INFLUENCE OF FORESTS UPON THE MELTING OF SNOW IN THE CASCADE RANGE.

Compiled by Alfred A. Griffin, Forest Examiner.

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The melting of snow in the forest and in the open has been the subject of much study, but without the accumulation, in America at least, of any large amount of data on the subject. Jaenicke and Foerster[1] found that a yellow pine forest at the Fort Valley Experiment Station in northern Arizona retained a thin layer of snow for 8 to 13 days after the open became bare. Similar data presented in several recent papers by Professor Church, of the Mount Rose Observatory, cover more extensive studies in the coniferous forests in the Lake Tahoe region of western Nevada, and show greater effects.

In order to find with some definiteness the effect, if any, of forests in representative portions of the Cascade Range on the melting of the winter snow cover, the Forest Service carried out studies of snow melting on three separate watersheds: The Tumalo area in central Oregon, the Wind River area in southern Washington near the Wind River Experiment Station, and the Yakima area on the headwaters of that river in central Washington. These locations permit the studies to show the value of forests to the irrigation interests, as well as to furnish a basis for comparing the effect of forests of this region with those of other regions.

The studies on the Tumalo area were carried through both the 1916 and 1917 seasons entirely by Forest Examiner W. J. Sproat of the Deschutes National Forest; those at the Wind River Experiment Station area by the writer in 1916, and by Forest Assistant C. J. Kraebel and Ranger A. E. Kloe in 1917; and those on the Yakima area, carried on in 1917 only, were conducted by Deputy Supervisor W. F. Ramsdell and Ranger W. G. Hellen, both of the Wenatchee National Forest. In each study the depth, density, and distribution of the snow cover were observed throughout the melting season at 8 to 20 typical observation points or stations.

Description of areas.

The first and third areas lie on the high eastern slopes of the Cascade Range; the Wind River area, however, lies in the region of west slope types along the Columbia River. The underlying rock is igneous in character and principally volcanic, with occasional outcrops of various size. Because of their altitude, and the consequently high annual precipitation, these timbered areas are an important source of water for the irrigation of the valleys below. Following is a brief description of the individual areas on which measurements were taken.

Tumalo Creek.—Snow stations lie at elevations of 6,000 to 6,800 feet, on the headwaters of a stream already furnishing water to a large irrigated area. In this region the average precipitation of 40 to 50 inches occurs principally in the form of snow, and at the higher elevations the snow cover may reach a depth of 15 to 25 feet. An irrigation reservoir to store the flood water of this creek, and already costing a half million dollars, has so far been only partially successful. Large areas of irrigable land need only water to become fertile.

[1] Jaenicke, A. J., and Foerster, M. H., The Influence of Western Yellow Pine Forest on the Accumulation and Melting of Snow. Monthly Weather Review, March, 1915, 43: 115.

The forest cover consists principally of broken stands of mountain hemlock up to 40 inches D.B.H. and 100 feet tall, and lodgepole pine averaging 10 inches D.B.H. and 60 feet tall, with an occasional western white fir. There is sometimes a scattered undergrowth of huckleberry bushes, willow, herbs, etc. The soil is a light pumice and usually rocky. Open areas are broken up with varying ground cover of grass, down logs, or forest reproduction up to 10 feet tall. Figure 1 shows the generally open character of much of the forest and the irregular burned over openings, usually but a few acres in extent. The study compares the snow melting in these openings with that under the forest cover.

Wind River.—Stations are in two main groups: On a flat at 1,200 feet elevation, and on mountain slopes at 2,500 to 3,000 feet. The first group is on a large alluvial bench covered with a typical Pacific slope forest. The Douglas firs are from 3 to 6 feet in diameter and up to 200 feet tall. Some western white pine and grand fir are intermixed; western hemlock frequently forms a thick understory. The moderate underbrush is principally vine maple and reproduction. Recent cuttings, some of which have been burned, furnish sites for the "open" stations. The sparse ground cover consists of weeds, vine maple and other brush.

The mountain slope snow stations are under a slightly lighter forest cover which contains noble fir in place of the grand fir. There are also some ledges and much loose rock in the local "shot" loam soil. Underbrush is but moderately dense and similar to that on the flat. The unprotected stations are, however, located in a large 15-year-old burn which is densely covered with vine maple, ceanothus, spirea, willow, cherry and reproduction.

The climate is generally moist but with a long drought through the summer, so that irrigation is practiced by some of the scattered valley ranches. The maximum depth of snow varies greatly, with the altitude and season, between depths of 2 to 5 feet and 6 to 12 feet on the flat and the high slopes, respectively. This snow makes up by far the greater proportion of the total precipitation.

The Yakima.—Stations are located immediately south of Lake Keechelus, an important irrigation reservoir on the headwaters of the Yakima River. The sites chosen are from 2,450 to 3,300 feet elevation (see Table 3) on the east slope of the Cascade Range near the Stampede Tunnel. Annual precipitation is about 50 inches, the largest part of which again is snow, accumulating to depths of 10 to 15 feet or more. The resulting water is partially but not entirely stored in reservoirs for use on the large areas of irrigable land in the lower valley. Any influence which will retard the melting will increase the efficacy of these reservoirs and make possible a more complete utilization of this snow water.

The forest cover is largely western hemlock, Douglas fir, western white pine, and some western red cedar, and is very similar to the Pacific slope forests. The undergrowth consists of huckleberry, willow, alder, vine maple, etc., with some herbs. The soil varies from sandy to clay loam and is frequently rocky. On this area also stations were studied both on the flat and on the steep slopes, facing mostly toward the east.

The "open" stations are on old burns and logged-over areas, with ground cover varying from grass to a fairly heavy mixture of goat brush with huckleberry bushes and forest reproduction up to 13 feet high.

FIG. 1.—Looking northeast across the north fork of Tumalo Creek. Some dense timber appears on the left, but most of the forest cover is very light. (Photo. by Sproat, Apr. 13, 1916.)

FIG. 2.—Small mounds of snow beneath the litter fallen from the forest cover. The unprotected snow has melted much more rapidly. (Photo. by Kraebel, May 2, 1917.)

Method of observations.

In order that the data might be definite and closely comparable, snow stations were located in the open and in the forest in pairs, the two stations being similar in all important respects except in forest cover. Aspect, degree of slope, and distance to trees, stumps, edge of timber, possibilities of drifting, and other factors each received careful attention. Frequently another pair of stations served as a check.

Snow depths were measured regularly at intervals of usually one week or less, from the period of greatest depth throughout the duration of the melting season of 9 to 17 weeks. In all cases where the snow was less than 5 feet deep from two to five or more measurements were taken at each station to give an average figure for that particular site. Permanent graduated stakes marked each place of measurement on the Tumalo area and the center of each station on the other areas.

The snow density, or water equivalent, was measured at each regular observation close to at least four typical stations. Both the standard United States Weather Bureau apparatus and sampling cans were used for the purpose, some difficulties being encountered and others avoided by each method. Because of deep snow and unsuitable apparatus on the Tumalo area these measurements were so difficult and irregular that only average figures were used.

Data.

Full reports for each of the studies are available in the Forest Service files. For the sake of brevity and clearness the results are given here, summarized by areas studied.

Tumalo.—The four pairs of stations observed on this area in the spring of 1916 were typical of small burns or open areas of from 1 to 4 acres in extent, and the immediate borders of the adjacent stands of mature timber. The greatest average depth of snow measured in the timber was 121.2 inches on April 5, 10 inches less than was measured in the open on the same date. On June 22 the first open station became bare of snow; on July 18 no snow was left on any of the stations in the open. As the snow disappeared from the individual stations in the open there remained at the corresponding forested stations an average of 19.3 inches of snow. At an average density of 45 per cent, this is equal to 8.7 surface inches of water; 2.1 inches, about 25 per cent, still remained two weeks later at the time of the last observation.

In the spring of 1917, with slightly less snow and a briefer melting season, the equivalent of 5.2 inches of water was retained by the forest-covered stations after the "open" stations became bare; at the end of the second week all were bare. In 1917 observations included eight pairs of stations, the new open stations being in larger openings.

Wind River.—The results for 1916 in the densely forested Wind River region are as follows: From a maximum average depth of 70.8 inches of snow[1] an average of 28.2 inches remained at the forested stations as the corresponding stations in the open became bare. Part of this remained for six weeks longer. The retarding effect of the forest cover was twice as strong on the deeply snow-covered mountain slopes as on the flat. About 66 per cent of the maximum water equivalent was conserved on the one and 38 per cent on the other.

In 1917 administrative exigencies permitted complete examinations of only three pairs of stations on the flat.

[1] Water equivalents are shown in Table 1.

The maximum average depth of snow in the forest was 25 inches. The stations in the open became bare in April, leaving an average of 6.2 inches at the stations in the forest. This was equal to 3 inches of water, or 40 per cent of the maximum water equivalent.

Yakima area.—The observations on the Yakima watershed cover the melting season of 1917 only. From a maximum of 88 inches of snow at the forested stations in early April, there was still an average of 19 inches left at each forested station when the corresponding station in the open became bare—about June 1. This snow, equal to 6.9 inches of water, gradually melted during the next four weeks. (Table 2 shows the results in detail.)

Correlation of results.

Table 1 summarizes the water value of the snow cover retained by the forested areas. The 7.5 inches of water equivalent, found to be the mean for all stations, lasted on the average for 17 days and at some forested stations for more than 42 days. The value of forests appears to be greatest on Wind River, and in 1916, probably because of the high mountain slope stations with deep snow mantle under heavy forest cover, and least on the Tumalo area, under the "dry slope" conditions.

TABLE 1.—*The water equivalent of the mean depths of snow retained by the forested stations when the corresponding open stations became bare, and for three weeks thereafter, expressed in inches and in per cent of the maximum snow cover.*

Study.	Maximum water equivalent.	Weeks after open stations became bare.							
		0		1		2		3	
	In.	*In.*	*P.ct.*	*In.*	*P.ct.*	*In.*	*P.ct.*	*In.*	*P.ct.*
Tumalo, 1916	47.0	8.7	18	6.0	12	2.1	4	......	......
Tumalo, 1917	44.0	5.2	12	0.1	......	......	......	......	......
Wind River, 1916[1]	25.8	13.5	52	9.5	37	8.0	31	5.3	21
Wind River, 1917	7.6	3.0	40	0.6	8	......	......	......	......
Yakima, 1917	24.6	6.9	28	3.2	12	1.6	7	0.3	1
Mean	29.8	7.5	30	3.9	14	2.3	9	1.1	4

[1] Average of flat and mountain slopes.

As an example of the data on which these averages are based, Table 2 gives the averages of the measurements at each station on the Yakima area during the season of rapid melting. Measurements on April 10 represent the maximum snow cover of the year. Other measurements, from February to May 3, are omitted, since they do not relate closely to the season of rapid melting.

Measurements of snow density (or water equivalent) were taken each week at practically every station on this area, and, after the middle of May, were repeated from two to four times at each station. The density was, of course, least in the early spring and greatest at the end of the melting season, increasing from averages of 30 to 40 per cent in March or April to 45 to 55 per cent in June or July. Measurements of this factor have varied to a considerable degree with site and season, and often without a suitable cause being apparent. Averaged figures have been preferred for consistent results. In general the snow density is from 1 to 5 per cent higher in the open than in the forest.

A tabulation of what have been found to be the more influential site factors of the stations on the Yakima areas appears in Table 3. Similar and more detailed observations (including also rocks, soils, and ground cover), were made of each of the 36 stations on the other areas and appear in the separate reports.

TABLE 2.—*Yakima Watershed: Depths of snow at stations in the open and in the forest—Averages of each and average snow densities (depths in inches).*

Station.	April 10.	May.			June.				July 3.
		9	17	20	4	12	18	25	
1 open	85.0	85.0	57.5	12.5	2.0	0	0	0	0
2 open	130.0	67.0	37.0	0	0	0	0	0	0
3 open	114.0	84.0	63.0	11.8	0	0	0	0	0
4 open	127.0	57.0	32.5	0	0	0	0	0	0
5 open	106.0	54.5	27.7	0	0	0	0	0	0
6 open	108.0	67.0	46.0	14.1	0	0	0	0	0
7 open	104.0	87.0	63.0	31.0	8.8	0	0	0	0
8 open	100.0	72.0	50.0	23.5	10.8	0	0	0	0
9 open	94.0	57.0	34.0	6.0	0	0	0	0	0
Average	107.6	70.9	45.6	10.7	3.4	0	0	0	0
Density (per cent)	31	40	46	43	52	......	......	......	......
1 forest	92.0	79.0	71.0	46.7	39.0	28.7	7.7	0.3	0
2 forest	80.0	54.0	39.0	7.7	4.2	0.2	0	0	0
3 forest	88.0	60.0	48.0	16.8	4.5	0.1	0	0	0
4 forest	78.0	41.0	23.3	1.0	0	0	0	0	0
5 forest	72.0	46.0	31.0	23.6	13.2	10.2	0.2	0	0
6 forest	99.0	73.0	58.0	37.0	22.4	4.8	0.3	0	0
7 forest	101.0	73.0	56.0	43.0	29.2	18.7	5.1	0.1	0
8 forest	98.0	68.0	61.0	45.7	43.0	28.3	23.0	12.2	0.2
9 forest	84.0	61.0	50.0	28.0	26.3	16.2	12.6	5.7	0.2
Average	88.0	61.7	48.6	27.7	20.9	11.4	5.4	2.0	......
Density (per cent)	33	40	40	40	38	36	32	50	53

TABLE 3.—*Yakima watershed snow stations. Influencing site factors and results upon snow cover.*

Station.	Altitude.	Aspect.	Slope.	Forest density.	Snow conserved, 1917.	
					Depth.	Weeks.
			Per cent		*Inches.*	
1 open	3,300	N. 70° E	21	......	......	......
1 forest	3,300	N. 30° E	30	0.8	28.7	3
2 open	2,900	S. 65° E	100	......	......	......
2 forest	2,900	S. 60° E	84	0.5	7.7	3
3 open	2,900	N. 40° E	58	......	......	......
3 forest	2,900	N. 40° E	70	0.45	4.5	2
4 open	2,650	N. 50° E	4	......	......	......
4 forest	2,650	N. 60° E	3	[1] 0.5	1.0	1
5 open	2,500	West	35	......	......	......
5 forest	2,500	S. 55° W	20	0.55	23.6	4
6 open	2,500	......	0	......	......	......
6 forest	2,500	......	0	0.65	24.4	3
7 open	2,650	N. 55° E	25	......	......	......
7 forest	2,650	East	25	0.6	18.7	3
8 open	2,450	......	0	......	......	......
8 forest	2,450	......	0	0.7	28.3	4
9 open	2,500	......	0	......	......	......
9 forest	2,500	North	3	0.8	26.3	5
Average	2,600	......	27	0.62	19.0	3.1

[1] On three sides the timber cover extends for only about 120 feet from the center of the station.

Although the study does not show any relation between the amount of snow conserved and either altitude, aspect, or slope, it appears that the density of forest cover does produce a distinct effect. In Table 4 a grouping of the stations according to density of cover into four classes brings out this relation quite clearly.

TABLE 4.—*Depth of snow conserved by the stations grouped according to forest cover.*

Stations.	Average forest density.	Snow conserved.	
		Inches.	Weeks.
1 to 9 open	0.00	0.00	0.0
2, 3, 4 forest	.49	4.4	2.0
5, 6, 7 forest	.60	21.5	3.3
1, 9, 10 forest	.77	27.8	4.0

On other areas this relation is hardly as clear as here or as pronounced, though it is evident all through the study.

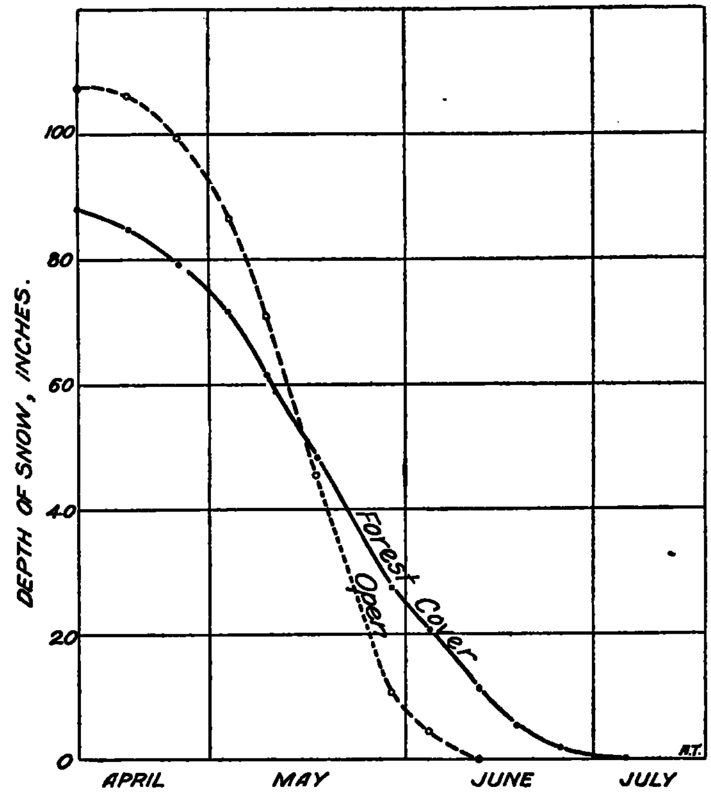

FIG. 3.—Depth of snow at station in the forest and in the open, Yakima watershed, 1917.

The curves of figure 3 show graphically for the Yakima study the more rapid melting at the open stations and the proportion of snow retained at the forested stations. As shown in Table 1, similar curves drawn for each of the other areas would tell very much the same story. The curves given also bring out the frequently observed fact that during the early spring there is a greater depth of snow at the stations in the open than at those under timber. This condition existed on the other areas excepting at high altitudes at Wind River where dry snow with less sunshine seems to have permitted a larger proportion of the total snowfall to reach the ground under the trees.

Comments.

The most important weaknesses of this study lie in the short period covered by the observations—two seasons at the most, and in small practically unavoidable differences in the site factors of the stations of each pair. Because of the severe conditions and amount of labor necessarily involved, it quickly appears that a long series of complete and accurate observations will be quite expensive. Such measurements might possibly be made in connection with annual snow surveys for irrigation purposes. The irregularities in factors of the stations are balanced through the selection of a considerable number of stations (54) in the different regions and by three different men.

Contradictory results appeared at one station: The lowest pair of stations on the Tumalo area became bare in 1916 in the same week, but at the last measurement the open station retained slightly more snow. This may have been due partly to its location in an opening of less than 125 feet radius, and partly to the location of the corresponding forested station less than 100 feet within a stand of thin crowned lodgepole pine. Under the latter conditions but slight protection is received from either direct sunshine or currents of warm air. A similar statement holds good for station *4 forest* of the Yakima area, as shown in Tables 2 and 3.

Because of defects in the sampling tube used, measurements of density on the Tumalo area were too irregular for complete confidence. The limits of the average densities used are from 36 per cent in the early measurements to 45 per cent for the last measurements.

Drifting by the wind was of comparatively small importance throughout the study. Very large and deep snow drifts occur on comparatively small areas near the summit of the Cascade Range, but are not found on the middle slopes or on these areas. The lesser blowing and drifting of snow, chiefly in the open areas, appears to be practically self-compensating.

The results of this study are in general accordance with Swiss figures quoted by Fernow[1]—that the retardation of snow melting in forests is 5 to 8 days in general and may be several weeks—and also with the above mentioned observations by Church. In agreement with the latter is the tendency of the snow in the forest to be deepest and last longest in the small openings of the denser forests. This tendency was especially noted on the Wind River area and may partly account for the late melting of the snow in the small open areas characteristic of the Tumalo area. In large openings the protecting influence from the forest would be dissipated and melting consequently more rapid.

An unusual factor in delaying the melting within the Douglas fir type of forest is the protection given by the irregular layer of even very slight bits of moss, twigs, bark, and other litter weathered from the trees. Fragments like those shown in figure 2, which in the open would materially hasten melting by absorbing solar heat, in the forest serve as a crude but effective insulation from the warmer air currents above the snow. In a more open forest this effect is less prominent.

An opposing influence appears in the ability of bushes, tree trunks, and other large objects to hasten melting by radiating or reflecting into the snow the heat which they receive from various sources. Hollows or bare spots around trees, etc., are frequently noted in the spring. They seem to be important in all coniferous forests but especially in those of the yellow pine type.

Application of results.

Expressed in irrigation terms, the figures given in Table 1 mean that on the areas studied the average square mile of forest cover retained the equivalent of between 720 and 160, averaging 400, acre-feet of water in the form of snow after the open areas had become bare. Neglecting losses through seepage and evaporation, the average of 400 acre-feet is sufficient supply for about 150 acres of cultivated land for the entire season, or for about 650 acres for one month during the peak of the irrigation season (during the summer low-water period). Of course some loss is to be expected in the natural flow of the water down to the lower valley; but it will, at a time when the ground is already saturated, be much less than the normal loss. It is also probable that some of the water will flow down stream too early to be of greatest use in irrigation. Making considerable allowance for these losses, it appears that the forest cover is a very important and very valuable factor in increasing water available for irrigation.

In terms of time, the effect of the forests was to spread the 400 acre-feet of retained snow water through a period averaging 17 days in length. The retardation of this amount of snow is sufficient to be of great importance to irrigation interests, especially as it is generally understood that a forest cover tends to "flatten out" the crest of a flood, and thus to increase the minimum flow at periods of low water. A forest cover thus supplements the possible artificial reservoirs. This study furnishes measurements, however, not of stream flow but only of the material out of which stream flow is made.

Summary.

The study of snow melting in the open and in the forests of three areas on the Columbia River watershed showed that the snow remains an average of 17 days longer in the forest.

Drifting occurred only on the higher ridges of these areas and chiefly in the open, though the late snowbanks in the forest had very much the appearance of drifts. Because of the retention of snow on the crowns of trees and the resulting increased evaporation, the snow cover usually reached a depth greater in the open than in the forest.

The depth of snow retained was considerably greater in a dense forest than in an open forest, at least during the latter part of the melting season. For the areas studied, the snow remaining in the forested stations, at the time the open stations became bare, was equal to 7.5 surface inches of water or about 30 per cent of the maximum snow blanket. With the forest areas at higher altitudes and with stations located so as to prevent completely the influence of open areas on the forested stations, and vice versa, the effect was found to be noticeably greater than this.

SNOWFALL ON MOUNT RAINIER, WASH.

By LAWRENCE C. FISHER.

[Dated: Weather Bureau Office, Seattle, Wash., May 24, 1918.]

Mount Rainier, standing to the west of the main range of the Cascades, rises to a height of 14,408 feet in nearly unobstructed view from the shores of Puget Sound. The low peaks about its base, which were originally a part of the mountain before glaciers cut its flanks, appear to merge into the contour of the mountain when viewed from the Sound, and the mountain itself towers high above the main range of the Cascades 12 miles to the east. The upper and more conspicuous half is clothed with an eternal mantle of snow, while a score of glaciers extend for several miles farther down the deep valleys. En route to the sea, a fraction of the power of its never-failing streams has been captured and transformed to illuminate towns and cities and turn the wheels of industry. One marvels at the rushing torrents of water, and wonders what may be the quantity of snow and rain this great and unshielded mountain takes from the passing winds each year. It is a subject worthy of extended observations and study.

A daily record of snowfall was made during most of the season 1916–17 at Paradise Inn on the south slope of Mount Rainier at an elevation of 5,500 feet. Although

[1] Fernow, B. E., Forest Influences, Bull. 7, Div. of Forestry, p. 137.