1967

Manipulation of Water Use in an Aspen Forest

John D. Schultz

George B. Coltharp

George E. Hart, Jr.

Michael Zan

Recommended Citation

Schultz, J. D.; Coltharp, G. B.; Hart, G. E. . Manipulation of Water Use in an Aspen Forest. Utah State University and Utah Center for Water Resources Research. 149-159.

MANIPULATION OF WATER USE IN AN ASPEN FOREST*

by
John D. Schultz, George B. Coltharp,
George E. Hart, Jr.
Assistant Professors
College of Natural Resources
and
Michael Zan
Graduate Research Assistant in Forest Hydrology
Utah State University
and Utah Center for Water Resources Research
Logan, Utah

Our society is continually searching for new sources of water to exploit. In some instances we may be able to tap supplies not previously used. Most searches, however, must necessarily be directed toward ways of using more efficiently what we now have. Manipulating wild land vegetation to augment water supplies is a field of activity which embodies both considerations--new supplies and more efficient use of existing supplies.

Vegetation in the wild requires water for its existence. In fact, were it not for abundant supplies of water, our forests would not occur where they do. Yet, it is often stated that some types of wild vegetation are extravagant users of water--using more than is actually required to keep them alive. Whether or not such claims are correct, it is true that some forest trees grow on sites and in climates where their water supply is not as great as it is in other places. Thus, the idea of manipulating wild land vegetation to decrease water use has been popular for quite some time. A growing body of evidence--both in research and in practice--indicates that definite increments to water supplies may be obtained when watershed vegetation receives certain treatments. Our paper relates only one instance of vegetation manipulation, but we believe it has implications for practical efforts which may be aimed at augmenting water yields in the future.

Some Basic Considerations of Vegetation Manipulation for Water Yield Improvement

Vegetation plays a greater role on watersheds than simply being a consumer of water; yet, we frequently do not take the protective role into account when we contemplate altering the plant cover to affect water use. Nonetheless, we may consider plants basically as pipelines for water flow from the soil water reservoir to the atmosphere. Without plants on a watershed, the evaporative water loss to the atmosphere would probably not occur from more than two or three feet of the soil. Consequently, if we remove the plant cover or alter it drastically, evapotranspirational losses can theoretically be reduced.

---

*The work upon which this publication is based was supported in part by funds provided by the United States Department of the Interior, Office of Water Resources Research, as authorized under the Water Resources Research Act of 1964, Public Law 88-379.

If we wish to reduce evapotranspiration, we must determine how drastic a treatment we can afford to apply to the vegetation and site. Only in rare instances is it acceptable to remove all vegetation. Usually some form of plant cover must be left to absorb the impact of falling rain drops and thus lower the hazards of erosion. On sites where the soil is shallow and soil water storage is minimal, any alteration of the plant cover is unwarranted. No savings in water can likely be realized. Likewise, if the existing plant cover consists of plants which have predominantly shallow root systems, little savings in water use will be gained by altering the vegetation.

Where deep-rooted trees occupy a deep soil, it is definitely possible to alter the water budget by manipulating the cover. Numerous studies have shown this to be true [5,6]. The theory underlying any manipulation of tree cover on a watershed relates to several main considerations. First, removal of all or part of the tree cover reduces the withdrawal of soil water. It also reduces the interception of moisture by the foliage, branches, and stems of the trees and permits this water to enter the soil. Second, if soil moisture withdrawal is reduced, less water will be required to recharge the soil mantle during the time of year when this phenomenon occurs. In this way, a greater quantity of water might be yielded as overland flow or as deep percolation to aquifers if it were able to infiltrate the soil surface.

For many reasons it is not always either feasible or desirable to destroy the tree cover on watersheds. Even so, it may be possible to alter the patterns of water use by forest trees in such a way that water yield increases are obtained. Disruption of the normal pattern of transpiration by trees may be just such a tool of vegetation manipulation. Two possible ways of accomplishing this are by defoliation and by the application of transpiration-inhibiting chemicals to the foliage. Both methods have been applied with various degrees of success, and the study we are reporting on herein pertains to the use of both techniques in a northern Utah aspen stand.

Manipulating the Use of Water by Quaking Aspen

Quaking aspen (*Populus tremuloides* Michx.) is only one of many tree species which occupy extensive areas in the mountain watersheds of the western United States, but it is one species which has been receiving considerable attention in the fields of watershed management research and administration. Several million acres of water-yielding land are classed as aspen forest land. From these lands it is hoped that increases in water yields can be obtained by manipulating the aspen forest.

Simple water budgets have been worked out for aspen and its companion species [1,4]. Some current projects are concerned with studying the nature of water use by aspen where it has been reduced in density by cutting or poisoning. In other projects, application of defoliating chemicals has taken place on entire watersheds. Our study is a plot study designed to evaluate in detail the effects which defoliation and application of antitranspirant spray may have on evapotranspiration in an aspen stand. The study is part of a broader study which has as its primary objective the development of remote sensing techniques for reconnaissance of watershed moisture conditions [2].[1]

Objectives of the Study

One objective of the study was to create three combinations of moisture stress conditions which might be detected in an aspen stand by infra-red remote sensing. A second objective was to measure, quantitatively, any changes in evapotranspiration which might be brought about by defoliation and application of antitranspirant spray to portions of the aspen stand.

The Study Site

A relatively uniform, dense stand of quaking aspen was selected for study in a side drainage of the Logan River in Cache County, northern Utah. Approximate elevation of the site is 7,800 feet above sea level and it is well within the aspen zone of vegetation in the Wasatch Mountains. The stand of aspen averages about 55 feet in height, and the site is on a south-facing hillside which has a slope of between 20 and 30 per cent. Mean annual precipitation at the site is approximately 30 inches. The soil is deep and generally well-drained but includes clay lenses and gravel pockets at various depths. Access to the study area is good. The site is approximately 15 airline miles northeast of the city of Logan, and it is 2.5 miles from an all-weather highway (U.S. 89). The latter mileage is via dirt road which can be traveled by jeep or pickup truck.

Establishment of Plots and Installation of Facilities

In the summer and fall of 1965, nine soil moisture plots were established within the aspen stand described above. The plots were chosen so that soil moisture might be measured by the neutron-scattering technique at regular intervals during the pre-treatment calibration period and after treatment. Thirty-six aluminum irrigation tubes were installed vertically to depths from six to ten feet. Four tubes were located in the approximate center of each of the nine plots on a 10- by 10-foot spacing. These tubes were then allowed to come to equilibrium with the surrounding soil over the winter months of 1965-1966.

For convenience of subsequent spraying treatments, the nine plots were segregated in clusters of three. Plots 1, 2, and 3 lie in a row down the western side of the slope; plots 4, 5, and 6 run up and down slope in the middle of the study area; and plots 7, 8, and 9 are on the eastern part of the hillside parallel to the other two lines of plots. Plot centers are 50 feet apart up and down the slope, and 100 feet apart across the slope. Trenches were dug to depths of two to three feet to sever root connections of each cluster of three plots from the others and from the adjacent areas of the stand.

---

[1]The full title of the project referred to above is "Evaluation of Remote Electro-magnetic Sensors for Detecting Transpirational Water Use by Plants Subjected to Various Foliar Chemical Treatments Designed to Reduce Transpirational Losses." It is Project No. CWRR-14 of the Utah Center for Water Resources Research.

Random selection led to the delineation of Plots 1, 2, and 3 as the portion of the stand which would be defoliated. Plots 4, 5, and 6 were designated as the control area; and Plots 7, 8, and 9 were selected to receive the anti-transpirant spray. Barbed wire fencing was then strung around the study area to exclude livestock which graze in the area during the summer months.

Climatic instrument stations were established at three locations in the stand. One is at the upslope part of the study area, one is near the middle, and a third is located in a clearing at the lower slope position. Air temperatures and relative humidity are recorded continuously on clock-driven charts, and a set of standard maximum and minimum thermometers is also mounted within each weather shelter.

Standard eight-inch diameter precipitation gages are located at each of the three climatic stations. In addition, a weighing-type recording rain gage is at the lower station in the clearing. Also at this station is a recording pyranometer (Robitzsch bimetallic actinograph) which records total incoming shortwave solar radiation.

In the summer of 1966, a 55-foot steel tower was erected at the approximate middle of the study area. A recording pyranometer and a totalizing anemometer were installed at the top of this tower at the tree canopy level. In 1967, two additional anemometers were added to this tower, one at mid-canopy level--about 12 feet below the upper instrument--and the other about halfway from ground level to the base of the live crown of the surrounding trees.

Shortly before the foliage spray treatments were made in June of 1967, thermocouples and heat sources were installed so that measurements of the rate of sap movement in treated and untreated stems could be obtained. The technique follows that described by Swanson and others [8,9].

Collection of Data

Measurements of precipitation were begun during the summer of 1965, and readings were taken after every storm until the cessation of the active growing season in October. In 1966, the precipitation gages were activated in early May and data were taken again after each storm until October. The same procedure was followed in 1967 except that snow did not leave the plots until late in May and the gages were not activated until that time.

Measurements of the other climatologic variables followed essentially the same schedule as that used for precipitation. The devices making continuous records of temperature, humidity, and solar radiation were serviced every six to eight days; and wind data were collected each time the research assistant climbed the instrument tower. This was every few days during the growing season.

A neutron-scattering soil moisture meter was used to obtain volumetric measurements of soil moisture at one-foot soil increments in each of the 36 access tubes at the site. In 1966, initial soil moisture readings were taken the first week of May, after snow had just disappeared from the plots and immediately prior to leafing-out of the aspen trees. Soil moisture data were collected every 7 to 14 days during 1966, and approximately every 14 days during 1967. The 1966 measurements continued into November, well after the trees had lost their leaves and into the soil moisture recharge period. Data were initially taken early in June of 1967, and measurements will be taken at bi-weekly intervals throughout the recharge period of 1967-1968.

In 1967, for several weeks after the trees on Plots 7, 8, and 9 were sprayed with the transpiration-inhibiting chemical, sap velocity readings were taken at short time intervals. In this way, profiles of sap movement during the day could be obtained and comparisons made between treatments. Data of this kind were collected from early July until mid-September.

Soon after the spray treatments were made, leaf samples were taken from trees on the control plots and from trees sprayed with the anti-transpirant. These samples were quickly "fixed" in an alcohol solution so that the status of stomata could be examined microscopically in the plant physiology laboratory. Subsequent samples were taken every few weeks for the remainder of the growing season.

Pre-treatment Calibration

In their rush to obtain immediate results, many researchers often overlook the necessity for careful study of the variability which may be inherent in their subject material. This is particularly true when one is dealing with plant-soil-water relations in the field. Hence, in this study, we feel more confident of our ability to interpret treatment effects because we were able to assess the variability of soil moisture change among the plots at our study site. An analysis of variance of the mean seasonal soil moisture change during the calibration year of 1966 indicated that no significant differences existed among the nine study plots. Furthermore, assigning of Plots 1, 2, and 3 and the others into groups for subsequent treatment did not produce significant differences between treatment groups with respect to 1966 soil moisture change.

Vegetation Treatment in 1967

On June 28, 1967, a helicopter equipped for treetop foliar spraying was used to apply chemicals to two portions of the aspen stand. Approximately 240 gallons of a 0.1 millimolar solution of phenyl mercuric acetate (PMA) were sprayed over Plots 7, 8, and 9. To dispense this amount of spray over such a small area of forest (about 0.4 acre) the helicopter pilot made 22 passes over the plots.

Phenyl mercuric acetate has been used by Waggoner [10,11] in selected forest stands of eastern United States with successful results. In multistoried hardwood stands of North Carolina it was not possible to determine whether the application of another anti-transpirant, decenylsuccinic acid, resulted in an increase in stream flow [12]. Too little of the chemical, it was believed, reached the underside of the leaves where most leaf stomata are located. Our expectation, borne out by observation, was that adequate amounts of the chemical would reach the underside of the quaking aspen leaves because wind movement caused by the helicopter would flutter the aspen leaves sufficiently to achieve the desired effect.

A solution of 2,4,5-T ester amounting to between 1 and 2 pounds acid equivalent per acre was sprayed on Plots 1, 2, and 3. Four helicopter passes were required to release the 60 gallons of aqueous solution. This concentration of defoliant proved to be inadequate to bring about the desired effect of a rapid and complete defoliation of the aspen. No subsequent spraying was done, however.

Results and Discussion

One ultimate objective of vegetation manipulation by foliar spraying of chemicals is to increase stream flow. Since we are unable to measure such results on a plot basis, some other criteria of success or failure must be used to evaluate the treatment effects. Two of these are available. One relates to the residual amount of moisture in the soil; the other is a measure of actual evapotranspiration. Let us first consider the former.

Depletion of moisture from the upper six feet of soil by the aspen on Plots 4, 5, and 6--the control portion of the stand--reached the same levels in 1966 and in 1967 before recharge began in the fall of each year. The depletion curves for both years are illustrated in Figure 1, and soil moisture data are presented in Table I.

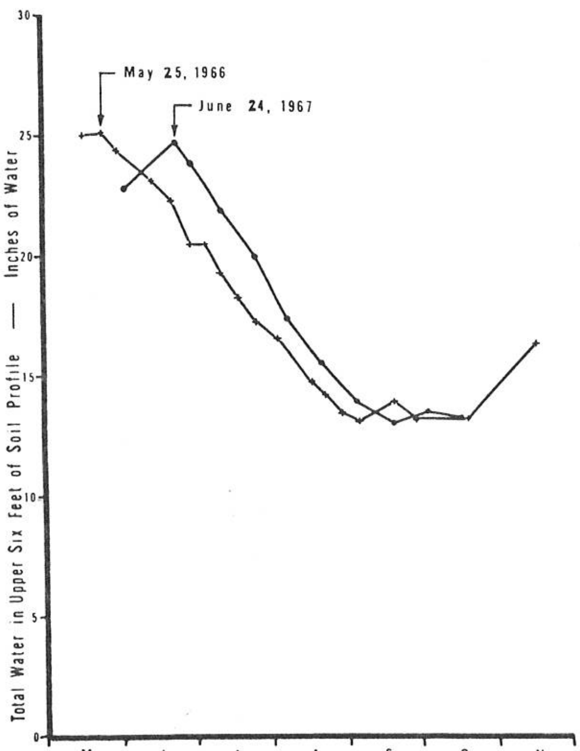

Figure 1. Seasonal patterns of soil moisture depletion by quaking aspen trees on control plots, 1966 and 1967.

Table I

Soil Moisture Conditions in a Northern Utah Aspen Stand

Event and Date	Water Content in Upper Six Feet of Soil Profile					
	2,4,5-T		Control		PMA	
	1966	1967	1966	1967	1966	1967
	(inches)		(inches)		(inches)	
Maximum Soil Water						
May 24-25	27.0		25.1		24.3	
June 23-24		26.6		24.7		23.1
Spraying of Foliage						
June 29-30		25.8		23.8		22.4
Minimum Soil Water						
Sept. 28-30	16.0		13.3		11.2	
Sept. 20-21		16.5		13.1		11.3
Seasonal Change in Soil Water	11.0	10.1	11.8	11.6	13.1	11.8

It is interesting to note that in 1967 the soil was recharged to about 0.4 inch less water content than was reached in 1966 on the same plots before the rapid depletion by growing plants began. The 1967 growing season was delayed by about four weeks because of a cool, wet spring. Aspen leaves came out nearly four weeks later in 1967 than in 1966. Even so, the soil moisture during 1967 was removed more rapidly than during 1966 so that the residual amount in the upper six feet of soil was about the same before accretion began in the autumn of both years. This would seem to indicate that only a certain amount of soil moisture was available to be removed by the vegetation no matter how the season progressed.

Our summers are usually warm and dry in northern Utah, and potential evapotranspiration far exceeds the actual amount. Both summers of 1966 and 1967 were normal in this respect, so we feel justified in concluding that vegetation and soil moisture are the limiting factors on this study site.

The plots which were sprayed with 2,4,5-T displayed a different pattern of soil moisture withdrawal. Early season moisture levels were also about 0.4 inch high in 1966 than in 1967, and the initiation of soil moisture withdrawal in 1967 was delayed by about the same amount of time as on the control plots. About 0.5 inch more moisture remained in the soil at the end of the growing season in 1967 than in 1966. Thus, we may conclude here that the spray treatment did affect soil moisture withdrawal. The quantity of water involved was not great, but because more water remained in the soil in 1967 than in 1966, it is clear that less would be required to recharge the profile during the winter of 1967-1968. Any excess precipitation might infiltrate and thus be yielded as increased deep seepage in 1968 or as overland flow if infiltration were not rapid enough to keep ahead of snowmelt. In this instance, although a difference of only 0.5 inch was measured between the low points of soil moisture depletion for both years, the amount could conceivably be greater if a more effective defoliation were obtained. The concentration of 2,4,5-T which we used was apparently insufficient to kill all the foliage on Plots 1, 2, and 3.

On the anti-transpirant (PMA) plots, a different situation was observed. The quantity of water in the upper six feet of soil was 1.2 inch less in 1967 than in 1966 at the beginning of the rapid depletion period in the summer. At the end of the growing season, however, approximately the same amount of water remained in the soil. When accretion began in the fall of 1967, only about 0.1 inch more water was in the soil than at the same time in 1966. Again, as for the control plot situation, we might conclude that water would be depleted only to a certain level in the soil. In this instance, even though sprayed with anti-transpirant, the aspen trees were able to deplete the soil to the same level reached a year earlier when they were not sprayed. Did the application of spray have any effect on these plots? That question may be answered by analyzing the moisture use data another way.

Figures 2 and 3 depict the cumulative evapotranspiration data for all three treatments for both 1966 and 1967. A note of explanation is necessary with regard to how we determined evapotranspiration. Typical use of soil-moisture depletion as a measure of actual evapotranspiration has employed a simplification of the hydrologic equation, i.e., Runoff = Precipitation - Evapotranspiration ± Soil Moisture Change ± Leakage. Where no runoff or yield is measured and where leakage is considered negligible, the equation may be transposed so that evapotranspiration is equal to precipitation plus or minus the change in soil moisture content. Discussions of this way of interpreting actual evapotranspiration are abundant [3,7,13]. We have used this simplified interpretation to evaluate the treatment effects in our study. The data depicted in Figures 2 and 3 represent calculated evapotranspiration between specified times of soil moisture measurement.

The zero point in both figures is based on the date in 1967 when soil moisture recharge was at a maximum for the study site. This was on June 23 and 24, 1967. The zero point for 1966, May 31, was the date on which the total water content in six feet of soil on the control plots was the same as at maximum recharge in 1967. In other words, both curves reflect situations of equal soil moisture content prior to treatment.

An examination of the 1966 data shows that cumulative evapotranspiration on the plots which received the anti-transpirant treatment in 1967 followed closely that of the control plots until June 25. At that date, the cumulative amounts on both areas were equal. From then on, however, the control plots indicated a lower amount of actual evapotranspiration. The plots which subsequently were sprayed with 2,4,5-T never transpired as much as the control plots.

Data for the year of treatment indicate a change in the cumulative evapotranspiration picture for each of the areas. It was 71 days after the beginning of soil moisture depletion before cumulative evapotranspiration on

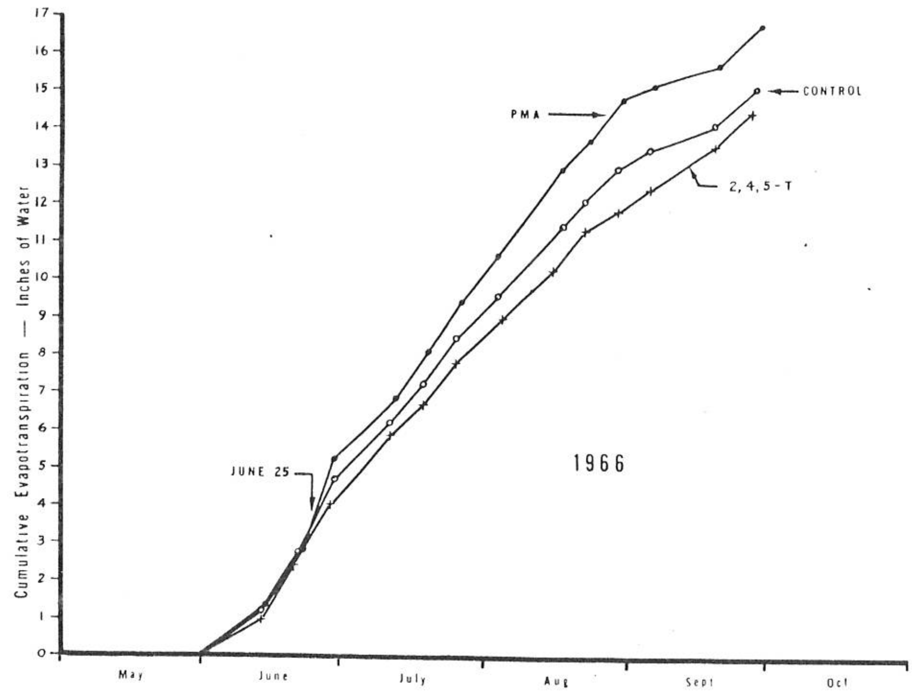

Figure 2. Cumulative evapotranspiration in quaking aspen stand during 1966, the year preceding foliar treatments.

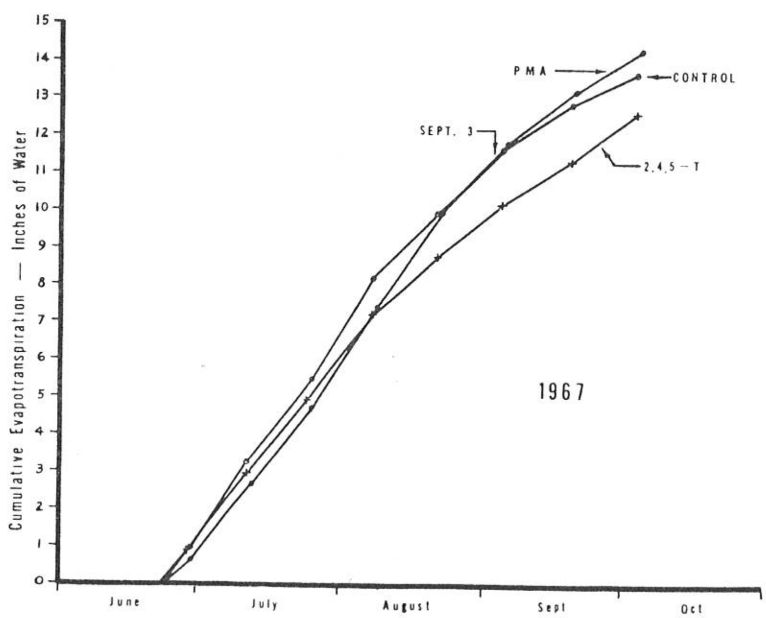

Figure 3. Cumulative evapotranspiration in quaking aspen stand subjected to anti-transpirant and defoliant spray treatments during 1967.

the plots sprayed with PMA equalled the amount on the control plots. Since this cross-over point in 1966 occurred 25 days after the initiation of soil moisture depletion, we may conclude that application of the anti-transpirant in 1967 delayed water use by approximately 46 days or six and one-half weeks. Thus, although the actual quantity of water extracted from the soil was not great, the delay in water use is probably critical in a water yield improvement sense. A discussion of this point is vital.

Analysis of the normal depletion curve observed for soil moisture in forest stands leads to the observation that the most rapid depletion occurs in the early part of the growing season. In the past, this has often been overlooked as an important point in time when vegetation manipulation might be attempted. It has been assumed that this depletion is due to the rapid foliation of deciduous trees and the commencement of active transpiration. This is indeed true to some extent, but in some instances the rapid decline in soil moisture actually begins several weeks before complete foliation of deciduous trees has taken place. Possibly the most reasonable interpretation of this occurrence is that soil water in detention storage (that which would drain on through the soil by gravitational force alone) is rapidly moving out of the zone where measurements are being made. If this is true, then anything which can be done to enhance this natural percolation of water will be a positive step in water yield improvement. When vegetation begins actively to remove soil moisture in growth and transpiration, some of the gravitational water referred to above becomes water of retention and may be used to maintain the soil at or near field capacity rather than to continue its gravitational movement downward. It is for this reason that the foliar chemical treatments of this project were applied soon after the trees reached full leaf. It was expected that the transpirational withdrawal of water would be impeded and that more of the gravitational water might be yielded as deep seepage.

Cumulative evapotranspiration on the defoliated plots again was less than that on the control plots, but the difference became progressively greater as the season passed. Had the defoliation treatment been effective, we believe that the difference in soil moisture withdrawal would have been much greater. This will be tested again in 1968 when a heavier application of defoliant is used on these plots.

Conclusions

We believe that our experimental data for the growing seasons of 1966 and 1967 indicate that significant changes in the water use budget in an aspen forest can be accomplished by vegetative manipulation. The possibilities of success are undoubtedly much greater in areas where greater amounts of precipitation are encountered, but it is apparent that these are tools of watershed management in water-scarce areas where even a slight increase in water yield is likely to be important.

References

[1] Brown, H. E., and J. R. Thompson, Summer water use by aspen, spruce, and grassland in western Colorado, *J. Forestry*, Vol. 63, pp. 756-760, 1965.

[2] Briscoe, Ralph D., and Frank W. Haws, Using remote infra-red sensors to detect changes in moisture conditions on natural watersheds. *Utah Center for Water Resources Research Rept.* CWRR-14(a)-1, 30 pp., 1967.

[3] Burroughs, Edward R., Jr., and John D. Schultz, Evapotranspiration and soil-moisture depletion, *Soc. American Foresters Proc.*, pp. 98-101, 1964.

[4] Croft, A. R., and L. V. Monninger, Evapotranspiration and other water losses on some aspen forest types in relation to water available for stream flow, *Trans. Amer. Geophys. Union*, Vol. 34, pp. 563-574, 1953.

[5] Douglass, James E., Effects of species and arrangement of forests on evapotranspiration, In *Forest Hydrology*, Pergamon Press, Oxford, pp. 451-461, 1967.

[6] Hibbert, Alden R., Forest treatment effects on water yield, In *Forest Hydrology*, Pergamon Press, Oxford, pp. 527-543, 1967.

[7] Schultz, John D., A critical appraisal of the soil moisture depletion technique in water budget investigations, *Proc. N.S.F. Summer Conf. on Water Resources, New Mexico State Univ.*, 1966 (in press).

[8] Skau, C. M., and R. H. Swanson, An improved heat pulse velocity meter as an indicator of sap speed and transpiration, *J. Geophys. Res.*, Vol. 68, pp. 4743-4749, 1963.

[9] Swanson, Robert H., An instrument for detecting sap movement in woody plants, *U.S. Forest Serv., Rocky Mtn. Forest and Range Expt. Sta. Paper*, No. 68, 16 pp., 1962.

[10] Waggoner, Paul E., Transpiration of trees, and chemicals that close stomata, In *Forest Hydrology*, Pergamon Press, Oxford, pp. 483-488, 1967.

[11] Waggoner, Paul E., and Ben-Ami Bravdo, Stomata and the hydrologic cycle, *Proc. National Acad. Sci.*, pp. 1096-1102, 1967.

[12] Waggoner, P. E., and J. D. Hewlett, Test of a transpiration inhibitor on a forested watershed, *Water Resources Res.*, Vol. 1, pp. 391-396, 1965.

[13] Zahner, Robert, Refinement in empirical functions for realistic soil-moisture regimes under forest cover, In *Forest Hydrology*, Pergamon Press, Oxford, pp. 261-273, 1967.