FORESTRY 499 B.S.F. THESIS

INFLUENCE OF FOREST COVER
ON SOIL TEMPERATURE

G. R. HILLMAN APRIL, 1967
Comments on:

"Influence of Forest Cover on Soil Temperature", by G. R. Hillman.

A competent professional study. Statistical analysis is handled very well and results are discussed fully and effectively. First class presentation.

Explanation on page 41 of "cool spots" is suspect; however, no better hypothesis exists.

On p. 11, peat has low specific heat.

Study is particularly useful in pointing out anomalies of data in relation to presently accepted theory.

W. W. Jeffrey
Acadia Camp,
University of British Columbia,
Vancouver 8, B. C.
April 15, 1967.

J. A. F. Gardner, M.A., Ph.D., F.C.I.C.,
Dean of the Faculty of Forestry,
University of British Columbia,
Vancouver 8, B. C.

Dear Sir,

I have the honour to submit my thesis entitled "Influence of forest cover on soil temperature", in partial fulfillment of the requirements for the degree of Bachelor of Science in Forestry.

Yours truly,

G. R. Hillman
INFLUENCE OF FOREST COVER ON
SOIL TEMPERATURE

by

GRAHAM ROBIN HILLMAN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
BACHELOR OF SCIENCE IN FORESTRY
in the Department
of
Forestry

I hereby accept this thesis as conforming to the
required standard.

[Signatures]

THE UNIVERSITY OF BRITISH COLUMBIA

April 21, 1967
ABSTRACT

A knowledge of soil temperature trends is essential for better understanding of biological, pedological, and hydrological processes taking place in the soil. The effects of environmental influences on soil temperature are discussed in the literature review, with special reference to forest cover—frost formation relationships.

The purpose of this thesis is to determine if, and in what way, soil temperature is influenced by stand structure, aspect, soil depth and time. Three stands, located on north (or northeast) and south aspects were investigated: 1) uncut spruce-fir, 2) partially-cut spruce-fir, and 3) 25-year-old lodgepole pine. Statistical and graphical analyses were used. Data for the 2-year period, August 4, 1964 to July 25, 1966 were utilized. Statistical analysis showed that all factors and interactions between stand structure, aspect, soil depth, and time were significantly different, except for the year-stand-depth interaction. Graphical analysis produced results similar to those obtained by statistical analysis. Two results were outstanding: 1) south-facing lodgepole pine had the highest temperatures at most depths throughout the year, 2) north-facing partially-cut spruce-fir site had higher soil temperatures than the south-facing partially-cut spruce-fir site. This unexpected result cannot be adequately explained.

Soil temperature inversions took place at the end of October and again in spring. Fluctuations in soil temperature occurred mostly in the upper 3 feet of soil with minimum fluctuations occurring at the
soil-humus interface. Below 3 feet, soil temperature was fairly uniform, both in time and depth. "Coal spots" were a noticeable feature of soil temperature profiles and are indicated by "kinks" in the graphs.
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INFLUENCE OF FOREST COVER ON

SOIL TEMPERATURE

Introduction

Much has been said, in contemporary scientific literature, about
the many beneficial effects of forest cover, especially the hydrological
effects. Forests play a vital role in the hydrologic cycle, modifying
the influence of insolation, precipitation, wind, frost, and flowing water.
The interaction between the forest and the soil is an extremely important
influence. In the forest ecosystem, soil usually has better drainage
characteristics, less rapid snow-melt, and less concentrated runoff over a
longer period of time, than has soil lacking a forest canopy. In the
latter case, deep soil freezing, high spring runoff rates, and soil erosion
are more likely to occur.

Soil freezing is a most critical physical factor influencing
drainage since deep concrete frost forms an impervious layer in the soil.
Precipitation falling on such a soil will, in all probability, eventually
be lost as runoff instead of being added to soil water reserves.

The degree of soil freezing depends on soil moisture and soil temperature. Though it is desirable to consider both of these regimes when investigating soil freezing, this paper is confined to a discussion of soil temperature regimes in an experimental basin of the Saskatchewan River headwaters in Alberta.

Marmot Creek Basin is located in the Kananaskis River Valley, about fifty miles west of Calgary, Alberta, at latitude 55°57’S and longitude 115°10’W. Total area of the basin is 3.63 square miles approximately. The basin ranges in elevation between 5,400 feet M.S.L. and 9,000 feet M.S.L. It is an experimental watershed established for study of subalpine spruce-fir (*Picea engelmannii* Parry) and *Abies lasiocarpa* (Hook) Nutt.) forest hydrology (Jeffrey, 1965).

During the summer of 1966, the author was employed by the then Canada Department of Forestry to work on this project. As a result, it was possible for him to obtain site descriptions for all sites mentioned in this paper.

The paper considers soil temperature as affected by stand structure, aspect, soil depth and time. Each factor is examined both separately and in combination one with another. Both graphical and statistical analyses are used to determine the relationships between soil temperature and environmental factors.

Analysis of variance of soil temperature data pertaining to a second basin was also carried out. This watershed, located in the Porcupine Hills of southwestern Alberta was established for the study of montane aspen (*Populus tremuloides* Michx.) forests and associated grass-
lands of the southern foothills. However, there was insufficient time to analyse the results, therefore the second basin will not be referred to again.

Literature Review

Relevance of soil temperature

Soil temperature has biological, pedological, and hydrological significance. It controls microbiological activity and processes involved in the production of plants. The rate of organic matter decomposition and the rate of conversion of organic forms of nitrogen to the mineral form increase with temperature. Soil temperature affects plant growth through its influence on germination and growth rate (Bever, 1956).

Soil temperature is closely related to soil frost formation. Thus low temperatures in moist soils result in soil freezing which may be either advantageous or disadvantageous, as listed by Sakharov (1945), as follows:

Advantages:
1) freezing contributes to the development of soil structure;
2) it contributes to an increase in moisture in the upper horizons;
3) it causes the migration of soil animals to deeper horizons of the soil, thus contributing to the improvement of the structure over a greater depth;
4) it increases the wind stability of growing stock;
5) it delays the beginning of spring growth, a factor of positive significance for species vulnerable to late frosts;
6) it prevents the rotting of the leaves of plants;
7) it causes the destruction of certain tree-damaging insects;
8) it improves operating conditions for timber harvesting (felling, bucking, and hauling).

Disadvantages:
1) freezing interrupts the continuity of micro-biological and chemical processes in the soil;
2) it reduces soil evaporation losses, an undesirable influence in the case of wet soils;
3) it decreases soil permeability thus contributing to surface run-off.
4) in a number of cases it builds conditions for physiological dryness;
5) it causes the frost heaving of tree seedlings;
6) it causes the soil to swell, a process which harmfully affects forest growth;
7) it delays the start of operations for forest culture.

The type of frost produced as a result of soil freezing greatly affects the water-bearing and drainage properties of the soil. Post and Dreifolbisch (1942) describe different types of structure which were arbitrarily classified into three groups:

Concrete frost which is characterized by many very thin "ice lenses", small crystals and an extremely dense complex of frozen soil particles. It usually occurred in soils previously frozen and thawed, or in soils settled by a heavy rain. It was more prevalent in bare soils or in those
with sparse vegetal cover. This structure was found in practically all cases in which more than 3 inches of freezing occurred. In this particular study, it was the only type that was found with a moisture content of less than 50% of the dry weight.

Honeycomb frost has a loose porous structure and is commonly found under shallow freezing conditions.

Stalactite frost structure is characterized by many small icicles connecting the heaved surface to the soil below. The force required to obtain samples was used as a basis for classifying the differences in structure of frozen soils.

Frost structure is related to the moisture content of the frozen soil. Studies have shown (Trumble et al., 1958 and Stoeckeler and Weitsman, 1960) that concrete frost renders soil impermeable to soil moisture. This is particularly true for silt loam soils. Hence the presence of concrete frost may have a definite affect on the rate of spring run-off. It is important, therefore, to know the type of frost to be expected within different ecosystems.

Trends in soil temperature change.

In a given soil, the closer to the soil surface, the greater is the amplitude of fluctuation of soil temperature. Seasonal variations of soil temperature are greatest at the surface and decrease with depth until, at a depth of 30 feet or more, they disappear (Smith et al., 1964). Surface layers are exposed to radiant solar energy, drying winds and abrupt changes in air temperature. At lower depths, the presence of a water table may contribute to constant temperatures at these depths. During winter, a water table may be a source of soil heat accumulated by
the ground water layer during the warm season (Salimov, 1945). This
supply of heat might be a factor in promoting thawing from beneath frozen
soil layers.

Since surface layers are usually occupied by plant roots and by
animals, they tend to be more porous, providing ready access to air and
water. Changes in the air temperature and the presence or absence of
cloud cover, rain or snow will readily influence soil temperature in these
layers. The composition of the soil at different depths is also an
important factor governing the soil temperature regime because heat
capacity and heat conductivity varies with the type of mineral and
organic constituents of the soil as well as with moisture content.

Soil moisture is not pure water but a solution of various salts,
the concentration of which varies within wide limits. Salts dissolved in
water lower the latter's freezing point. Therefore the soils begin to
freeze in most cases, at a temperature which is below zero °C. (32°F),
the exact figure being dependent on the concentration of salts in the
soil solution (Rode, 1955).

Heating of the soil surface in the summer months leads to higher
temperatures in the upper soil layers. Where winter air temperatures are
low, in winter the reverse may be true - the lower levels of the soil
having higher temperatures than the surface layers. Soil temperature
inversion occurs when there is a change from one sequence to the other.
This inversion usually takes place twice annually, in spring and autumn
(Fraser, 1957; Jeffrey, 1963; Schneider and Stransky, 1966).

The thermal conductivity (rate of transfer of heat through a
body by conduction) property of the soil governs the rate at which heat
will be transferred from one soil layer to another. Invariably there is
a time lag between the time at which diurnal and seasonal maximum and minimum temperatures are attained at the surface and the time when extremes of temperature are reached at lower soil depths (Shanks, 1956).

Factors affecting soil temperature

Soil temperature may be influenced by numerous factors. These have been grouped very conveniently by Sekharov (1945). The basic groups, reproduced here, include climatic, orography, edaphic factors and biotic factors.

Climatic influences include: a) the regional climatic characteristics, b) characteristics of the course of weather during the year in question, and seasonal variations.

Orographic factors include a) altitude, b) relief, c) aspect, d) degree of slope. Edaphic factors determine the thermal properties of the soil and include a) chemical composition, quantity of humus, concentration of soil solutions, and b) physical properties - structure, colour, moisture, etc.

Biotic factors are divisible into three sub-groups: a) vegetation, comprising the ecological characteristics of forest types. Vegetation indirectly controls soil temperature through age, composition, stocking, separation of stories, distance from the edge of openings and similar influences. b) Fauna (1) surface animals. These influence the thermal balance of the soil, chiefly through their effect on vegetation, (eg. bark beetles), (2) soil-animals; these have a direct as well as an indirect influence on the soil's thermal properties. c) Human activity, creating changes in (1) soil - its chemical and physical properties, (2) vegetation, and (3) fauna.
Influence of climate

Climate is the major factor governing soil temperature. Climatic agents determine the degree of soil development and the type of vegetation cover. Solar insolation, air temperature and air humidity influence soil temperature through their effects on heat flow and evaporation. High air temperatures result in steep temperature gradients from the air to the soil, hence there is a rapid transfer of heat energy from the atmosphere to the soil surface.

Where moist soils occur together with low relative air humidity, high air temperatures will cause evaporation of surface soil moisture. Some cooling of the soil will be affected together with upward movement of water in the soil. Conversely, when air temperatures are lower than soil temperatures, heat is transferred from the soil to the atmosphere since differing temperatures of two bodies (air-mass and soil in this case) in contact tend towards equality or equilibrium. This characteristic of heat transfer is responsible for both the seasonal and diurnal variations in soil temperature.

The foregoing effects, however, are greatly modified by the presence or absence of vegetation cover, leaf litter, humus or other organic matter, and by snow cover. Organic matter and snow are characterized by low heat conductivity properties, high heat capacities, and specific heats, hence changes in the temperature of these materials are not abrupt. These materials provide an effective barrier to heat flow either into or out of the soil. A large amount of heat would be necessary to remove an insulating snow layer, before heat conduction could continue between soil and atmosphere.
Influence of orographic factors

Of the orographic factors affecting soil temperature, altitude is the most important. Change in altitude may be considered as somewhat analogous to change in latitude since the climate in each case is modified in a similar way. Increase in altitude usually results in increased precipitation together with lower air temperatures, both of which affect soil temperature and its modifying influences, eg. snow depth.

The relief of an area may influence soil temperatures through its modifying effects on micro-climate. Thus some areas may be sheltered from drying winds or shaded from the sun. Relief features such as depressions may accumulate water, snow or frost, resulting in a nearly uniform soil temperature for long periods. Such features may not readily permit drainage of water or melting of snow. The high specific heat of water indicates that changes in the water temperature, and that of the soil affected by the water, occurs at a slow rate.

In the northern hemisphere, southerly aspects are warmer than north-facing since they are exposed to the direct rays of the sun for a greater duration than are the northerly aspects. This is especially true in winter. South-facing slopes are, therefore, more subject to the drying effects of the sun. This usually results in dryer and warmer soils.

The degree of slope will determine the drainage characteristics of a given area and also the intensity of incident solar insolation. Flat land or low lying ground is more likely to be characterized by poor drainage than is steep, sloping ground because the gravitational removal of water is not so significant in the former case. This is particularly true where soil permeability is poor. Such conditions often lead to water
accumulation and cool soils.

The amount of radiant energy incident upon a point is dependent upon the angle of incidence between the incoming solar rays and the ground. Maximum radiation intensity will occur when the sun's rays are normal to the ground, i.e. the angle of incidence is 90°. Hence when the sun's altitude is low, as during the winter months, maximum insolation will be received by steep, southerly slopes and the soil temperature will be modified accordingly.

Influence of edaphic factors

The chemical and physical properties of soils are the most important edaphic factors governing soil temperatures. The nature of the mineral soil will predetermine, in part, the physical characteristics that govern soil temperature. Bauer (1956) describes several properties of soils affecting soil temperature. The chemical composition of the soil determines the degree of water retention and heat conductivity. Thus clay, for example, retains water far more readily than does quartz, and in the absence of water, quartz transmits heat much faster than either humus or clay due to its lower specific heat. The ability to retain water is an important property of soils because it causes an increase in the specific heat of the soil and a subsequent increase in heat capacity since 

\[ Q = M \cdot S \]

where:

- \( Q \) = heat capacity
- \( M \) = mass of soil
- \( S \) = specific heat of soil

Heat conductivity is increased through increased inter-granular
contacts between soil particles such as may occur through compaction or through addition of water to the soil. Thus soil temperature is governed by porosity as well as by soil composition.

Soil colour is another physical property that influences soil temperature. A black body absorbs and loses radiant heat energy at a greater rate than does a similar, but lighter coloured, body. Thus dark soils show greater seasonal and diurnal fluctuations in soil temperature than do lighter coloured soils.

The presence of organic matter may strongly modify the temperature of the soil, even though the organic matter content of soils is usually small. The effect of organic matter is such that granulation of the soil is facilitated and the soil is able to retain more water. There are two general groups of organic matter: 1) original and partially decomposed tissue and 2) humus (Buckman and Brady, 1960).

Included in the first group are litter, duff or mor, and organic soils such as peat which is characterized by high hygroscopicity, high specific heat, low heat capacity, low heat conductivity, and low temperatures. According to Waksman (1938), litter comprises the upper, slightly decomposed portion of the forest floor. He describes duff as being the intermediate layer of raw humus, and is more or less decomposed organic matter located just below the litter. Mull is a mixture of organic and mineral soil.

Humus is undecomposed organic matter modified from original plant tissue. Colloidal in nature, its capacity to hold water greatly exceeds that of clay. It has the low specific heat and poor heat conductivity characteristic of organic materials.
Duff and litter have important hydrological significance because they protect the mineral soil from compaction by rain and from soil freezing. Over a period of three winters of soil frost observations in a northern hardwood forest in New Hampshire, it has been found that concrete frost occurs at only 4% of 2,800 sampling points. However, 78% of these points where frost was found were on mounds where little or no humus had accumulated. Nor occupied 67% of the study area, null 19%, and duff null 9%, the remainder, 5%, was bare mineral soil (Hart et al., 1962).

The pattern of freezing in organic soils is similar to that in mineral soils, but frost lasts much longer in organic material (Weitzman and Ray, 1963). However, the depth of freezing is less because of the high specific heat of organic soils.

Influence of vegetative factors

Forest type and condition determine the type and depth of the humus layer which, in turn, affect soil freezing. Of the cover types studied by Striffler (1959), those which permit deeper snow accumulation also produce humus types which are associated with less soil freezing. The type of vegetation has a profound effect on frost depth. This is borne out by studies near Cass Lake, Minnesota (Ray, 1959), where the average frost depth (below ground surface) under a white pine-hardwood stand reached 1.9 inches; under aspen, 3.5 inches; under balsam fir, 5.9 inches; and in the open, over 8 inches. This and other studies (Striffler, 1959) show that hardwood forests are subject to less severe freezing than coniferous forests. Where frost occurs under hardwood stands, it is generally of the honeycomb or granular type and therefore infiltration is not appreciably affected. Under coniferous forests, however, concrete
frost often prevails, rendering the soil impermeable. In addition to occurring more frequently and penetrating more deeply into soils under coniferous forests, concrete frost will remain longer in these soils than it will in soils under a hardwood stand (Sarts, 1957).

The deciduous nature of the hardwoods is the main reason that such stands are characterized by deeper snow layers and lesser soil freezing - both in depth and duration. The autumn leaf fall provides ready insulating material to the soil. The crown closure changes from dense to negligible, permitting snowfall ready access to the forest floor, thus providing further insulation for the soil. The humus types produced by hardwood forests are incorporated into the mineral soil and are associated with the formation of granular and honeycomb frost. The pure conifer stands, however, produce thin organic layers which do not mix with the mineral soil.

A forest canopy has three main, indirect effects on soil temperature:

a) it intercepts solar radiation above the forest floor, and conversely, it retards soil heat loss to the atmosphere.

b) it intercepts precipitation.

c) it provides a litter or humus layer above the mineral soil.

The effect of a) is to reduce the seasonal and diurnal ranges of air and soil temperatures and to retard snow-melt and ground thaw. The importance of leaf fall and litter has already been discussed. Interception of precipitation, especially snow, by the canopy is related to the morphology and slope of the branches that form the crowns and hence, depend on the tree species. Crown closure, length and width of crowns are all
factors that influence the interception of precipitation. Studies in the Adirondacks (Lull and Rushmore, 1961) have shown that the feathery, flexible, and downward-sloping branches of hemlock form a poor platform for snow accumulation in contrast to balsam fir with its stiff branchlets which has the best platform for snow support. The mean difference in snow carried was nearly one inch less for hemlock than for balsam fir. Further study will be needed to decide whether this intercepted snow eventually reaches the ground as snow or in the form of water.

Since the size of the crown may be related to the age of the tree, it would be expected that young trees, being smaller, would permit greater snow accumulation on the forest floor. This is not true, however, since even-aged stands of young trees are often so dense that the snow is unable to penetrate their canopies to a large extent. The effect of density of young trees on snowfall and frost frequency is well illustrated by Striffler's (1959) study in northern Lower Michigan. It was found that red pine plantations with closed crowns accumulated less snow on the ground and froze to greater depths than any of the other forest conditions studied. Frost encountered in this stand was primarily of the impermeable concrete form, and both snow and frost persisted longer in this closed pine plantation than in the other forest types.

The different stages through which land passes under forest management may greatly influence soil temperature, with subsequent effects on the hydrology of the area. Thus planting or seeding a bare or cut-over area may eventually benefit the site because the new cover will modify the effects of low temperatures by reducing depth of concrete frost occurrence, and preventing accelerated run-off in the spring. The net
effect, in time, will be a reduced run-off rate.

The species planted will also influence the temperature characteristics of the soil. It has been shown that replacement of an aspen-brush cover by a red pine plantation will result in an increase in frost penetration and occurrence (Bay, 1960). If forests are planted for hydrological reasons, it is more desirable to produce a mixed stand of hardwood and coniferous species than a pure stand of either type (Weitzman and Bay, 1963; Bay, 1958).

Thinning, besides reducing competition and improving tree growth rates, also modifies the soil temperature. The canopy becomes temporarily less dense, permitting more solar radiation and precipitation to reach the forest floor. Thinning of coniferous and hardwood stands may result in the reduction of depth, occurrence and duration of frost (Weitzman and Bay, 1963).

The silvicultural system adopted will also influence soil temperature. Cutting may be partial or complete, the practice depending on terrain and species involved. Patch logging, strip clear-cutting, and the seed tree method all involve exposing relatively large areas of soil to precipitation and insolation and the effects of extreme climatic conditions. Partial cutting systems such as the selection and shelterwood systems may not produce equally pronounced effects on soil temperature, although a greater insulating snow layer may result owing to the decrease in precipitation interception.

Protection of the forest, especially from insects and fire, has an important bearing on soil temperature. Defoliators and bark beetles, in epidemic proportions, may cause the destruction of whole stands of
timber, coniferous forests being rendered leafless. In the winter, there will be little interception of snow, but there will no longer be a continuous production of humus to act as a protective insulating layer above the mineral soil. Fire may remove thousands of acres of forest cover consequently changing the hydrological characteristics of the region quite drastically. Forest protection, therefore, is essential for soil and water conservation as well as timber preservation.

Site Descriptions

For comparative purposes, soil temperature measurements have been taken on six sites within the Kootenay Creek watershed basin. Three distinct forest stands are included: a) uncut spruce-fir forest (Plot nos. C1 and C4), b) partially-logged spruce-fir forest (C2 and C5), and c) dense lodgepole pine (Pinus contorta var. latifolia Engelm.) forest (C3 and C6) which followed a fire in 1936. The number, aspect, and cover type of each plot are shown in Table 1, the locations within the basin in Fig. 1.

Uncut spruce-fir

The north-facing site (C1) is located at approximately 5900 ft. M.S.L. and is covered, for the most part, by Engelmann spruce and subalpine fir. Some old lodgepole pine are also present. An indication of stand density is given in Fig. 2 and Table 2. Table 3 shows measurements of 5 dominant and codominant trees on all sites. Ground cover on the site is dominated by feathermoss which covers 60% of the study area. Vaccinium sp. accounts for another 35%, and the remaining available ground space is
Table 1. Narnot Creek soil temperature plots  
(Celsius units)

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Forest Cover</th>
<th>Aspect</th>
<th>Date of Installation</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Uncut spruce-fir</td>
<td>North</td>
<td>Nov. 1963</td>
</tr>
<tr>
<td>C2</td>
<td>Partially-cut spruce-fir</td>
<td>North</td>
<td>Nov. 1963</td>
</tr>
<tr>
<td>C3</td>
<td>Lodgepole pine</td>
<td>Northeast</td>
<td>Nov. 1963</td>
</tr>
<tr>
<td>C4</td>
<td>Uncut spruce-fir</td>
<td>South</td>
<td>Nov. 1963</td>
</tr>
<tr>
<td>C5</td>
<td>Partially-cut spruce-fir</td>
<td>South</td>
<td>July 1964</td>
</tr>
<tr>
<td>C6</td>
<td>Lodgepole pine</td>
<td>South</td>
<td>July 1964</td>
</tr>
</tbody>
</table>

* A thermistor unit was later installed on the north-facing aspect of the lodgepole pine stand. This location will be referred to as T2.

---

Fig. 2. North-facing uncut spruce-fir (C1)
<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Site</th>
<th>Trees 4.0 in dbh and greater</th>
<th>Live stems per acre</th>
<th>Trees below 4.5 ft. in height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>spruce</td>
<td>fir</td>
<td>pine</td>
</tr>
<tr>
<td>C1</td>
<td>North-facing uncut spruce-fir</td>
<td>240</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>Total 4.0</td>
<td>440</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>in. dbh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>South-facing uncut spruce-fir</td>
<td>360</td>
<td>220</td>
<td>n11</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>640</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>North-facing partially-cut spruce-fir</td>
<td>260</td>
<td>40</td>
<td>n11</td>
</tr>
<tr>
<td></td>
<td>Total 4.5</td>
<td>220</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C5</td>
<td>South-facing partially-cut spruce-fir</td>
<td>200</td>
<td>40</td>
<td>n11</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>Northeast-facing dense lodgepole pine</td>
<td>n11</td>
<td>n11</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C6</td>
<td>South-facing dense lodgepole pine</td>
<td>n11</td>
<td>n11</td>
<td>n11</td>
</tr>
<tr>
<td></td>
<td>Total 4.5</td>
<td>10,600</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>in. dbh</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Species distribution, on the basis of dbh and height, for the 6 sites
Table 3. Average values for measurements of 5 dominant or co-dominant trees on each of the 6 sites

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Site</th>
<th>Species measured</th>
<th>Dmb (in)</th>
<th>Height (feet)</th>
<th>Age (years)</th>
<th>Crown length (feet)</th>
<th>Crown width (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>North-facing</td>
<td>Spruce</td>
<td>9.3</td>
<td>54</td>
<td>196</td>
<td>35</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>uncut spruce-fir</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C4</td>
<td>South-facing</td>
<td>Spruce and fir</td>
<td>6.7</td>
<td>57</td>
<td>191</td>
<td>34</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>uncut spruce-fir</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C2</td>
<td>North-facing</td>
<td>Spruce, fir and</td>
<td>9.6</td>
<td>58</td>
<td>164</td>
<td>30</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>partially-cut</td>
<td>pine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>spruce-fir</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C5</td>
<td>South-facing</td>
<td>Spruce *</td>
<td>10.2</td>
<td>55</td>
<td>191</td>
<td>30</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>partially-cut</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>spruce-fir</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C3</td>
<td>North-facing</td>
<td>Lodgepole pine</td>
<td>3.7</td>
<td>21</td>
<td>23</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>dense lodgepole pine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C6</td>
<td>South-facing</td>
<td>Lodgepole pine</td>
<td>3.2</td>
<td>19</td>
<td>26</td>
<td>14</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>dense lodgepole pine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* 4 individuals only measured

covered by hunchberry, grouseberry, lichen and club mosses. A study of the soil profile description (Appendix II) reveals a litter/humus layer 13 cm. thick and the soil, derived from colluvial till, has a texture ranging from gravelly silt loam to loamy, very fine sand. It can be described as a well drained site with a 7° slope, and is classified as a degraded acid brown wooded soil.

1Botanical names of lesser vegetation are given in Appendix I.
The south-facing uncut spruce-fir site (C4) is located at approximately the same elevation as the corresponding north-facing site. Table 2 shows that C4 is less dense than C1 although there is a greater percentage of larger trees on C4. Table 3 shows that the dominants and co-dominants on this site are not notably different from those on site C1. One noticeable feature of the south-facing site is that regeneration consists entirely of alpine fir. Feathermoss covers 75% of the ground in the plot and bunchberry, twinflower, grouseberry, and lichen occupy the remaining area. Windfalls are also prevalent both in and around the plot (Fig. 3). Appendix V indicates that the soil in this plot is covered

---

**Fig. 3. South-facing uncut spruce-fir (C4)**
with a 5 cm. thick litter/humus layer and has a texture that ranges from
gravelly, silt loam to clay loam. The soil is derived from colluvial till,
and is classified as an orthic grey wooded soil. This site is well drained
and has a 30° slope.

**Partially-cut spruce-fir**

The partially-cut, north-facing spruce-fir site (C2) is situated
at an elevation of about 5900 ft. M.S.L. The area was selectively logged
after the 1935 fire. Reference to Table 2 shows that the stand density is
little over half that of the north-facing uncut spruce-fir (C1). Table 3
shows that the dominants and co-dominants are larger on the partially-cut
site (C2). Fig. 4 shows the open nature of this stand.

**Fig. 4. North-facing partially-cut spruce-fir (C2)**

(Note instrumentation location in centre photo)
again the dominant ground cover and covers 50% of the plot. The next most common ground vegetation is *Vaccinium* sp. which covers 25% of the plot.

Five percent of the forest floor is covered with leaf litter and rotten wood. The remainder is covered with twinberry, grouseberry, bunchberry and *Astilbe* sp. Ground cover conditions are shown in Fig. 4. The soil of this site (Appendix III) has a texture ranging from gravelly, very fine sandy loam to clay-loam-clay. Well drained, it has a slope of 10°, and is classified as a brunisolic gray wood soil.

The south-facing partially-cut spruce-fir site (C5) is located at about 5350 ft. M.S.L. The stand density (Table 2) is similar to that of the north-facing partially-cut spruce-fir site. These sites have approximately the same number of trees equal to or greater than 4.0 in. dbh. The south-facing stand is shown in Fig. 5. Ground cover is variable on this

Fig. 5. **South-facing partially-cut spruce-fir (C5)**
Fig. 6. Northeast-facing lodgepole pine (C3)

Fig. 7. South-facing lodgepole pine (C6)
site - more so than on the other sites, with feather moss occupying 50% of
the plot ground surface. Ten percent of the plot is devoid of vegetation.
Grass covers 2% of the plot and ground juniper another 5%. The balance is
occupied by Vaccinium sp., fireweed, buffalo berry and other associated
species. Extensive windfall also characterizes this site. The soil,
derived from colluvial till, is classified as an orthic podzol soil
(Appendix VI). Its texture varies from a loamy very fine sand to a
silt-clay loam. Covered with a litter-humus layer 7 cm. deep, the soil is
moderately well drained and has a slope of 10°.

Lodgepole pine

Both northeast- and south-facing lodgepole pine stands are under
30 years of age and have densities in excess of 20,000 stems per acre
(Tables 2 and 3). The soils of these sites are classified as brunisolic
grey wooded soils.

The northeast-facing stand (C3), located at 5700 ft. M.S.L. has
few trees greater than 4.0 in. dbh (Fig. 6). There is a heavy understory
of spruce regeneration. Twenty-five percent of the plot is either bare
or covered with lichen, and dense clumps of conifer regeneration prevent
invasion by other plants. Pine litter covers large areas within the plot.
Tree stumps and willows are also present together with grass and fireweed
on more open patches. Soil texture varies from a very fine sandy loam to
a clay-loam-clay. The soil is well drained, and has a litter/humus layer
1 cm. thick. Ground slope is 8° (Appendix IV).

The south-facing lodgepole pine plot (C6), located at 5,800 ft.
M.S.L., has the highest number of stems per acre of all the sites under
discussion (Fig. 7). It also has a heavy spruce understory. There are no
stems in the plot greater than 4.0 in. dbh, and there are fewer trees
Table 4. Comparison of soil temperature sites

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>Cover type</th>
<th>Feather moss layer % cover</th>
<th>Herb layer %</th>
<th>Shrub layer %</th>
<th>Litter/ humus depth (cm.)</th>
<th>Slope (degrees)</th>
<th>Soil texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>North-facing uncut spruce-fir</td>
<td>60</td>
<td>5</td>
<td>35</td>
<td>19</td>
<td>7</td>
<td>grvSIL-Lvfls</td>
</tr>
<tr>
<td>C2</td>
<td>North-facing partially-cut spruce-fir</td>
<td>50 *</td>
<td>15</td>
<td>30</td>
<td>not known</td>
<td>10</td>
<td>grvSIL-CL-C</td>
</tr>
<tr>
<td>C3</td>
<td>Northeast-facing lodgepole pine</td>
<td>trace</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>8</td>
<td>vFL-CL-C</td>
</tr>
<tr>
<td>C4</td>
<td>South-facing uncut spruce-fir</td>
<td>75</td>
<td>25</td>
<td>ndl</td>
<td>5</td>
<td>20</td>
<td>SIL(gr)-CL</td>
</tr>
<tr>
<td>C5</td>
<td>South-facing partially-cut spruce-fir</td>
<td>50</td>
<td>25</td>
<td>15</td>
<td>7</td>
<td>10</td>
<td>Lvfls-SIL</td>
</tr>
<tr>
<td>C6</td>
<td>South-facing lodgepole pine</td>
<td>trace</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>13</td>
<td>vFL-CL-C</td>
</tr>
</tbody>
</table>

* Where the total percentage of feather moss, herb and shrub layers is less than 100%, the difference is accounted for by the presence of logs, stumps, litter, dense tree regeneration, and bare patches.
greater than 4.5 ft. in height than there are on the northeast-facing site. Dense clumps of spruce, fir, and pine regeneration occupy 65 to 70% of the site. Twenty-five percent of the plot is devoid of vegetation except for patches of grass, and is covered with pine needles. From 5 to 10% of the area is covered by willow, aspen, feather moss, fireweed, twinflower, and Vaccinium sp.

The soil is derived from colluvial till. Its texture ranges from a very fine sandy loam to clay-loam-clay. The litter/humus layer is only 1 cm. thick. This site is well-drained and has a slope of 13° (Appendix VII).

A comparative summary of plot characteristics is given in Table 4.

Methods

Measurement

Installation procedures and use of temperature measuring units in Harriet Creek Basin have been adequately described by Thompson (1966).

Six sites were selected on Harriet Creek Basin (Fig. 1 and Table 1), in 1969. Instrumentation with Fiberglas soil moisture units (Model 351) described by the California Forest and Range Experimental Station (1950), was completed by July 1964. In addition to the moisture sensor, these units contain thermistors accurate to one degree Fahrenheit. Both temperature and moisture are read on the same read-out instrument,
Beckman ohm meter. One other site was instrumented with YSI\textsuperscript{2} (Model 4003) thermistor units in fall 1965. This instrument reads in degrees Centigrade and is accurate to 0.1° C.

For each installation, a pit 72 inches was dug in each plot. The soil was removed in 1-foot intervals so that it could be replaced in the same position after the sensors were installed.

Ten sensor units were installed in each plot at the soil-humus interface and at the following depths: 3, 6, 12, 18, 24, 36, 48, 60 and 72 inches. Unit number 1 was installed at the soil-humus interface and then in ascending order to number 10 at the 72 inch level. A slot was made in the face of the pit with a knife and the Model 351 units were inserted tightly. The soil was replaced as each unit was installed. YSI thermistors were installed in holes made by a 4-inch spike. Wires from each unit were carried in a conduit to a 10-position switch mounted in an enclosed box on a post 5 feet above ground level (Fig. 4). The switch box is fitted with a plug to receive the connector on the read-out instrument (Modified Wheatstone bridge for YSI units and Ohm meter for soil moisture units).

Readings have been recorded weekly since the units were installed.

Temperature readings are obtained directly in the case of YSI units, but tables and charts are necessary to convert Ohm meter readings to temperature values (Bixm 1969).

Data processing and statistical analysis procedures

A comprehensive statistical analysis was undertaken using data

\textsuperscript{2}Yellow Springs Instrument Co., Yellow Springs, Ohio.
for the 2-year period, August 4, 1964 to July 25, 1966. The purpose of the analysis was to determine the effects of different site and time factors on soil temperatures in Marced Creek Basin.

The factors considered were year, week, aspect, stand, and depth. Three cardinal forest cover types were segregated for comparative purposes. Sites were chosen on both north- and south-facing aspects in the case of uncut spruce-fir and partially-cut spruce-fir, and on north- and south-facing aspects in the case of lodgepole pine. Temperature values from all 10 levels in the soil profile were used for analysis.

Several interactions between different factors were also tested; the pertinent interactions have been listed below:

- aspect and depth
- aspect and stand
- stand and depth
- aspect, stand, and depth
- year and aspect
- year and stand
- year and depth
- year, aspect, and depth
- year, aspect, and stand
- year, stand, and depth
- week and aspect
- week and stand
- week and depth

Factorial design was used to test for significant differences between and among factors. The analysis of variance of factorial design permits the study of the effects of all combinations of the levels of several factors. The significance of these main effects and interactions was assessed from an analysis of variance table and F-test. The total sum of squares was first computed and then the component sum of squares for the main effects, replicates, and interaction were calculated, and subtracted from the total sum of squares to obtain the residual. The
mean square for each factor or interaction was obtained by dividing each component sum of squares by the number of degrees of freedom. Division of the value so obtained, by the residual variance produced the F value required for the test of significance. For this test, the null hypothesis, that the means of the relevant factors and interactions came from the same population, is initially adopted. If this hypothesis is rejected, then the alternative hypothesis of a difference between means is accepted.

A graphical analysis comparing all sites was also carried out using graphical representations of data for a one year period. These graphs are shown in Figs. 8 to 16.

Results and Discussion

Comparison of north-facing and northeast-facing lodgepole pine sites

Because records were available for a longer period of time for the northeast-facing lodgepole pine site (C3) than for the north-facing one (32), it was decided to use data from the former for analysis of variance. The north-facing site is equipped with a rack of YSI (44003) thermistors and not standard Colman units such as are installed on the other six sites. In case it might be possible to consider both sites simultaneously in subsequent analyses, an analysis of variance was carried out to determine if there was any significant difference between soil temperatures under the north-facing lodgepole pine stand and those under the northeast-facing stand. The results of the analysis are shown in
the following table.

Table 5. Analysis of variance for multi-factor experiment comparing north-facing and northeast-facing lodgepole pine sites

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean squares</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week (W)</td>
<td>51</td>
<td>44.104</td>
<td>524.54 * *</td>
</tr>
<tr>
<td>Aspect (A)</td>
<td>1</td>
<td>72.453</td>
<td>84.46 * *</td>
</tr>
<tr>
<td>Depth (D)</td>
<td>9</td>
<td>13.033</td>
<td>15.39 * *</td>
</tr>
<tr>
<td>W x A</td>
<td>50</td>
<td>16.972</td>
<td>19.67 * *</td>
</tr>
<tr>
<td>W x D</td>
<td>459</td>
<td>9.3594</td>
<td>10.09 * *</td>
</tr>
<tr>
<td>A x D</td>
<td>9</td>
<td>5.1146</td>
<td>5.96 * *</td>
</tr>
<tr>
<td>Error</td>
<td>159</td>
<td>0.69785</td>
<td>0.8  * *</td>
</tr>
<tr>
<td>Total</td>
<td>1029</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* * Highly significant (0.01 probability level)

The results show highly significant differences for all the factors and interactions tested. Examination of mean soil temperature values show that the north aspect has a higher mean soil temperature (36.3°F) than the northeast aspect (35.6°F). Furthermore, 70% of the weekly soil temperature means are higher on the north aspect. The north-facing aspect has higher mean temperatures at all depths except for the 60-inch depth.

In subsequent discussion on statistical analysis, the northeast-facing lodgepole pine site will be referred to as a north-facing one in
order to facilitate presentation of descriptions. However, the fact that
the temperatures on the two sites (north- and northeast-facing lodgepole
pine) are significantly different must be kept in mind.

Statistical analysis

The results of the analysis of variance are summarized in the
following table.

Table 6. Analysis of variance for multi-factor experiment

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>Mean square</th>
<th>( F )</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Y) Year</td>
<td>1</td>
<td>4271.1</td>
<td>406.4</td>
<td></td>
</tr>
<tr>
<td>(W/Y) Week/Y</td>
<td>99</td>
<td>962.95</td>
<td>745.96</td>
<td></td>
</tr>
<tr>
<td>(A) Aspect</td>
<td>1</td>
<td>270.64</td>
<td>215.69</td>
<td></td>
</tr>
<tr>
<td>(S) Stand</td>
<td>2</td>
<td>1629.9</td>
<td>1292.60</td>
<td>745.96</td>
</tr>
<tr>
<td>(D) Depth</td>
<td>9</td>
<td>109.51</td>
<td>86.84</td>
<td></td>
</tr>
<tr>
<td>AD</td>
<td>2</td>
<td>627.41</td>
<td>486.03</td>
<td></td>
</tr>
<tr>
<td>AD</td>
<td>9</td>
<td>134.19</td>
<td>103.96</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>18</td>
<td>62.619</td>
<td>50.16</td>
<td></td>
</tr>
<tr>
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* * Highly significant (0.01 probability level)
* Significant (0.05 probability level)
N.S. Not significant
The results show that in nearly all cases, the P ratio is too large to accept the null hypothesis. They indicate significant causes of variation working between factors, and show that one or more of the sample means comes from different populations. The interaction between year, stand, and depth is not significantly different, demonstrating that the pattern of soil temperature at different depths, for different stands does not vary greatly from year to year over the 2-year period of study. This conclusion can be supported by the fact that, although the variation due to time (average annual soil temperature) is significantly different, it is not highly significant.

It is now necessary to refer to group mean values for further analysis. Considering one site factor only in combination with soil temperature the following conclusions can be drawn:

a) the mean soil temperature for the second year \((34.6^\circ F)\) is higher than that of the first \((32.9^\circ F)\).

b) the mean soil temperature for the southerly aspect \((34.0^\circ F)\) is slightly higher than that of the northerly aspect \((33.6^\circ F)\).

c) the highest mean soil temperature \((34.7^\circ F)\) is found under lodgepole pine stands and the lowest \((32.9^\circ F)\) under the uncut spruce-fir cover.

d) depth of soil contributes to variation in soil temperature, the highest mean value \((34.6^\circ F)\) being obtained at the soil-immisc interface, and the second highest \((34.1^\circ F)\) at depth of 12 inches. In contrast, the lowest mean temperature \((33^\circ F)\) is found at a depth of three inches. At a depth of 18 inches and below, the means are fairly uniform.
Stand Interactions

Highest mean soil temperatures prevail on the southerly aspect at nearly all soil depths in the case of lodgepole pine and uncut spruce-fir stands (Appendix VIII, sheet 3). However, except at depths of 3 inches and 49 inches, mean soil temperatures under partially-cut spruce-fir are highest on the north aspect. On this aspect, partially-cut spruce-fir also has the highest mean soil temperature (34.1°F) of the three stands (sheet 2). The coolest soil on both aspects is found under uncut spruce-fir, at nearly all depths (sheet 2). The most significant differences in soil temperature with respect to aspect occur in the surface layers of the soil down to about 3 or 4 inches (sheet 2).

These trends apply to both years under study, but the northeast-facing lodgepole pine has a higher mean soil temperature (35.4°F) than the partially-cut spruce-fir on the north aspect (34.9°F) for the second year. The mean soil temperatures for all depths were higher in the second year than in the first (sheet 3).

On lodgepole pine sites, the highest mean soil temperatures occur at the soil surface, and the lowest at depths of 13 inches and 26 inches (sheet 3). Soils under uncut spruce-fir are characterized by relatively high temperatures at a depth of 72 inches (sheet 3). The highest mean soil temperature for partially-cut spruce-fir occurs at a depth of 12 inches (sheet 3). During the first year, mean soil temperatures in the surface layer under this stand were among the lowest of the 10 depths, but the mean temperature at the soil-humus interface was the second

3 All subsequent references to sheet nos. apply to the paging of Appendix VIII.
highest during the second year (sheet 3). At depths of 12 inches, highest
temperatures were found under partially-cut spruce-fir (sheet 3).

Throughout the year, some fairly definite patterns can be
recognized. During the summer, lodgepole pine has the highest mean soil
temperature and uncut spruce-fir the lowest (sheets 5-7). This trend
continues until early November. In 1965, this sequence prevailed from
February 23 to April 13, in addition to the succeeding summer and fall.
The same sequence was also apparent between February 6 and July 25, 1966.
It can be inferred from these observations that high summer temperatures
and temperature time lag produce their greatest effect in the lodgepole
pine stands. In winter and spring less definite patterns are observed.
During the period November 12, 1964, and February 16, 1965, soils under
partially-cut spruce-fir registered the highest mean temperatures; in the
same period lodgepole pine recorded the lowest mean temperatures (sheet 6).
This effect could be the result of greater snow accumulation on the
partially-cut spruce-fir site.

Three periods of fluctuation are recorded (sheets 6-7). The
first period is between April 20, 1965 and May 24, 1965 when no definite
pattern is distinguishable. The second period, between November 15, 1964
and February 1, 1966, has a general trend towards highest mean soil
temperatures under partially-cut spruce-fir and lowest under uncut spruce-
fir. This same trend is followed in the third period of fluctuation between

Aspects Interactions

The highest mean soil temperatures for both years occur on the
southerly aspect (sheet 3). On the basis of mean values, aspect has little
effect on soil temperature at 6 inches and below (sheet 2), although at a depth of 48 inches, the mean temperature on the south aspect is 1°F. higher than that of the corresponding depth on the north aspect. Mean temperature values are higher on the southern aspects down to a depth of 18 inches. Beyond this depth no particular bias is apparent. The most noticeable differences in mean soil temperature values occur in the surface layers down to a depth of 3 inches. The soil surface temperatures on the south aspect are about 2°F higher, on the average than the mean soil surface temperatures of the north aspect. At depths of 6 inches and below the soil temperature means of the north aspect and their southern counterparts are almost equal. On the north aspect, the highest mean soil temperature occurred at depths of 12 inches and below. On the south aspects, however, highest values were found at the surface.

Results (sheet 3) indicate that there is little difference between the soil temperature means of each aspect in either year, but there is a definite tendency towards higher weekly mean soil temperatures on the southerly aspects during the summer of each year, from early May to the end of July (sheets 4-5). Between the beginning of August, 1964 (limit of data) and the end of the same year, mean weekly soil temperatures also tended to be higher on the south aspect. Since the highest mean value fluctuated between north and south aspects during the other periods no definite pattern was established for those other intervals.

**Depth interactions**

The mean soil temperatures for the second year were higher at all depths than those of the first year (sheet 3). Examination of the data (sheets 7-11) shows that a time lag occurs before the surface
conditions exert their greatest effect on the temperature at the lower depths. For example, the highest mean soil temperature was recorded at the surface on August 2, 1965. The highest mean temperature at depths of 60 inches and 72 inches was not recorded until September 20, 1965. On March 30, 1965, lowest mean temperatures were recorded at depths between 3 inches and 24 inches. Lowest mean temperatures at 36 inches and below were not recorded until April 26 of the same year.

Temperature inversion occurs twice a year, in spring and autumn. In spring, temperature inversion is preceded by nearly uniform average temperatures throughout the soil profile. Inversions occurred on September 8, 1964 and on August 30, 1965. However, these inversions were only temporary; more stable inversions persisted on and after October 22, 1964 and on September 13, 1965 respectively. These are fall inversions, when the soil temperature increases with depth. Nearly uniform average temperatures through the soil profile were obtained on May 3, 1965 and April 25, 1966. These were followed by temperature inversions on May 17, 1965 and May 24, 1966 respectively. These spring inversions are characterized by higher surface soil temperatures and lower temperatures in the soil below. The lowest average temperatures at all depths occurred on February 28, 1966. Lower soil temperatures were recorded on other occasions but these minima did not occur at all depths at the same time. Except for a few weeks in summer, the average soil temperature at the 3-inch depth is nearly always lower than that of the surface or 6-inch depth.

The following table shows the mean maximum and minimum soil temperatures at different depths in the soil profile for each of two years.
The maximum range for each depth is also indicated.

Table 7. Mean maximum and minimum soil temperatures for 6 sites, 10 depths and 2 years

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</thead>
<tbody>
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<tr>
<td>72</td>
<td>39.0</td>
<td>29.0</td>
</tr>
</tbody>
</table>

The table shows that the annual range gets progressively smaller with increasing depth. This is the case for both years. The maximum range for all sites, at all depths for the two year period is 25.9°F.

Graphical analysis

In order to show the annual march of soil temperature at different depths, data are presented in the form of 9 three-dimensional graphs. They are based on a technique used by Hise (1942) and cover a one year
period from August 4, 1964 to July 26, 1965. Individual mid-month values are plotted as vertical profiles.

The graphs can be read by dropping a perpendicular through the intersection of the mid-monthly plane and the top left hand edge of the framework. A rule measuring tenths of inches is then placed so that the 6-inch graduation lies over the 60°F. perpendicular axis. Soil temperatures at any depth can then be read directly at any point to the right of the perpendicular.

Scrutiny of the data show that the trends indicated in the graphs are approximately the same each year. This is confirmed in one respect by the statistical analysis where the year-stand-depth interaction was not significantly different. Comparisons are made for the following pairs of sites:

1) north- and south-facing uncut spruce-fir;
2) north- and south-facing partially-cut spruce-fir;
3) northeast- and south-facing lodgepole pine;
4) north-facing uncut and north-facing partially-cut spruce-fir;
5) south-facing uncut and south-facing partially-cut spruce-fir;
6) north-facing uncut spruce-fir and northeast-facing lodgepole pine;
7) south-facing uncut spruce-fir and south-facing lodgepole pine;
8) north-facing partially-cut spruce-fir and northeast-facing lodgepole pine;
9) south-facing partially-cut spruce-fir and south-facing Lodgepole pine.

1. **North- and south-facing uncut spruce-fir (Fig. 8)**

From mid-August until mid-November, the south aspect has higher
temperatures at all depths. From mid-November until after the following
May, the soil temperatures on the south aspect are lower at all depths
below the 6-inch level. These effects can probably be attributed to a
less dense stand on the south-facing aspect and a deeper insulating humus/
litter layer (13 cm.) on the north-facing aspect. The south-facing stand
has a higher percentage of feathermoss than the north-facing stand. Moss
has low thermal conductivity, high moisture capacity, and hygroscopic
capacity. In June, the soil temperatures on the south aspect are higher
again at all depths; the trend continues through the summer.

The fall soil temperature inversion occurs after mid-October on
both aspects. In spring, the soil temperature inversion takes place in
April on the south aspect, and after the middle of May on the north aspect.

Between 3 and 6 inches below the soil surface, both north and
south temperature profiles exhibit distinct "cool spots". These are
indicated by "kinks" in the graph. This area lies within the root zones
of ground plants where there is a continuous uptake of water that maintains
this soil layer at a lower temperature. This contention is supported by
the fact that "kinks" are lacking between the 3- and 6-inch depths under
Lodgepole stands, below which there is little growth of ground cover.
Water retention is also facilitated by a clay-loam layer located at these
depths on the south aspect.

The graph shows that at depths of 36 inches and below, temperature
changes are very slow. On referring to available snow-course records it was found that the aspect that had the deepest snowfall also experienced the highest surface temperatures. More snow accumulated and persisted after April on the south aspect than on the north aspect.

2. **North- and south-facing partially-cut spruce-fir (Fig. 9)**

The south-facing aspect has lower soil temperatures for most of the year down to a depth of 3 or 4 feet. It has higher soil temperatures at the surface in June and July; and also from January to the beginning of May at depths of 3 to 6 feet. Temperature inversion occurs on both sites after mid-October. In the spring, soil temperature inversion occurs on the north-facing site in April and on the south-facing site after the end of May.

The north-facing aspect receives a slightly deeper snow covering than does the south-facing site. The snow disappears from both sites at the same time in spring.

Both north and south aspects have "cool spots" at depths of 3 and 6 inches. These may be the result of water uptake by plants and, in the case of the north-facing aspect, the presence of a water-retaining clay-loam-clay layer at a depth of 10 inches.

It is difficult to account for the higher soil temperatures on the north-facing site since conditions on both north- and south-facing sites are similar. For example, there is little difference between the stand densities of each site; the ground slope and percentage snow covering (19° and 50% respectively) are the same for each site. Soils on both sites are moderately well drained internally, although the north-facing site has slightly better external drainage. Further investigation will be necessary
to determine why soil temperatures are higher on the north-facing aspect than they are on the south-aspect, in the case of partially-cut spruce-fir.

3. Northeast- and south-facing lodgepole pine (Fig. 10)

Soil temperatures on the south-facing aspect are definitely higher than those on the northeast-facing aspect. A few isolated cases occur where temperatures at depths below 2 feet are higher on the north-facing aspect. This situation prevails in the fall. Relatively high soil-surface temperatures occur on both sites in July, August and September.

The fall soil temperature inversion occurs after mid-October for both north- and south-facing aspects. In spring, the second temperature inversion occurs on both aspects during April.

The two aspects have very similar stand structures, ground cover and soil characteristics. In winter, the south-facing slope has a slightly greater snow cover. Snow disappears rapidly from both sites in spring.

It would appear that the south-facing aspect has higher temperatures because it receives a greater amount of insulation and has a slightly steeper slope than the northeast-facing aspect.

It was mentioned earlier that soil temperatures under the north-facing lodgepole pine stand were significantly different from those under the northeast-facing stand. Therefore, since the temperatures under the north-facing stand were higher, it is possible that there will be little difference between these temperatures and those under the south-facing lodgepole pine stand. Time did not allow this analysis to be made.

4. North-facing uncut, and north-facing partially-cut spruce-fir (Fig. 11)

Higher soil temperatures prevail under partially-cut spruce-fir
than occur under the uncut stand. This applies to temperatures at all depths down to 3 feet, throughout the year. During the winter and spring months, soil below 3 feet tends to be warmer under the uncut stand.

A persistent soil temperature inversion is observed under both stands in November, and again after mid-May in the case of the uncut spruce-fir stand. The spring temperature inversion for the partially-cut stand occurs in April. High soil temperatures do not occur on either site. The highest temperatures recorded are 46°F under the partially-cut stand and 43°F under the uncut stand.

Snow records show that there is little difference in snow accumulation under each stand, but snow is depleted sooner in the spring under the partially-cut stand.

The foregoing results indicate that the more open nature of the partially-cut spruce-fir stand permits a greater amount of radiant energy to strike the forest floor, producing higher soil temperatures and more rapid snow melt.

5. **South-facing uncut and south-facing partially-cut spruce-fir (Fig. 12)**

Soil surface temperatures under the uncut spruce-fir are higher than those under the partially-cut stand for every month except December. Subsurface temperatures are also higher under this stand for the months August through November, after which subsurface temperatures become higher under the partially-cut stand until the following May. In June and July, all subsurface temperatures are higher under the uncut spruce-fir. Soil temperature inversions occur under both stands after mid-October, and again in April in the case of uncut spruce-fir. The spring soil temperature inversion under the partially-cut spruce-fir occurs at the end of May.
One would expect to find higher soil temperatures prevailing under the partially-cut spruce-fir stand because of its more open nature. However, the reverse is true. No adequate explanation can be given for this finding although the fact that the uncut spruce-fir site has a ground slope 10° greater than that under the partially-cut stand may be a contributing factor. External drainage is slightly better on the uncut spruce-fir site.

The higher temperatures below the soil surface during winter are probably due to the insulating snow cover. The partially-cut spruce-fir has a slightly higher snow accumulation in winter and a more rapid snow depletion in spring. Both partially-cut and uncut spruce-fir stands have extensive, mossy, ground covers which exert a cooling effect through their water holding properties.

6. **North-facing uncut spruce-fir and northeast-facing lodgepole pine**

(Fig. 13)

From the end of May until the end of October, temperatures are higher at all depths under the lodgepole pine stand. From November to the beginning of February, the uncut spruce-fir stand has the highest soil temperatures at all depths. During the period between February and mid-May, surface temperatures are the same on both sites. The subsurface temperatures are still higher, however, under the spruce-fir stand, except at a depth of 2 feet where there is a definite “cool spot”.

The fall soil temperature inversion occurs about the end of October for both sites. Spring soil temperature inversions occur under lodgepole pine in April and a little later under spruce-fir forest.

It would appear that the closed canopy and the deeper litter/humus layer (together with an extensive featheriness covering) of the uncut
spruce-fir stand is more effective than the dense understory of lodgepole pine in reducing soil cooling. Snow accumulation was only slightly greater on the spruce-fir site, but it persisted longer than it did under lodgepole pine. This fact may explain why the subsurface temperature during the winter period was higher under the uncut spruce-fir forest.

7. South-facing uncut spruce-fir and south-facing lodgepole pine (Fig. 14)

The south-facing lodgepole pine stand has higher soil temperatures at all depths, with a few rare exceptions, throughout the year. The exceptions occur at depths of 3 and 5 feet in late fall and early winter. On these occasions, the soil under the uncut stand has higher temperatures at these depths. The end of December is the only time of the year that the surface temperature under lodgepole pine is lower than that under uncut spruce-fir. In January, the temperature profiles of the two sites are nearly identical. As summer progresses, there is a wide divergence between the temperatures of the uncut and lodgepole pine sites.

Fall soil temperature inversions occur about the end of October for both sites. Spring temperature inversions occur on both sites at the beginning of April.

Snow accumulation was deeper on the pine site, but it persisted longer in the spring under the uncut spruce-fir stand. Lack of sufficient ground cover under lodgepole pine permits the soil to heat up rapidly under the sun's influence. The larger canopy and heavier ground vegetation that covers the soil on the uncut spruce-fir site restrict the amount of solar energy reaching the forest floor, hence the soil is cooler on this site. At the coldest time of the year, a deep snow blanket provides cover for the soil under lodgepole pine.
8. **North-facing partially-cut spruce-fir and northeast-facing lodgepole pine (Fig. 15)**

The soil under partially-cut spruce-fir is warmer at all depths between the end of October and the middle of May, although at the 3-inch depth the lodgepole pine site usually has higher temperatures. During the period between the middle of May and the end of October, the lodgepole pine site has higher soil temperatures, a noticeable difference being observed in June and July, between soil temperatures of the two sites.

The first temperature inversion occurs about the end of October on both sites. The second temperature inversion is observed for both sites in April.

More snowfall and persisted on the partially-cut spruce-fir site than on the pine site. This, together with an abundance of feather-moss protected the spruce-fir site from undue cold. The regeneration under the lodgepole pine overstory does not provide such effective protection for the soil under the lodgepole pine stand.

9. **South-facing partially-cut spruce-fir and south-facing lodgepole pine (Fig. 16)**

The lodgepole pine site has higher soil surface temperatures all through the year. It has the highest soil temperatures at all depths between the end of April and the end of November. During the rest of the year, no definite trends in subsurface soil temperatures are recognized.

The fall soil temperature inversion occurs on both sites at the end of October. In spring, inversion occurs under the lodgepole pine stand about the middle of April. Under the partially-cut spruce-fir, soil temperature inversion occurs at the end of May.
Table 8. General trends of soil temperature as influenced by stand structure and composition, aspect, and other factors.

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</table>
Snowfall was slightly higher on the lodgepole pine site but it persisted longer under the partially-cut spruce-fir stand.

One possible factor that might contribute to the higher temperatures under the lodgepole pine stand is the slightly steeper slope on this site. Another factor might be the abundance of feathermoss on the partially-cut spruce-fir site producing lower temperatures on the partially-cut site.

The general trends of the foregoing results have been tabulated in Table 8 for convenience.

Since the foregoing analyses are based on once-weekly soil temperature readings, the effects of diurnal soil temperature variation have not been taken into account. Usually, highest air temperatures are experienced in the early hours of the afternoon. Climate is the major factor governing soil temperatures, therefore high air temperatures may be followed by peak soil temperatures in the shallow soil layers.

It is expected that higher soil temperatures would be recorded in these layers during the middle of the day than would be recorded in the early hours of the morning or late at night when air temperatures are generally lower.

The diurnal soil temperature range is controlled by insolation, precipitation, cloud cover, wind, presence of snow, vegetation cover, organic matter, and ground slope.
Conclusion

Soil temperatures for six sites on the Marmot Creek watershed basin located in the foothills of Alberta, were analyzed by statistical and graphical methods to determine the effect of stand structure, aspect, soil depth, and time on soil temperature trends.

Three types of stand were considered: uncut spruce-fir, partially-cut spruce-fir, and 25-year old lodgepole pine. Stands on north- and south-facing aspects were compared, except in the case of lodgepole pine, where northeast- and south-facing aspects were used for analyses. Soil temperature was measured at 10 depths, from the soil-humus interface down to a depth of 6 feet. Data for 2 years were used in the statistical analysis (August 4, 1964 to July 25, 1966) and data for one year in graphical analysis (August 4, 1964 to July 25, 1965).

Significant differences were found between all factors and interactions except in the case of the year-stand-depth interaction, which indicated that the annual march of soil temperature under different stands, at various depths, does not change significantly from year to year.

The following paragraphs describe general trends. South-facing lodgepole pine has the highest soil temperatures of all the sites, at most depths throughout the year. Northeast-facing lodgepole pine has higher summer soil temperatures and lower winter soil temperatures than other north-facing sites.

Comparison of the north-facing and south-facing uncut spruce-
fir show lower summer and higher winter soil temperatures on the former site. Comparison of the partially-cut spruce-fir on different aspects reveals higher soil temperatures on the north aspect throughout the year. It is difficult to explain this unexpected result in terms of site factors since stand density, ground slope and ground cover are similar for each site. Further investigation will be needed to find an answer to this problem.

When the north-facing uncut spruce-fir site is compared with the north-facing partially-cut spruce-fir site, soil temperatures are found to be higher under the partially-cut stand. However, on the south-facing slope, the reverse is true. The steeper slope of the south-facing uncut spruce-fir site might be one of the factors that led to this unexpected result.

Soil temperature inversions usually occur at the end of October in the fall, and again in the spring, during April or May. In the former instance, air temperatures govern the time of inversion. However, the spring soil temperature inversion is influenced by the presence of snow as well. This is indicated by the widely different times at which the spring soil temperature inversions occur.

Fluctuations in soil temperature occur mainly in the upper 3 feet of soil, with maximum fluctuations occurring at the soil-humus interface. Below 3 feet, temperature fluctuations are quite small. Graphical analysis shows that several "cool spots" occur, and they are indicated by "kinks" in the soil temperature profile. The most noticeable of these occur at depths between 3 and 6 inches below the soil-humus interface. These "cool spots" might be attributed to the uptake of water by ground vegetation.
keeping these layers in a moist and cool condition.

Soil temperature, influenced as it is by stand structure, aspect, soil depth and time (climate effects) is a useful measure for determining the hydrological characteristics of a watershed basin. It can be used, together with soil moisture content, to determine the degree of frost that might be expected under various climatic conditions. Soil temperature measurements become more useful, however, if they are used in combination with other soil measurements and soil profile descriptions.
Literature Cited


Appendix I. Botanical names of lesser vegetation

Aster sp.
Gorma canadensis L.
Epilobium sp.
Hylcomum splendens (Hedw.) BSG.
Juniperus communis L. var. depressa Pursh
Limnea borealis L.
Lonicera involucrata (Richards) Banke
Isocodon sp.
Feltigera sp.
Fleuroseris schreberi (Brda.) Mitt.
Ranulus tremuloides Michx.
Ptilium crista-castrensis (Hedw.) De Not.
(and associated species)
Salix sp.
Shepherdia canadensis (L.) Nutt.
Vaccinium sp.
Vaccinium scoparium Ledeb.
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Classification - Degraded
Parent Material - Colluvial Till
Lime/Salinity -
Vegetation - Picea, Abies, Mortaniaceae
Drainage - external - well
Position - 7° NE
Slope - 7°
Topography -
Elevation -

Appendix II. Description of soil profile under north-facing uncut spruce-fir site
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Classification - Brumisole Grey Wooded  Vegetation - P. can, Abies, P. menziesii Position - Hill
Parent Material -  Height
Lime/Salinity - N.B. very weak 30 cm ill development.  Drainage - external - Vale Soap Moss Slope - 10° 1 NE

Appendix III. Description of soil profile under north-facing partially-cut spruce-fir site.
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Classification - Brunisolic Grey Wooded
Parent Material - Till
Lime/Salinity -
Vegetation - Pinus Cont.
Drainage - external - well
internal - mod-well
Appendix IV. Description of soil profile under northeast-facing lodgepole pine site
### Soil Profile Description

**Horizon** | **Depth** | **Thickness** | **Boundary** | **Check** | **D(ry)** | **M(oist)** | **Temp.** | **Texture** | **Structure** | **Consistency** | **Reaction** |
---|---|---|---|---|---|---|---|---|---|---|---|
L-H | 0-0 | 25 | D | D | M | | | | | | |
Aa | 0-9 | 25 | D | D | M | | | | | | |
T-Bt | 9-28 | 25 | D | D | M | | | | | | |
T-B texture | 28-49 | 25 | D | D | M | | | | | | |
T-C | 49-100 | 25 | D | D | M | | | | | | |

**Classification:** Lithic Grey Wooded

**Parent Material:** Colluvium/tilt

**Vegetation:** Picea

**Drainage:** external - well

**Lime/Salinity:**

**Position:**

**Slope:** 19.5° SW

**Topography:**

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*Appendix V. Description of soil profile under south-facing uncut spruce-fir site.*
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Classification - Orthic Podzol  
Parent Material - Colluvium/Till  
Vegetation - Picea  
Drainage - external - mod. - well  
Internal - mod. - well  
Position - 5490W  
Slope - 10°  
Topography -

Appendix VI. Description of soil profile under south-facing partially-cut spruce-fir site
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Classification - Brunisolic Grey Wooded  
Parent Material - Colluvium  
Lime/Salinity -  
Vegetation - Pinus Cont.  
Drainage - external - well  
internal - mod. well  
Position - 55°E  
Slope - 13°  
Topography -

Appendix VII. Description of soil profile under south-facing lodgepole pine site.