Snow Catch by Conifer Crowns

DONALD R. SATTERLUND

Washington State University, Pullman

HAROLD F. HAUPT

Forestry Sciences Laboratory, Moscow, Idaho

Abstract. Study of interception storage of snow by two species of sapling conifers in northern Idaho revealed that cumulative snow catch follows the classical law of autocatakinetic growth, or

$$I_s = S/[1 + e^{-k(P-P_0)}$$

where I_s is interception storage, S is the interception storage capacity of the tree, e is the base of the natural logarithm, k is a constant expressing the rate of interception storage, P is accumulated snowfall, and P_0 is accumulated snowfall at the time of most rapid storage (i.e., the point of inflection of the sigmoid curve). Interception storage conformed to the law in five storms in which snowfall began while the trees were bare, and in two storms in which snow fell while snow from previous storms persisted on the trees. Several small storms yielded insufficient data to define the appropriate constants, but inspection indicated no serious deviation from the general law. (Key words: Coniferous trees; interception; snow; Idaho)

INTRODUCTION

Probably no element of the hydrologic cycle has been as widely studied as the interception process, whereby precipitation is caught by vegetation and redistributed to the atmosphere and the ground. Interception loss, or the return of precipitation to the atmosphere by evaporation, was observed by *Horton* [1919] to be the sum of (a) the precipitation stored on plant surfaces at the end of the storm (hereafter termed interception storage), and (b) evaporation from the precipitation held by plant surfaces during the storm.

The interception loss equation. Merriam [1960] developed a general equation to describe the interception loss process on the basis of rain and snowfall data found in the literature as follows:

$$L = S(1 - e^{-P/S}) + RET \qquad (1)$$

where

L is interception loss in inches depth over the projected area of the canopy;
S is the interception storage capacity of the vegetation;
e is the base of the natural logarithm;
P is storm precipitation in inches;
R is the ratio of vegetation surface area to the projected area of the canopy;
E is the evaporation rate in inches depth per hour during the storm; and
T is the duration of the storm in hours.

The first term on the right-hand side of the equation should be considered interception storage, and the second term represents evaporation during the storm.

During light or short storms, the interception storage term of the equation dominates, and the evaporation during the storm is minor to negligible. Similarly, very low evaporation rates during long periods of precipitation have the same tendency to cause the storage term to dominate. Evaporation from intercepted precipitation could be expected to be high only during short storms and to decrease as the storm continued, as demonstrated by *Abraham* [1962] in his analysis of evaporation from falling raindrops. *Miller* [1966], considering the low vapor pressure of snow and the lack of heat energy available during the cold and humid conditions of snowfall, suggests that evaporation of intercepted snow must be very slight during storms. Therefore, snow interception losses must primarily be limited to losses from interception storage between storms.

Interception storage of snow. In most studies of snowfall interception, interception storage has been measured indirectly as the difference between the amount of snowfall reaching the ground in the open and that reaching the ground under a forest canopy. As a result, many of the data are of questionable value, because all inaccuracies and errors of measurement are included in the residual term, and because of the questionable assumption that snowfall in a forest opening is an accurate measure of snowfall above the forest canopy.

A few studies have been made by directly measuring the amount of snow caught by coniferous trees. *Goodell* [1959] found that a small Engelmann spruce (*Picea engelmannii* Parry) held about 0.2 inch, water equivalent, after a dry, cold snowfall of about 0.4 inch. *Miller* [1964] weighed snow beaten off a young lodgepole pine (*Pinus contorta* Dougl.) as equivalent to about 0.24 inch of water. In Japan, a cryptomeria (*Cryptomeria japonica?*) tree was weighed continuously through several snowstorms. The catch varied from storm to storm, being least at low temperatures near 23°F but moderate to heavy at higher temperatures (32–34°F). The snow loads accumulated in variable fashion, closely following the curve of accumulated storm precipitation in a storm when air temperature remained between 25–27°F., but accumulating rapidly and uniformly in a storm when the air temperature, initially slightly above freezing, fell to near 30°F [*Miller,* 1964]. The limited data suggested that interception storage of snow may depart from the convex upward form indicated in equation 1.

Therefore, a study was set up to determine the factors influencing snow catch by conifers. This paper reports on the mechanism of interception storage during snowfall.

METHOD OF STUDY

Sapling Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and western white pine (*Pinus monticola* Dougl.) trees were suspended in a very small opening in a sapling lodgepole pine stand near the headquarters of the Priest River Experimental Forest in northern Idaho. The trees were suspended by a light cable that passed through an overhead pulley and was attached to a spring-tension scale. Water level recorders were modified to provide a continuous weight record of each suspended tree. A complete description of the recording apparatus and its construction will be reported separately.

Each tree was suspended for a period of approximately one month, after which it was replaced by a freshly cut tree of the same species. A quantitative description of each tree is given in Table 1.

The hourly snow catch, in pounds, was converted to the depth in water equivalent over the projected crown area of the tree to the nearest 0.001 inch in each storm. Hourly precipitation records were obtained from the headquarters weather station, about 100 yards away. Also available were continuous records of tem-

TABLE 1. Description of Trees Used in Snow Interception Study, 1967

Species	Tree No.	Dates Suspended	Height to Top Whorl, ft	Projected Crown diam., ft	Projected Crown area, sq ft	Needled Surface Area,* sq ft
Douglas-fir	1	1/10–2/2	13.7	10.68	89.58	514.61
	2	2/2–3/8	12.8	7.90	49.02	119.39
W. white pine	1	1/10–2/2	12.0	10.00	78.54	95.31
	2	2/2–3/8	12.2	8.12	51.78	97.07

* Needled surface area is the total surface area of needled branches measured as needled branch length times the distance between needle tips perpendicular to the branch axis.

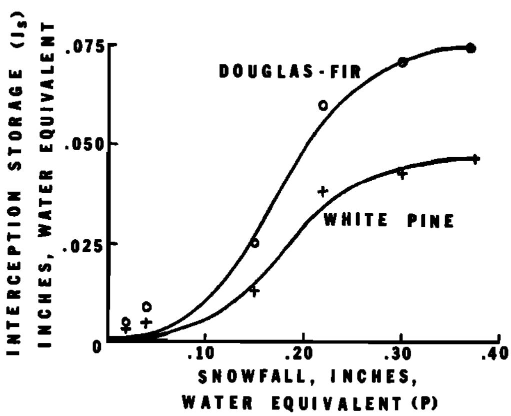

Fig. 1. Snow catch during storm of January 10, 1967. Computed curve fitted to field observations (circles and crosses).

perature, relative humidity, and solar radiation. Accumulated wind movement was measured daily. Wind was not an important factor in this study, as all snowfall occurred under calm or nearly calm conditions.

RESULTS

When accumulated interception storage was plotted against accumulated snowfall for each storm and tree, a surprising similarity of form appeared. Each plot, though differing in slope and varying in height, seemed to define the well known sigmoid growth function. Consequently, the formula for each curve was derived from the data according to methods outlined in *Lotka* [1956], and a computed curve was fitted to the data. Figures 1 and 2 illustrate typical results.

The general equation for snow catch is

$$I_s = S/[1 + e^{-k}(P - P_0)] \qquad (2)$$

where

S, e, and P are as previously defined;
I_s is interception storage;
k is the constant expressing rate of interception storage;
P_0 is the amount of snowfall accumulated at the time of most rapid storage (i.e., the point of inflection of the sigmoid curve).

Equation 2 held when the trees were bare of snow at the start of the storm and when trees loaded with dry snow were subjected to a more moist snowfall at higher temperatures than the previous snowfall.

Complete comparisons of computed and observed snow catch were made for all storms that yielded sufficient data to define the curve. Tables 2 and 3 present the data upon which figures 1 and 2 are based. Most of the differences between computed and observed catch were less than 0.01 inch. The largest difference, 0.036 inches, arose when snow slipping from a small, overloaded branch fell and the force of its fall dislodged larger masses of snow from lower branches. However, accumulation resumed and was approaching the computed storage capacity when snowfall ended.

Several small storms yielded insufficient snow to define a relationship between catch and snowfall, but inspection of the data gave no indication that the general form of the curve was different in small than in larger storms.

DISCUSSION

Growth of any kind in which the substance or structure itself acts as the base for the further accumulation of the same substance or

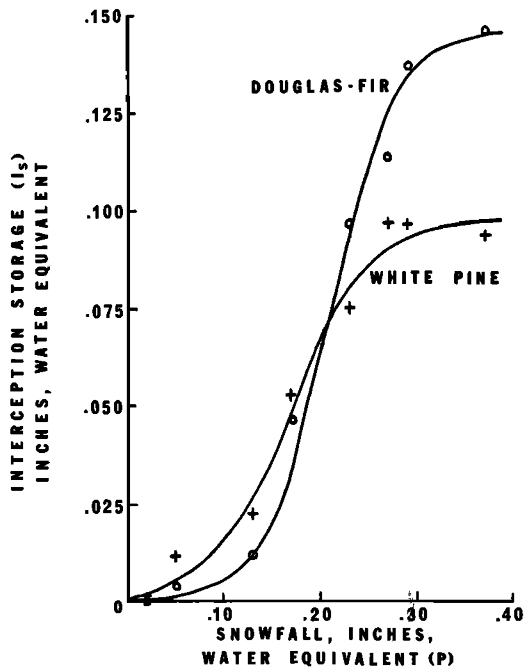

Figure 2. Snow catch during storm of January 12, 1967. Computed curve fitted to field observations (circles and crosses).

TABLE 2. Snow Catch by Douglas-fir and Western White Pine. Trees Bare at Start of Storm. Priest River Experimental Forest, Idaho. Storm of January 10, 1967

Cumulative Hourly Snowfall, inches, w.e.	Interception Storage, Inches Water Equivalent: Douglas-fir Observed	Douglas-fir Computed*	Douglas-fir Difference	Western White Pine Observed	Western White Pine Computed†	Western White Pine Difference	Temp., °F
0.02	0.005	0.002	0.003	0.004	0.001	0.003	32
0.04	0.008	0.003	0.005	0.005	0.002	0.003	32
0.15	0.025	0.027	0.002	0.013	0.015	0.002	32
0.22	0.060	0.055	0.005	0.038	0.034	0.004	32
0.30	0.071	0.071	0	0.043	0.044	0.001	32
0.037	0.074	0.074	0	0.046	0.046	0	33

* $I_s = 0.075/1 + e^{-23.07(P-0.175)}$
† $I_s = 0.047/1 + e^{-23.66(P-0.180)}$

structure may be termed 'autocatakinetic' growth [*Lotka*, 1956]. According to this concept, growth would continue at an ever accelerating rate in the absence of external constraints. In any complex system, however, constraints exist that limit growth at some point. There are two points of equilibrium: a lower, in which growth is absent for want of the growth substance, and an upper, at which growth is limited by the constraints of the system. Starting at the point where the substance is first present, growth begins to accelerate and continues until the limits of the system are approached, then decelerates until a new equilibrium is established at the limits of the system. For example, a bacteria population in a petri dish containing agar defines the locus of the well known equation of population growth.

An analogous situation exists in the development of interception storage of snow by coniferous trees. The first snowflakes striking the canopy often bounce off the needles and fall through all but the smallest spaces between them, bridging across the smallest. With continued snowfall, more and more bridges are formed across larger and larger gaps, providing a continuously increasing platform upon which more flakes can come to rest. As the snow builds up, however, most of the bridgeable gaps are bridged, and the platform area increases at a slower rate. Heavier snow loads on flexible branches bend them downward, and at some point the tree can hold no more snow. Thereafter, the excess slides or falls from the canopy, as rapidly as it falls from the sky.

During calm periods the size, form, and wet-

TABLE 3. Snow Catch by Douglas-fir and Western White Pine. Trees Bare at Start of Storm. Priest River Experimental Forest, Idaho. Storm of January 12, 1967

Cumulative Hourly Snowfall, inches, w.e.	Interception Storage, Inches Water Equivalent: Douglas-fir Observed	Douglas-fir Computed*	Douglas-fir Difference	Western White Pine Observed	Western White Pine Computed†	Western White Pine Difference	Temp., °F
0.02	0	0.001	0.001	0.001	0.002	0.001	33
0.05	0.004	0.001	0.003	0.012	0.005	0.007	32
0.13	0.012	0.012	0	0.023	0.026	0.003	32
0.17	0.047	0.034	0.013	0.053	0.049	0.004	31
0.23	0.090	0.094	0.004	0.075	0.080	0.005	31
0.27	0.114	0.125	0.011	0.097	0.091	0.006	32
0.29	0.137	0.134	0.003	0.097	0.093	0.004	32
0.37	0.146	0.145	0.001	0.094	0.097	0.003	33

* $I_s = 0.146/1 + e^{-29.75(P-0.210)}$
† $I_s = 0.098/1 + e^{-25.04(P-0.170)}$

ness of the snowflakes determine the rate and degree of bridging during any given storm, whereas the form, surface area, and strength of the branches determine the ultimate snow load that can be borne. There is an interaction between snow cohesion and branch strength, for snow bridges distribute the load so that branches give each other mutual support, increasing the load capacity of the tree.

Interception storage of snow therefore differs from interception storage of rain. Liquid water forms a thin film surrounding the existing surfaces of the tree, whereas snow bridges across gaps and thereby creates its own surface upon which further snowfall can be retained. In short, there is no universal interception storage equation, and since interception storage is the dominant element in either snow or rainfall interception loss, there can be no universal interception loss equation.

Further consideration of the redistribution of interception storage to the atmosphere and the ground also suggests differences of great magnitude between snow and rain. But that is a separate question and is also under investigation.

Acknowledgments. Scientific Paper No. 2977. Washington State University Agriculture Research Center, Pullman, project 1849. This investigation was supported in part by Cooperative State Research Service Funds from the McIntire-Stennis forestry research program and was conducted in cooperation with the U. S. Forest Service, Intermountain Forest and Range Experiment Station, Moscow, Idaho.

REFERENCES

Abraham, F. F., Evaporation of raindrops, *J. Geophys. Res., 67,* 4673–4682, 1962.

Goodell, B. C., Management of forest stands in western United States to influence the flow of snow-fed streams, *Intern. Assoc. Sci. Hydrol. Publ., 48,* 49–58, 1959.

Horton, R. E., Rainfall interception, *Monthly Weather Rev., 47,* 603–623, 1919.

Lotka, A. J., *Elements of Mathematical Biology,* Dover Publications, Inc., New York, 465 pp., 1956.

Merriam, R. A., A note on the interception loss equation, *J. Geophys. Res., 65,* 3850–3851, 1960.

Miller, D. H., Interception processes during snowstorms, *Pacific S.W. Forest and Range Expt. Sta. Res. Paper PSW-18,* 24 pp., 1964.

Miller, D. H., Transport of intercepted snow from trees during snow storms, *Pacific S.W. Forest and Range Expt. Sta. Res. Paper PSW-33,* 30 pp., 1966.

(Manuscript received June 1, 1967;
revised August 1, 1967.)