THE SNOW RESEARCH PROGRAM AT THE FRASER EXPERIMENTAL FOREST, COLORADO

by

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The Fraser Experimental Forest is a unit in the Branch of Research, Forest Service, U. S. Department of Agriculture. Of many such units throughout the country, it is one of three engaged in special research on snow and the relations between snow and forest. Of the other two, one is in the east in New Hampshire, the other in California where the old Central Sierra Snow Laboratory of the Corps of Engineers and Weather Bureau is being reactivated by the Forest Service.

The Fraser Experimental Forest is located in the Rocky Mountains of Colorado, about 65 miles northwest of Denver. It has an elevational range of 9,000 to nearly 13,000 feet and accordingly has the two well known seasons of winter and the Fourth of July. It is representative of much of the high water-yielding lands of the central Rocky Mountains where melting snow forms the principal source of four major rivers. Dense timber covers most of these water yielding lands but at higher elevations extensive areas of alpine tundra and rock are also important.

Although a prime source of water, the Colorado Rockies receive only moderate precipitation. On areas above 8,000 feet, annual precipitation probably does not average more than 30 to 40 inches and it decreases rapidly with lower elevation. Of the 30 to 40 inches, probably 60 to 80 percent occurs as snow, and this snow accounts for 80 to 90 percent of annual streamflow. To snow surveyors of the coastal mountains of the United States and Canada, our snow packs of 4 to 8 feet in depth would look puny, but to thirsty folks and thirsty crops in many states, not excluding California, they are mighty important.

This precious snow pack and its environment, particularly its forest environment, has been a subject of study at the Fraser Experimental Forest for several years. Prompted by our past results plus those of other researchers, we are now planning some expansion of our efforts. First, however, a look at some of our past results:

One of our first studies was that of the relation between snow accumulation and size of forest openings or clearings. The study was made in a forest stand where tree heights averaged 80 feet and openings up to 60 feet in diameter existed. Least snow was found under dense groups of trees and the deepest snow was near the center of the largest openings. From the edge of the canopy outward toward the center of the opening, the water equivalent of the snow pack increased by about 0.07 inch for each foot of horizontal distance (6).

A similar study was made in a stand of second growth pine where trees averaged 23 feet in height and openings ranged in diameter from 4 to about 50 feet. In this case the maximum snow pack was in openings 20 feet in diameter and larger. In smaller openings the water equivalent of the pack decreased sharply with size (5).

A third study in natural stands made comparison among an open field, a stand of aspen, and a stand of young pine with respect to snow accumulation. In the open field and aspen the pack was 114 and 130 percent respectively of that in the pine (2).

These studies were all intended to give clues as to the effect that would be realized when forest stands were harvested for timber or thinned to stimulate tree growth. With the foregoing results we proceeded to tests of different intensities and patterns of timber cutting in stands of different ages and composed of different tree species.

In one such study, we thinned stands of young pine averaging about 23 feet in height. The average number of trees per acre was about 4,000. Under one type of thinning we reduced this number to 650 trees per acre, under another type to 2,000. In terms of water equivalent the snow pack response to the heavier thinning was 2.3 inches or 23 percent; to the lighter thinning it was 1.7 inches of 17 percent. The thinning also increased the average rate of melt by 0.11 inches per day or from 0.26 to 0.37 inches. There was no significant difference in the melt rate between the two intensities of thinning (3).

In a stand of mature lodgepole pine averaging about 75 feet in height, we applied four intensities of cutting, as shown in the following tabulation (7).

Intensity of cut Percent removed	Snow Pack Inches of water	Increase by cutting Percent
100	17.1	29
83	16.0	20
67	15.6	17
50	15.0	13
0	13.3	0

Here, the effect on snow pack was distinctly evident.

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Still another test of harvest cutting was applied to a stand of mixed Engelmann spruce and subalpine fir. Here we applied but one intensity of cutting but used three different patterns. Sixty percent of the sawtimber volume was removed on each plot but on one plot we clear cut alternate strips 66 feet wide, on another we clear cut groups 66 feet in diameter, on a third we cut in a uniform pattern to leave trees approximately evenly spaced over the area. We not only studied the effect on snow accumulation but also the change in rate of snow melt. The cutting gave an increase of 23 percent in the water equivalent of the snow pack. There was no difference in the snow pack among the patterns but the snow melt rate was slightly lower on the plot cut in a groupwise pattern where shading from sunlight was more complete.

All of the foregoing studies were on relatively small plots where there was no opportunity to translate the effects on the snow pack directly into terms of streamflow. It is, of course, desirable to test such plot results on larger areas and particularly on watersheds where the effects of timber cutting can be evaluated in terms of streamflow.

Early in the history of the Fraser Experimental Forest the study of two watersheds was begun with the intent of eventually cutting some of the timber from one and observing the streamflow change. Cutting is now underway on this watershed with the pattern of cutting one of alternate clear cut strips. Preliminary data already suggest an increase in streamflow caused by the cutting. However, conclusions must await completion of the cutting and several years of subsequent measurements.

While awaiting results from this watershed experiment, the opportunity came to study any change in streamflow caused by a catastrophe to the forest cover of a watershed. The catastrophe was a beetle epidemic that killed the timber on 226 square miles of the 762 square mile watershed of the White River in western Colorado. The killing took place during the years 1941-1946. Streamflow records starting in 1934 existed for both the White River and a neighboring stream, the Elk River, where there was no beetle epidemic. Thus it was possible to make comparisons between the two streams for each of the three periods: before tree killing by the beetles, during the epidemic, and after killing was complete.

The results indicate a marked increase in streamflow associated with the death and subsequent defoliation of the timber. The indicated average annual increase was 2.28 inches or 24 percent of the flow before the epidemic. On a monthly basis, the greatest increases were in the months of May, June, and July with small increases in most of the other months (4).

Since this beetle epidemic caused a great loss in timber values and increases in both fire and soil erosion hazards, it can hardly be considered a beneficial event even though water yields were increased. However, it did offer further evidence of the water yield benefits that may be realized from forest management in which timber values, land protection, and water quality are considered along with water quantity.

In line with our plot results, we attribute the increased streamflow of the White River to an increased snow pack following the forest defoliation. Our explanation of this effect and that of many other investigators is based on the fact that tree crowns intercept snow and withhold much of it for some time from the snow pack. We further assume that during this time much of the intercepted snow is evaporated or sublimated and thus never does reach the snow pack.

Implicit in this explanation is that snow on trees must evaporate at a considerably faster rate than does snow in the snow pack surface. However the measurement of snow evaporation presents many problems. As far as is known, no satisfactory measurements of evaporation from the snow pack have ever been made and no measurements at all of the evaporation of snow on tree crowns.

This leaves unanswered the disturbing question whether the evaporation from intercepted snow is actually sufficiently faster than from the snow pack surface to account for the apparent gain in snow when trees are cut. If not, then there is the question whether the cutting of timber actually increases the snow pack or simply alters its distribution so that snow in clearings is at the expense of snow in the surrounding forest.

In the absence of any direct measurements by which to compare the evaporation from intercepted snow with evaporation from the snow pack, we can gain some insight into the question by making use of the energy balance relationship offered by Sverdrup's equation for water vapor exchange. As given by Diamond (1), this equation is

$$F = \frac{0.623\ R\ Ko^2\ U\ (e - e_s)}{\ln \frac{a}{Z}\ \ln \frac{b}{Z}\ P}$$

where F = evaporation rate, R = density of air, Ko = Von Karman's constant, U = wind velocity at height a, e = vapor pressure of air above a snow surface, e_s = vapor pressure of snow at 0° C., P = atmospheric pressure, a = height of temperature and humidity instrument above snow surface, b = height of anemometer, Z = roughness parameter for snow pack surface = 0.25 cm.

Certain of the above factors are constants over the range in elevation from snow pack surface to forest canopy surface. These are: coefficient 0.623, R, P, Ko, and e_s. The factor e should also be essentially a constant because of the effect of snow at both elevations; a and b are also constants if we consider measuring temperature, humidity, and wind above the forest canopy to get data comparable to such data collected with reference to the snow pack. In one case a and b would be measured with respect to the snow pack, in the other with reference to the canopy.

From one of our plot studies at Fraser we estimated that during winter and spring 2 inches of water was lost by evaporation from the snow in an open area and 5 inches from intercepted snow.

If we set up two equations for F having a ratio of 2/5 between their values and recognize the constants assumed above, then:

$$2/5 = \frac{\dfrac{U_1}{\ln \dfrac{a}{Z_1} \ln \dfrac{b}{Z_1}}}{\dfrac{U_2}{\ln \dfrac{a}{Z_2} \ln \dfrac{b}{Z_2}}} = \frac{U_1}{U_2} \; \frac{\ln \dfrac{a}{Z_2} \ln \dfrac{b}{Z_2}}{\ln \dfrac{a}{Z_1} \ln \dfrac{b}{Z_1}}$$

where subscript 1 refers to open area, snow pack variables and subscript 2 refers to variables at the forest canopy.

Data collected at Fraser over a period of one month by anemometers in an opening about 200 yards in diameter showed wind flow at a height of 100 feet to be about 1.5 times that at 6 feet above the ground. In this case $\frac{U_1}{U_2} = \frac{1}{1.5}$.

Entering this ratio in the above equation and assuming values of a and b at 600 and 200 centimeters respectively we can solve for Z_2 and get a value of 1.2 centimeters for the roughness parameter.

It is not known whether a value of 1.2 for the roughness parameter of snow on tree crowns is reasonable or not. However, it does seem reasonable that it should be higher than for a snow pack surface. If some such magnitude can be accepted then it, together with a higher wind velocity at tree crown level, could explain the apparent greater evaporation rate from intercepted snow.

Actually, however, we do not need to explain the higher rate of evaporation from snow on trees solely on the basis of more wind and a higher value for the roughness parameter. A phenomenon that is common in our region and that may cause evaporation loss from intercepted snow is the blowing of snow from tree crowns following its interception. It is a common sight to see clouds of snow rise like smoke from the forest canopy and be dispersed into the air. Low daytime dew points are also the rule and thus it seems possible that much of this blown snow is sublimated during transit. There is also the fact, of course, that snow on trees presents more surface than if it had fallen directly to the snow pack.

These questions concerning losses from intercepted snow point up some of the problems with which we hope to deal in our future research at the Fraser Experimental Forest.

Several years ago a number of snow lysimeters were installed at the Experimental Forest for the primary purpose of getting measurements of snow evaporation. This objective was not realized, chiefly it is believed, because of the lateral movement of water along density planes in the snow that caused large experimental errors. We hope to reactivate these lysimeters, overcome the earlier difficulties and, perhaps for the first time, get accurate measurements of evaporation from a snow pack.

If this can be done, we may then be in a position to devise portable equipment for the measurement of evaporation so that we can measure snow evaporation as we now measure precipitation--wherever the need arises.

In our region there is much interest in what happens to the snow on south slopes. Many people feel that most of the snow on such slopes is evaporated and contributes little to streamflow. A ready means of measuring evaporation from the snow pack would be highly valuable in answering such questions.

We are bothered by many questions concerning snow melt. It is often argued that convection and condensation are the two important factors in snow melt and that direct solar radiation plays a minor role. This does not seem to be the case in our region but we have insufficient data to prove the point. We hope that our snow lysimeters can serve to answer this question. They may also enable us to test the effects on snow melt of tree trunks and entire small trees--such things as can actually be put into place on the lysimeters.

The data presented earlier to show the effects of timber cutting on the snow pack all pertained to initial effects observed within a few year period following logging. We are still ignorant of how this initial effect diminishes with time. We plan periodic remeasurements to follow the effect of regrowth of the forest on snow accumulation. Thus we should eventually be able to make long term plans for the management of the forests on a watershed to get a sustained increase in streamflow.

The final test of the hydrologic effect of any forest management practice must still be made on entire watersheds. With recognition of this, we are preparing a series of new watersheds for future treatment. Two streams have been recently gaged and other watersheds are being investigated for their experimental suitability. These are in addition to the watersheds mentioned earlier, which have been gaged for some time and from which results will soon be forthcoming.

Last but not least among our lines of snow research is that concerned with alpine snow fields.

Although we have few glaciers in our mountains, we do have many snow fields that last until late summer. In fact, a number do not melt completely in average years but only during those abnormally warm and dry.

Our interest in these fields stems from the possibility that they contribute importantly to summer streamflow when water demands are highest and the peak rate of supply has passed. Furthermore, if these fields do yield significant volumes of water, it is possible that they can be augmented by the creation of windbreaks to make them even more valuable.

We first need to learn the importance of these fields to streamflow. In the literature one can find testimony to the effect that most of the snow at high elevations is dissipated by evaporation and other testimony that most of it appears as runoff. Preliminary observations suggest the latter for our region and indicate at least the local importance of these snow fields.

In addition to knowing how effectively fields can be augmented by barriers of various kinds we need to know whether the resultant prolongation of snow melt favorably or adversely affects total water yield. Another interesting possibility is that of controlling both storage of snow in these alpine fields and its time of release; the storage by barriers to accentuate drifting, the melt by the use of lampblack or a similar substance to speed melting as desired.

In our region there is much interest in any approach that offers promise of more water. We believe such a promise is offered by the management of forests and alpine lands to reduce evaporation losses.

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