

SNOW AND FROST MEASUREMENTS
IN A WATERSHED MANAGEMENT RESEARCH PROGRAM

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INTRODUCTION

I am going to tell you about our snow and frost work on the Hubbard Brook Experimental Forest in the White Mountains of New Hampshire. Hubbard Brook is one of several experimental areas scattered throughout the country on which personnel of the United States Forest Service are seeking to learn how different kinds of forests and methods of managing them affect streamflow behaviour. Formerly known as "Forest Influences Research," this work is now officially called "Watershed Management Research" in the Forest Service.

Some of you may be familiar with the work that is being done, for example, at the San Dimas Experimental Forest in Southern California, at Coweeta in North Carolina, or at the Frazer Experimental Forest near the Continental Divide in Colorado. The Hubbard Brook Experimental Forest is, you might say, New England's counterpart of experimental areas such as those.

The experimental forest is located about 13 miles north of Plymouth, New Hampshire, in the White Mountain National Forest. It covers about 7,500 acres — most of the Hubbard Brook Watershed. The terrain is steep, rugged, and rocky, typical of the glaciated mountains in that part of the country.

A TWO-PHASE PROGRAM

Our winter program of research here is centered around two distinct efforts. One is the continuous recording of streamflow and the periodic measurement of frost and snow on small gauged watersheds. We need this kind of data for determining the relationships between these variables and streamflow on those individual watersheds where the effects of vegetation changes will eventually be studied. We also use this periodic measurement program as a proving ground, so to speak, for different sampling techniques and measuring devices.

In the other phase of our program, study plots, instead of whole watersheds, are the basic research area. Plot studies — or special studies as we sometimes call them — are made to find out, for example, how different intensities of cutting affect the incidence and depth of soil freezing or the accumulation and melt of snow. Although these studies are independent of the watershed studies, they are designed to give us the basic information that will be needed to correctly interpret the results of the watershed studies.

As our program is only in its second year of operation, we do not yet have many special studies under way. However, we have completed one study on the effect of small hardwood forest openings on the accumulation and melt of snow. This has been reported in the August 1956 *Journal of Forestry*, if any of you are interested. We also have one complete season's measurements of frost and snow on one of our gauged watersheds. The remainder of my time will

be given to discussing the techniques we used in taking these measurements and the results we got.

DESCRIPTION OF AREA AND MEASURING PROCEDURES

The area on which the data were taken is a small, wedge-shaped watershed about five-eighths of a mile long and about 40 acres in area. It faces southeast. The average slope is about 25 percent. The forest cover is mostly sawtimber and pole-size northern hardwoods.

We have three precipitation measuring stations on the area. These are about equally spaced in horizontal distance, but not vertically. Station No. 1 is near the stream-gauging installation. The elevation here is 1,600 feet. Station No. 2 is at an elevation of about 1,800 feet, and Station No. 3 at about 2,400 feet. Station No. 3 is just about 50 yards below the top of the watershed.

Each station has a standard rain gauge mounted in the center of a circular opening on which all the trees have been cut. The diameters of the openings are 80 to 120 feet — about twice the height of the surrounding trees. The gauges are equipped with modified Alter I windshields and are tilted so that the orifices are parallel with the slope, according to the recommended practice for precipitation measuring in mountainous terrain. To have the gauge and windshield clear the surface of the snow with an expected snowpack of 4 or 5 feet, the gauges had to be installed with their orifices about 7 feet above the ground.

To check the catch of the gauges, a snowboard was put out at each station. This is simply an 18- by 24-inch piece of plywood covered with white flannel. Snow accumulation since the last visit was measured by taking a core from the board with the rain gauge funnel.

As a further check, and also for possible clues as to the amount of sublimation losses from the snowpack, the centers of the openings were cleared of slash and other obstructions so that snow-tube measurements could be taken concurrently with measuring the gauge and snowboard catches.

Since the amount of snow that accumulates in the openings would differ from the amount that accumulates in the woods, permanent snow courses were laid out in the woods just south of each precipitation station. The data from these courses are used to determine the amount of snow on the watershed.

Station No. 1 has, in addition to the standard gauge and snowboard, a recording precipitation gauge and an instrument shelter that houses a hygrothermograph, standard, and maximum and minimum thermometers.

All stations were visited once a week throughout the year. On these weekly visits, charts were changed, thermometers were read and reset, and the gauge catch was weighed. Prestone and oil were added when necessary. Snow depth and a core for weighing the water equivalent

were taken from the snowboard, and the board was reset on the new snow surface.

Ten snowpack measurements were taken in each opening and on each snow course in the woods. We used the Mt. Rose snow tube and tubular scales. We started measuring snowpack water equivalent only after a continuous snowpack of 1 to 2 inches of water had begun to build up. The snow courses in the woods serve also as frost courses. At each sampling point we checked for concrete frost in the ground, and where it was found we measured the depth of freezing.

RESULTS OF 1955-1956 FROST SURVEY

There is, I believe, a rather widely held belief among laymen about frost in the ground. It is that soil freezing is simply a function of air temperature: sometime in early winter the ground begins to freeze and the frost gets progressively deeper as long as sub-freezing temperatures persist. The weakness of this theory is that it overlooks the fact that there are other important variables that affect soil freezing. In a paper he gave at last year's meeting at Hanover, Bob Pierce, of our organization, reported the influence of land use, or type of vegetation.^{2/} One of the main points of his paper was that much less concrete frost was found in hardwood forests than in softwood forests or on nonforest land.

Our measurements of last winter also showed relatively little frost under hardwoods. Frost was first found on January 3. The 2-week period that preceded this date was the coldest spell of the year. The average mean daily temperature for this period was 4 degrees F. The minimum recorded was -23 degrees.

The highest incidence (percent of ground frozen) of concrete frost was 23 percent. This was found on January 30, at which time the snowpack averaged about 8 inches deep. The average frost depth at points where it was found on that day was only 2.6 inches. Coincidentally, this was also the average depth for all points for the whole season. The maximum depth measured during the season was 6.0 inches.

In general, what frost there was had gone out of the ground by February 27. The snowpack was about 22 inches deep then. We did find frozen ground at one sampling point, however, on March 12. This was under 23 inches of snow, the least depth recorded on that day. According to such observations as we were able to make with snow on the ground, where we did find frost, it was usually at places where the mineral soil had been exposed by windthrow or other natural occurrences.

THE 1955-1956 SNOWPACK

Some of you may have been wondering why, as long as we measure the water content of the snowpack, we also measure precipitation as it falls. This would be a perfectly natural question, since streamflow is much better correlated with water content of the snowpack at time of melt than it is with seasonal precipitation.

There are two good reasons for it. First of all, we need to know precipitation on the watershed by days, months, and seasons for water-accounting purposes. The second reason is that in this part of the country, as contrasted with the mountains of the West, snowpack measurements do not always account for all of the precipitation that falls during the winter and early spring. Figure 1 illustrates this point. This shows the accumulated gauge catch for each gauge from December 5, when the first snowpack measurements

were made, to April 30, date of the last snowpack measurements, as compared with the water content of the snowpack at the precipitation stations on the peak date of March 19. The figures are: for Station No. 1, gauge catch 17.9 inches, snowpack, 9.7 inches; Station No. 2, 18.8 and 11.0; Station No. 3, 19.4 and 13.4. The gauge catch figures as of March 19, the peak snowpack date in the openings, are 13.1, 13.8, and 14.4. Even at this point the gauge-catch and snowpack differences were quite large. This is due, besides normal snowpack losses, to a period of thaw accompanied by heavy rains during the second week of January.

The affect of midwinter thaws — quite common occurrences in the Northeast — is further illustrated in Figure 2. This gives the snowpack picture under the forest canopy in inches of water for the whole season. Measurable amounts of snow began to accumulate early in December. By January 3, the depth averaged 16 inches and the water content 2.8 inches. Then we had the thaw. Nearly 2 inches of rain fell along with it. The snowpack almost disappeared in a few days, and most of the rainfall went directly into streamflow, along with the water from the melting snowpack.

After the January thaw, a second snowpack began to build up, and this continued for the rest of the normal season. The peak in the woods was reached on April 3 when water equivalents ranged from 7.6 to 11.6 inches. Snow depths on that day were from 25 to 38 inches.

Spring was late in coming last year. Although the snow had gone from the lower part of the watershed, and the buds were beginning to open, there were still 5.8 inches of snow containing 2.1 inches of water at Station No. 3 on April 30.

COMPARISON BETWEEN GAUGE CATCH, SNOWBOARD, AND SNOWPACK MEASUREMENTS

The next slide (Figure 3) shows a comparison between gauge catch, snowboard, and snowpack measurements. The gauge and snowboard figures are totals of six weekly measurements, and the snowpack figures are totals of the weekly increments to the snowpack during the same period. Only 6 weeks' measurements were used because only 6 snowboard catches were meaningful for this kind of comparison. Since all measurements were made at weekly intervals, the snowboard values for those weeks during which rainfall or thaw occurred were useless.

The differences between gauge, snowboard, and snowpack are not statistically significant. In a sample of only 6 observations, individual deviations would have to be in relatively close agreement with each other to show a significant relationship. In this case, the individual deviations were not even always in the same direction.

This could be due either to sampling error or to natural climatic causes. For example, the snowpack could lose water through both sublimation at the surface and melt at the ground line. Or the weekly snowboard catch could have fallen late in the week, after the snowpack had already lost water through sublimation. Windiness during snowfall would, of course, affect gauge catch, and drifting could affect either or both snowboard and snowpack accumulations. In view of these possibilities, the lack of consistency between individual values does not seem surprising.

The lower figures are the values expressed as a percentage of the snowboard catch. It is interesting that the relative difference between the snowboard and snowpack

measurements was almost exactly the same at all three stations, the respective values being 97.6, 97.5, and 97.5 percent. The gauge catch was the largest value at stations 1 and 2, but the smallest at station 3. The comparatively low gauge catch at station 3 (8.3 percent less than the snowboard) is, I believe, a reflection of the windier site. This station is very close to the ridge top. Expressed in terms of gauge catch, the snowpack measurements were 4.7 and 7.4 percent less for stations 1 and 2, but 5.8 percent more for station 3.

In studying relative efficiency of different types of gauges and shields in the mountains of the West, Helmers^{3/} and Warnick^{4/} made similar comparisons. In Helmers' study the snowpack measurements for two periods were 29.5 and 14.5 percent greater than the catch of his "best" gauge (a recording gauge with stereo orifice and tilted shield). Warnick compared various gauge catches with snowboard measurements in the same manner that we did. For nine

1. Talk presented by Richard S. Sartz at the Fourteenth Annual Meeting of the Eastern Snow Conference, Syracuse, New York, February 7 and 8, 1957.
2. Pierce, Robert S. The effect of land use on the depth and duration of soil freezing in the Northeast. Paper presented at the Thirteenth Annual Meeting of the Eastern Snow Conference, Hanover, N.H., Feb. 9-10, 1956.
3. Helmers, Austin E. Precipitation measurements on windswept slopes. *Amer. Geophys. Union Trans.* 35:471-474. 1954.
4. Warnick, C. C. Influence of wind on precipitation measurements at high altitudes. *Univ. Idaho Engin. Expt. Sta. Bul.* 10. 63 pp. 1956.

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periods of snowfall that totalled about 30 inches of water, his gauge catches ranged from 5.8 percent less to 8.2 percent more than the snowboard value. Our comparable figures are 8.3 percent less at station 3 and 5.4 percent more at station 2.

EFFECT OF EVALUATION

The effect of elevation on snowfall can be seen in this figure (Figure 3) as well as on the first two that you have seen. Figure 1 perhaps shows it more clearly. The snowpack difference is somewhat greater than the gauge catch difference. This is as would be expected since, even with the same precipitation, the snowpack would change with elevation because of temperature differences. However, deficient gauge catch, particularly at station 3, might have made the gauge differences less than the actual precipitation differences.

EFFECTS OF FOREST OPENINGS

I want to show you the next slide (Figure 4) just as a matter of interest. This is a plotting of the snowpack measurements in the gauge opening and in the forest below station number 2. The greater water content and earlier peak date in the openings were found at all three stations. I don't want to emphasize the magnitude of the differences because these particular measurements were not designed for this kind of comparison. However, for those who might be interested, I have here some reprints of the Journal article I mentioned earlier. You are welcome to them.

FIGURE 1

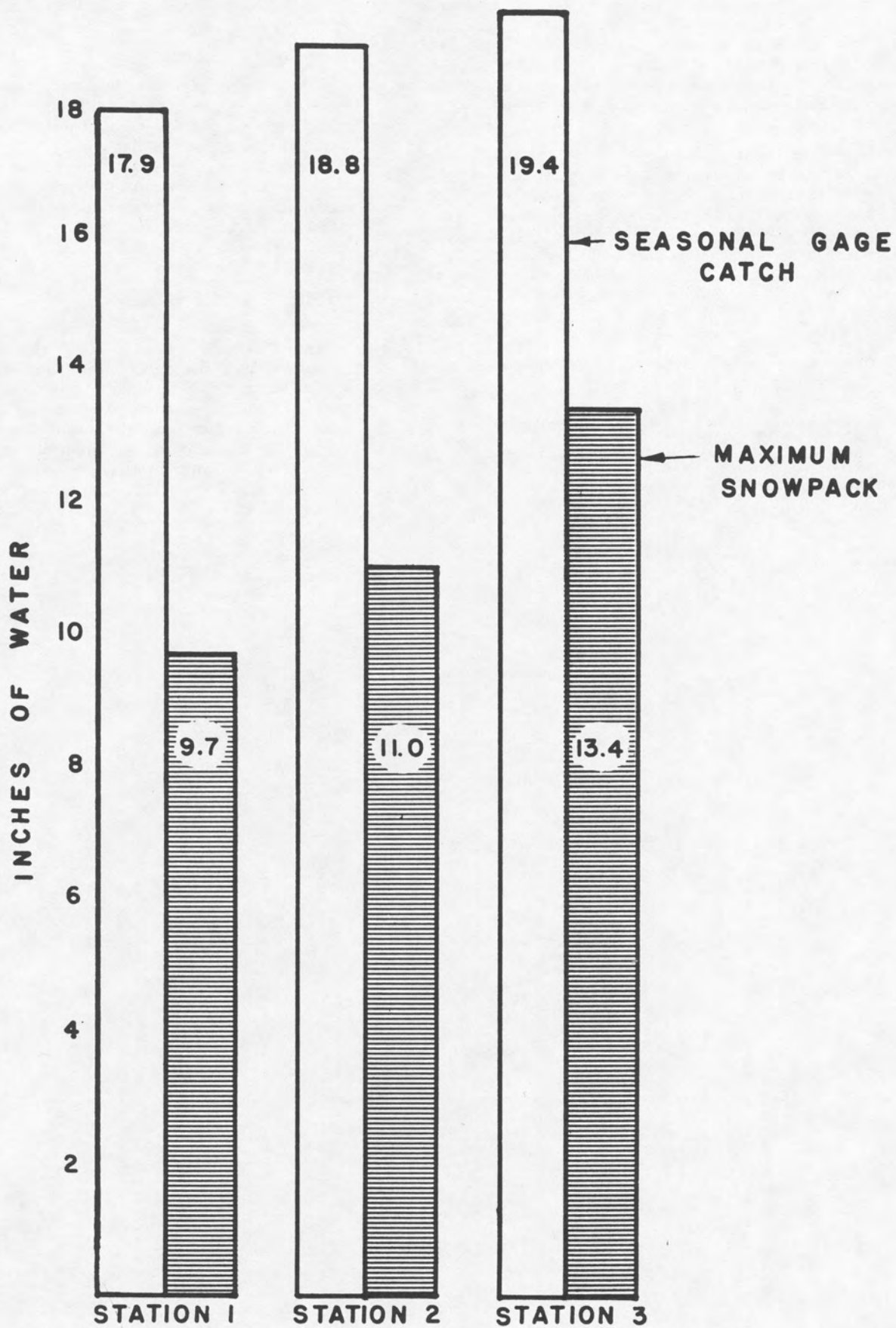


FIGURE 2

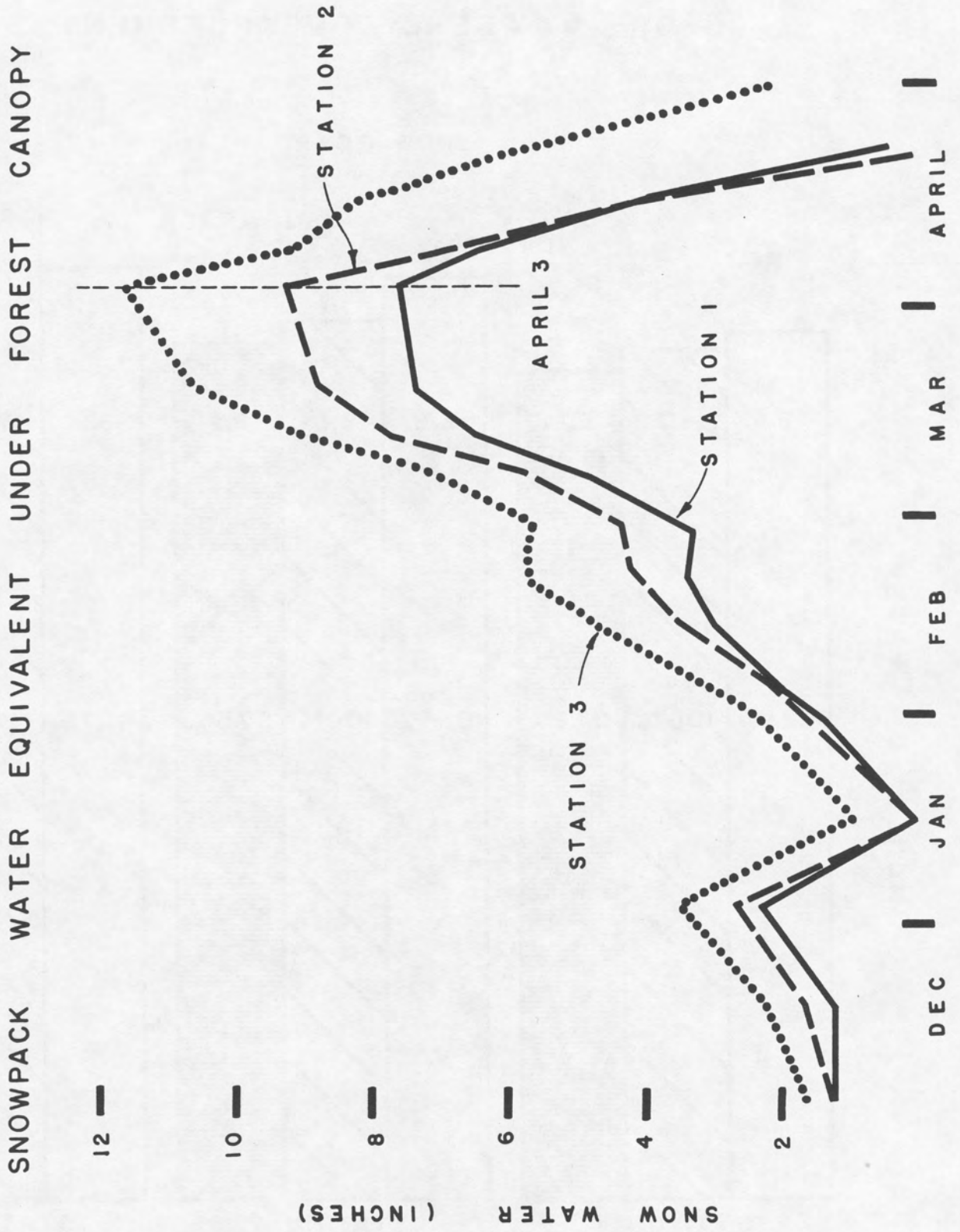


FIGURE 3

ACCUMULATED PRECIPITATION
FOR 6 WEEKLY MEASUREMENTS

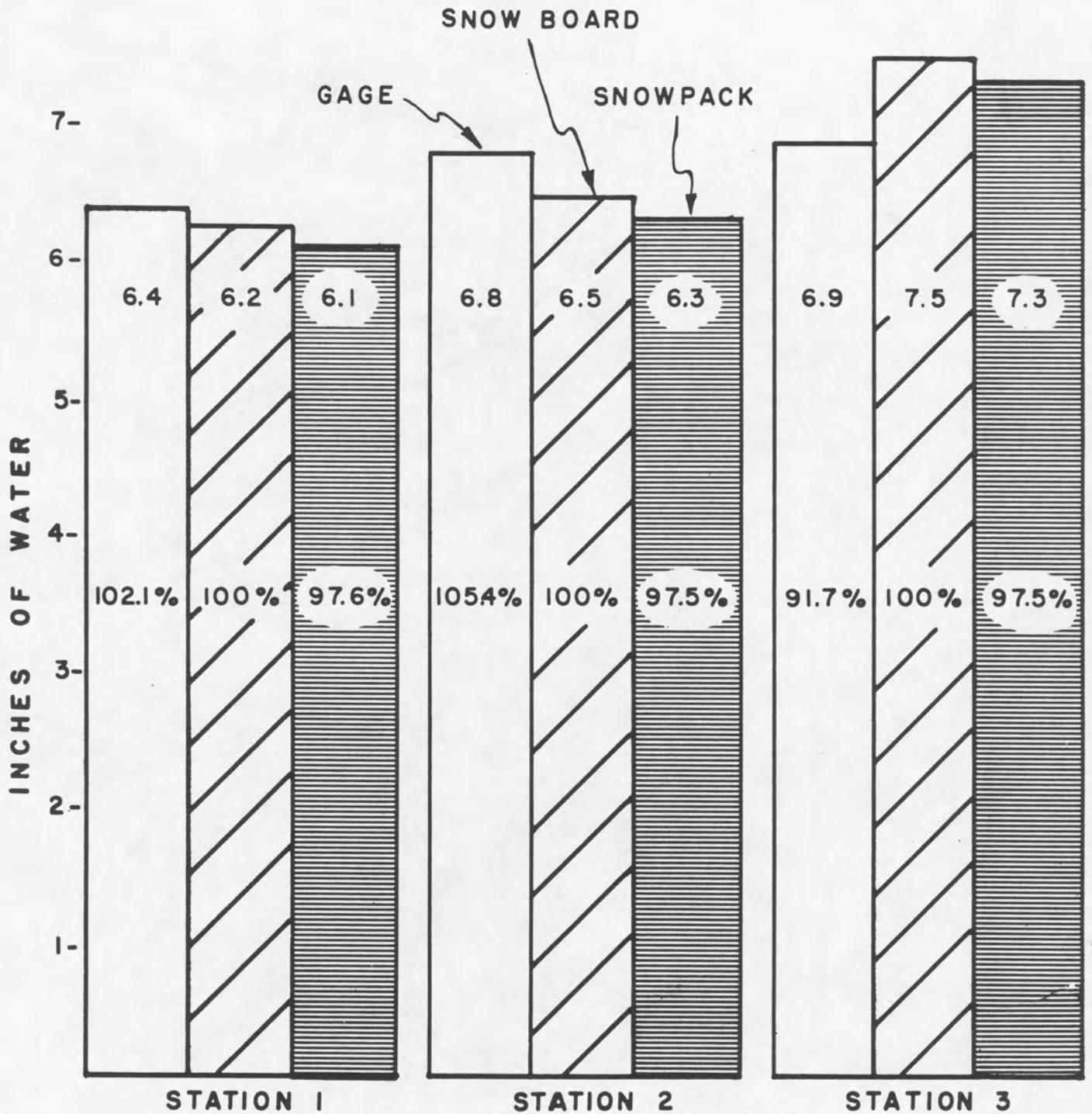


FIGURE 4

SNOWPACK WATER EQUIVALENT IN FOREST AND OPEN

STATION 2

