WINTER INFILTRATION STUDIES ON ABANDONED AND REFORESTED FIELDS IN CENTRAL NEW YORK [1/] [2/]

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The occurrence, nature and hydrologic effects of frozen soil are often misunderstood. Storey (1955) has summarized some of the common misconceptions:

> "Many persons think that if subfreezing temperatures persist for some time, the soil will freeze uniformly over large areas or that once the soil is frozen it becomes impermeable and stays frozen until the spring thaw."

If such were the case, it would then follow that after the soil has frozen, water available through snow melt or winter rains would run over the soil until the frost has thawed. The unfortunate choice of a title for an early study reported by Augustine (1941); "Infiltration Runs on Frozen Ground," certainly did little to allay this misconception.

Winter and early spring flooding has long been a problem in Central New York. A twenty-one year record of Onondaga Creek reveals that nearly half of all flood occur during the winter between December 21 and March 21 (Syracuse Intercepting Sewer Board, 1927). In an area such as this, a relationship could exist between frozen soil and runoff. This study was established to investigate the influence of cover type on frozen soil and infiltration during the winter of 1959-1960 in the vicinity of Syracuse, New York.

Past Studies on Winter Infiltration

A search of the literature soon reveals that most infiltration studies have been conducted during late spring, summer and fall, even in areas where winter flooding is common. Thus a large gap, which is just beginning to be filled, exists in our knowledge of winter floods.

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Soil frost has been long recognized to be a contributing factor in winter runoff, and over the years there have been many studies. This research seems to have progressed in three fairly distinct stages. First, there have been studies which related the occurrence and depth of frost to land use, especially forest cover. The second stage was characterized by an awareness that not only depth and occurrence of soil frost varies with land use, but that frost types also vary. Qualitative observations revealed that some frost types associated with forests permitted rapid infiltration, while others did not. The third stage in soil frost research, in which quantitative studies were made of the effect of frost depth, occurrence and type on infiltration in relation to land use, began only in the past few years.

Pierce, et al (1958) gave an excellent review of the literature into the second stage, and contributed importantly by presenting the results of a comprehensive survey of concrete frost in relation to land use. They found that generally, concrete frost occurred most frequently in open areas, followed by coniferous and hardwood forests. The depth of penetration, from greatest to least, was in the same order. This investigation, however, was concerned only with concrete frost; unfrozen soils and those containing non-concrete frost types were not distinquished.

Trimble, et al (1958) reported on a series of infiltration tests through the predominant frost types occurring in New England. Their data revealed that concrete frost was impermeable, but in the forest it contained holes that allowed water entry, while granular frost was more permeable than unfrozen soil.

Stoeckler and Weitzman (1960) conducted a similar study in Minnesota They classified frost into four types: concrete, porous-concrete, partly frozen and unfrozen. Porous-concrete frost resembled concrete, but air could be blown through it easily. Partly frozen frost consisted of an irregular scattering of ice crystals. In sandy soils they found infiltration rates of 0.47, 2.19, 3.97 and 13.22 inches per hour in concrete, porous-concrete, partly frozen and unfrozen soils, respectively. Concrete frost was found most frequently in grassy fields, while timberlands contained mostly porous-concrete, partly frozen or unfrozen soils.

Method of Study

The objective of this study was to investigate the influence of cover type on frozen soil and infiltration during winter. Three different cover types; abandoned field, hardwood forest, and conifer forest were selected as representative of common cover types in Central New York. Plots in these types were selected to minimize the effect of other variables upon infiltration. All plots were located in close proximity of one another in or near the Experiment Station of the College of Forestry in Syracuse, New York, at about 700 feet in elevation on the upper eastern slopes of the Onondaga Creek watershed. All were located on Ontario fine sandy

Table 1. COMPARISON OF PLOTS SELECTED FOR INFILTRATION STUDY. COLLEGE OF FORESTRY EXPERIMENT STATION, SYRACUSE, N. Y.

Attribute		Plot		
		Abandoned Field	Hardwood	Softwood
Aspect		WSW	W	WNW
Slope (per cent)		10	11	8
Vegetation: (type)		Mixed Herbaceous	Sugar Maple	Norway Spruce
(age)		Annuals & Perennials	46	37
Basal area (sq.ft./acre)		0	65.37	113.01
Humus type		Sand mull-p	Firm mull-p	Duff mull-p
Litter (lbs./acre)		2045	6415	12782
Soil Texture	Sand	68.0	53.0	70.0
	Silt	22.5	28.0	22.5
	Clay	9.5	19.0	7.5
Bulk Density (0-2.5 in.)		1.436	1.528	1.222
Organic Matter (% D.W. 0-6 in.)		3.30	4.58	4.58
Total Porosity (% Vol. 0-2.5 in.)		45.8	42.3	53.9
Macro Pore space (0-2.5 in.)		9.7	2.3	11.9
Micro Pore space (0-2.5 in.)		36.1	40.0	42.0

loam soils which had been cultivated in the past. Table 1 presents comparative descriptions of the plots.

Each plot consisted of 100 contiguous subplots 5 x 5 feet in size, numbered from one to one hundred. Five subplots were chosen by use of a table of random numbers on each day that infiltration runs were to be made. On several occasions time limitations prevented sampling all five subplots, but no less than three runs were made in any one cover type on a single day.

Air and soil temperatures were taken at each plot whenever infiltration runs were made. Snow depth measurements were made and soil samples were collected in order to determine soil moisture content at each subplot, a hole was dug, and the occurrence, depth and type of frost recorded. Frost types were based on the classification of Trimble, et al (1958).

After the frost type and depth (or lack of frost) was noted, the unfrozen litter was cleared away and a single ring infiltrometer 4.5 inches in diameter by 4 inches long was driven 3 inches into the soil. Sometimes the driving head was hit off center, or the ring hit a stone, causing the ring to cant to one side. This resulted in a poor seal and necessitated removal of the ring and driving it into another spot.

Ice water was added in 64 cc. increments (0.33 inches depth) to the ring and the time required for infiltration was noted. Similar increments were added until the time required for infiltration was within 10 per cent of that of the preceding increment. The last rate was then considered to be a constant and simulated a wet infiltration rate. Except where noted, infiltration rates are considered as "wet" in the remainder of this paper. After the infiltration run was completed, the ring was removed with the soil core intact and inspected to check the previously determined frost type and depth and to insure that infiltration took place through the frost. When it appeared that the ring ruptured the frost so that the infiltration recorded occurred between the sides of the ring and the soil core, the run was considered invalid and the data rejected. When infiltration occurred through naturally occurring holes in frost such as incompletely frozen root channels, however, the data were included.

Results of the Study

Frost type, depth and occurrence followed in a general way the trend noted in earlier studies. A notable exception occurred on the abandoned field, which had less frequent and shallower frost than the spruce plantation, but more frequent and deeper frost than the hardwoods. It is possible that deeper snow in the field, which was protected from the wind by forest on the north and west, could account for this difference. Figure 1 illustrates snow and frost depth throughout the winter on the three plots.

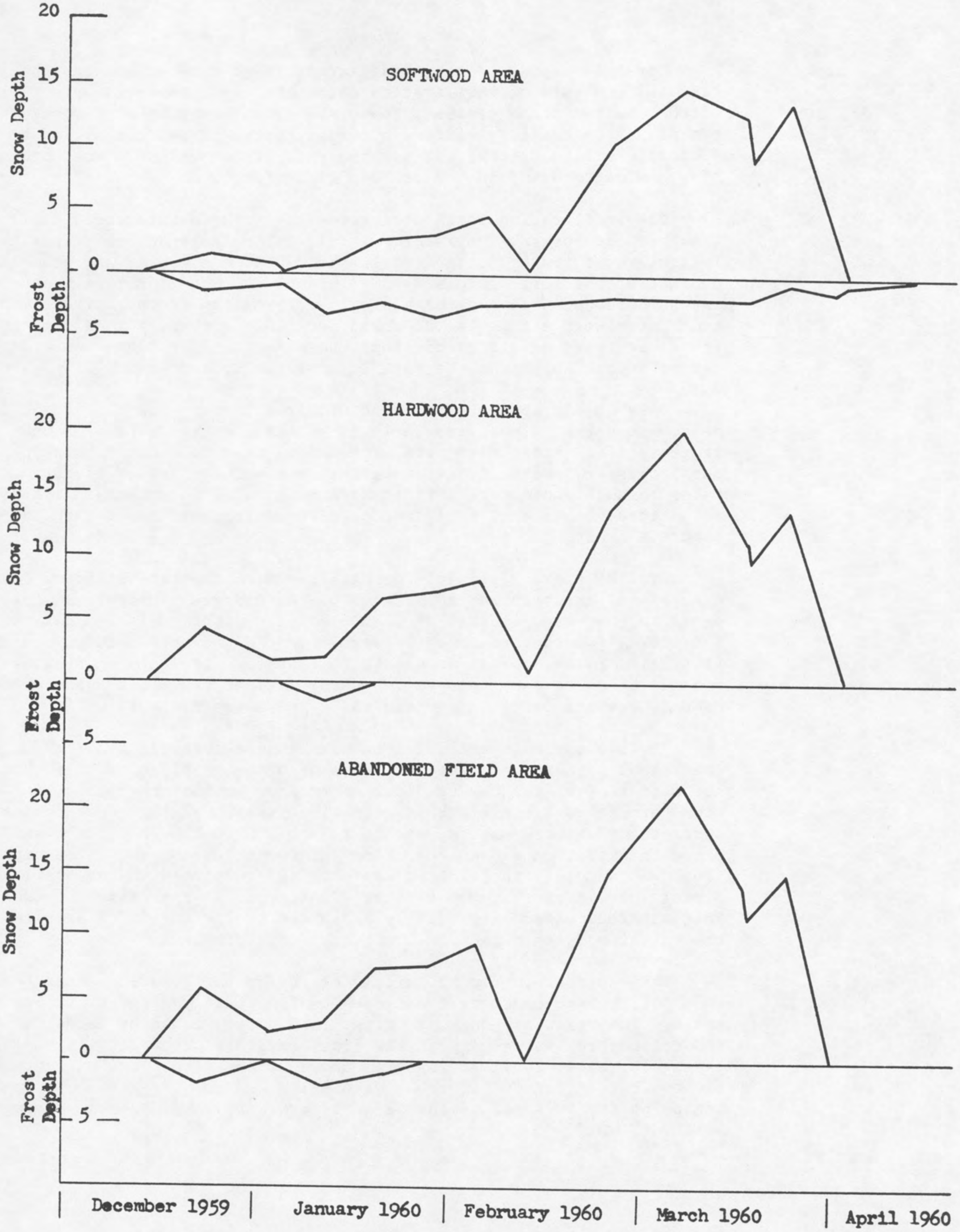

Figure 1. Frost depth as related to snow cover and vegetative type during the winter of 1959-60.

For the purpose of providing larger frost type groups for the statistical analysis of infiltration data, the types observed were reclassified into two broad classes; "concrete" and "non-concrete" frost. If the sample contained a mixture of frost types, it was classified as "concrete" if concrete frost was present. Table 2 lists frost occurrence, type and depth based on the revised classification.

The infiltraaion tests were revealing. In the abandoned field and in the hardwood forest, the rate of infiltration declined but slightly and irregularly through unfrozen soils throughout the winter as the moisture content of the soil increased. On the one day when concrete frost occurred in the hardwoods, a peculiar glaze-like formation in the litter, infiltration rates were zero. In the abandoned field a thin, porous concrete frost developed on three occasions, through which infiltration did not differ appreciably from the rate in unfrozen soil. Figure 2.

Only in the spruce plantation did frost occur with sufficient frequency to permit a detailed analysis of infiltration rates through frozen soils. Frost data were broken down by a combination of type and depth classes, and it became apparent immediately that infiltration rates through non-concrete frost were much more rapid than infiltration rates through unfrozen soil, which in turn were more rapid than through concrete frost.

Preliminary analysis of the data revealed that the standard deviation of infiltration rates for each of the classes was approximately equal to the mean, indicating that a Poisson distribution of data existed. Therefore, in order to test for significant difference between mean infiltration rates, it was necessary to transform the data on a square root basis. Since some of the samples were small an $\sqrt{x + 1}$ transformation was used (Snedecor, 1956). The results of these tests are shown in Table 3.

It is clear that infiltration through non-concrete frost types exceeds that through unfrozen soil to a highly significant degree, but does not differ significantly by depth of frost. On the other hand, infiltration through concrete frost is significantly slower than that through non-concrete or unfrozen soils, except in the 4.0 to 4.9 in depth class. Since infiltration did not occur on the two occasions when this deep frost was sampled, the limited variance (0) coupled with the small sample size (2) provides slightly different test results than might be expected. This apparent paradox is readily explained by the number of samples and the variation within each of the other frost classes.

The explanation for the widely differing infiltration rates through non-concrete and concrete frost becomes immediately apparent in Figures 3 and 4. The granular-honeycomb frost in Figure 3 contains large, interconnected pore spaces between the frost crystals which permits rapid passage of water infiltrating from above, whereas the dense structure of the concrete frost in Figure 4, with solid lenses of ice almost completely occupying the pore spaces in the soil, prevents water passage through the soil.

Table 2. MEAN FROST DEPTH BY COVER TYPE

	ABANDONED FIELD				SPRUCE PLANTATION				HARDWOOD PLANTATION			
Date	Total Samples	Conc.	Non-Con.	Unfrozen Samples	Total Samples	Conc.	Non-Con.	Unfrozen Samples	Total Samples	Conc.	Non-Con.	Unfrozen Samples
12-22	5	1.9(5)	0	0	5	0	1.6(5)	0	3	0	0	3
1-2	5	T	T	5	5	1.8(1)	0.7(4)	0	5	0	0	5
1-3	3	0	0	3	5	1.2(2)	1.3(2)	1	0	-	-	-
1-10	5	1.9(5)	0	0	5	3.3(4)	2.6(1)	0	5	1.4(5)	0	0
1-19	5	1.1(5)	0	0	5	3.0(3)	1.6(2)	0	3	T	0	3
1-27	5	0	0	5	5	3.4(5)	0	0	5	0	0	5
2-3	5	0	0	5	5	3.1(3)	2.5(2)	0	5	0	0	5
2-4	5	T	0	5	5	2.5(3)	1.2(2)	0	5	0	0	5
2-11	5	0	0	5	5	2.8(4)	1.5(1)	0	5	0	0	5
2-24	5	0	0	5	5	2.0(4)	1.0(1)	0	5	0	0	5
3-6	5	0	0	5	5	2.7(3)	0.6(2)	0	4	0	0	4
3-16	5	0	0	5	5	3.5(4)	1.2(1)	0	5	0	0	5
3-17	5	0	0	5	4	1.5(2)	0	2	5	0	0	5
3-23	3	0	0	3	5	1.5(2)	0.6(3)	0	3	0	0	3
3-30	4	0	0	4	5	2.3(3)	0.3(2)	0	5	0	0	5
4-1	5	0	0	5	5	2.2(2)	0.5(2)	1	5	0	0	5
4-17	5	0	0	5	5	0	0	5	5	0	0	5

(5) Numbers in parenthesis indicate number of samples

T - Trace, frost discontinuous at point of sampling

Table 3. MEAN INFILTRATION RATES BY FROST TYPE AND DEPTH CLASS, SPRUCE PLOT, WITH COMPARISON OF SIGNIFICANT DIFFERENCES[1)]

Frost type and depth	non-Concrete 0-0.9	non-Concrete 1.0-1.9	non-Concrete 2.0-2.9	Unfrozen	Concrete 1.0-1.9	Concrete 2.0-2.9	Concrete 3.0-3.9	Concrete 4.0-4.
Actual Mean I. rate in./hr.	159.8	92.3	129.6	20.9	12.5	12.1	10.8	0
Concrete 4.0-4.9	N.S.	N.S.	N.S.	*	* *	*	N.S.	---
3.0-3.9	* *	* *	* *	*	N.S.	N.S.	---	
2.0-2.9	* *	* *	* *	* *	N.S.	---		
1.0-1.9	*	* *	* *	* *	---			
Unfrozen	* *	* *	* *	---				
non-Concrete 2.0-2.9	N.S.	N.S.	---					
1.0-1.9	N.S.	---						
0-0.9	---							

1) Infiltration data coded (x + 1) and transformed on a square root basis.

N.S. No significant difference.

* Significant (at 95% level).

* * Highly significant (at 99% level).

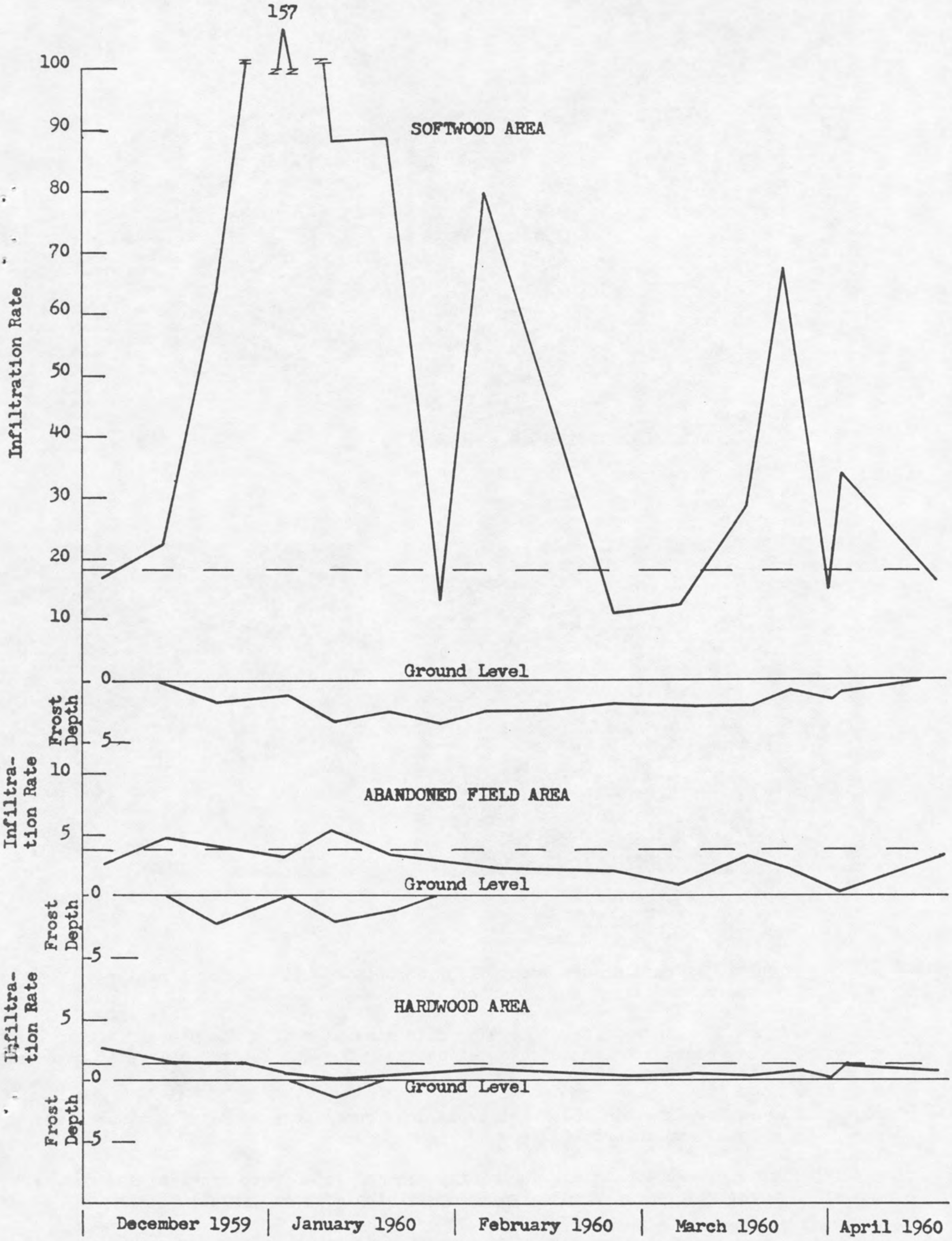

Figure 2. Mean infiltration rates as related to frost depth and vegetative cover during the winter of 1959-60.

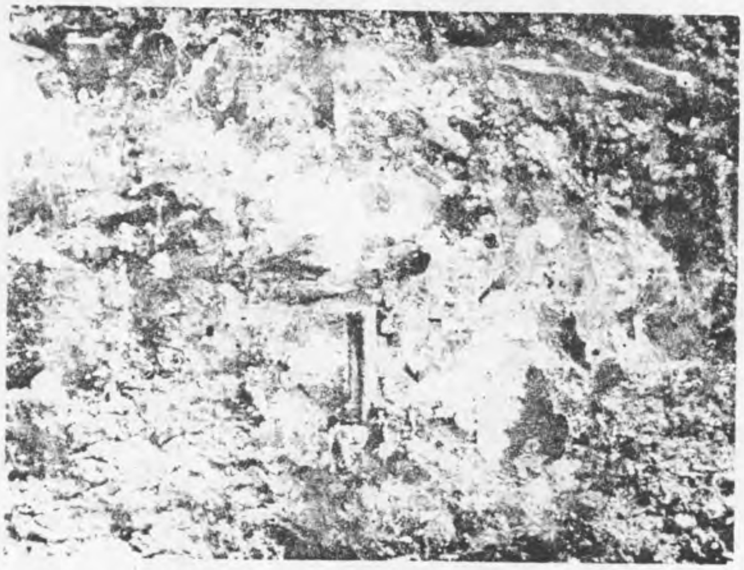

Fig. 3

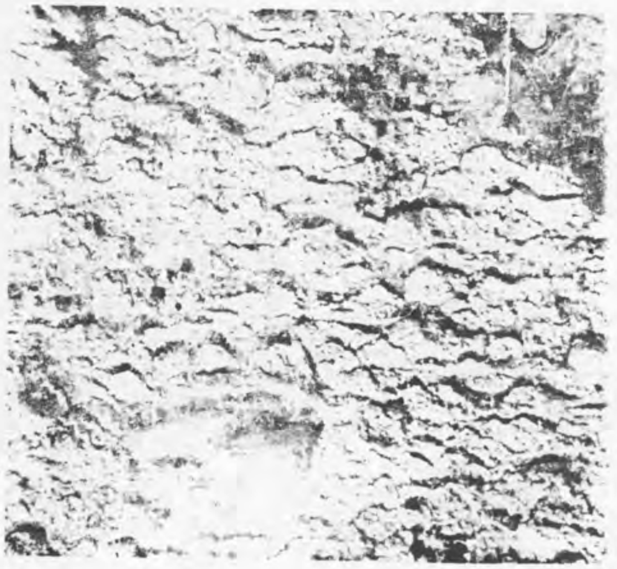

Fig. 4

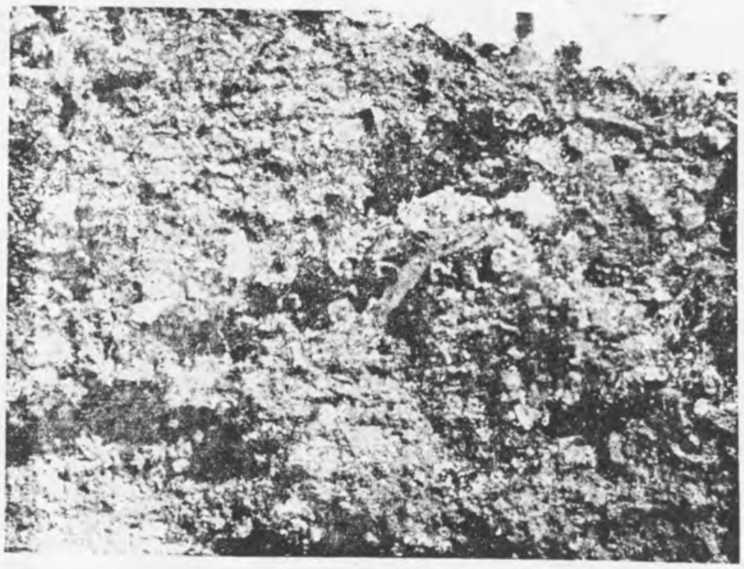

Fig. 5

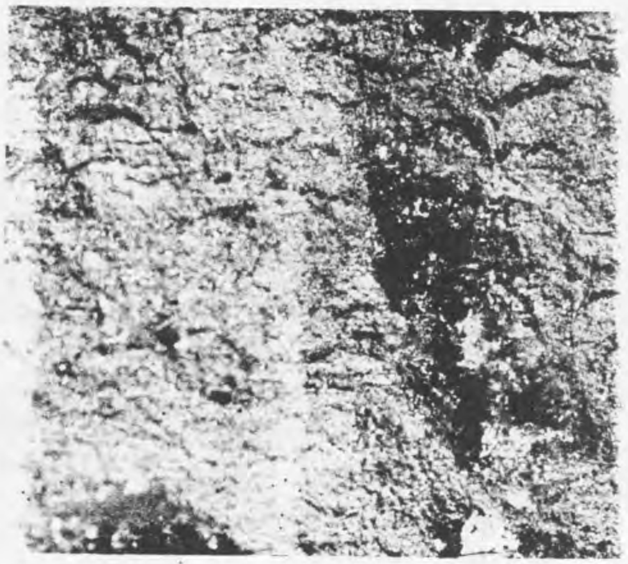

Fig. 6

Figure 3. Granular-honeycomb frost associated with humus. The large, open po spaces readily transmit water.

Figure 4. Concrete frost developed in mineral soil. The dark irregular strea are solid ice lenses which effectively prevent substantial water movement through the soil.

Figure 5. Intermingled frost types are found where pockets of mineral and org soils are intermixed.

Figure 6. Root channels containing non-concrete frost provide passageways for water movement through soils containing concrete frost.

Even concrete frost, however, permits some infiltration. Near the soil surface, as in Figure 5, several frost types may be intermixed. The concrete frost appears to be restricted to the predominantly mineral soil underlying the humus layer. Where pockets of predominantly organic material exist, frost of the non-concrete types may develop. The development of non-concrete frost is not limited to the organic layers on the soil surface. Figure 6 illustrates the loose crystalline frost formed in a root channel passing through an area of concrete frost. Such channels are not uncommon in forested areas, and thus limited infiltration may be expected even through concrete frost.

Discussion

Infiltration rates are largely determined by the amount, size and distribution of the pore spaces in the soil and the extent to which they are filled with water. In non-concrete frost large, interconnected pores are formed which permit more rapid infiltration than through unfrozen soils. Even concrete frost, with its solid ice lenses that create a dense, hard mass with little pore space, frequently contains root channels characterized by scattered, loose frost crystals which permit limited infiltration.

The presence of non-concrete frost appears to be related to accumulations of loose organic material in the spruce plot, where large empty pore spaces disrupt water columns extending into the finer pores which might otherwise provide water transport to enable continued growth of the crystals into solid ice lenses. In the lower lying, predominantly mineral soil, ice lenses build up forming an essentially impermeable mass.

Even though impermeable concrete frost is formed beneath the humus, resulting in a wet infiltration rate of zero, it does not mean that surface runoff occurs during every rainfall or snow melt period. The initial increments applied during the infiltration runs were readily absorbed in the overlying humus material containing non-concrete frost to the extent that up to one inch of water could be applied before infiltration ceased.

During the period of rapid spring snowmelt, surface runoff was observed on the abandoned field, while slight puddling occurred in the hardwoods. At no time were such phenomena noted in the spruce stand. Thus while this limited study suggests that conditions which are conducive to the formation of porous soil-frost complexes encourage rapid rates of infiltration, when considering potential winter and spring flood danger, one cannot ignore variations in total amounts of snow, conditions affecting melt rates, and the entire environmental complex which is peculiar to each cover type involved.

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