

A STUDY OF SOIL FREEZING IN WESTERN MASSACHUSETTS¹
AND TECHNIQUES OF MEASUREMENT

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Measurement of soil frost, which is the depth of frozen soil, is necessary for understanding the hydrologic effects of soil freezing. Frost surveys carried out at Hubbard Brook Experimental Watershed in the White Mountains of New Hampshire by Sartz (1957) and Hart (1963) did not indicate any effects on streamflow from soil frost formation. The absence of effect is a result of the early accumulation and depth of snowpack which insulates the soils from the low winter temperatures, thereby inhibiting frost formation. However, the climatological situation differs in Massachusetts. The snowpack develops later in the year and the depth of accumulation is less than in New Hampshire. Also, in Massachusetts the snowpack often disappears or is severely decimated during mid-winter thaws. These are all factors which favor frost formation.

A review of the literature on snow and frost surveys conducted in Massachusetts indicated a lack of information on the subject. The soil frost data which had been taken in Massachusetts by Sartz (1957) was used to infer the effect on flooding of the soil frost associated with the different kinds of land uses. He reported that open land had twice as much frost penetration as undisturbed well stocked hardwood and coniferous pole and sawtimber stands. Sartz's study (1957) indicated that concrete frost promotes surface runoff during periods of potential flooding caused by spring thaws and rainfalls. Because of the uncertainty about occurrence and duration of frost in Massachusetts forests and hydrological effects, we decided to undertake the investigation of whether forest stand density manipulation had an effect on soil frost formation and, if present, how this soil frost might affect streamflow.

The first phase of the research was a snow and frost survey conducted during the winters of 1969-70 and 1970-71 on the upper 421 acres of the 1,798 acre Cadwell Creek Experimental Watershed located in the towns of Pelham and Belchertown, Massachusetts, as seen in Figures 1 and 2.

The second phase of the research was a frost survey conducted during the winter of 1970-71 on a grassy knoll in Ware, Massachusetts, which was kept snow free, using a shoulder mounted mist blower. The objective of the frost survey in Ware was to compare various methods of measuring frost.

As seen in Figure 3, the study areas on Cadwell Creek consisted of (1) an unthinned red pine, *Pinus resinosa* Ait., stand, (2) a thinned red pine stand, (3) an open area on the east bank of Cadwell Creek, (4) an open area on the west bank of Cadwell Creek, (5) an unthinned hardwood stand, (6) a thinned hardwood stand, and (7) a thinned red pine stand with deadened trees left standing. As illustrated in Figure 4, all the study areas were approximately 120 feet long and 50 feet wide. They were divided into two fifty foot square sections, with a 20 by 50 foot wide center strip as seen in Figure 4. In the study areas which were thinned, all the stems and slash were removed from one of the fifty foot square sections to allow snowpack measurement with a Mount Rose Snow Tube.

Area 1 - The unthinned red pine stand was approximately 40 years old and had been planted at a four by four spacing. Areas 2 and 7 - The two thinned red pine stands were sections of the unthinned red pine stand rigorously thinned to 56 trees per acre; Areas 3 and 4 were the open areas from which all trees were removed. In these areas the brush

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Figure 1.

CADWELL CREEK WATERSHED

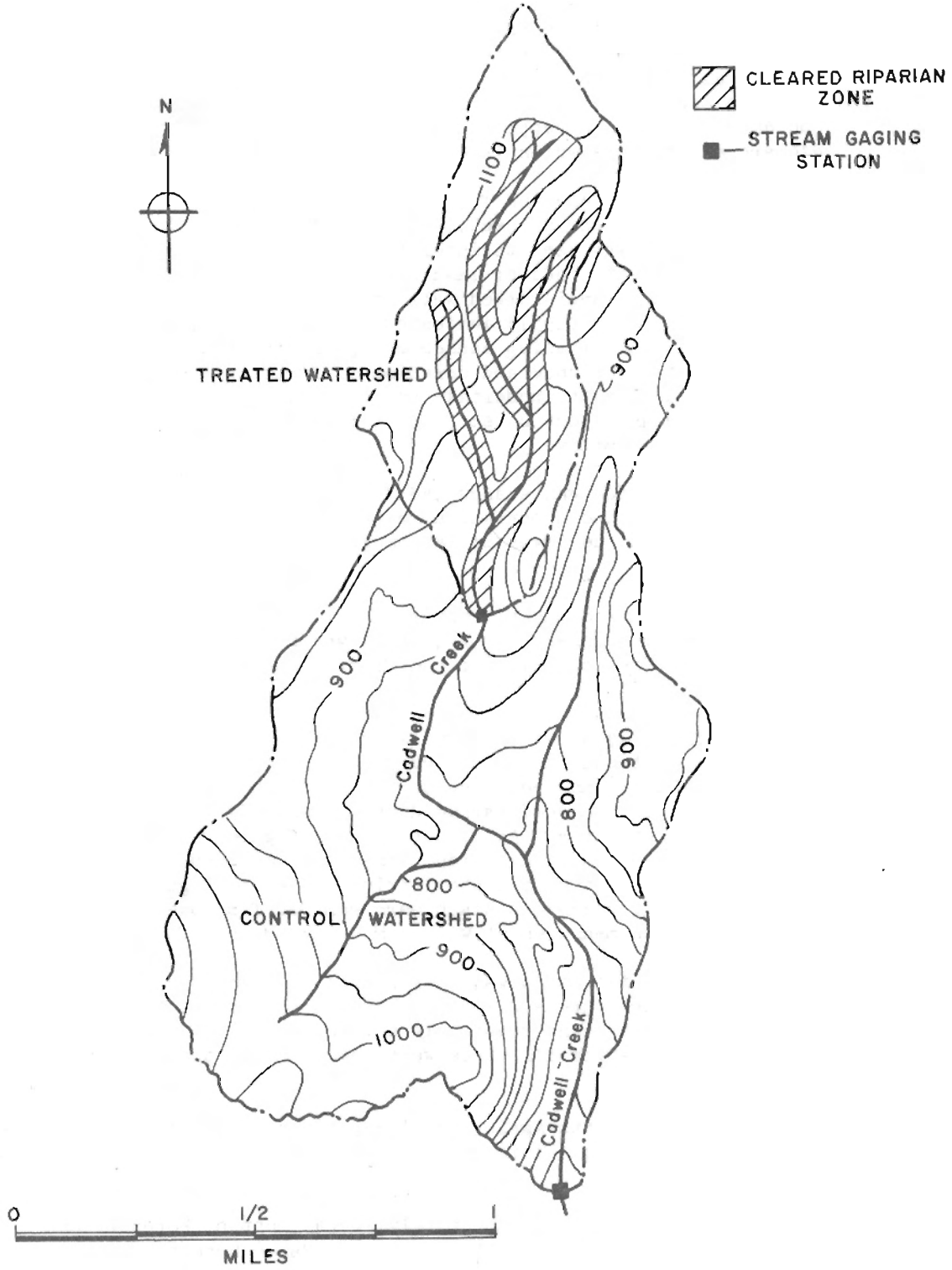
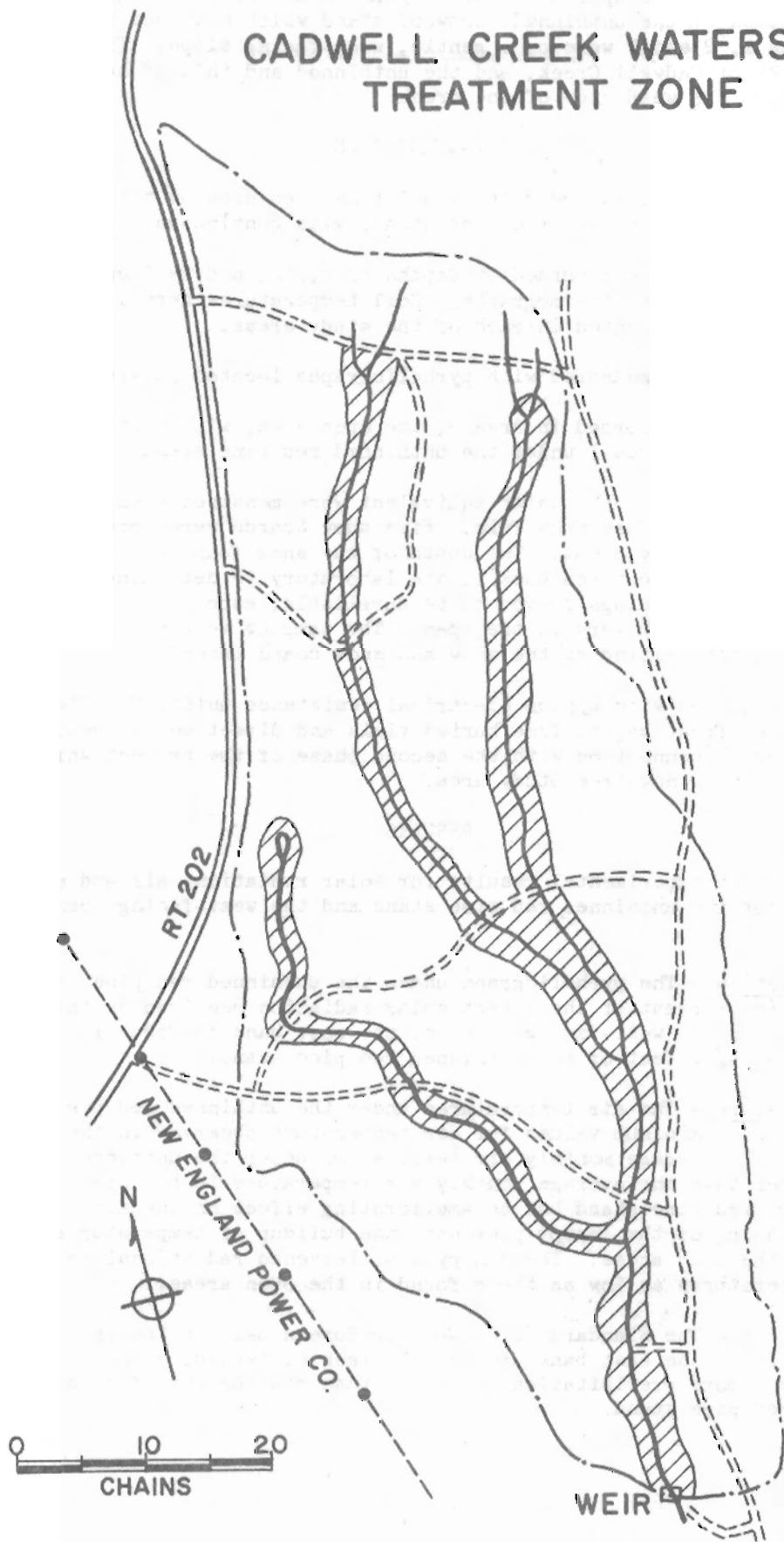


Figure 2

CADWELL CREEK WATERSHED TREATMENT ZONE



was completely controlled by heavy deer browsing, but grass and herbs grew abundantly during the summer. Area 5 - The unthinned hardwood stand was a fully stocked, even-aged, mixed hardwood stand approximately 40 years old. Area 6 - The thinned hardwood stand was a section of the unthinned hardwood stand which had been thinned to 77 trees per acre. Areas 1, 2 and 7 were on a gentle, west-facing slope. The open areas were on opposite banks of Cadwell Creek, and the unthinned and thinned hardwood stands were on a level area on the west side of the creek.

INSTRUMENTATION

Air temperatures were recorded in Area 3 (the open area on the east bank of Cadwell Creek) and Area 1, the unthinned red pine stand, with continuously recording thermographs.

Soil temperatures were recorded at depths of 6, 12, and 24 inches in Areas 3 and 1 with continuously recording thermographs. Soil temperatures were also measured with five stacks of thermocouples located in each of the study areas.

Solar radiation was measured with pyrlieliographs located in Area 3 and Area 1.

Precipitation was recorded in Area 3, the open area, with a standard U. S. Weather Bureau Rain Gage and in Area 1 under the unthinned red pine stand with a roving rain gage.

The snowpack depth and the water equivalent were measured weekly in each of the study areas with a Mount Rose Snow Tube. Five snow boards were located in the center strip of each of the study areas. The depth of the snow found on the boards was measured each week and samples were taken back to the laboratory to determine their water equivalent. The snow board readings proved to be unreliable, especially the readings taken from the snow boards which were in the open. The samples were decimated by wind action, sublimation loss, and melting at the snow and snow board interface.

Frost was measured with gypsum electrical resistance units, Modified Fernow Frost Gages, U. of Mass. frost gages, free buried vials and direct measurement. These gages will be discussed in connection with the second phase of the project which was a frost survey conducted in a snow-free study area.

RESULTS

A sample of the experimental results for solar radiation, air and soil temperatures, and snow depth for the unthinned red pine stand and the west-facing open area can be seen in Figure 5.

Solar radiation - The pyrlieliograph under the unthinned red pine stand received approximately five percent of the direct solar radiation received by the pyrlieliograph in the open area on the west-facing slope of the east bank of Cadwell Creek. This data reflects the shading effect of the unthinned red pine stand.

Air temperature - The air temperatures under the unthinned red pine stand did not reach the maximum or minimum values for air temperature observed in the open area on Cadwell Creek. The average monthly air temperature under the unthinned red pine stand was 4.5° F. lower than the average monthly air temperature in the open area. The canopy of the unthinned red pine stand had an ameliorating effect on the air temperature extremes. The shading of the canopy prevented the buildup of temperatures as high as those found in the open areas. The canopy also lessened radiational cooling, thus preventing temperatures as low as those found in the open areas.

Precipitation - The Standard U. S. Weather Bureau Gage in the open area on the west-facing slope of the east bank of Cadwell Creek collected, on an average, approximately 35 percent more precipitation per storm than did the roving rain gage under the unthinned red pine stand.

Figure 3

STUDY AREAS ON CADWELL CREEK

1. Unthinned Red Pine Stand
2. Thinned Red Pine Stand
3. Open Area on the East Bank of Cadwell Creek
4. Open Area on the West Bank of Cadwell Creek
5. Unthinned Hardwood Stand
6. Thinned Hardwood Stand
7. Thinned Red Pine Stand with Deadened Trees Standing

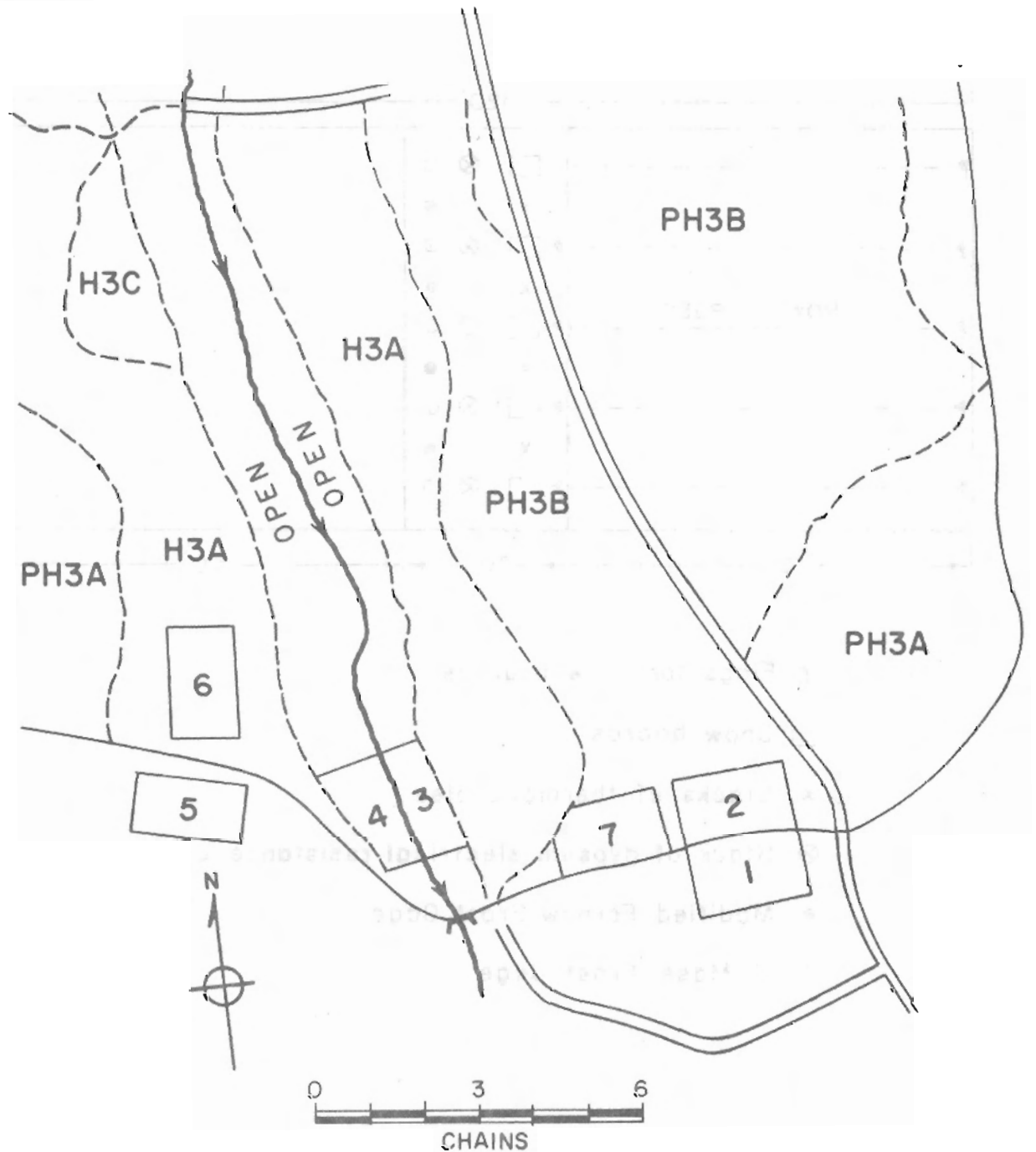
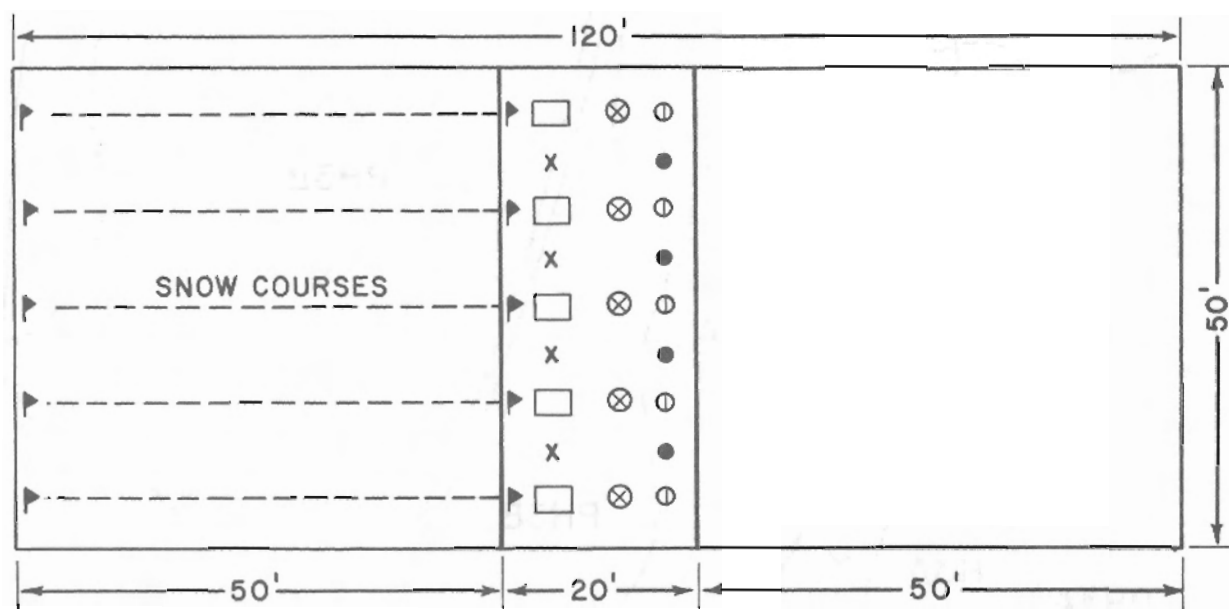


Figure 4. Layout of snow and frost survey plots at Cadwell Creek.



▸ Flags for snow courses

□ Snow boards

x Stacks of thermocouples

⊗ Stack of gypsum electrical resistance units

● Modified Fernow Frost Gage

⊙ U. Mass. Frost Gage

Figure 5. Comparison of solar radiation, air temperature, snow depth and soil temperature between the unthinned red pine stand and the open area on the west-facing slope on the east-bank of Cadwell Creek.

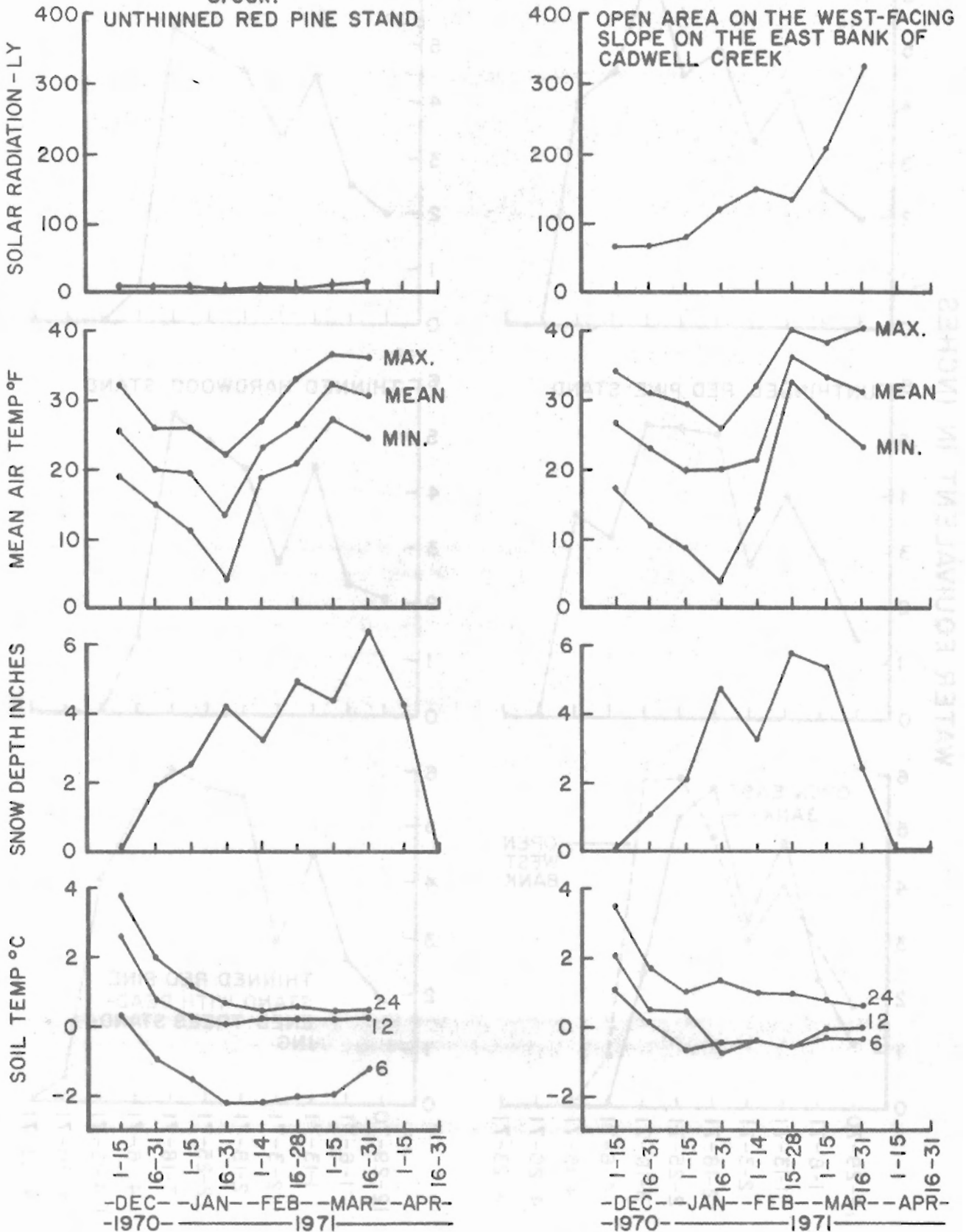
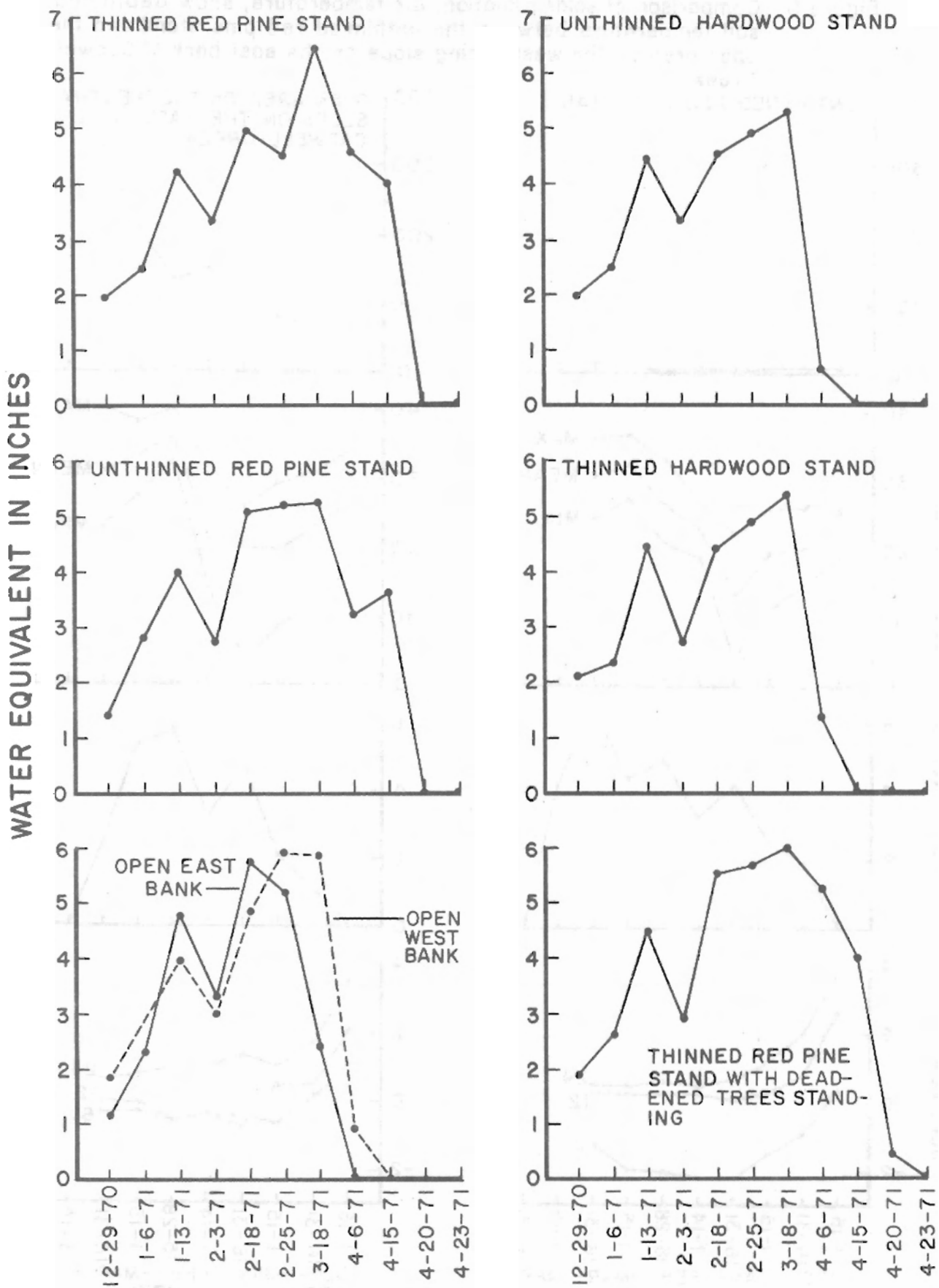


Figure 6 Water equivalents of the snowpacks on the Cadwell Creek Plots.



The snow surveys with the Mount Rose Snow Tube indicated that the snowpack in the open area increased on an average approximately 30 percent more during each storm than did the snowpack under the unthinned red pine stand. This difference resulted from sublimation loss from the red pine canopy and precipitation redistribution caused by wind turbulence. In spite of the lesser amounts of snow received under the unthinned red pine stand, the maximum water equivalent of its snowpack was only 15 percent less than the average maximum water equivalent of the snowpack in the open areas. Even though the snowpack of the unthinned red pine stand received less snow from each storm, slower melting caused by shading of the canopy enabled the snow to be held longer; so that the snowpack accumulated almost as great a water equivalent as was found in the open areas. The maximum water equivalent of the snowpack under the unthinned red pine stand occurred a month later than in the open area on the west-facing slope of the east bank of Cadwell Creek.

Soil temperatures - The soil temperatures at 6 and 24 inches in the open area on the east bank of Cadwell Creek started out 3.0° C. and 1.0° C. higher, respectively, in the fall than the soil temperatures at the depths of 6 and 24 inches under the unthinned red pine. These differences probably resulted from the larger amounts of direct solar radiation reaching the soil in the open area, as well as higher air temperatures there.

Soil temperatures under the unthinned red pine stand dipped slightly lower than the soil temperatures in the open area because of lower mean air temperatures and a shallower snowpack for insulation against those lower temperatures.

Soil in the open area warmed up faster at all depths than the soil under the unthinned red pine stand because it received more direct solar radiation, it was exposed to warmer mean air temperatures, and lost its snow cover ten days earlier than the soil under the unthinned red pine stand. The earlier loss of the snowpack by the open area was an important factor in allowing the soil there to warm up faster than the soil under the unthinned red pine stand. Snow insulates soil from both warm and cold temperatures.

Snowpack - The thinned red pine stands had the greatest water equivalent and depth of snowpack as seen in Figures 6 and 7. The water equivalent for the snowpacks for the seven study areas during the winter of 1970-71 from the greatest to the least were: thinned red pine stand, thinned red pine stand with deadened trees standing, open areas on the east bank of Cadwell Creek, open area on the west bank of Cadwell Creek, thinned hardwood stand, unthinned hardwood stand, and unthinned red pine stand.

The thinned red pine stands accumulated the greatest water equivalent and depth of snowpack apparently because of their position adjacent to and on the north side of the unthinned red pine stand. Wind turbulence effects over the thinned and unthinned red pine stand caused snow to be dumped into the thinned red pine stand. The snowpack persisted under the thinned red pine stand as long as under the unthinned red pine stand because of much greater snow accumulation and because of the shading from the unthinned stand to the south.

The effect of the position of the thinned red pine stands to the unthinned red pine may have practical application in extending the period of spring runoff. A sample of the snowpack data for the winter of 1970-71 can be seen in Figures 8 and 9. Those figures show the development of a snow drift in the thinned red pine stands. The deepest part of the drift was the edge closest to the unthinned red pine stand, and the drift tapered off farther away from the unthinned red pine stand.

Thinning fifty foot wide strips running east and west across a slope in red pine stand plantations for the purpose of trapping and holding snow to extend the period of spring runoff should have practical application in watershed management. The data taken on Cadwell Creek indicated that the depth and water equivalent of the snowpack in the thinned strip was increased approximately 20 percent. The snowpack was released in step with the unthinned red pine stand because of the shading effect from the stand.

Figure 7. Snow depths of the snowpacks on the Cadwell Creek plots.

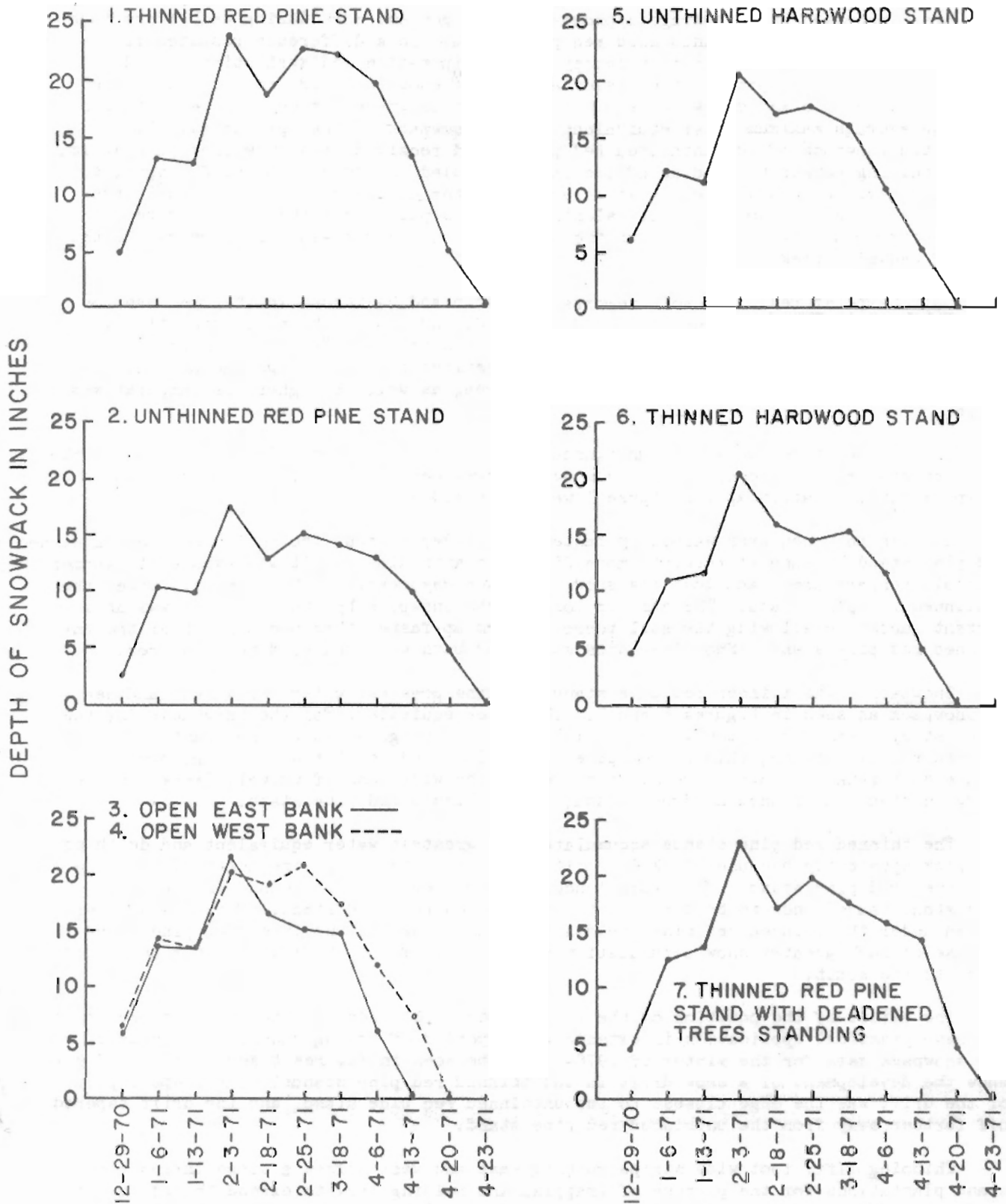


Figure 8. Water equivalent of snowpack under the thinned red pine stand.

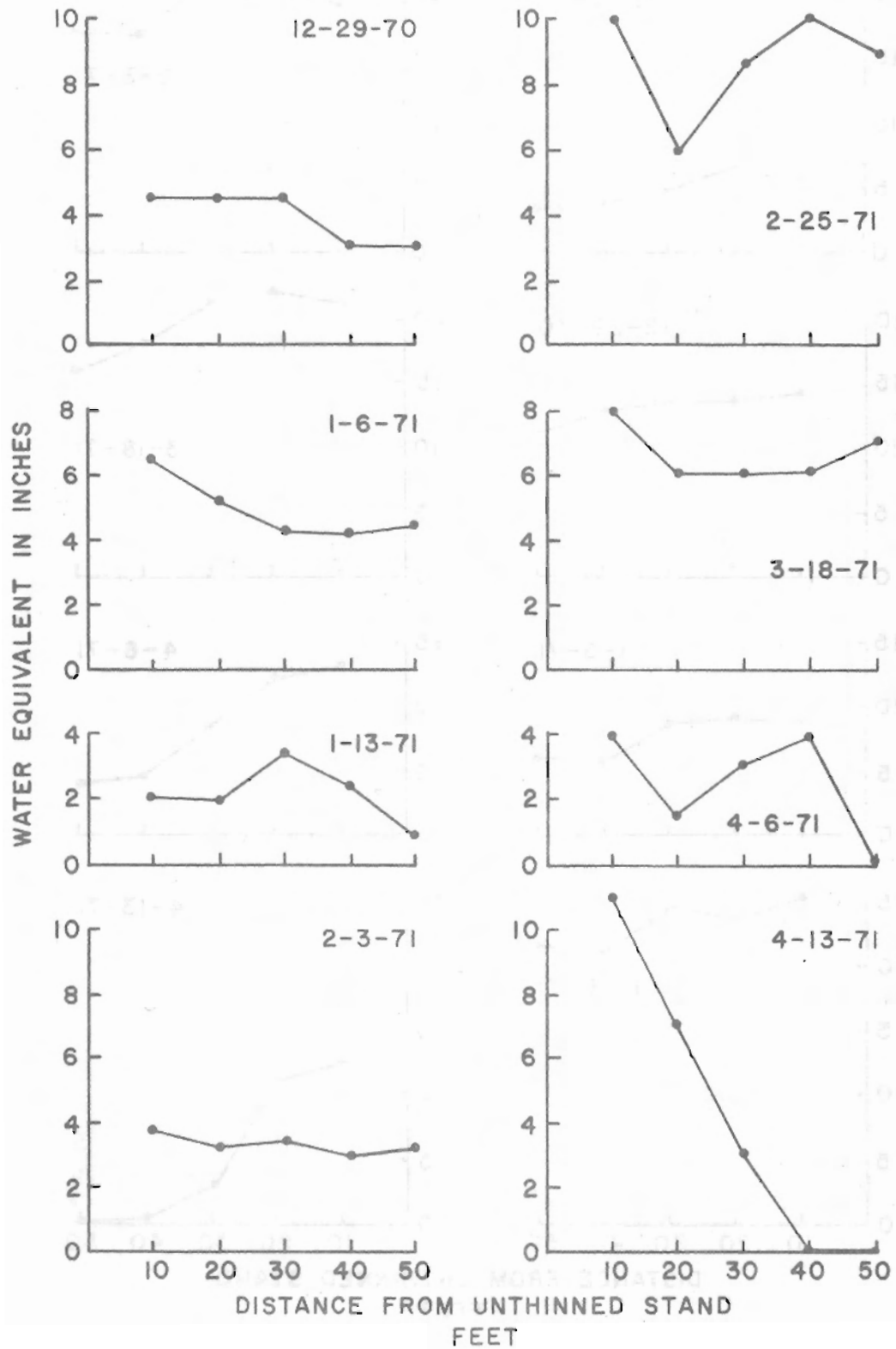
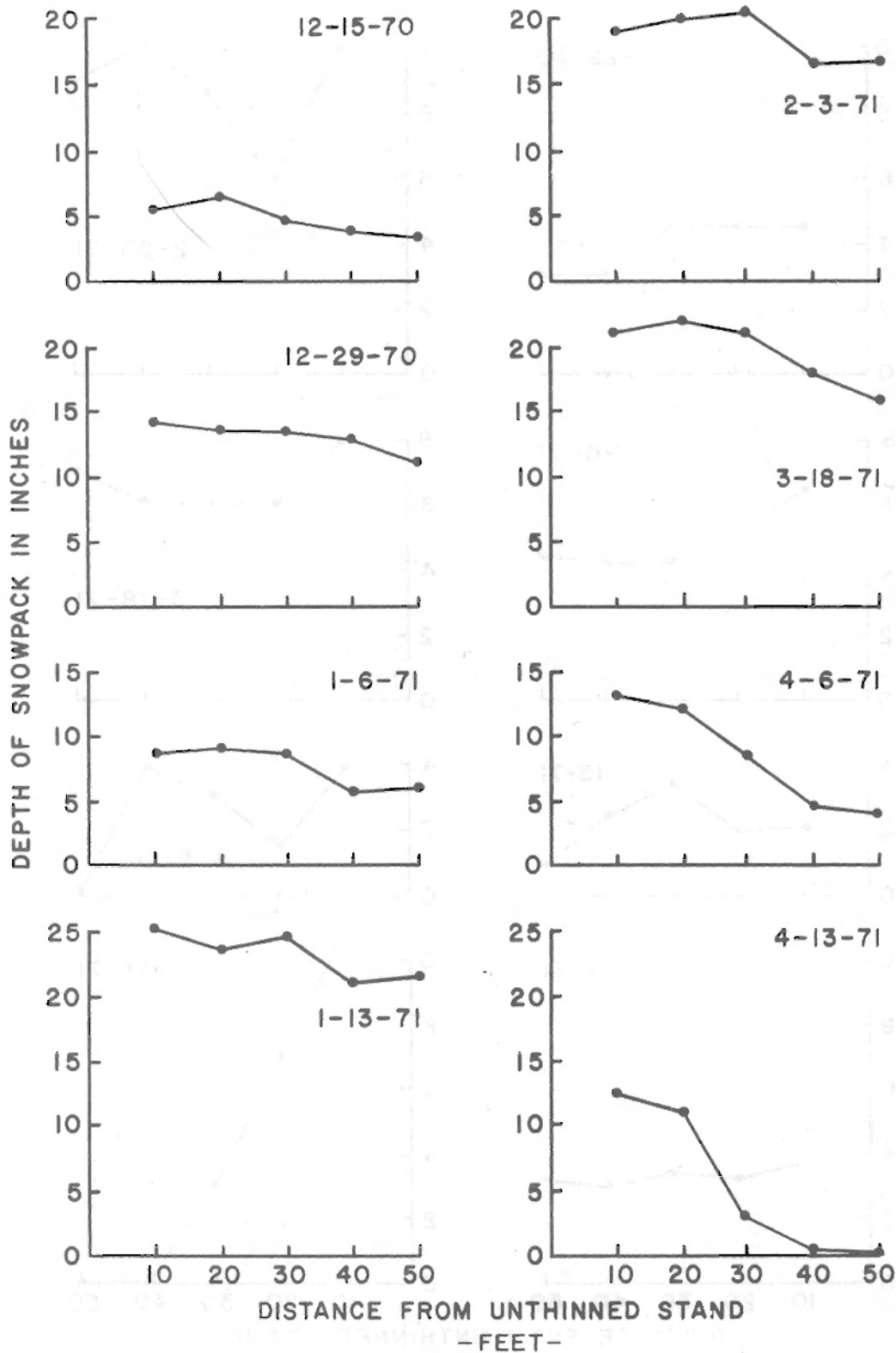


Figure 9. Depth of snowpack under the thinned red red pine stand.



MICHELSON AND LORD (1962) SOIL MOISTURE UNITS

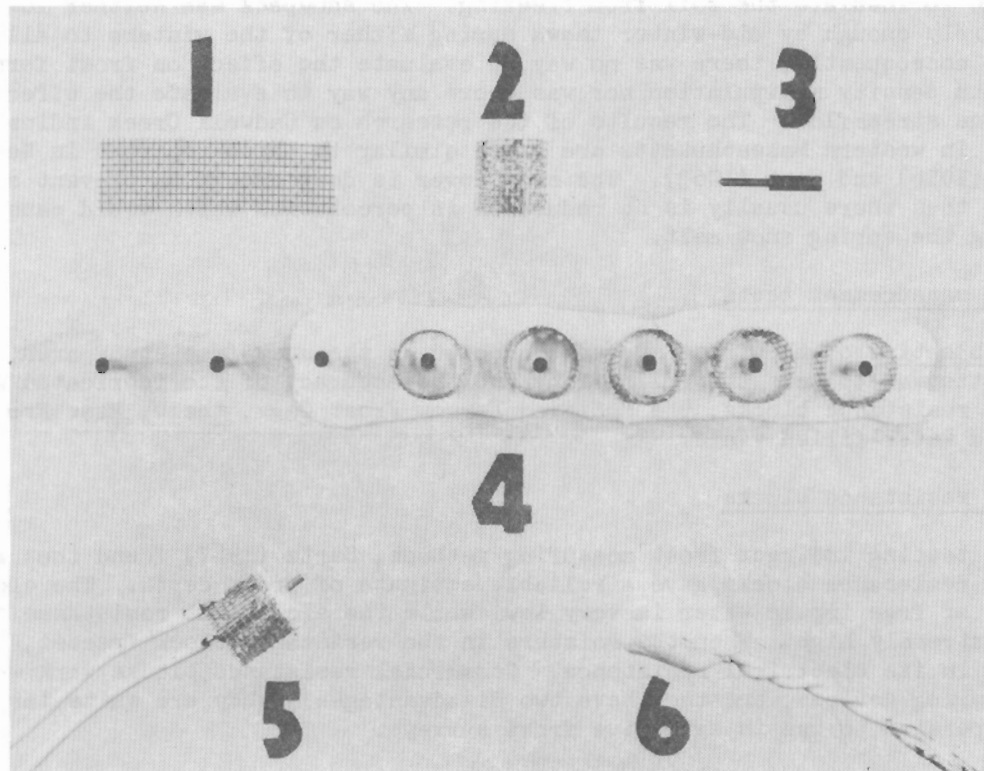


Figure 10. Component parts of concentric sensing units.

The development and loss of the snowpack under the thinned red pine stand seemed affected more by the location of the adjacent unthinned red pine stand than by stand density manipulation. For this reason, no conclusions could be drawn from this study about the effects of general thinning on snowpack development and loss.

The snowpack on the open area on the east bank of Cadwell Creek melted before that on the west bank probably because of greater heat energy received by the west-facing slope from afternoon sun as compared to the east-facing slope.

No appreciable difference in snowpack accumulation and melt between the thinned and unthinned hardwood stand occurred because of the negligible difference in canopy during the leafless winter period. This result indicates that hardwood stand density manipulation will have little or no effect on snowpack development and loss.

Soil frost

The frost surveys conducted on Cadwell Creek during the winters of 1969-70 and 1970-71 indicate no general frost formation because the snowpack came early enough and was deep enough to insulate the soil from freezing. The snowpack was neither lost nor decimated severely enough by mid-winter thaws during either of the winters to allow frost formation; consequently, there was no way to evaluate the effect on frost formation of forest stand density manipulation nor was there any way to evaluate the effect of frost formation on streamflow. The results of the research on Cadwell Creek indicate that conditions in western Massachusetts are often similar to those reported in New Hampshire by Pierce (1956) and Hart (1963). The snow cover is deep enough to prevent soil frost formation, thus there usually is no reduction in percolation which would cause overland flow during the spring snow melt.

Soil frost measurement tests

The objective of the frost survey conducted on the snow-free study area in Ware, Massachusetts was to test the reliability and the accuracy of the fabricated gypsum electrical resistance blocks, the Modified Fernow Frost Gage, the U. Mass Frost Gage and free buried water-filled vials.

Electrical resistance blocks

While testing indirect frost measuring methods, Sartz (1967) found that gypsum electrical resistance blocks gave a reliable estimate of frost depth. The electrical resistance of free impure water is very low, while the electrical resistance of frozen water is extremely high. When the moisture in the resistance block freezes, there is a sharp rise in its electrical resistance. Commercial resistance blocks work well as soil frost measuring devices, but they have two disadvantages: they are quite large and they are too expensive to use in extensive frost surveys.

Michelson and Lord (1962) developed an inexpensive, small electrical resistance block. It is approximately 3/4" in diameter and 1" long. The procedure for making the units is very simple and the cost for making them is less than five cents per unit. The unit consists of a strip of copper window screen 5/8" wide and 2-1/8" long. The strip is acid cleaned, dip tinned and then shaped and soldered into a 5/8" diameter cylinder as seen in Figure 10. A standard phone tip is also tinned (Fig. 10, No. 3), and the unit assembled as shown (Fig. 10, No. 4). A wooden slab with holes to support the phone tips is covered with plaster of Paris. When the plaster is dried, the units are removed and the excess plaster is broken off. The center electrode wire is soldered to the phone tip, and the ground wire is soldered to the screen (Fig. 10, No. 5). In the last step the cylinder is filled with plaster and the outside of the unit is formed (Fig. 10, No. 6).

A sample of the daily morning data for the gypsum electrical resistance blocks can be seen in Table 1. The solid black line encloses the soil which was established to have

TABLE 1.--Resistance of Gypsum Electrical Resistance Blocks in Thousands of Ohms Shown over Soil Temperature in Degrees Fahrenheit. All Measurements Taken in Soil Kept Free of Snow in 1971

Soil Depth in Inches	The Frozen Soil is Enclosed in the Solid Black Line										
	Feb. 2	Feb. 3	Feb. 4	Feb. 6	Feb. 7	Feb. 15	Feb. 16	Feb. 17	Feb. 19	Feb. 21	Feb. 26
1	55.0 3.0	+* 18.0	+ 20.0	+ 25.0	+ 25.0	+ 29.0	+ 28.0	+ 24.0	3.5 24.0	1.5 34.0	1.5 32.0
3	+ 4.0	+ 16.0	+ 11.0	+ 24.0	+ 25.0	+ 28.0	+ 25.0	+ 21.0	55.0 32.0	5.5 33.0	1.5 31.5
6	+ 7.0	+ 14.0	+ 9.0	+ 23.0	+ 25.0	+ 27.0	+ 24.0	+ 21.0	55.0 31.5	16.0 31.0	3.5 31.5
9	+ 9.0	+ 15.0	+ 9.0	+ 24.0	+ 25.0	+ 27.0	+ 26.0	+ 23.0	55.00 31.5	55.0 31.0	13.0 31.0
12	+ 12.0	+ 14.0	+ 10.0	+ 24.0	+ 26.0	+ 28.0	+ 28.0	+ 23.0	55.0 31.0	55.0 31.0	17.8 31.0
15	+ 16.0	+ 18.0	+ 16.0	+ 24.0	+ 27.0	+ 29.0	+ 28.0	+ 26.0	55.0 31.0	55.0 29.5	17.8 31.0
18	+ 19.0	+ 22.0	+ 18.0	+ 24.0	+ 29.0	55.0 29.0	55.0 28.0	55.0 26.0	55.0 31.0	55.0 29.0	22.5 31.0
21	+ 21.0	+ 21.0	+ 21.0	+ 25.0	+ 28.0	55.0 29.0	55.0 29.0	55.0 27.0	55.0 30.5	55.0 28.0	15.9 31.0
24	+ 26.0	+ 25.0	+ 22.0	+ 28.0	+ 28.0	55.0 30.5	55.0 30.0	55.0 29.0	55.0 30.5	55.0 28.5	7.0 31.0
27	55.0 25.0	+ 27.0	+ 24.0	+ 28.0	+ 28.0	55.0 30.0	55.0 31.0	55.0 29.0	55.0 31.0	51.8 29.0	5.0 31.0
30	1.5 28.0	16.3 31.0	55.0 28.0	+ 29.0	55.0 29.0	11.1 29.5	6.0 33.0	2.7 31.0	1.5 32.5	1.5 29.0	1.5 31.0
33	1.5 29.0	1.5 31.0	22.5 30.0	55.0 31.0	55.0 31.0	1.9 31.0	1.5 32.0	1.5 30.0	1.5 32.5	1.5 30.0	1.5 32.5
36	1.5 29.0	1.5 32.0	1.5 31.0	2.1 33.0	9.1 31.5	1.7 31.0	1.5 32.0	1.8 29.0	1.5 32.5	1.5 31.0	1.5 33.0

*The + symbol indicates that the needle exceeded the maximum scale of 55,000 ohms on the meter.

soil frost and separates it from the soil which was found to be frost free. The course of soil and air temperature and soil frost occurrence are shown in Figure 11.

The depth of frost penetration was established daily by direct observation to a depth of twelve inches. Deeper frost penetration was established with a stack of gypsum blocks buried at the same depths as the thermocouples and a Modified Fernow Frost Gage. Maximum frost penetration for the winter was established with free buried vials and a modified frost meter, the U. Mass Frost Gage.

Three observations are readily made from scanning Table 1: (a) There is a sharp rise in the electrical resistance in the fabricated gypsum blocks between frozen and unfrozen soil. The smallest difference in electrical resistance between frozen and unfrozen blocks was 9,000 ohms. (b) The temperature of unfrozen soil can be considerably below the freezing point of water as seen from the data of February 2, 1971 in Table 1. (c) Gypsum electrical blocks can detect frozen ground beneath unfrozen soil, revealed by the data of February 19, 21, and 26.

Since the blocks are small, they respond quickly to the freezing and thawing of a relatively limited test area. The fabricated gypsum electrical resistance blocks should be of great value in frost measurement because the units are inexpensive, easy to construct, and they lasted two years without failure even in the acidic soils under the red pine stands on Cadwell Creek.

The results of these tests demonstrate that the fabricated non-commercial gypsum blocks are as reliable for measuring soil frost as the commercially manufactured blocks tested by Gartska (1944), Harrold and Roberts (1960), Colman and Hendrix (1949), Bethlahmy (1952), and Sartz (1967).

Modified Fernow Frost Gage

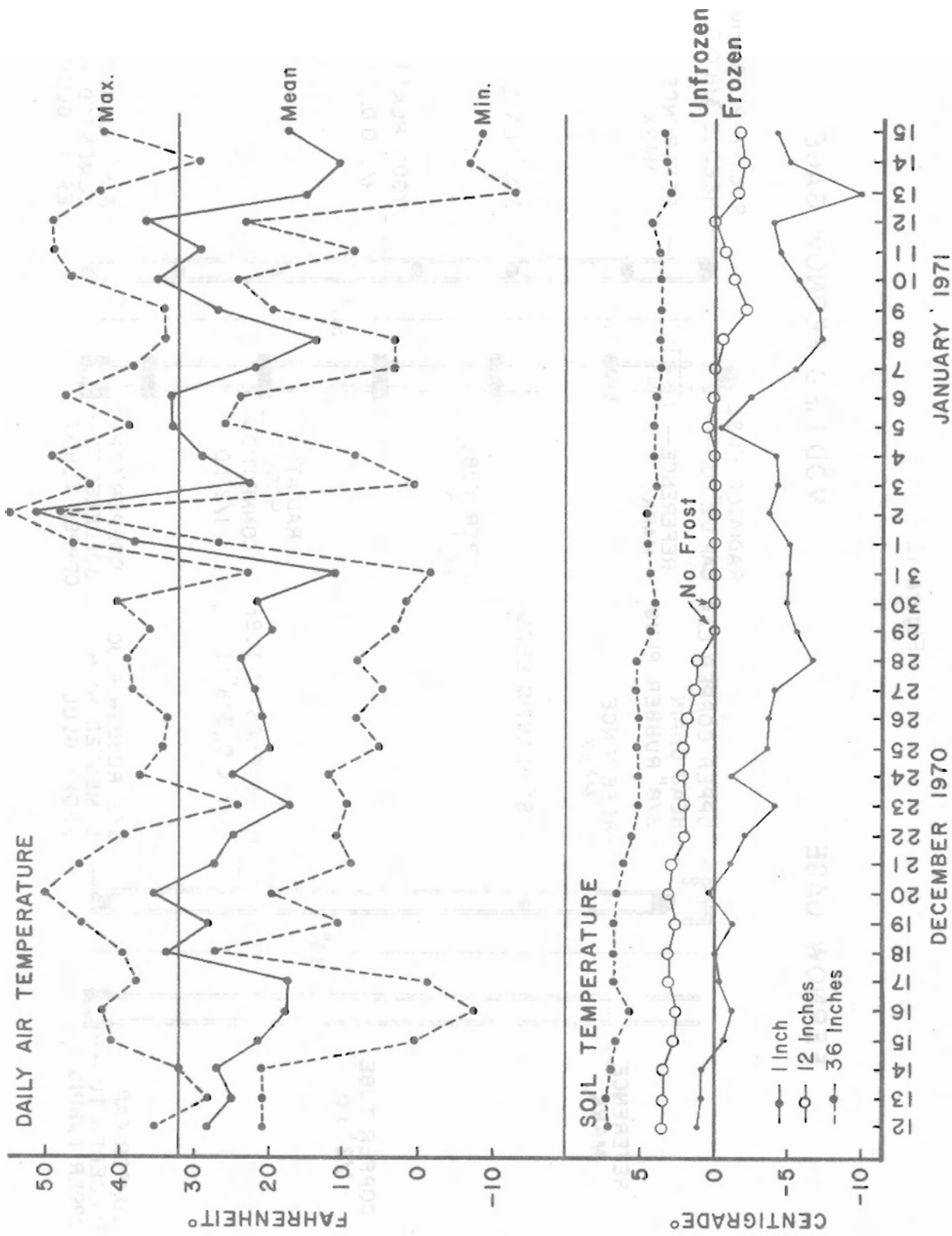
Patric and Fridley (1969) decided that a frost measuring device had to be constructed that would:

1. React to soil freezing and thawing with reasonable speed and accuracy.
2. Cause minimum alteration or damage to the sampling site.
3. Be economical in construction and operation to permit frequent and repeated observations."

The instrument they developed was called the Fernow Gage, as seen in Figure 12. It had two major deficiencies. The first was that the well casing of the Fernow Gage conducted heat into and out of the soil. This problem was recognized by both Harris (1970) and Patric and Fridley (1969). The second deficiency was the gage's inability to measure subsurface frost when the surface of the soil was unfrozen. As the soil started thawing from its surface, the solution in the upper part of the gage would melt. The liquid solution was replaced by the frozen solution from below because the frozen solution was lighter than the liquid. Thus the frozen solution kept rising as it melted until the entire column was melted, indicating no soil frost when there was subsurface frost. This deficiency was not previously reported and was not realized until it was confronted when the Modified Fernow Gage was tested in the snow free study area in Ware, Massachusetts.

Researchers at the U. S. Army Cold Regions Research and Engineering Laboratory solved the problem of vertical heat conductivity of the copper well casing by using a plastic tube. Working at the Intermountain Forest and Range Experiment Station, DeByle (1970) painted the exposed part of the tube white to lessen vertical heat conductivity. We used the copper because of the need for good lateral heat transfer between the soil and gage during periods of quick freezing and thawing, thus cutting down the lag time in gage response to freezing and thawing. Copper has a thermal conductivity of 3.90 W/cm-C while aluminum is 2.22, tin is 0.63, steel is 0.50, iron is 0.47, and plastic is even less. We interrupted the vertical heat conductivity of the casing by cutting the well casing into sections and separating the sections with radiator hose connections. The top joint was installed exactly at the ground level so the section above the ground did not touch the sections below the ground.

Figure 11. A sample of the continuous soil temperature data and the daily air temperature data for the study area in Ware, Massachusetts.



The gage's inability to measure subsurface frost when the surface of the soil was unfrozen was solved by DeByle (1970) when he placed a string through the center of the gage. This string would hold the ice in place when thawing occurred from the surface down. We used plastic beads to restrict the movement of the submerged frozen solution during periods of surface thawing. The reason the beads were used was because of their secondary utility of preventing the need of a complete overturn of all the solution in the inner tube of the gage before ice formation could begin. The beads would restrict the thermal overturn of the solution to a compartment of the inner tube rather than its entire length. The beads facilitate the measurement of quick freezing, thus cutting down on the lag time as well as facilitating the measurement of subsurface frost.

We used a small diameter tube to lower the cost of the gage and to avoid the increase in the lag time of freezing caused by larger volumes of water. We did not try the florescein and sand mixture used by the Cold Regions Research and Engineering Laboratory, the Russians, and the Canadian Department of Transport because during periods of rapid freezing and thawing the color separation lines become diffused and mixed on occasion. The color separation line between the clear ice and the unfrozen food coloring dye solution in the Fernow Frost Gage was always distinct and clear. We also wanted to avoid the problem of color changes in the fluorescein which result from exposure to extended periods of sunlight.

The Modified Fernow Frost Gage is one of the easiest to read of any tube type gage. It should have the shortest lag time of any gage of this type because it has the best lateral thermal conductivity and the smallest volume of water which has to respond to freezing and thawing temperatures. Harris (1970) reported that the Fernow Gage performed well, but this version of the gage is better and possibly the best direct reading, tube type frost gage available.

The U. Mass Frost Gage is a porous celluplastic cylinder in which the soil profile of the study area is reconstructed. Water-filled vials are placed horizontally across the width of the cylinder at given intervals. The celluplastic cylinder was placed in a drill hole so that the surface of the reconstructed soil profile coincided with the actual soil surface. In the spring the cylinder was easily pulled out and the bottles examined. The lowest broken bottle indicated the greatest depth of frost formation.

In the spring of 1971 the U. Mass Frost Gage was pulled out of the soil and the vials were examined. All the vials were broken except the vial at 36 inches. This indicated a frost penetration to a depth of between 33 and 36 inches. This coincided with the depth of frost measured by the other frost measuring methods and the free buried vials. The celluplastic cylinder which is the major component of the U. Mass Frost Gage did not affect the breaking of the vials in the trial testing, and it saved three hours in retrieving the vials for examination. The U. Mass Frost Gage has two disadvantages. The first is that it does not allow periodic examinations. The second disadvantage is that it depends upon soil temperature as an indirect indicator of soil frost. In the test area at a depth of 36 inches, a minimum soil temperature of $-1 \frac{3}{4}^{\circ} \text{C}$. was recorded, but the ice in the vial did not expand enough to break the vial.

CONCLUSIONS

Frost Occurrence and Importance

The frost surveys during two winters encountered no general frost formation at the Cadwell Creek area because of continuous winter snow cover so no effects of soil frost on percolation or runoff occurred to increase spring runoff. These results are comparable to those reported by Pierce (1956) and Hart (1963) for New Hampshire.

Snowpack Development

The forest stand density manipulation affected the maximum depth of snowpack development and time of snowpack melt, but not enough for practical application. The

effect of the position of the thinned red pine stand to the unthinned red pine stand may have practical application. The thinned stand was adjacent to and north of the unthinned stand. Wind turbulence effects over the thinned and unthinned red pine stands caused snow to be dumped into the thinned red pine stands. The shading from the unthinned red pine stand caused the snow to stay abnormally long in the thinned stand indicating a potential for extending the period of spring runoff up to a week or more.

Instrumentation

Comparisons made between the gypsum electrical resistance units, the Modified Fernow Frost Gage, the U. Mass Frost Gage, and the free buried vials indicated that gypsum electrical resistance units were the most reliable because the resistance units do not depend on soil temperature but rather on the formation of frost to indicate soil freezing.

The Modified Fernow Frost Gage had an advantage over all other frost measuring methods because it allowed exact measurement of frost depth while the electrical resistance units can only measure frost at predetermined intervals. It also had an advantage over the U. Mass Frost Gage and the free buried vials because it allowed repeated measurements. The U. Mass Frost Gage and the free buried vials gave a single measurement of maximum depth of frost penetration. The advantage of the U. Mass Frost Gage over the free buried vials was in the ease of excavation and examination of its water-filled vials.

All these frost measuring devices have their application in certain situations. Measurement of soil frost, which is the depth of frozen soil, is necessary for studying the hydrologic and ecological effects of soil freezing. The common factor in all the frost gages described is that they are relatively inexpensive and can be constructed easily in the laboratory.

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