SAMPLING FOR DIRECT TRANSPIRATION ESTIMATES

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ABSTRACT

Heat-pulse velocities are directly indicative of transpiration rate. The transpiration of individual trees or stands can be compared provided the heat-pulse velocity values are representative of and from comparable water-conducting xylem.

The results of a pre-sample to determine the statistical sampling intensities necessary to obtain comparable heat-pulse velocity data from lodgepole pine showed that 10 trees would constitute an adequate sample in most instances. For length-of-transpiring-day comparisons, two trees would suffice. This number of samples can be easily handled by one man, with one instrument, on an hourly sampling sequence.

INTRODUCTION

The transpiration of an isolated tree relative to itself can be estimated from a knowledge of the ratio of the heat-pulse velocities at two or more times. That is, within an isolated individual tree heat-pulse velocity is a linear function of transpiration. Within this tree, measurements of heat-pulse velocity taken over some time interval, and from the same set of sampling points, will be indicative of the relative magnitude of any transpiration change (Swanson, 1970). If some estimate of absolute transpiration volume exists for that tree, then the heat-pulse measurements are indicative of the true transpiration volume as well.

The above has been demonstrated twice for an isolated single tree (Decker and Skau, 1964; Swanson, in press). Extensions of these results to include comparisons of transpiration rate between individual trees within a stand, or between stands of trees is desirable. Within one tree any heat-pulse velocity within the water-conducting xylem is indicative of the total flow. Thus it can be compared with subsequent or previously made measurements at the same point to ascertain relative transpiration magnitude at some specified time or over some specified time interval. However, the heat-pulse velocity within the water-conducting xylem is not constant, nor is it known at present whether or not the areal

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distribution of velocity magnitude with time follows any regular, predictable pattern (Swanson, 1967). To compare transpiration rates of one tree against another, the heat-pulse velocities used must represent comparable portions of the water-conducting xylem. Given the unknown nature of the velocity patterns within the water-conducting xylem, this presents a sampling problem, the magnitude of which is not known.

The problem of sampling heat-pulse velocities, representative of stands of trees, in order to make intra-specific or inter-specific transpiration comparisons, is thought large. The known natural variability of trees coupled with differences that are due to environmental parameters has probably prevented wide use of the heat-pulse technique as a means of estimating transpiration. In fact, most of the published material has been on inherent errors and problems associated with heat-pulse instrumentation, rather than on its use as a transpiration indicator. However, transpiration is an important hydrologic parameter: the problems associated with using heat-pulse velocity as an indicator of transpiration are no greater than those using aerodynamic or energy-budget techniques. It is a direct method that quite likely gives more reliable results than soil-water budgets. Heat-pulse instrumentation is readily constructed and is not expensive. Therefore, if transpirational use of water by trees is an important part of a hydrologic model, it should be estimated by the heat-pulse technique.

Marmot experimental basin in southwestern Alberta is set aside for two timber-manipulation tests. One is to determine the influence of the present commercial logging practice on water quality and yield. The other is to test some treatment purposely designed to alter regime or to increase yield (Jeffrey, 1964). It is principally with regard to this latter test that we are concerned with transpiration. Marmot presents a complex array of slopes, aspects, elevations, soils, vegetation and geologic formations. Water yield or regime is influenced by groundwater recharge-discharge relations within the basin. These in turn are altered by soil moisture use on the watershed. In order to properly prescribe and predict the outcome of some treatment, on-site water use must be accounted for. Transpiration probably accounts for the majority of on-site use after snow melt. Thus our interest in measuring it.

The study reported here deals with the sampling variability, from all causes, associated with heat-pulse velocity measurements in lodgepole pine. Lodgepole pine is important because it is the majority species in Marmot basin. It occupies 8.6% of the basin in pure stands, and is a substantial fraction of an additional 41.3%

that exists as spruce-fir-pine mixture. These two types together comprise almost 100% of the timbered area of Marmot, as 40% is alpine (Kirby and Ogilvie, 1969).

This study was designed to determine the variance associated with lodgepole-pine heat-pulse velocities. The average velocities for stands should be comparable with each other in terms of transpiration, provided the variation associated with these averages is known and accounted for. These results are essentially a pre-sample that will allow us to properly design a study of transpiration in Marmot basin.

METHODS

A pure stand of lodgepole pine 15 to 21 meters tall, on the Kananaskis Forest Experiment Station immediately adjacent to Marmot basin, was chosen as a study area. Twenty trees were instrumented with a single set of heat-pulse velocity sampling probes in each; 10 with probes placed at random depths into the wet xylem, and 10 with probes placed at $\frac{1}{4}$-, $\frac{1}{2}$- or $\frac{3}{4}$-depth points in the wet xylem. The average dbh was 15.2 cm; average wet-xylem thickness was 4 cm. Each instrumented tree was 'read' at prescribed times over 24 hours on 3–4 June, 8–9 July, and 5–6 August in 1969. The results are shown in Table 1.

TABLE 1 — Average heat-pulse velocities from 20 lodgepole pine at the Kananaskis Forest Experiment Station, Seebe, Alberta, Canada.

Date		*Hour*												*Average*
		11	13	15	17	19	21	01	05	07	09	11	13	05–21
	R	5.6	5.9	5.9	5.6	4.5	1.8	0.2	0.7	2.9	4.5	5.6	5.6	4.43
3–4 Jun	S^2	1.9	1.7	1.9	2.0	1.1	1.7	0.4	0.7	1.9	3.8	2.0	1.3	—
	P	6.3	6.6	6.4	6.0	4.6	1.4	0.0	2.3	4.0	5.6	6.2	6.3	—
	R	5.5	5.6	5.6	5.7	3.5	1.9	0.8	0.0	2.0	4.9	5.8	6.0	4.21
8–9 Jul	S^2	1.8	1.8	1.9	2.7	0.9	1.5	0.9	—	1.7	2.1	2.8	1.8	—
	P	6.1	6.1	6.0	5.4	4.7	1.3	0.2	0.2	3.8	5.4	5.8	6.0	—
	R	3.4	3.7	4.0	3.5	1.3	0.7	0.2	0.0	0.9	1.7	5.1	5.5	2.82
5–6 Aug	S^2	2.2	1.2	1.2	0.8	2.0	0.9	0.4	—	1.4	2.8	2.1	4.5	—
	P	3.5	3.5	3.3	3.0	1.3	0.2	0.0	0.0	1.3	2.9	4.3	4.9	—

R=random probe depth; P=prescribed depth probe.
Sample variance S^2 associated with the random depth probe data below each value.

The values from the probes placed at prescribed depths are higher in June and July that those from the randomly placed probes. The difference is slight, and it is doubtful if there is any real difference in the two averages for each hour. The use of statistical methods — such as the t test — to examine the difference between these averages is not legitimate in this case, since one set of samples is not random. However, one is tempted to do so anyway, and the result of the t test on each set of hourly averages (for what it is worth in this case), suggests that they are significantly different at 05.00 on 4 June and at 07.00 on 9 July only.

DISCUSSION

The use of statistics to determine the number of samples (n) necessary to describe the mean within some error is applicable to the data from those probes placed randomly.

$$n = (S^2 t^2) / E^2 \qquad (1)$$

where S = sample variance (from Table 1).

t = value at some level of probability for $n-1$ observations ($P = 0.05$, $n = 10$ in this case),

E = error in average value one is willing to accept (± 1 cm/hour used in this case).

The type of study one wishes to conduct will govern the sampling intensity. For instance, comparison of transpiration between sites on the same day requires a knowledge of the daylight values for heat-pulse velocity. These data indicate that such a comparison could be made using 10 sampling units on each site.

A more useful comparison is that involving the transpiration of a group of trees at one time of the year versus the same or some other group of trees at a different time of the year. Differing day lengths are involved in this comparison, making an estimate of the average heat-pulse velocity for the entire day mandatory. This comparison would also require 10 or more sampling units for significance.

A third type of comparison is that of unequal transpiring time intervals between sites on the same day. This parameter appears to be related to unequal soil-moisture availability (Swanson, 1967). This comparison involves only the existence of morning and evening heat-pulse velocity values and not their actual magnitude. The chance of entirely missing a velocity is much less than that of wrongly estimating its true value. This comparison is much less difficult; two sampling units would be adequate in this case.

Even though the estimated number of samples is high for all but the last comparison, they may be possible with a lesser number. A comparison of heat-pulse velocity between the months of June or July versus August for the trees used in this pre-sampling study shows a significant difference between August and either of the other two months. If one is willing to accept a larger percentage difference as the minimum (in this case 40% rather than 20% as used to derive the number of samples above), then of course, the number of samples necessary to yield a valid comparison is less. Any number of samples greater than five would have given valid results.

It may also be possible to lower the sample variance through stratification of the water-conducting xylem into layers or sectors and sampling in a more efficient manner. The above were samples taken at random within the outer 4 to 5 cm of xylem. These readings include not only the variation due to differences in placement in the xylem, and that which normally occurs between trees of the same species, but also the variance that would be attributable to transpiration demand and instrument error. However, even with these error sources the number of samples necessary should not discourage one from attempting transpiration estimates using the heat-pulse technique.

At high heat-pulse velocities as large as those reported here for the daylight hours, it is quite practicable to sample 20 units with one instrument in an hour. In the evening and morning, the number of sample units that can be read is less, but with some experience in using the heat-pulse-velocity instrument and interpreting the meter deflections, one can ascertain whether or not a particular reading is going to be 'zero' or something slightly greater long before the meter actually indicates it. Thus, 10 sampling units are not an unwieldy number for one person with one instrument to handle hourly on a 24-hour sampling sequence, provided transit time between sample trees is kept short.

CONCLUSIONS

These data indicate that the sampling variance associated with lodgepole-pine heat-pulse velocities is high, but that if the type of comparison is properly chosen, the number of sample units can be kept at a workable level. A comparison of heat-pulse velocities between sites on the same day can be made with as few as 10 samples per site. A similar comparison over an extended time period and a significant change in day length would involve a like number of sampling units unless the mean difference was quite large.

These data give no hint as to the variance that one might expect between species. It probably would be greater, thus making inter-specific comparisons more difficult than comparisons within the same species.

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