has decreased to 2.9 inches, after 10 years to 1.2 inches, and after 12 years to 0.7 inch. A projection of the regression indicates that the moisture saving at maximum depletion will become negligible 16 years after cutting.

INTRODUCTION

By 1980 the demand for fresh water in the United States is expected to reach 600 billion gallons a day-an amount equal to the present fresh water supply [*U. S. Public Health Service, 1958*]. When demand exceeds supply, as it already has in many parts of California, efforts to increase the supply will become crucial to economic growth. One possible approach is to develop timber management practices that will increase the quantity while still maintaining the quality of the water flowing from mountain watersheds and assure delivery to the consumer at the desired time.

If we are to manage our forests to increase water values, we must harvest timber in a manner and at times that will maximize the water value to be derived. In this study an attempt was made to relate the quantity of summer soil moisture loss from logged forest openings to the length of time since the opening was created and to determine the seasonal pattern of soil moisture depletion.

THE STUDY AREA

The study area was in some of the better commercial subalpine forest sites on western slopes of the Sierra Nevada, at 6000 to 7000 feet elevation. The forest consisted chiefly of California red fir and lesser amounts of lodgepole pine, white fir, and Jeffrey pine.

Annual precipitation averages 51 inches. Of this amount, 42 inches of water are present in the maximum snowpack, on or about April 1. The summer soil moisture depletion period generally extends from June to October. Total summer precipitation averages less than 3 inches for the 4-month depletion period, occurring generally as light showers, with an occasional high-intensity convection storm of short duration.

The general soil pattern of the area is variable in both type and depth. The study was restricted to sites located on the Lytton soil series [Nelson, 1957]. The Lytton series are well-drained, cobbly sandy loam textured forest soils which have been developed in place from andesitic agglomerate rock. The effects of glacial action and the amount of glacial debris are generally negligible, except in localized areas where the soil is classified by parent material phases. These phases of the Lytton soil series consist of significant amounts of morainal granitic erratics, basaltic rocks, and rhyolitic rocks. For the purposes of this study the sites have been grouped by field

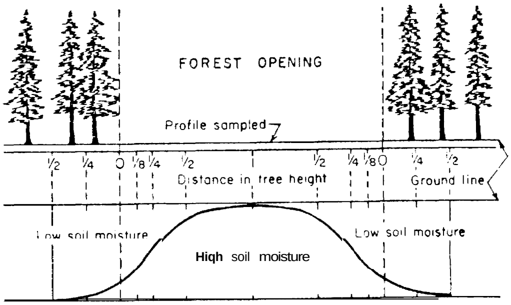

Fig. 1. Location of soil moisture sampling points within a typical forest opening and a hypothetical profile of soil moisture content within that opening at maximum depletion.

capacity characteristics. Only moisture depletion from soils having a field capacity range of 16 to 18 inches of water per 4 feet of soil are discussed.

METHODS

Soil moisture depletion was measured during the summers of 1960 and 1961 at sampling sites in ten forest openings created by logging in 1959, 1955, 1950, and 1948 and in the forest surrounding these openings.

The criteria for selecting sample sites were: (a) comparable timber stands on both the opening and surrounding forest before logging, (b) well-drained soils with no water table evident, and (c) a stand of trees with little or no evidence of logging and with a definite forest boundary around the logged opening.

Sampling points were on transects based upon a logarithmic progression from the forest into the opening and into the forest on the other side of the opening. If no definite forest boundary existed on the other side, the transect extended from the forest into the approximate center of the opening. Sampling points were spaced logarithmically along the transect in terms of the average height of the dominant and codominant trees surrounding the plot (Figure 1). The value for tree height (H) for all plots studied was found to be 90 feet. Expressing the size of openings in units of tree height (H) has been found useful in other studies [*Moulopoulos*, 1956; *Anderson,* 1956].

Soil moisture was measured with a neutron soil moisture probe and portable scaler. Readings were made at a depth of 6 inches and thereafter at l-foot intervals to bedrock. After summer and fall precipitation, measurements at the 3- and 9-inch levels were also taken. Each transect was sampled at monthly intervals throughout the summer moisture depletion season and into the fall moisture recharge period.

RESULTS

Seasonal trend of soil moisture depletion in a recent opening. By June 22, soil moisture had attained field capacity (35 per cent by volume) nearly everywhere within the forest opening logged in 1959 (Figure 2). In isolated areas, particularly near the southern forest border, the soil was above field capacity at this time. These were areas where snow had accumulated in greater than average depth during winter, and where spring melt was consequently delayed. Hence, melt water was added to the soil there for a longer than average period of time, and the soil drained to field capacity at a later date there than in other parts of the plot. Toward the center of the opening, the soil remained at field capacity except in the top 6 inches.

Less than a month later, most of the melt water in the surface foot of soil beyond a distance $\frac{1}{2}H$ within the forest (one-half times the average height of surrounding dominant and codominant trees from the edge of the opening) had been lost bv evapotranspiration. Soil moisture became progressively greater toward the center of the opening. About half of the available moisture had been depleted from the soil within the forest and 10 to 20 per cent from the opening, After June 22, 0.02 inch of precipitation was recorded at the site.

By August 10 only 10 per cent of the available moisture remained within the forest. The soil moisture gradient at the south edge of the opening was greatest within the opening, at a point about $\frac{1}{8}H$, or about 11 feet beyond the tree border. At the north edge of the opening the moisture gradient appeared to be greatest at a distance of about $\frac{1}{8}H$ within the forest. Only a trace of precipitation was recorded after July 20.

Maximum total seasonal soil moisture depletion had occurred by September 9. Nearly all available moisture had been depleted from the forest, but soil moisture increased abruptly toward the center of the opening. Soil moisture loss within the opening was confined to the upper 6 inches of soil. Even at this late date the central part of the opening was only slightly below field

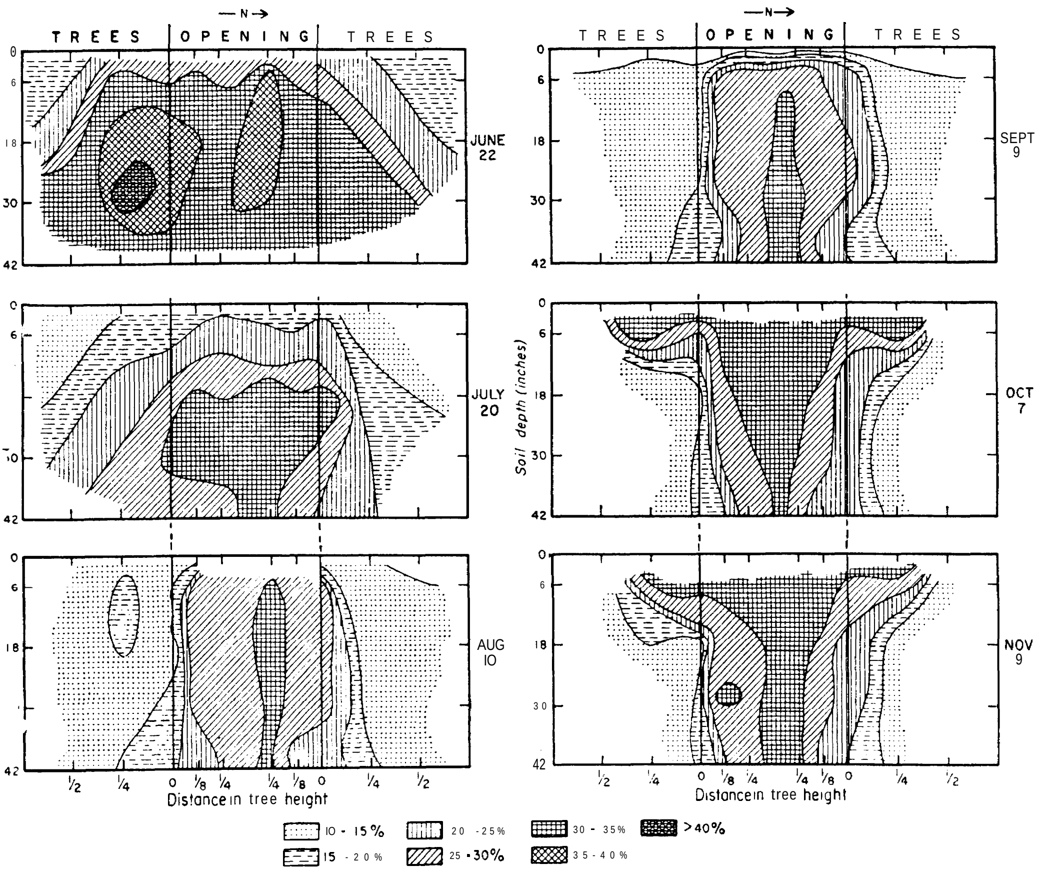

Fig. 2. Soil moisture in per cent by volume at 0- to 42-inch soil depths in plot L-la, logged in 1959, for various dates through the summer moisture depletion season and into the fall moisture recharge season, 1960 to 1961.

capacity. Again, the northern or downslope part of the plot had a smaller vertical gradient of soil moisture than did the southern part of the plot. After August 10, 0.01 inch of precipitation was recorded. It is perhaps significant to note that total June to September precipitation was 0.03 inch, which is substantially less than the long-term average of about 3 inches for this period.

On October 7 an inch of rain fell on the soil in the center of the opening, wetting it to field capacity throughout the 4-foot depth. Yet within the forest, only the top foot of soil showed any degree of wetting. More water was needed to recharge the dry forest soil because a greater quantity of moisture was lost from this area during the depletion period than from the opening, and less precipitation reached the soil owing to interception by the tree canopy.

By November 9 an additional 1.3 inches of precipitation had fallen. Within the plot the only apparent change in the soil moisture pattern was a slight movement of moisture to lower depths.

Loss of moisture from logged openings increased with the age of the opening (Figure 3). In the more recently created openings, moisture loss was limited to surface evaporation from bare soil because few seedlings were established by this time and their use of moisture was small Moisture loss by evaporation began at the soil surface and gradually proceeded to a greater depth. The dry surface acted as an insulator against further loss through surface evaporation. In the older openings, moisture was lost through surface evaporation and through transpiration by the vegetation which had become established in the opening. The availability of

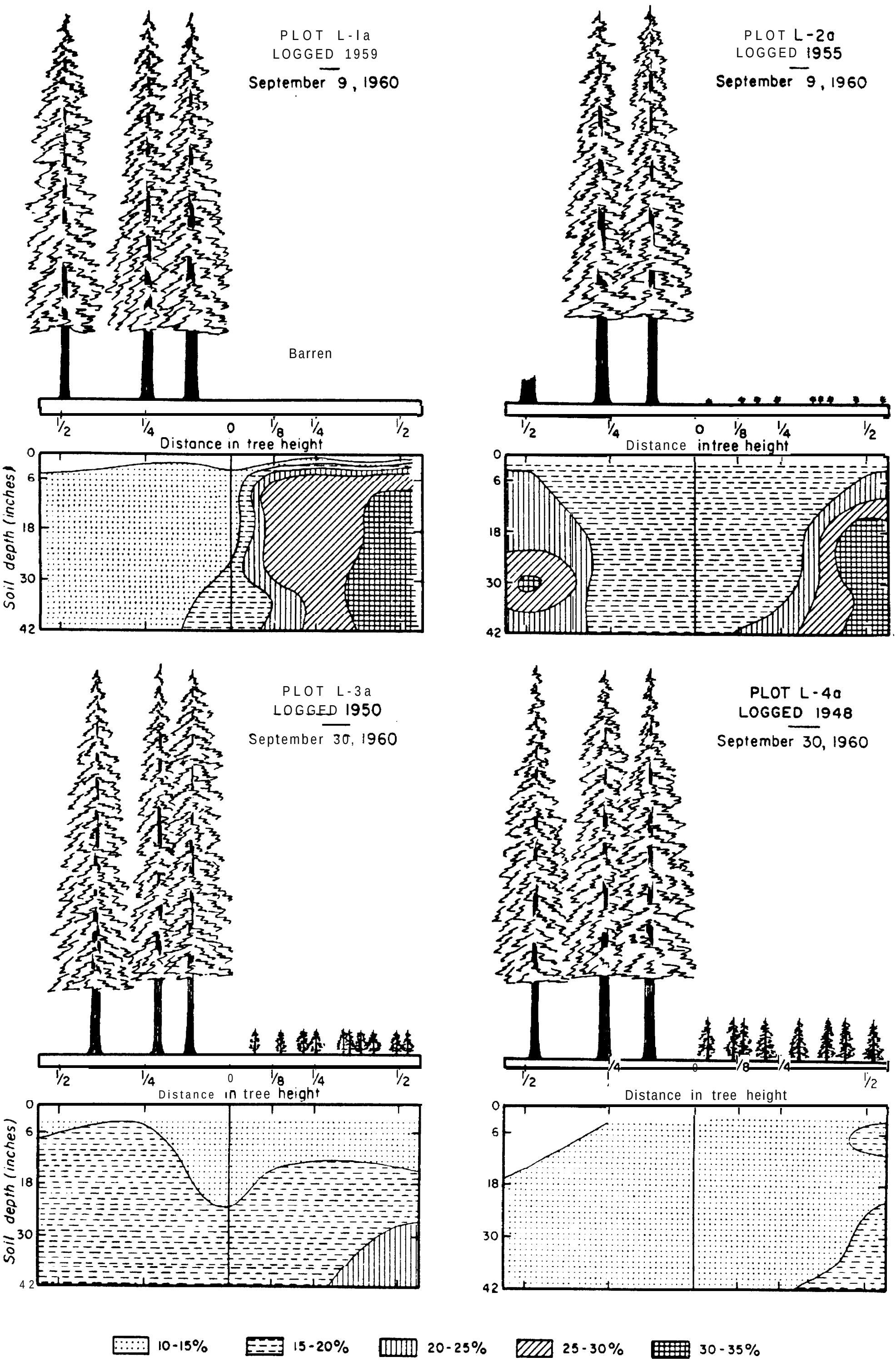

Fig. 3. Soil moisture in per cent by volume at 0- to 42-inch soil depths at maximum moisture--depletion for logged openings of various ages.

moisture in the older openings was probably limited only by the distribution of roots of the vegetation throughout the soil profile.

The losses measured in this study from logged openings of 1948 and 1950 agree closely with Knoerr's [1960] results of moisture depletion from natural forest openings. Knoerr reviewed the methods of estimating potential evapotranspiration as applicable to the Sierra Nevada. He developed an index based upon a relative day-length ratio times the vapor pressure deficit at 2 PM ($DR \times VPD_{2PM}$) . His index is similar to that used by *Halstead* [1951] and *Haude* [1952] and is closely correlated to soil moisture loss rates observed in a 2-year study at the Central Sierra Snow Laboratory in northern California. After an accumulation of 20 index units ($DR \times VPD_{2PM}$) since the time the soil had drained to field capacity, Knoerr found that 4.3 inches of soil moisture had been lost from his red fir reproduction plots on Lytton soil of 4-foot depth. On the basis of a comparable accumulation of Knoerr's index, this study indicates that the openings logged in 1950 had lost 4.0 inches of soil moisture in a 4-foot soil and those logged in 1948 had lost 4.5 inches for the same period. Total depletion from June to September accounted for an average loss of 8.1 inches of moisture in the openings logged in 1950 and 9.4 inches in those logged in 1948. Knoerr's natura1 openings lost 8.4 inches.

Soil moisture distribution at maximum depltion in openings of various ages. The distribution of soil moisture at maximum depletion should be the best single indication of changes in depletion patterns caused by differences in the age of the opening because (a) a measurement at that time would represent the summation of the seasonal depletion within the plot and (b) any differences in soil moisture depletion between plots would be at a maximum and readily ascertained (Figure 3).

Five years after logging, the soil moisture pattern differed greatly from that in the l-year-old openings. The 5-year-old openings supported a vegetative cover of small and scattered red fir and lodgepole pine seedlings and a smaller number of *Ceanothus* brush seedlings. Soil moisture remained greatest near the center of the opening. Moisture loss near the center of the opening extended downward 6 inches beyond that in the l-year-old logged opening and might account for 0.1 inch of the increased depletion over the area. The primary change represented an increase of about 1.6 inches in moisture depletion within the opening in the first 5 years after logging. It was probably caused by roots of the surrounding forest extending into the opening. An abrupt change in moisture occurred about 30 feet ($\frac{1}{3}$ *H*) from the tree canopy. This difference represented a 20-foot shift in active moisture depletion into the opening during the 5 years after the opening was created. Summer season moisture loss from the 5-year-old opening was 5.5 inches per 4 feet of soil and from the l-year-old opening it was 3.8 inches. This difference represented an increase of 1.7 inches in depletion per season 5 years after treatment. Thus, soil moisture loss from the 5-year-old openings appears to be a strong function of opening size expressed in units of tree height (*H*).

Ten years after logging, the effect of roots from the surrounding forest still appeared to extend a distance of 1/3 *H* into the opening as was observed in the 5-year-old opening. But the influence of new vegetation in the opening had become even greater. Six-foot red fir and lodgepole pine trees and *Ceanothus, Arctostaphylos,* and *Ribes* shrubs were scattered throughout the opening. Soil moisture still increased toward the center of the opening, but the gradient was much less striking in this 10-year-old opening. Total loss of available moisture within the opening extended throughout the entire 4-foot profile, except for an area 2 feet below the center of the opening.

Twelve years after logging the loss pattern of summer soil moisture of the opening had essentially returned to the uncut condition, as indicated by the small amount of moisture remaining within the soil at the end of the summer depletion season. All available moisture within the plot had been depleted, except at the lowest depths near the center of the plot. Apparently the roots of new vegetation had almost fully occupied the site.

Summer moisture savings at maximum depletion as affected by the age of the opening. Water savings at maximum depletion were plotted versus the logarithm of age of opening in years to determine the effect of logging on summer soil moisture loss (Figure 4). 'Moisture saving' is defined as the difference between the soil moisture losses in the forest and in the open-

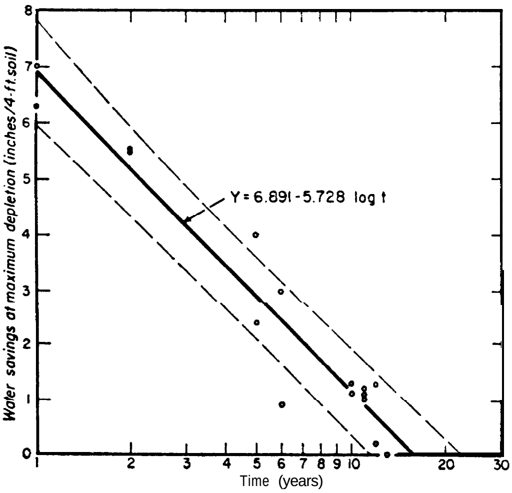

Fig. 4. Effect of age of logged openings on water savings at maximum soil moisture depletion for soil having a field capacity ranging from 16 to 18 inches per 4 feet of soil, with 90 per cent confidence interval,

ing. When losses in the forest equal the losses in the opening, the effect of logging on the summer soil moisture regime has become negligible, and the area must be cleared again if the sole function of the cutting is to control summer moisture losses.

A regression was fitted to the values of moisture saved in the various plots, plotted versus time since logging :

$$Y = 6.891 - 5.728 \log t$$

where Y is the moisture savings per season at maximum depletion in inches of moisture per 4 feet of soil and log t is the logarithm of the age of the opening in years. The fit of this line to the data had a coefficient of determination, r^2, of 0.928. The standard deviation of the predicted value of Y was ± 0.6404.

The regression indicated that soil moisture saving at maximum depletion would become negligible about 16 years after cutting. Computation of the 90 per cent confidence interval for a specific value of Y [*Snedecor*, 1950, p. 120] indicated that moisture savings would become negligible between 11 and 23 years after cutting. Extended over 10 years, the predicted total quantity of summer soil moisture saved within the logged openings equals 34 inches. I obtained this amount by summing the predicted values of Y from the regression for the 16 years. A summation of the value of Y along the lower and upper 90 per cent confidence intervals indicated that a total long-term savings would range between 24 and 49 inches of moisture per 4 feet of soil, respectively.

I have indicated the effect of logging and its duration on summer soil moisture loss for the conditions of the study. Soil moisture loss in summer does form the major part of the water loss in the Sierra Nevada. To determine the total effect of logging on the yearly moisture loss, however, it would be necessary to study losses occurring during the remainder of the year.

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