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SOME OBSERVATIONS ON SOIL FREEZING IN FOREST AND RANGE LANDS OF THE PACIFIC NORTHWEST

By

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It is well known that freezing and thawing of the surface soil and humus greatly affect their capacity to absorb water. Post and Dreibelbis (1) in Ohio reported that percolation was materially reduced or ceased entirely when the frost depth was three inches or greater. They also stated that "freezing of the surface soil undoubtedly has considerable influence on the base flow of streams." Lassen and Munns (2) concluded that the structure, penetration, persistence, and areal extent of frost are directly influenced by the vegetative cover, especially forest, and by snow. Observations in this region indicate that problem areas exist where frost has a decided effect upon runoff. In the hydrologic analysis required for the Columbia River flood-control survey, data on frost occurrence, character, and penetration are needed.

1/ The author's thanks are extended to all who assisted in carrying out this frost study, especially to E. W. Stevenson and G. A. Garrison for assistance in establishing the frost plots and observing the freezing conditions in eastern Oregon, and to R. S. Rummell and R. W. Steele for assistance in establishing the plots in eastern Washington and the Wind River Experimental Forest, respectively.

This paper summarizes the data obtained from a preliminary study and makes some interpretation of their hydrologic significance. It does not attempt to answer the many questions that might be raised regarding soil freezing. Rather, it serves as a progress report outlining problem areas, types, and conditions. It is hoped that it may be useful in planning and designing further frost and snow studies in the region.

EXPERIMENTAL PROCEDURE

The data in this paper were collected during the winter and spring of 1949-50. The experimental area included the Cascade Range and the range lands in eastern Oregon and Washington. Forty-five experimental plots were located on representative sites in the following forest and range types:

Ungrazed forest: Douglas-fir (west slope)
Lodgepole pine (west slope)
Lodgepole pine (east slope)
Upper slope mixture

Forested range: Ponderosa pine (old growth)
Ponderosa pine (second growth)
Ponderosa pine and grass

Nonforested range: Grass (east-side range)
Sagebrush (east-side range)

Fourteen of these plots were located along Highway 50 between Zigzag, Oregon and Maupin; eight in the Trout Creek watershed at the Wind River Experimental Forest near Carson, Washington; fifteen along U. S. Highway 10 between North Bend, Washington and Vantage; and eight plots in ponderosa pine and grass, and in sagebrush types near La Grande, Oregon.

Most of the plots were established in the fall of 1949 before the ground was covered with snow, so that the soil and vegetal cover data could be accurately recorded. The plots were located in areas accessible from highways that remained open throughout the winter. Each individual plot consisted of a circular area, approximately one acre in size, wholly within one particular forest or range type. The center of each plot was marked with a stake and used throughout the observation period as a reference point from which to locate the actual sampling spots during the periodic observations. When the original plot was established, a pit was dug to the C horizon and the soil profile described. Data on topography, vegetation, and geology were also recorded at this time. The locations of the plots were shown on the U. S. Geological Survey quadrangles.

Periodic observations were made monthly throughout the winter and biweekly during the spring snow-melt period. Each time the plots were visited the soil surface was examined for frost occurrence at paired spots.

On the first visit these were located one pace north and south of the center stake; the second time, one pace east and west of the center. This procedure was followed throughout the observation period, increasing the distance from the center by one pace each time the plot was visited so that the soil and snow remained undisturbed where the observations were made.

The periodic observations at each plot included: snow depth; snow water equivalent; frost depth, type, and location in the soil profile; and soil moisture. Snow depth and water equivalent were measured with the standard snow sampling tube and balance. The depth and type of frost were observed in a section of the soil profile removed with a tile spade. Where the snow depth was over three feet, a section of the top soil was removed with the cutting head of the snow sampling tube and the soil and frost conditions observed.

Frost structure was classified into the three general types described by Post and Dreibelbis (1) in Ohio, as, "concrete," "honeycomb," and "stalactite." "Concrete" frost is characterized by many very thin "ice lenses," small crystals, and an extremely dense structure; "honeycomb" frost has a loose porous structure and permits free vapor movement, while "stalactite" frost structure is characterized by many small needle-like ice crystals aligned vertically and connecting the heaved surface to the soil below. Stalactite frost, when partly thawed and remelted, often has impermeable panes or layers of ice at the base. An additional type recognized in this study was granular frost, found generally in the litter and F horizons in the forest and characterized by scattered granules of ice binding the litter and F particles together. Granular frost appears very porous and is easily crushed in the hands. The moisture content of the soil at the surface or below the frost, if the ground was frozen, was estimated by squeezing a small sample of the soil in the hands. The soil was then arbitrarily classified as dry, slightly moist, moist, or wet.

FINDINGS

To simplify the presentation of results, the data have been assembled into three physiographic groups: West slope forests of the Cascade Range; East slope forests of the Cascade Range; and range lands of eastern Oregon and Washington. Each group will be discussed separately.

West Slope Forests of the Cascade Range

Effect of topography, elevation, and snow depth on the occurrence of frost. -- Snow began to accumulate in these forests about the first week of December at elevations above 1500 feet. As the temperature dropped with the approach of winter, the fall rains turned to snow, and the forest floor was protected by a snow cover before the soil was exposed to freezing temperature. The snow continued to accumulate and the soil remained unfrozen throughout the winter under the insulating protection of the deep snow pack. Bare ground was not exposed again until warmer weather had arrived.

Table I shows the snow accumulation and recession during the winter of 1949-50.

Effect of stand density on snow accumulation. -- Eight plots were established on the Trout Creek watershed in Douglas-fir stands which had undergone different cutting intensities. Two of these plots were in a clear-cut area, two in a stand where 40 percent of the volume had been removed, two in a 20 percent cut, and the remaining two in a virgin stand which had a crown density of 90 percent. The topographic, geologic and vegetative conditions were the same on all the plots.

As the snow arrived late in the fall and remained well into the spring, the soil was free of frost throughout the winter. The plots, however, presented a good opportunity to measure the effect of stand density on snow accumulation and recession.

There was no snow on the ground at the time the plots were established on December 9, but a heavy snowfall occurred a few days later. Due to heavy snows in January, the area was inaccessible until the middle of February. Table II shows how the intensity of cutting influenced the rate of snow accumulation and recession; and Table III shows how it influenced the density of the snow pack. Snow depth and density varied inversely with stand density throughout the winter. In late spring the snow in the clear-cut and partial-cut areas began to melt more rapidly than in the dense stands. The clear-cut areas were free of snow first, the partial-cut areas next and the virgin area last. All the plots were free of snow on May 24. Figure I shows the accumulation and recession graphically.

TABLE I

Snow Accumulation and Recession in the West Slope Cascade Forests

Forest type	Location	Elev.	Snow depth in inches on dates of observations. 1949-50.										
			12/14	12/16	12/21	1/17	1/19	2/13	2/22	3/21	3/23	4/18	4/19
Douglas-fir	Near Zigzag	1500'	0.0"		9.0"	36.0"		33.0"		0.0"		0.0"	
"	" "	1500'	1.0"		7.0"	33.0"		32.0"		0.0"		0.0"	
Lodgepole	" Rhododendron	2000'	4.0"		15.0"	57.0"		37.0"		26.0"		14.0"	
"	" "	2000'	4.0"		11.0"	55.0"		40.0"		26.0"		18.0"	
"	" Gov't Camp	3600'	8.0"		29.0"	118.0"		94.0"		82.0"		81.0"	
"	" " "	3600'	8.0"		29.0"	92.0"		92.0"		92.0"		89.0"	
Upper slope mixture	" Barlow Pass	3800'	1.0"		22.0"	74.0"		78.0"		65.0"		72.0"	
"	" " "	3800'	1.0"		18.0"	73.0"		72.0"		74.0"		64.0"	
"	" Camp Mason	2200'		6.0"			75.0"		53.0"		51.0"		27.0"
"	" " "	2200'		6.0"			70.0"		48.0"		36.0"		23.0"

TABLE II

Snow Accumulation and Recession Under Different Crown Densities in Douglas-fir Type of Wind River Experimental Forest

Crown Density	Elevation	Snow depth in inches on dates of observations. 12/9/49	2/14/50	3/22/50	4/21/50	5/15/50	5/24/50
0	1750'	0.0"	80.0"	56.0"	41.0"	0.0"	0.0"
0	1750'	0.0"	80.0"	63.0"	35.0"	0.0"	0.0"
33%	1700'	0.0"	74.0"	60.0"	36.0"	9.6"	0.0"
45%	1700'	0.0"	77.0"	50.0"	30.0"	9.0"	0.0"
50%	1700'	0.0"	79.0"	43.0"	23.0"	1.8"	0.0"
65%	1700'	0.0"	79.0"	47.0"	42.0"	3.6"	0.0"
90%	1650'	0.0"	63.0"	50.0"	25.0"	10.6"	0.0"
90%	1650'	0.0"	60.0"	39.0"	27.0"	11.2"	0.0"

TABLE III

Water Content of Snow Pack Under Different Crown Densities in Douglas-fir Type at Wind River Experimental Forest

Crown Density	Elevation	Inches of water in snow pack on dates of observations. 12/9/49	2/14/50	3/22/50	4/21/50
0	1750'	0.0"	28.0"	27.0"	19.0"
0	1750'	0.0"	27.0"	27.0"	18.0"
33%	1700'	0.0"	24.0"	24.0"	19.0"
45%	1700'	0.0"	25.0"	22.0"	14.0"
50%	1700'	0.0"	26.0"	21.0"	11.0"
65%	1700'	0.0"	27.0"	20.0"	22.0"
90%	1650'	0.0"	24.0"	22.0"	14.0"
90%	1650'	0.0"	24.0"	18.0"	14.0"

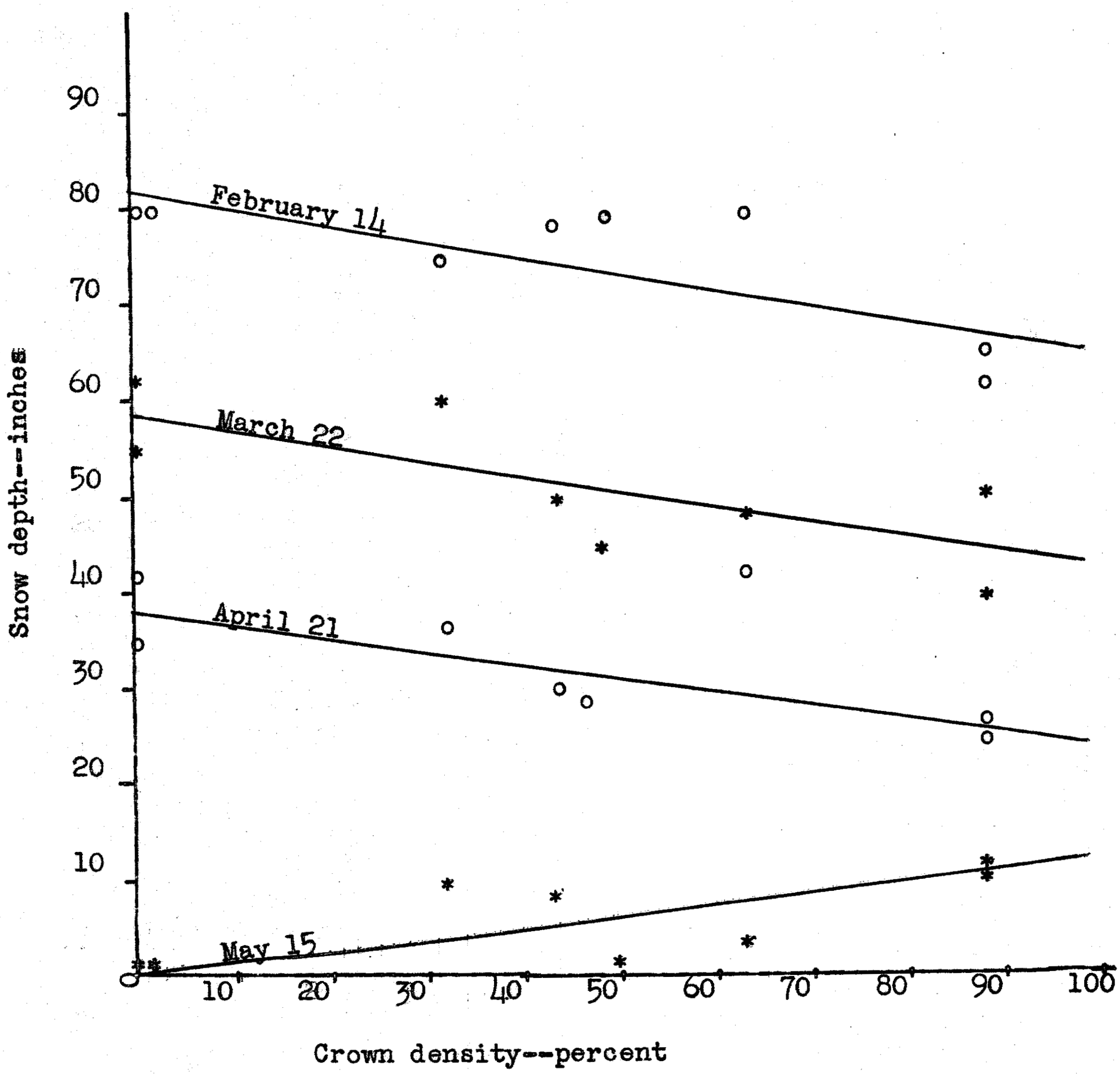

Figure I. -- Snow recession under different crown density

Probable hydrologic significance of frost in the west slope Cascade forests. -- As a result of this preliminary frost study it appears that frost is not an important factor hydrologically in the west slope Cascade forests. The forest floor remained friable throughout the winter and did not appear to be much less permeable to the movement of water and air than at other times of the year.

Belotelkin (3), in New Hampshire, in studies of ground freezing under different vegetal cover conditions, found that a good forest cover had a favorable effect on winter floods. Studies showed that two factors were mainly responsible: (a) delay of ground freezing prior to snowfall in soils protected by tree growth; (b) the type of freezing occurring in these soils. Under forest canopies, soils did not freeze until continuous low temperatures set in. Moisture present in the litter, humus, and upper layers of mineral soil formed snow-like crystals enabling the soil to maintain a good degree of permeability far into the winter.

Cullings (4), in New York, reported that the snow surveys found "little or no frost in the ground where the snow exceeded 24 inches." Roberts (5), in New Hampshire, also found that at about 25 inches of snow the ground surface below the snow began to thaw. Bullard (6) made similar observations near Carson, Washington in 1948.

Snowfall in most of the west-slope Cascade forests above 1500 feet usually starts early in the fall, accumulating to well over 25 inches and remaining throughout the winter and spring. It is not likely that frost has much influence on runoff from this area.

East Slope Forests of the Cascade Range

Effect of topography, elevation, and snow depth on the occurrence of frost. -- The upper slopes of the east-side Cascade forests remained nearly free of frost throughout the winter. The snows arrived early and remained quite deep throughout the winter and spring. There was some light granular frost in the litter in the upper-slope forest before the snow had accumulated to a depth of more than a few inches, but it remained only for a short period. The frost disappeared when the snow depth reached about 30 inches and the soil remained moist throughout the rest of the winter. The lodgepole pine stands on the east slope remained free of frost.

At lower elevations in the ponderosa pine type the snow started to accumulate later in the fall, did not build up as deep a pack, and melted earlier in the spring. Here spotty freezing was noted. However, at no time were there large areas of frozen ground. The frost was confined to places where the snow was shallow or near the base of trees where the soil was exposed. This freezing was confined to the litter and F horizons in most cases, and usually was a permeable granular or honeycomb frost.

Two plots in the ponderosa pine type did have concrete frost in the top horizons about the middle of January, but one month later all this frost had disappeared. Though the snow was 26 inches deep where this frost occurred, most of the snow pack was freshly fallen, and it is believed that the frost formed before the new snow arrived. In March, after the snow began to melt on the southern exposures, patchy spots of concrete and honeycomb frost began to form. Most of this frost appeared to be the result of low temperatures at night and usually melted each day. Observations made late in the afternoon usually showed no frost where an inch or two had been present in the morning. This daily freezing and thawing usually resulted in a stalactite type frost which appeared to cause the soil to fracture and heave near the surface; it continued into April on the south exposures.

Where there was snow covering the soil surface, no freezing was noted even though the soil was moist below the snow. More and more of the soil surface became exposed to freezing temperatures as spring approached, but the areal extent of frost remained about the same. As the soil surface on the southern exposures began to dry out about the middle of April, frost no longer appeared. The northern slopes, however, began to expose surface soil to nocturnal freezing about this time, and freezing and thawing similar to that on the southern exposure took place. The northern exposures seemed to lag behind the southern about three to four weeks with respect to snow melt and the occurrence of frost.

Table IV shows the occurrence of frost and the accumulation and recession of snow from December through April.

The observations show some light freezing in December before the snow was very deep. In January the frost was beginning to disappear with increased snow depth. Two additional plots were established in the ponderosa pine at this time. By February there was no frost anywhere. In March the snow began to recede and some light ground freezing was noted. In April the frost was completely out of the ground on all the east-slope Cascade plots.

<u>Probable hydrologic significance of frost in the east-slope Cascade forests.</u> -- During the winter of 1949 and 1950, frost did not appear to have an influence on infiltration of snow melt water to the forest soils of the east-slope Cascade forests.

In general the frost was restricted to small areas and in most cases it was a permeable type of frost. The impermeable frost that was found occurred near the base of trees and on wind-swept areas where the snow melted early and the bare moist soil was exposed to low temperatures at night.

TABLE IV

Snow and Frost Conditions in the East Slope Cascade Forests

Forest Type	Cover Complex	Elev	December 1/ Snow 2/	December 1/ Frost 3/	January Snow	January Frost	February Snow	February Frost	March Snow	March Frost	April Snow	April Frost
Ponderosa (Grazed)	2nd Growth & Reproduction	2700	1.0	G-.3	24.0	G-.5	14.0	0	0	0	0	0
"	"	2700	2.0	G-.5	26.0	G-.5	28.0	0	6.0	GC-.7	0	0
"	"	2800	-	-	-	-	16.0	0	11.0	0	0	0
"	"	2000	-	-	23.0	GC-1.8	25.0	0	15.0	0	0	0
"	"	2000	-	-	-	-	24.0	0	6.0	0	0	0
"	Old Growth	3000	9.0	0	40.0	0	36.0	0	26.0	0	10.0	0
"	"	3000	15.0	0	36.0	0	50.0	0	28.0	0	21.0	0
"	"	2500	-	-	-	-	18.0	0	0	GC-1.0	0	0
"	"	2500	-	-	26.0	GC-1.8	28.0	0	25.0	0	0	0
"	" (Mixture)	3400	8.0	0	37.0	0	48.0	0	28.0	0	25.0	0
"	"	3400	7.0	G-.4	38.0	0	53.0	0	30.0	0	28.0	0
Upper slope	"	2500	8.0	GC-1	58.0	0	75.0	0	76.0	0	69.0	0
"	"	2500	8.0	0	65.0	0	60.0	0	61.0	0	65.0	0
Lodgepole	Sapling pole	2300	8.0	0	57.0	0	60.0	0	56.0	0	43.0	0
"	"	2300	10.0	0	61.0	0	58.0	0	58.0	0	42.0	0

1/ All observations were made during the last two weeks of each month.

2/ Snow and frost depth in inches.

3/ G-Granular frost, C-Concrete frost, GC-Granular and concrete frost.

Effect of topography, vegetal cover, and snow depth of the occurrence and character of frost. -- Six plots were established in eastern Oregon and four in eastern Washington to determine the occurrence and character of frost in the forested and nonforested range land types. Only two of these 10 plots were established before the winter snow arrived, so it was not possible to follow the freezing conditions throughout the winter as was done with the forest types in the Cascades.

The first two plots were established in December in "poor condition" nonforested range land near Ellensburg, Washington. The cover on these two plots indicated that the range had been used heavily. Bitterbrush, rabbitbrush, cheatgrass, mullein, plantain, and Canada thistle were the predominant species on the plots, with a cover density of about 40 percent. Both plots were established on nearly level land. The top few inches of the soil were compacted from heavy grazing. The soil was a gravelly silt loam, with fair drainage.

When these two plots were established there was no snow on the ground, and a two-inch depth of concrete frost was observed in the surface soil. One month later there were 13 inches of new snow, and the frost had penetrated to a depth of 7.5 inches. This snow had fallen a few days before the observations were made, and it is believed that the deeper frost developed while the surface was free of snow. In February, one month later, the snow had settled to 10 inches and the frost was only 2.3 inches deep. Over five inches of concrete frost had melted under the insulating effect of the snow. This melting had started at the bottom of the frost layer and progressed upward.

The soil below the frost was moist, showing that the frost was still going out of the ground at the time of the observation. In March this area was entirely free of snow and frost. The soil was dry and there were no indications that the snow-melt water went off as surface runoff. The soil remained free of snow and frost throughout the rest of the winter and spring. Figure II shows the snow and frost conditions as found at the time the periodic observations were made, near the middle of each month.

Six plots were established in February near La Grande, Oregon. Two of these six were located in sagebrush type, two in ponderosa pine and grass type, and two in grass type. A brief discussion of the occurrence and character of frost on these plots follows:

Sagebrush plots --

A random check of the sagebrush country east of La Grande showed the south slopes free of frost by the middle of February.

The north slopes, however, still had concrete frost. There was no snow on the ground at this time. The soils in general were medium textured, deep and well drained. The soil on the south slopes was quite dry and the surface appeared to be heaved and pedestaled, showing that the ground had been frozen. The soil on the north slopes was free of frost in the top three inches, but there were two inches of concrete frost immediately below this frost-free zone. This indicated that the frost was thawing from the top as well as from beneath. One plot was established on a north-facing slope and one on a south-facing slope to follow the effect of exposure on the occurrence and character of frost through the remainder of the winter and spring. When these two plots were visited two weeks later, on March 1, the soil on all exposures was free of frost. Periodic checks throughout the remainder of the winter and spring showed no further freezing.

Ponderosa pine and grass plots --

The two plots established in the ponderosa pine and grass type showed no impermeable frost until after the snow had disappeared. On March 1, two inches of concrete and granular frost had formed where the snow had melted and exposed the soil. Ground still having a snow cover remained frost free. These two plots were not visited again until April 18. At this time the ground was free of snow and frost. Vegetation showed signs of spring growth indicating that the surface had been free of snow for some time. No further ground freezing was experienced through the remainder of the spring.

Grass plots --

At the time the two grass plots were established, February 15, a deep snow pack covered the ground. No frost was present under the snow cover. Two weeks later one of the plots still had 13 inches of snow over the unfrozen ground. The second plot, however, had a slightly southern exposure and was nearly free of snow. The ground surface was saturated and the rapidly melting snow water was running over the soil surface. This water was running clear and did not appear to be causing any surface erosion. About 1 inch of concrete frost was present just under the unfrozen soil surface. When these two plots were visited on April 18, the snow had disappeared and the ground was free of frost except for a few patchy spots that were protected from the morning sun. Here up to 1/2 inch of discontinuous permeable frost was present. The presence of pedestaled soil and rock particles indicated nocturnal freezing was still going on. No further observations were made on these two plots the remainder of the spring.

Two additional plots were established on nonforested range land near Vantage, Washington, in February.

One plot was established on lightly used range which had a good cover of blue bunch wheatgrass, bluegrass, buckwheat, phlox, and sagebrush, making up a cover density of 50 percent. The second plot was established on a heavily used range with a cover density of about 10 percent made up of bunchgrass, bluegrass, sagebrush, and other minor species. The soil on both plots was light textured, deep, and well drained. Both plots were located on north-facing slopes. About 3 inches of concrete frost were present on all the north slopes on February 20. Three weeks later, on March 10, there was no frost on the good range, while the poor range had 4 inches of concrete frost. On March 22, both plots were completely free of snow and frost and no further freezing occurred.

Table V summarizes the data collected on the ten range land plots in Eastern Oregon and Washington.

Probable hydrologic significance of frost in the range lands of eastern Oregon and Washington. -- Impermeable concrete frost occurred frequently throughout the winter and spring in the ponderosa pine and grass, grass, and sagebrush types of eastern Oregon and Washington. The degree of effect on runoff and infiltration cannot be determined from the results of this preliminary study, but there are indications that frost does have a decided effect on the entrance of spring snowmelt water to the subsoil. In the ponderosa pine and grass type, surface flow from melting snow was noted over a one-inch layer of concrete frost in the top horizon.

Ideal conditions were present for severe soil erosion in the sagebrush type during the spring melt period. Frost melting from above caused the surface soil to be saturated above the remaining impermeable frozen layer. Should heavy spring rains fall on soil in this condition, severe sheet erosion and mud flows would probably occur. Tigerman and Rosa (7) reported mud flows and sheet erosion resulting from similar conditions on the open range lands in Utah.

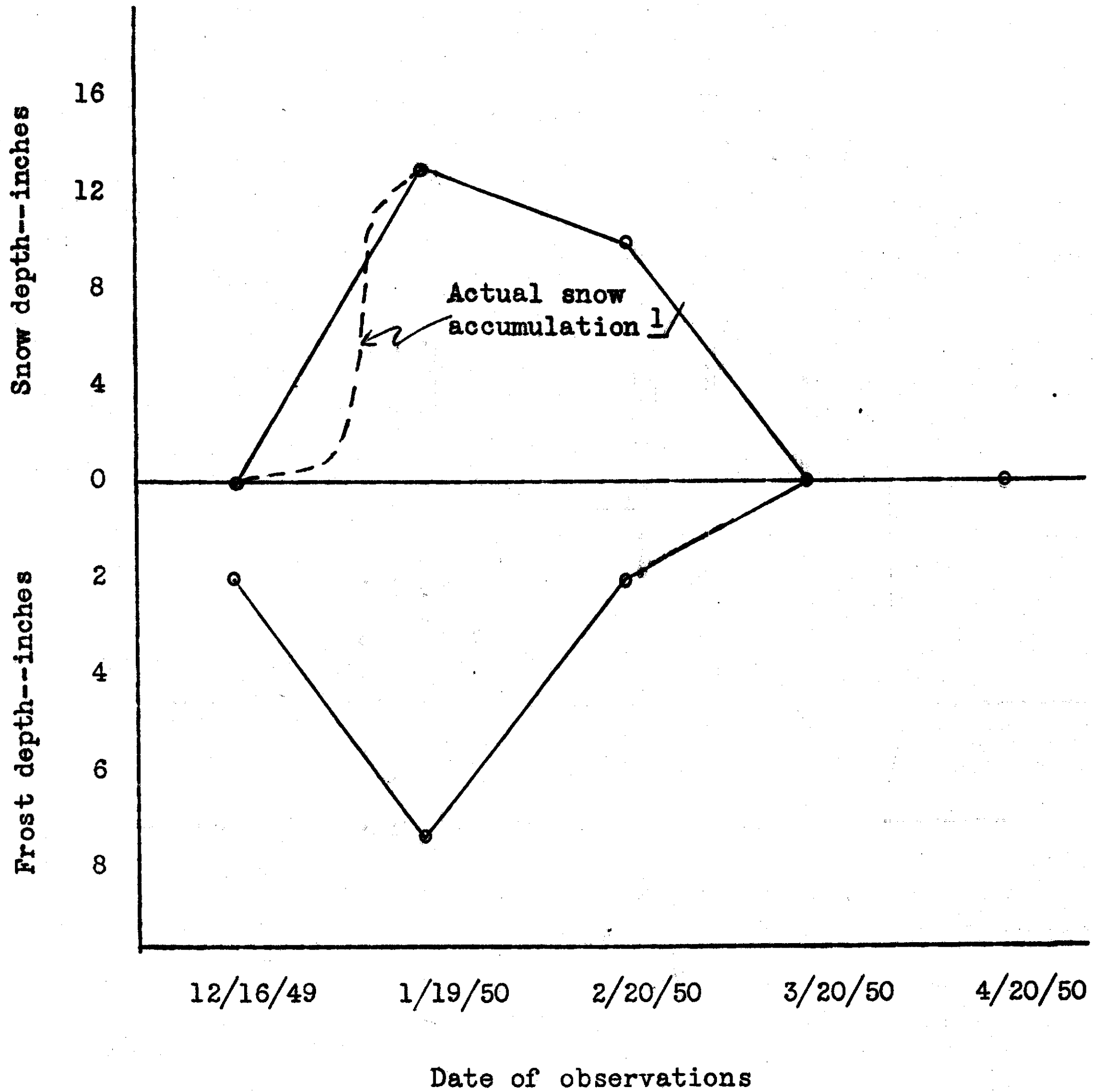

Figure II. -- Snow and frost conditions as found throughout the winter on poor condition range land near Ellensburg, Washington.

1/ Snow accumulation as recorded by U. S. Weather Bureau at Ellensburg, Washington.

TABLE V

Snow and Frost Conditions in the Range Lands

of Eastern Oregon and Washington 1949-50

Cover Type	Complex	Elev	12/16/49 S [1]	12/16/49 F [2]	1/19/50 S	1/19/50 F	2/15 S	2/15 F	2/20 S	2/20 F	3/1 S	3/1 F	3/10 S	3/10 F	3/22 S	3/22 F	4/11 S	4/11 F	4/18 S	4/18 F	4/20 S	4/20 F
Bitterbrush Rabbitbrush	Poor Condition Range	1600	0	C-2	12	C-75	-	-	10	C-2	-	-	0	0	0	0	-	-	-	-	0	0
Bitterbrush Rabbitbrush	Poor Condition Range	1600	0	C-2	14	C-7	-	-	10	C-23	-	-	0	0	0	0	-	-	-	-	0	0
Sandburg Bluegrass	Mod. Grazed	3400	-	-	-	-	24	0	-	-	0	C-1	-	-	-	-	-	-	0	0	-	-
Almost barren	Heavily Grazed	4000	-	-	-	-	14	0	-	-	13	0	-	-	-	-	-	-	0	0	-	-
Sagebrush, Rabbitbrush, grasses	Mod. Grazed Range (N. Slope)	3000	-	-	-	-	0	C-2	-	-	0	0	-	-	-	-	0	0	-	-	-	-
Sagebrush Cheatgrass	Mod. Grazed Range(S. Slope)	3000	-	-	-	-	0	0	-	-	0	0	-	-	-	-	0	0	-	-	-	-
Sagebrush, Bluegrass, Bunchgrass	Good Condition Range (N. Slope)	1500	-	-	-	-	-	-	6	C-3	-	-	0	0	0	0	-	-	-	-	0	0
Sagebrush, Bluegrass, Bunchgrass	Poor Condition Range (N. Slope)	2000	-	-	-	-	-	-	8	C-4	-	-	0	C-4	0	0	-	-	-	-	0	0
Ponderosa pine Bunchgrass	Mod. Grazed	3400	-	-	-	-	12	G-1	-	-	1	GC -1	-	-	-	-	-	-	0	0	-	-
Ponderosa pine Bunchgrass	Heavily Grazed	4000	-	-	-	-	15	0	-	-	0	GC -2	-	-	-	-	-	-	0	0	-	-

1/ Snow and frost depth in inches.

2/ C-Concrete frost, G-Granular frost.

SUMMARY

The purpose of this study was to determine the occurrence and character of frost under the predominant forest and range conditions of the Pacific Northwest portion of the Columbia Basin.

The results obtained from this preliminary study can be summarized as follows:

1. The forest soils of the high Cascade forests, both east and west side, remained unfrozen throughout the winter and spring of 1949-50.

2. Discontinuous permeable frost occurred in the ponderosa pine and grass type at the lower fringes of the east slope Cascade forests.

3. Up to 7.5 inches of impermeable frost occurred in the sagebrush types and grass ranges of eastern Oregon and Washington during the winter and spring snow-melt period.

4. Aspect appeared to be a significant factor in determining the time of occurrence of frost, but not the depth or duration of freezing. Snow on the north slopes prevented the soil from freezing while the bare south slopes were exposed to the early spring low temperatures. The north slopes lagged about three weeks behind the south slopes with respect to spring snow melt and soil freezing and thawing.

5. One inch of concrete frost appeared to be sufficient to cause surface runoff from melting snow.

6. When frozen ground that had started to thaw still had a snow cover, thawing took place only from below the frozen layer.

7. Thawing of frost where there was no snow cover took place from above as well as beneath the frozen layer, with the last trace of frost being found about half way between the greatest depth of freezing and the soil surface. Ideal conditions for severe soil erosion were present when the snow cover had disappeared while there was still impermeable frost in the ground.

8. Light nocturnal freezing and thawing late in the spring appeared to cause more surface soil heaving than did long periods of deep freezing.

9. Intensity of cutting had a decided effect upon snow accumulation and recession in the Douglas-fir forest of the Cascade Range.

CONCLUSION

From this preliminary study we can conclude that frost is not a problem in the dense forest types of the Cascade Range. No further study is proposed in this area. However, a more intensive study is needed in the ponderosa pine and grass, grass, and brush types of eastern Oregon and Washington where the results have shown soil freezing and thawing throughout the winter and spring. Such factors as aspect, slope, cover density, intensity of use, and soil depth and drainage should be studied to determine their influence on the formation of frost.

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