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A Working Paper presents results of investigations which are to some extent limited or incomplete. Therefore, conclusions or recommendations--expressed or implied--are tentative.

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Depth and time of frost penetration are important design criteria that control or limit underground domestic water supply and waste disposal systems in any climate where winter temperatures cause soils to freeze. In Alaska, especially the Interior, these factors become important because of the extreme cold and the duration of below-freezing temperatures. Many areas of Interior Alaska are free of permafrost, but still experience deep seasonal freezing of soils. Near Fairbanks a range of low hills, mantled with silty soils, is becoming important for home sites and all these slopes with a southerly exposure are free of permafrost. On such sites it is important to know the seasonal depth of freezing because a frozen waste disposal system here poses a serious pollution problem that may be a significant health hazard. This temperature station was established because data on soil freezing were not readily available.

METHOD

The site for this station is about eight miles northwest of Fairbanks on a deep, silty soil under a birch and aspen forest where the trees were 40-50 feet tall (Figure 1). This site was representative of soils, vegetation, and other aspects of much of the permafrost-free building sites in the vicinity of Fairbanks. The surface at the site has a slope of 17% at south 70° west.

Temperature sensing was by thermistors imbedded in the soil at 11 depths, one in the shallow duff layer and others at 0.5, 1, 1.5, 2, 2.5,

Figure 1. Deciduous forest at the site; larger trees are birch with aspen in background (19 September 1969)

3, 4, 5, 6, and 7 feet deep. A twelfth thermistor measured air temperature about 1 dm above the ground or snow surface. Measurement was with a Yellow Springs Instrument Co. Telethermometer. Before being installed, thermistors were tested in a water bath at 26° and 1°C and found to read within 0.5°C.

To install thermistors, a pit was dug by hand to a depth of six feet on the afternoon of October 5, 1966, and moisture samples collected for each horizon; the installation was complete and the pit refilled by noon of October 6. The thermistor at 7 feet was emplaced in a small hole (1 inch in diameter) bored into the bottom of the pit. All other sensors were emplaced in holes 12 inches deep, bored perpendicularly into the upper face of the pit. All bored holes were backfilled with material from the same depth by tamping with a wooden rod. Leads from thermistors were brought to the surface and led through a 3-foot section of electrical conduit whose lower end was about 6 inches below the surface. This measure was taken to prevent rodents from gnawing the insulation off the leads. All leads plugged into a switch box that permitted readings to be taken by plugging a single lead to the Telethermometer and switching from one thermistor lead to the next. The terminal box was housed in a metal can mounted atop the conduit to protect it from weather and animals (Figure 2).

After each thermistor was emplaced, the pit was backfilled to the next level by material approximately the same as that in which the thermistor was placed. As backfilling progressed, the material was compacted by trampling with the feet in 3- or 4-inch increments. This compacting

Figure 2. Closeup of the temperature measuring station. The switch box had been removed the previous fall. (19 September 1969)

proved effective, since all material taken out during excavation was returned without an excess and slumping after 3 years was not more than 1 to 2 inches.

Temperatures were first read on October 7, about 26 hours after installation. For the remainder of October, temperatures were read twice a week to determine if opening the pit had caused a temporary disruption of the soil thermal regime. Apparently it had not because temperatures at depth remained constant until cold weather set in. Table 1 presents data showing moisture content and two sets of temperature measurements:

TABLE 1. DEPTH OF INSTALLATION, MOISTURE CONTENT AND INITIAL TEMPERATURE

PROBE NUMBER	DEPTH (INCHES)	% WATER AT INSTALLATION	TEMPERATURE, °C 26 hrs after installation	8 days after installation
1	Air (1 dc above surface)	NA	+5.5	+2.5
2	2" (duff)	25.8	+3.5	+2.5
3	6"	7.5	+4.5	+3.0
4	12"	7.4	+5.5	+4.0
5	18"	6.3	+5.5	+4.0
6	24"	6.4	+5.5	+4.5
7	30"	6.3	+5.5	+5.0
8	36"	6.0	+5.0	+5.0
9	48"	6.1	+5.0	+5.0
10	60"	7.5	+4.5	+4.0
11	72"	9.2	+4.0	+4.0
12	84"	10.7	+4.0	+4.0

After October 1966, temperatures were measured weekly throughout the year, usually between the hours of 1200 and 1300 every Monday. Temperatures were read for two full years and terminated on October 14, 1968, although the sensors were left in the ground. The switching box was removed and used on another project.

On January 23, 1969, a set of readings was made by hand switching with a short section of wire through phone jacks. The reason for this set of readings was to compare soil temperatures after the severe winter of 1968-69 with those of the previous two years. Another set of readings was made on April 1 to determine maximum depth of freezing after the severe winter and compare it with previous years. A final set of readings was taken on September 14, 1969, after which all thermistors were removed from the soil and the experiment terminated.

RESULTS AND DISCUSSION

Moisture content at the time of installation was low and was near wilting point for this soil texture down to about 4 feet deep. The summer of 1966 was extremely dry with almost no rain from August 1 through the date of installation. Table 1 includes these data. After breakup in 1967, moisture from melting snow penetrated to 21 inches as noted in a post-hole near the temperature measuring site.

Temperatures measured on October 7 and 14 are also shown in Table 1. It will be noted that soil temperatures to a depth of 30 in. are gradually decreasing as ambient temperatures decline. Below 30 in., temperatures at both dates were identical and form the basis for the earlier statement that opening the pit caused a minimal disturbance of the temperature regime.

Subsequent data for two years record are presented in Figures 3 and 4 with some selected data presented by Figure 5. Temperatures at each depth were averaged monthly and grouped by 6-month intervals. Group A represents a cooling trend in fall from October, when deep horizons are at maximum temperatures, through March, when these horizons are nearly at

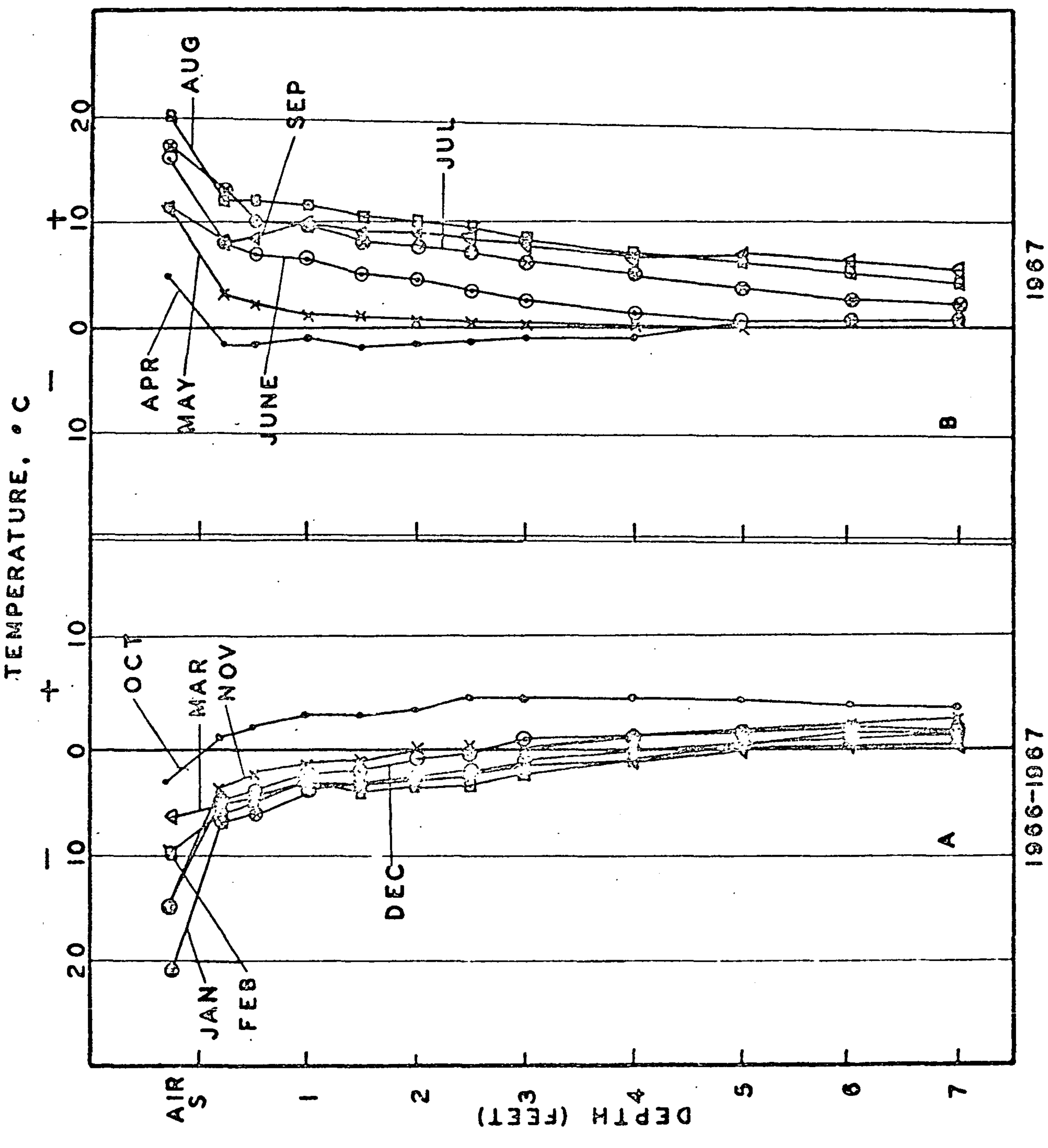

Figure 3. Temperature cooling curves for 1966-67 (A) and warming curves for 1967 (B).

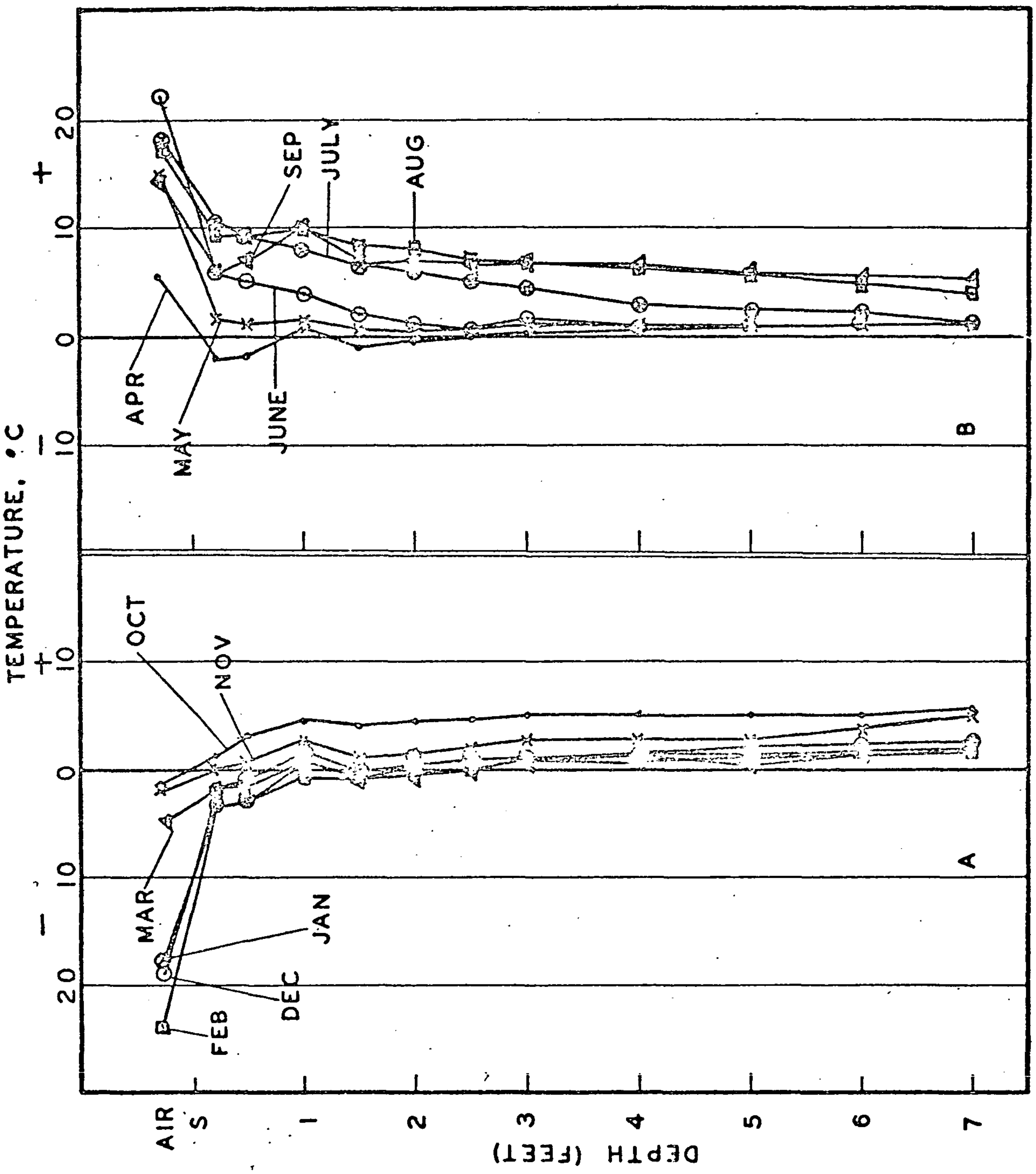

Figure 4. Temperature cooling curves for 1967-68 (A) and warming curves for 1968 (B).

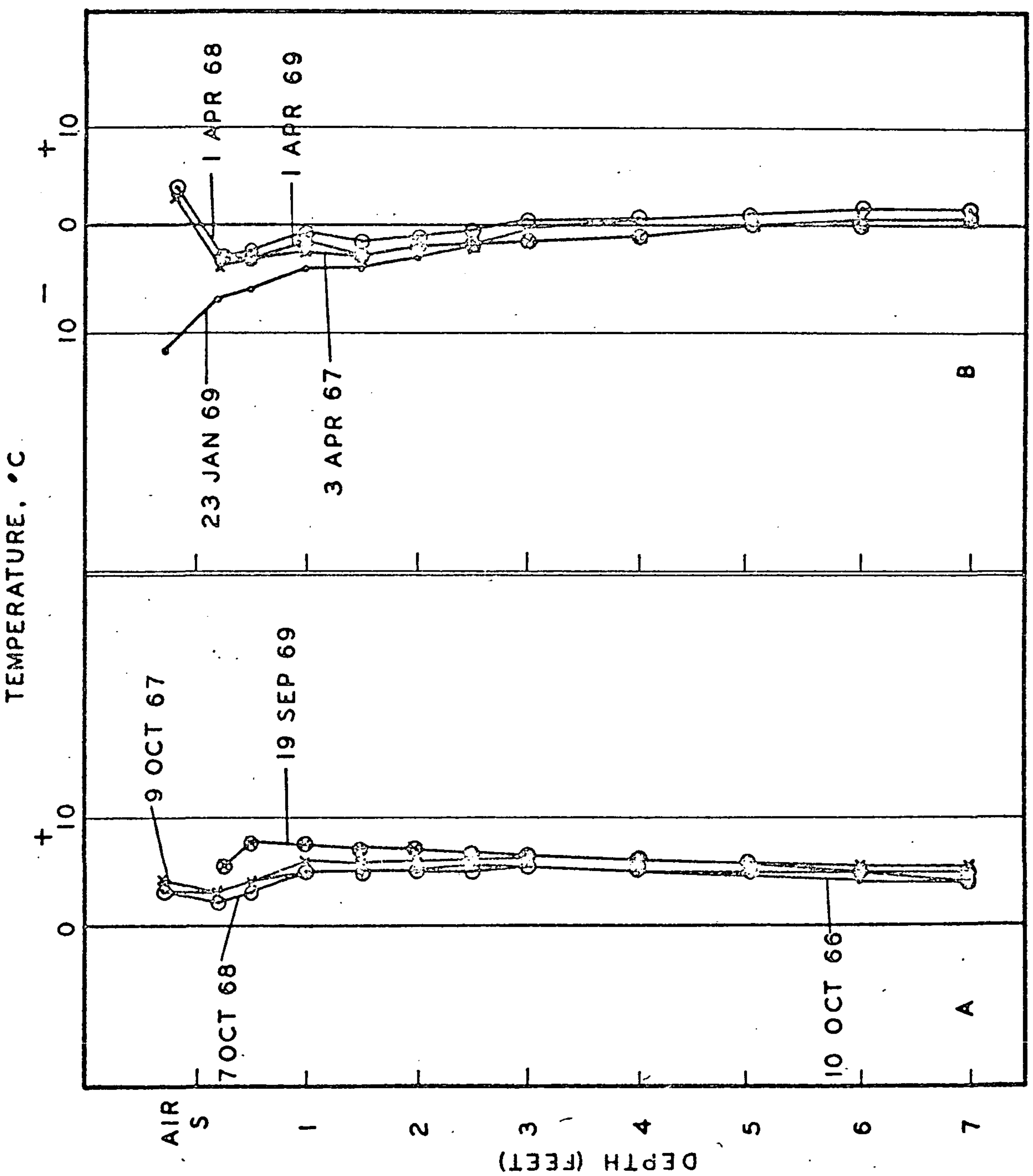

Figure 5. (A) Maximum soil temperature at the onset of cooling in autumn, (B) Minimum soil temperature at the end of cooling cycle.

their coldest. Group B represents the 6 months of warming of deep horizons from April through September when these horizons are gaining heat through the summer.

Although the graphs are self-explanatory for the most part, several interesting points will be discussed briefly. The most rapid cooling is from October to November for the entire profile; this trend held for both years as shown by A in Figures 3 and 4. However, total cooling was much less in 1967-68 than for 1966-67 because the winter of 1967 was milder than normal. By November 1966 the soil had frozen to a depth of 2 1/2 feet. From November through the cooling phase, cooling progressed slowly until February, when final depth of freezing reached 5 feet. It appears that the entire profile cools and warms as a unit with different portions responding at different rates; i.e., the amplitude decreases with depth. During the mild winter of 1967 total depth of freezing was only 2 1/2 in. and was reached by February, the same month as for the previous year, which was near normal; depth of freezing after the severe winter of 1968-69 was 6 feet.

Warming curves are almost mirror images of the cooling curves with maximum warming occurring in the interval from May to August. Part "B" of Figure 1 shows that the entire profile was just at freezing by May and above freezing by June. From June until September the deeper horizons continue to warm although surface horizons (0-36 in.) start to cool with the onset of fall weather and shorter days. Similar trends are shown by "B" of Figure 2 for 1968 with the depth of freez ng much less. In 1968, the deep horizons reached a slightly higher temperature than for the previous year, 5.5° as opposed to 4°C. In 1968 the maximum temperature at 7 ft. reached 5°C even though the minimum at this depth on October 68 was 1.5°C.

Figure 5 presents soil temperatures at times of the seasons when maximum warming had occurred, shown in "A", and at maximum cooling shown in "B". In "A", curves for 3 years show that temperatures for all horizons are only a degree or so apart even though individual years had widely different climatic conditions. 1966 was very dry with average summer and winter temperatures. Accumulated snowfall during 1966-67 reached 6.5 dm on April 3 with about 4 dm on the ground by November 2,, so insulation was present during cold wather. The summer of 1967 was much wetter than normal. Weather Bureau records show the combined rainfall for July and August was 5.5 inches above normal, although summer temperatures were near normal. Winter temperatures for 1967-68 were milder than normal and, although total snow accumulation was similar to the previous year, 4 dm had not accumulated until January 8, 1968.

Summer temperatures and rainfall for 1968 were near normal; records show temperatures for June, July and August as being +1, +6, and +4 degrees above normal and rainfall for the same period as being +0.1, +1, and -1 inches from normal. However, winter temperatures were considerably below normal. A record for prolonged cold temperatures was set for the period from about Christmas 1968 to near the middle of January 1969. Temperature for January 1969 showed a -15° departure from normal because of this prolonged cold snap. Despite the varying seasonal temperatures throughout the year, the final temperatures near October 1 are close. The curve for September 1969 will probably move close to the October curve as plotted, since at the 1-foot depth on 1968, the temperature was 10°C, yet by October it had dropped to 5°C.

Part "B" of Figure 5 depicts minimum soil temperatures following three winters with varying weather. Again, as for maximums, the final temperatures are close, although they do follow trends established by the nature of the previous winters. Thus, temperatures after a mild winter are higher than those following a severe winter. It is interesting that warming commences as cold weather ends, as indicated by the curves for January 23 and April 1, 1969, even though a snow cover remains.

It should be pointed out that these measurements were made under undisturbed conditions in birch and aspen forest. If the forest is removed, the shape of curves and depth of freezing will be different. If a measuring site is disturbed by trampling or other traffic, the depth of freezing will increase.

Based on the first year's data, a waste disposal system was installed for a new home built in 1967. This system consists of a steel septic tank followed by a concrete block leaching pit. Both of these structures were buried deep enough so that the top was at least 4 ft. deep. During an average winter such as that of 1966-67, it was Janaury before the soil was frozen to 4 ft. and the minimum reached at this depth for the three winters was only -1°C. Moreover, heat in wastewater is sufficient to add to a heat sink built up throughout the year and helps prevent freezing to greater depths. The system referred to earlier has functioned satisfactorily for 2 winters, one of which was abnormally cold. Although the forest had to be removed during construction, the area overlying the septic tank and leaching pit is not disturbed during the winter to minimize loss of heat caused by trampled snow.

CONCLUSIONS

Depth of freezing of silty soils on a forested site near Fairbanks, not underlain by permafrost, ranged from 2 1/2 ft. for a mild winter to 6 ft. for a severe one. These depths were for undisturbed forest; disturbance will increase the depth of freezing and severe trampling of snow may cause much deeper frost penetration.

The entire profile cools and warms as a unit, but different portions do not react at the same rate; the amplitude of change decreases with depth. Maximum temperature measured at 7 ft. was 5.5°C and the minimum was 0.5°C. At the 1 ft. depth the coldest temperature measured was 4°C below freezing and the warmest was 12.5°C.

A domestic waste disposal system, installed with its uppermost surface at a depth of 4 ft., functioned satisfactorily during a severe winter. Such a depth of installation is deemed satisfactory if the site remains undisturbed during the winter season. Deviation from conditions described in this study such as presence of permafrost, traffic over the disposal system, texture of the soil, and soil moisture at the site, will cause significant differences in depth and time of freezing as reported here.

An additional precaution is that the slopes on which these measurements were made are generally 20-25°F warmer during severe cold than are the nearby lowlands. As cold snaps persist, a strong inversion develops over the lowlands and slopes a few hundred feet higher in elevation become warmer. Therefore, data for depth of freezing from slope sites should not be extrapolated directly to valley stations.