The Characterization and Estimation of Soil Temperatures in Manitoba

by

John Daniel Brian Krpan

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Arts
in
Department of Geography

Winnipeg, Manitoba, 1982

THE CHARACTERIZATION AND ESTIMATION OF SOIL TEMPERATURES IN MANITOBA

BY

JOHN DANIEL BRIAN KRPAN

A thesis submitted to the Faculty of Graduate Studies of
the University of Manitoba in partial fulfillment of the requirements
of the degree of

MASTER OF ARTS

ACKNOWLEDGEMENTS

Sincere appreciation is extended to my advisor, Dr. C.F. Shaykewich for his assistance and above all for his willingness to help. Special thanks are also extended to the members of my committee, Dr. D. Milton and Mr. Gordon Mills for reviewing the thesis and for offering their valuable suggestions.

Thanks are also due to Mr. Ab Reimer of the Atomic Energy of Canada Limited, for whom I relied upon for consultation, and to Agriculture Canada for their financial support.

Last but not least, a very special thank you to my mother and father for all that they have done.

ABSTRACT

Soil temperatures at the 2.5, 5, 10, 20, 50, 100, and 150 cm soil depths have been recorded for up to ten years throughout Manitoba. A best fitting sine wave (as a function of the time of year) was utilized to represent the data for each depth and each soil site. In general the correlation between observed data and the best fitting curve was very good ($R^2 > 0.80$ in most cases) and correlation coefficients improved with depth.

Based on the best fitting sine waves, mean annual and mean summer soil temperature, frost free days, days above 5 and 15C, and degree days above 5 and 15C were calculated. This data was graphically illustrated with the aid of a computer mapping program (Symap) which plotted isolines connecting points of equal value. The symaps provided a good summary of the distribution of soil temperatures across the province and the change in soil temperature with elevation, latitude, drainage and genetic soil type.

Warmest soil temperatures at all depths occur in fine and coarse textured Chernozemic Black soils in south central Manitoba. Cooler soils at the same latitude (50 degrees north) are associated with Luvisolic and Organic soils in eastern Manitoba, and in elevated regions west of the Manitoba Escarpment. In general, soil temperatures decrease with soil depth and poorly drained soils are cooler throughout the year.

An attempt was made to determine the influence of individual properties (e.g. texture) on soil temperature. This was made difficult by the fact that in only a few instances was it possible to compare soils which differed in only one property. As a result, very few consistent relationships between soil temperature and soil physical properties were observed.

A test of Reimer's model for estimating soil temperature from meteorological measurements was conducted. Unfortunately, insufficient weather information prevented a reliable test of the estimation procedures. Soil temperatures estimated from the model deviated significantly from observed values.

CONTENTS

Appendix

page

LIST OF TABLES

LIST OF FIGURES

Chapter I

INTRODUCTION

Soil temperature is very important to many agricultural and engineering applications since it (a) influences the rate of biological and chemical activity within the soil, and therefore facilitates higher crop yields, (b) affects maintenance costs for roads and buildings subjected to frost heaving, and (c) is diagnostic for the optimum placement of subsurface cable and piping systems.

A majority of the energy which heats the soil is received from the sun in the form of short wave radiation. The transfer of the radiant energy from the sun to the soil and back to the atmosphere is governed by the soil's physical properties, vegetation cover, soil water content, and potential gradients. Geographical location (e.g. longditude or elevation), and the seasonal or diurnal variation of soil temperature are also key factors in the energy budget of a soil. Therefore, the determination of the effects of individual soil properties on soil temperature provides valuable information for the delineation and classification of soil climatic zones. In addition, the calculation of frost free days or degree days above critical soil temperatures (e.g. approximately 5C for the germination and growth of rye) provides insight as to the suitability of a given soil to various agricultural crops.

Despite its numerous applications, relatively few soil temperature data are available in Canada. Since atmospheric measurements are much more common, scientists have strived to estimate soil temperature from meteorological data. The testing of these estimation procedures is often complicated by a lack of observed data.

In order to deal with these two aspects of soil temperature, the major objectives of this study were (a) to determine soil temperature characteristics across a wide variety of soil conditions at seven soil depths in Manitoba, (b) to establish the effect of soil physical properties and geographical location on soil temperature, and (c) to test Reimer's model which constitutes a set of procedures to estimate soil temperatures from meteorological measurements.

Chapter II

LITERATURE REVIEW

2.1 INTRODUCTION

The initial input of radiant energy to a soil occurs at the earth's surface. The quality and quantity of radiant heat which penetrates the earth's surface is dependent on geographical location, slope, aspect, soil color, and surface vegetation. Subsequent heat transfer to lower soil depths is a function of the soil's physical properties, water content, and potential gradients. The practical application of soil temperature data and subsurface heat transfer is enhanced by models which are utilized to estimate soil temperature. Therefore, the present literature review summarizes pertinent literature concerning (a) the energy budget near the earth's surface, (b) factors affecting soil temperature (e.g. the transport of heat below the surface by conduction, and liquid and vapour transport), and (c) various approaches to soil temperature modeling.

2.2 SIGNIFICANCE OF SOIL TEMPERATURE

2.2.1 Agricultural Applications

In terms of agricultural productivity, soil temperature is an extremely important factor. In fact, in some cases it may be ecologically more important than air temperature. For example, Oak trees can withstand air temperatures as low as -25C, but soil temperatures less than -13 to -16C may be fatal (Chang, 1968).

Soil temperature influences various biological and chemical processes such as organic matter decomposition, nitrogen production, nutrient uptake, and the growth and emergence of seedlings. These processes occur near an optimum soil temperature above and below which the rate of reactions decrease.

Mack (1973) observed that as soil temperatures deviated from the optimum value, the vine weight of pea plants decreased significantly. However, as soil temperatures increased to an optimum level, the concentration of phosphorous (P) and potassium (K) increased in the plant's top growth. Overall yield decreased once soil temperatures exceeded 21C.

MacLean and Donovan (1973) reported decreases in hybrid corn production as soil temperature cooled from 16C to 10C. A significantly higher uptake of nitrogen, phosphorous, and potassium occurred in warmer soils. In terms of corn emergence, soil temperature was more influential than seeding depth (Alessi and Power, 1971). More specifically, a high degree of relationship between percent emergence and cumulative degree days above 10C was observed. In addition, only minor soil temperature fluctuations were required for significant changes in crop growth and nutritional status. For example, a 1C change in soil temperature altered growth and nutritional uptake by 40 percent in maize seedlings (Walker, 1969).

Soil temperature has been linked to the nitrogen status of soil in a rather complex manner. In particular, the influence of soil temperature varies depending on the crop type, stage of development, and stage of symbiosis (Vincent, 1965). Numerous experiments were conducted with various nitrogen fixing plants to determine the upper and lower limits of soil temperature for nitrogen production.

Pate (1961) showed that in Medicago tribuloids, total nitrogen fixation was reduced by as much as 50 percent when soil temperature was increased from 24C to 30C. However, in soyabeans, growth limitations occurred at a much higher temperature. For example, as soil temperature increased from 32.2C to 37.8C, nitrogen fixation and total protein production were significantly reduced (Kuo and Boersma, 1971). In terms of lower thresholds, soyabeans were restricted in growth and nitrogen fixation between 15C - 18C (Weber and Miller, 1972) and nitrogen production in clover was reduced when temperatures cooled to below 14C.

Certain crops were more sensitive to deviations from optimum soil temperature than others. For example, in clover, optimum nitrogen fixation occurred at 22C and small deviations from this value resulted in significantly lower nitrogen production (Gibson, 1961). However, for soyabeans, Jones (1921), Kuo (1971) and Weber (1972) agreed that adequate nitrogen fixation occurred between a much larger temperature interval (18 - 32C).

2.2.2 Engineering Applications of Soil Temperatures

The response of soil to heat, moisture, and ice is important in many engineering applications including road and building construction, and subsurface cable or piping systems. Therefore, an understanding of soil temperature characteristics and patterns of heat flow through various types of soil is a prerequisite for the success of numerous engineering endevours.

In cooler climates road and railroad construction has been plagued by frost heaves formed from the subsurface freezing of soil moisture. The ice crystals, or ice lenses, are commonly a result of cryosuction which induces moisture migration to cooler regions with subsequent ice formation. Laws concerning the simultaneous flow of heat and moisture have been applied to reduce frost heaving near the surface (Penner, 1970). More commonly, soil temperature models based on heat conduction alone have led to predictions of soil thermal regimes (Frivik et al., 1977; Dirksen and Miller, 1966) with subsequent measures to reduce frost damage. For example, engineers have incorporated insulating layers below road bases to eliminate moisture from the freezing zone and thus minimize frost heaving.

Frozen soils also pose problems when man made heat is introduced to a frozen environment. An elevated pipeline will lose heat to the surrounding air and raise the temperature of underlying soil. Similarily, housing complexes built above permafrost suffer structural damage when the heat that they radiate thaws frozen soils. To minimize environmental, industrial, and domestic shortcomings in permafrost regions, researchers have strived to fully understand soil thermal conductivity, temperature profiles, and the depth to which soils thaw during summer (Musselman, 1978; Brown, 1966; Brown, 1970). For example, it has been shown (Mussulman, 1978; Brazel and Outcalt, 1973) that moss or peaty soils placed below an elevated pipeline effectively insulate underlying soil.

In unfrozen soils, soil temperature effects the efficient transmission of fluids, electricity, and heat in underground distribution systems. For example, water pipes must be buried deep enough to prevent freezing, and yet shallow enough to maintain easy accessibility with minimal excavation costs. In terms of electrical cables, current carrying capacity is limited by the maximum allowable electrical insulation temperature. This temperature depends primarily on the rate at which heat generated within the system can be transferred to the surrounding earth or other cooling systems (Abdulhadi and Chato, 1978; Chato and Abdulhadi, 1978). Therefore, cables buried at the coolest soil depth encounter maximum heat loss and thus achieve more efficient electrical conduction.

Subsurface heating or irrigation pipes modify soil temperatures, moisture transport, and ultimately agricultural productivity. Soil heating may increase the growing season but it may also be detrimental to plant growth. For example, it was shown (Slegel and Davis, 1977; Baladi and Ayers,1981) that soil drying around heated pipes adversly effected plant growth. The problem was partially compensated for by utilizing porous heating pipes which secreted moisture into the surrounding soil. However, the most effective solution was to model heat and moisture flow between pipes to determine the optimum positioning of pipes with respect to crop type and rooting depth. Using the latter system, heated soil lost moisture through liquid and vapour flow, but water was returned by capillary action.

2.2.3 Additional Applications of Soil Temperature

In hydrometeorolgical studies, soil temperature data are combined with information concerning heating degree days and precipitation to form flood prediction models for river basins. Soil temperatures contribute to a more complete knowledge of water tables, subsurface lateral flow, and the potential intensity of spring runoff (Wiesner, 1970; Bruce, 1966).

Entomologists take advantage of soil temperature prediction models to control insect populations which hibernate in the soil. It is difficult and inconvenient to monitor subsurface soil temperatures across a wide range of insect domains. However, by utilizing soil temperature prediction models, the time of emergence and therefore successful control of insects was accomplished in a California study (Bonham and Fye, 1970; Fye et al., 1970).

2.3 ENERGY BALANCE

2.3.1 Global Radiation Balance

The revolution and rotation of the earth results in annual and diurnal cycles of solar radiation incident on the earth. The intensity of solar radiation is a function of latitude, time of year, and time of day. Depending on these variables, the angle of incident radiation determines the intensity of solar energy. Vertical rays deliver maximum energy to the earth's surface while the same quantity of oblique radiation is distributed over a large surface area. Therefore, equatorial regions receive large quantities of radiation throughout the entire year while higher latitudes display strong seasonal differences.

The slope and aspect of the earth's surface also influences the amount of radiation absorbed per unit area of ground surface. For example, in winter, a north facing slope with an inclination of 35 degrees or greater receives no direct sunlight (at 32 degrees north latitude). In contrast, south facing slopes are never shaded from the sun's rays and they receive maximum radiation at solar noon (if the ground surface is perpendicular to the incoming radiation).

Since the surface of the earth does not generate its own energy, it depends on solar radiant energy for heat. Geothermal heat from the center of the earth is an insignificant energy supply to the surface since it provides only 1/2000 of the energy received from the sun (Flint and Skinner, 1974). The original input of solar radiation to the earth-atmosphere system is at the top of the atmosphere where energy is received as waves of electromagnetic radiation. Shortwave (S.W.) radiation is the term applied to visible and ultraviolet solar light, while longwave (L.W.) radiation is the term applied to radiant energy loss from the earth's surface (Sellers, 1965).

Once solar radiation enters the atmosphere it is either transmitted, absorbed or reflected. Radiant energy which is reflected or transmitted is lost to the surface on which it was incident, but radiation which is absorbed serves to heat the object which intercepted it. The atmosphere is almost transparent to S.W. radiation and yet it is nearly opaque to terrestrial L.W. radiation. Therefore, S.W. radiation is transmitted through the air to the soil surface, but when the energy is reradiated as L.W. radiation, it is absorbed by atmospheric water vapour particulate matter and CO_2. Owing to the reflection and scattering by the atmosphere, only 50 percent of the radiant energy incident on the top of the atmosphere is absorbed by the surface of the earth.

The surface of the earth loses this absorbed energy (a) via longwave radiation, (b) by latent heat through evaporation processes, and (c) by sensible heat transfer with subsequent distribution by convection. Ninety percent of terrestrial radiation is absorbed by the atmosphere and seventy seven percent of this is reradiated back to the earth (Sellers, 1965).

2.3.2 Energy Exchange Within the Boundary Layer

2.3.2.1 Bare Surfaces

The potential temperature of a soil depends, in part, on the amount of radiant energy it can absorb. Therefore, the temperature of the earth's surface is not uniform since various surfaces have different transmission, absorption and reflection properties. For example, water will transmit radiation to subsurface levels while soil is opaque to the sun's rays.

Soil reflectivity (albedo) depends mainly on water content, particle size, organic matter content, angle of incidence and color. For example, at all wavelengths, albedo decreased as the surface moisture content increased (Bowers and Hanks, 1964). The absorption of solar radiation by soil water is due mainly to internal reflection of light at air-water interfaces (Monteith, 1963). In addition, soils which had organic matter removed through oxidation possessed higher albedos than untreated soils. This was attributed to increased absorption by darker soils which contained more organic matter. For natural occurring soils, Monteith claimed that reflection coefficients ranged from approximately 10 percent, for soils with a high organic matter content, to 30 percent for desert sand (Monteith, 1963). Additional albedo values for a variety of surfaces are included in Table 2.1

A very rapid increase in reflectivity occurs as particle size decreases. For example, as particle size increased from 22 to 2650 microns, 14.6 percent more solar energy was absorbed (Bowers and Hanks, 1964). Increases in radiation absorption by larger particles is due to the greater scattering of radiant energy between soil particles (see Figure 2.1). For similar reasons the albedo of peat soils is very low.

The albedo (and thus the energy balance) of a bare soil can therefore be modified by various tillage and mulching operations. When the surface layers of a soil are tilled, increased aeration provides insulation for subsurface soils. Similarily, hay or straw mulches contain trapped air which insulates underlying soils. The results of Waggoner's (1960) research with various types of mulches are included in Table 2.2.

Angle of incidence and the wavelength of incident radiation also influences the reflection of radiant energy from soils (Gieger, 1950). Larger zenith angles result in higher albedos, and as wavelengths increased from the ultraviolet to the infrared, albedo increased (Tables 2.3 and 2.4).

The radiation budget and energy balance of a bare soil site is summarized by Figure 2.2. The top portion of the illustration (a) depicts the energy balance during daylight hours, while the lower segment of the diagram (b) illustrates energy exchange at night in the absence of S.W. radiation. Non radiative fluxes directed away from a surface are positive. Therefore "+" symbols on the right hand side of equations represent losses of heat from the surface, and a positive value on the left side of the equations depicts an energy gain.

During daylight hours there is a net all wave surplus of energy (since net S.W. exceeds L.W. loss) and soils gradually warm. During the night the reverse is true. Radiation loss from the surface is replenished by heat transported from lower soil depths through conduction. A seasonal imbalance of this energy exchange is responsible for the alternate warming and cooling of soils on an annual basis. For example, in summer the day time storage slightly exceeds nocturnal losses which maintains warm soils. The imbalance is reversed during the winter.

2.3.2.2 Vegetated Surfaces

The addition of vegetation to a bare soil surface complicates the energy exchange of the earth-atmosphere system. Scientists do not agree unanimously upon the energy balance within vegetative canopies. A majority of the controversy revolves around the reflectivity of various vegetated surfaces since albedo fluctuates considerably with moisture, vegetation density, and color. Therefore, each form of vegetation possesses a distinctive reflecting property. Inconsistent measurements from different studies contribute to an even greater range of albedo. For example, the average albedo measured for agricultural crops range from 0.16 (Stanhill et al., 1966) to 0.26 or higher (Monteith, 1959). The variability of albedo for various crops is illustrated in Table 2.5

Table 2.1 : Albedos for the Shortwave Portion of the Electromagnetic Spectrum $(< 4.0\mu)$

Type of Surface	Albedo
Water	
Winter 0 Latitude	6
30 Latitude	9
60 Latitude	21
Summer 0 Latitude	6
30 Latitude	6
60 Latitude	7
Snow (fresh)	75 - 95
Snow (several days old)	40 - 70
Sand (dry)	35 - 45
Sand (wet)	20 - 30
Soil (dark)	5 - 15
Soil (moist,gray)	10 - 20
Soil (dry,gray)	20 - 35
Forest, Deciduous	10 - 20
Forest, Coniferous	5 - 15
Tundra	15 - 20
Crops	15 - 25

(reproduced from Sellers, 1965)

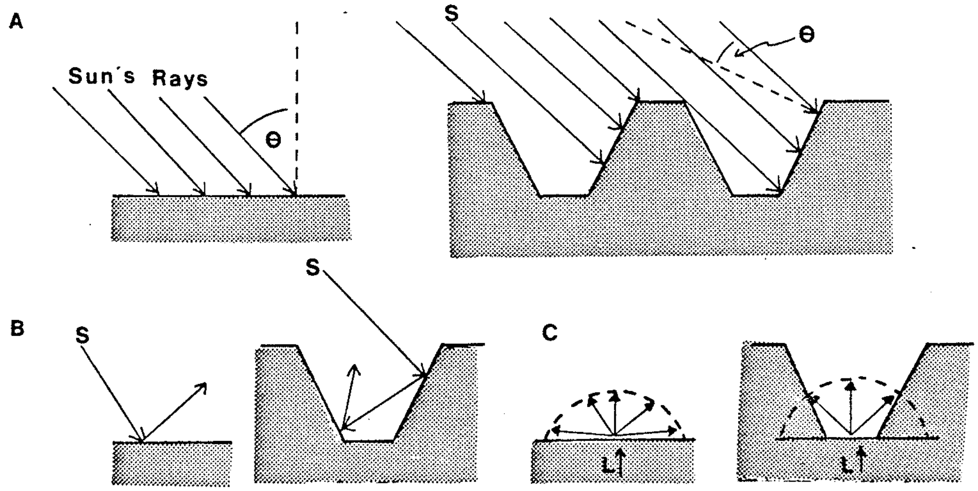


Figure 2.1: Role of Surface Geometry and Radiation Exchange(Comparisons of Convoluted and Horizontal Surfaces) in (a) Receipt of Direct Beam Short-Wave (S) (b) Reflection of S, and (c) Emission of Long-wave (L) Radiation. (Reproduced from Oke, 1978).

Table 2.2: Components of the Radiation and Energy Balance of a Bare Soil and Three Mulch Covered Surfaces. (Reproduced from Oke, 1978).

	Bare Soil	Black Plastic	Paper	Hay
Radiation Budget				
K^*	819	993	631	840
L^*	-177	-282	-199	-233
Q^*	642	711	432	607
Energy Balance				
Q_h	363	635	349	488
Q_e	195	0	42	84
Q_g	84	77	42	35
Albedo	0.24	0.08	0.42	0.22

Radiation Values are for June, 1959 with unit of Measure Equal to W m^{-2}.

K^* = Net short wave
L^* = Net long wave
Q^* = Net all wave radiation
Q_h = Sensible heat flux
Q_e = Latent heat flux
Q_g = Subsurface heat flux

Table 2.3 : The Dependence of the Albedo of Various Surfaces on the Wavelength of Incident Radiation.

Surface	Violet 0.4	Green 0.5	Orange 0.6	Red 0.7	Infrared 0.8
	Wavelength (μ)				
Dry Sand	20	23	29	30	30
Wet Sand	10	12	15	16	19
Pure Ice	44	54	56	48	32
Polluted Ice	24	33	36	31	19
Pure Dry Air	29	13	6	3	2

Table 2.4 : The Infuence of Solar Zenith Angle (Deg.) on the Albedo of Various Surfaces.

Surface	40	50	60	70	80	90
	Solar Zenith Angle (Deg.)					
Dry Sand	35	41	51	63	81	100
Wet Sand	26	28	33	43	60	100
Moving Water	7	10	16	26	47	100

(Tables 2.3 and 2.4 Reproduced from Sellers, 1965)

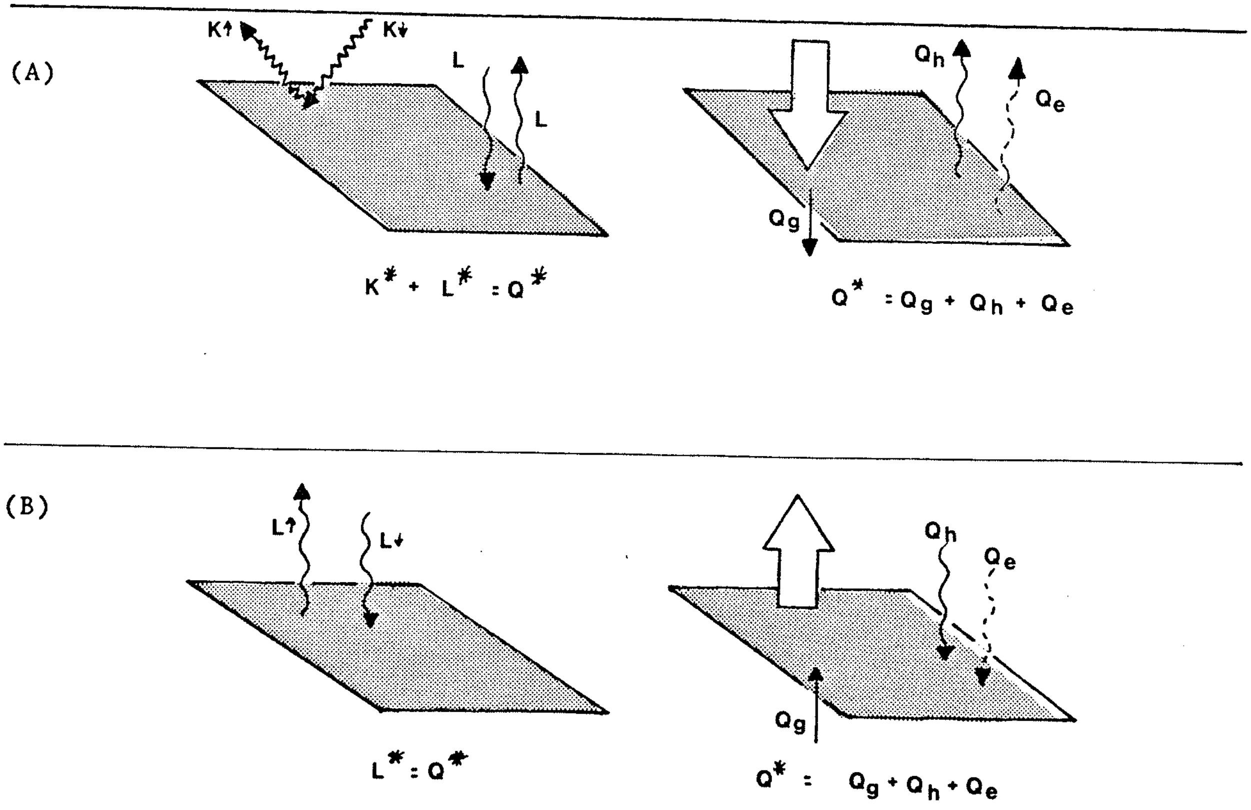


Figure 2.2: Schematic Summary of the Fluxes Involved in the Radiation Budget and Energy Budget of a Bare Surface (A) by Day, and (B) by Night. (Reproduced from Oke, 1978). L↓ and K↓ are incoming radiation, and L↑ and K↑ are reflected or emitted radiation.

Table 2.5: Range of Albedo for Various Crops

Crop	Albedo	Source
rye	0.10 - 0.25	Budyko(1963)
wheat	0.10 - 0.25	Budyko(1963)
cotton	0.20 - 0.25	Budyko(1963)
grass	0.22 - 0.32	Angstrom (1925)
grass,long	0.26	Oke (1978)
meadow	0.24 - 0.26	Monteith (1959)

Less variable albedo values were obtained for forested areas and agricultural crops such as corn and potatoes in a given stage of development (Monteith, 1959; Sellers, 1965; Chang, 1968). Regardless of the percent reflection measured, the albedo of a surface increased almost linearly as the zenith angle increased (Monteith and Szeicz, 1961).

The radiation (S.W. and L.W.) within a vegetative layer is important since it directly affects energy transfer between the soil and the atmosphere. The factors which govern the transfer of energy within plant canopies are summarized as follows (Ross and Nilson, 1975; Legg and Monteith, 1975; Businger, 1975).

1. Incident solar radiation and diffuse radiation from the sky, their spectral composition and angular dependence.
2. Optical properties of leaves, stems and flowers.
3. Foliage area density and the distribution of foliage inclination and orientation.
4. Spatial distribution of vapour pressure, CO_2 concentration and temperature. These factors determine how energy is portioned between convection, transpiration and photosynthesis.

5. Mechanically produced turbulent eddies (and the transport of latent and sensible heat).
6. Exponential decrease in wind speed and diffusivity with increasing height of a canopy.

The interaction of these factors within a vegetative layer is illustrated in Figure 2.3, and the energy balance of such a system may be represented by the equation:

$$Q^* = Q_h + Q_e + \Delta Q_s + \Delta Q_p$$

where ΔQ_s = the net rate of physical heat storage
ΔQ_p = net rate of biochemical heat storage

Q^* = net all wave flux density
Q_e = turbulent latent heat flux density
Q_h = turbulent sensible heat flux density

2.3.3 Energy Balance of Snow Covered Surfaces

Snow cover interupts the flow of energy between the earth and the atmosphere because of its insulating properties. Although snow is capable of transmitting some S.W. radiation, flux decreases exponentially with depth. Very poor heat conductivity and diffusivity, combined with an albedo of 0.80, results in a very low overall energy status for snow packs. Therefore, as little as 0.1 m of fresh snow effectively insulates the soil from temperatures at the snow surface (Oke, 1978, p. 78). For example, Reimer (1978) observed that average winter snowfalls near Pinawa, Manitoba eliminated diurnal temperature variation during winter months. The energy balance of a snow pack depends upon variations in moisture, temperature and snow compaction as illustrated in Figure 2.4.

2.4 HEAT TRANSFER IN SOILS

2.4.1 Introduction

There exist certain phenomenonological laws describing irreversible processes such as the relationship between heat flow and temperature gradients. Although a great deal could be written on the topic, it is practical to mention only a few of the fundamental laws related to the thermodynamics of irreversible processes. Irreversible processes can be expressed by phenomenological relations of the general type (de Groot, 1958);

$$Ji = \sum Lik\ Xk \quad i = 1,2,3...n \qquad (2.2)$$

where Xk are forces
Lik are the so called phenomenological coefficients (i.e.) heat diffusion, and
Ji = flux.

which states that any flow is caused by contributions of all forces such as temperature gradients, concentration gradients or potential gradients. An important concept in irreversible thermodynamics is Onsager's relation which states that the coefficients expressing the effects of the temperature gradient on the moisture flow, and the effects of the soil moisture tension gradient on heat flow are equal. In a very general sense, the thermodynamic theory of an irreversible process can be summarized as the delineation of related fluxes and forces from entropy production and phenomenological equations (such as equation 2.2; de Groot, 1958).

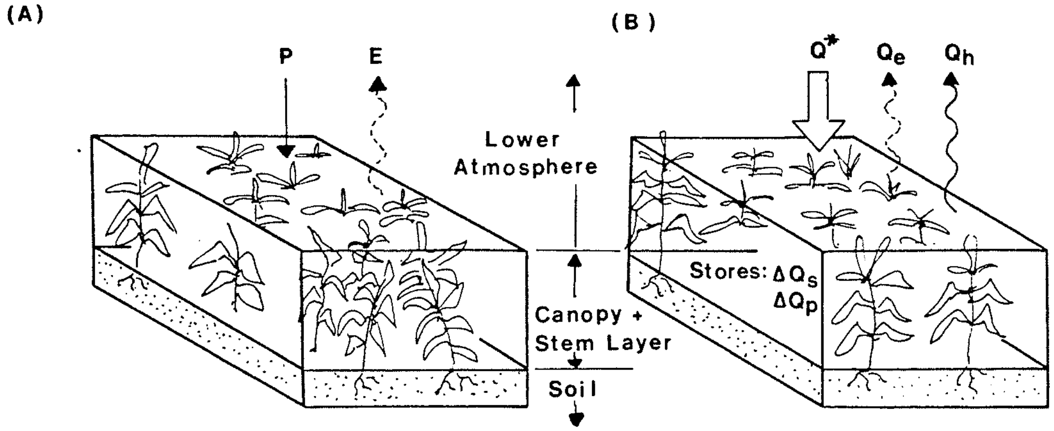


Figure 2.3: Schematic Depiction of Fluxes Involved in the Energy Balance and Water Balance of a Soil-Plant-Air Volume. (P = Precipitation, E = Evapotransperation, Q_s = Net Energy Storage, Q_p = Energy Storage Due to Photosynthesis) (Reproduced from Oke, 1978).

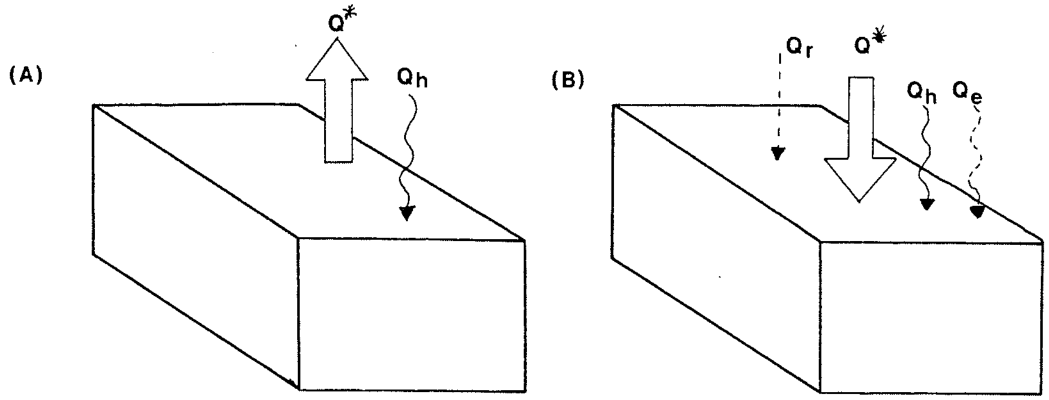


Figure 2.4: Energy Balance for (a) a Frozen Snow Pack, and (b) a Wet or Melting Snow Pack. (Reproduced from Oke, 1978).

2.4.2 Heat Transport by Conduction

Heat flux below the soil surface occurs predominantely by conduction, although the transport of latent heat by vapour diffusion is also important. Although conduction occurs through all soil components, it is most prevelant in the solid and liquid portions (de Vries, 1963; de Vries, 1975; Westcot et al., 1975; Wierenga et al., 1970; Wierenga, 1969; and Erh et al., 1971). In addition, rainfall and irrigation are responsible for the transfer of small quantities of heat (Wierenga, 1971), while radiation contributes marginally to heat flux in soils with large pores (de Vries, 1975).

Heat flux via conduction in a soil is related to its volumetric heat capacity (C_v) and thermal conductivity (K). Thermal diffusivity (D) is a combination of the amount of heat an object can hold and the ease with which it conducts heat ($D = K/C_v$). Substances with high heat capacities have low diffusivities because a greater amount of energy is required to heat them. The thermal conductivities of some common substances are included in Table 2.6.

The heat capacity per unit volume of soil is estimated from the heat capacity of the soil constituents (de Vries, 1963). For example, if V_s, V_w, and V_a denote the volume fractions of solid material, water (or ice) and air respectively, the heat capacity of a given soil is estimated from equation 2.3:

$$C_v = V_s C_s + V_w C_w + V_a C_a \qquad (2.3)$$

The volumetric heat capacity for a moist mineral soil is represented by Equation 2.4, where B.D. is the bulk density, θ is the water content (dry mass fraction), C_w is the specific heat capacity of water, and C_{dry}

is the average specific heat capacity of dry soil constituents (Taylor, 1972).

$$C_v = B.D. \; (C_{dry} + \theta C_w) \qquad (2.4)$$

The heat capacity of dry mineral soil is relatively constant and does not deviate significantly from 0.2 cal/g deg., regardless of the soil type.

The thermal conductivity of a soil is more difficult to estimate. An increase in volumetric water content (θ), causes an increase in K, but K levels off once an optimum water content is reached. Of course soil texture is also related to thermal conductivity since it influences the fractions of air, water and particulate matter in a soil. For example, soils with high bulk densities (sand) yield more area for heat flux than soils with abundant pore space (Brady, 1974). de Vries (1963) devised a method to estimate the thermal conductivity of a soil when the size and thermal conductivity of solid soil constituents was known (Equation 2.5). Here, the soil is considered to consist of water as a continuous medium in which soil particles (and air pockets) are distributed.

$$K = \frac{\theta K_w + \sum W_i \theta_i K + W_a V_a K_a}{\theta + \sum W_i V_i + W_a V_a} \qquad (2.5)$$

where K = thermal conductivity
θ = volumetric water content
V = volume fraction of each soil constituent
= sumation notation
i = type of soil grains
a = air
w = water
W = weight factor of soil constituents.

Summation extends over the different solid constituents and W_i represents the ratio of the average temperature gradient in the soil grains (of type i), and the average temperature gradient in the water. Similarly, W_a represents the same ratio for the gradients in the soil air and soil water (de Vries, 1975). In other words, the soil constituents are characterized by their thermal conductivity and size.

The equation commonly used (Monteith, 1973; Sellers, 1965; de Vries, 1975; Wierenga et al., 1969; Westocot et al., 1974) to describe heat transfer in a one dimensional isotropic medium is:

$$\partial^{C_v} \partial T/\partial t = \partial/\partial z(K \partial T/\partial z) \quad (2.6)$$

where z = depth
K = thermal conductivity
C_v= volumetric heat capacity
T = temperature
t = time

When C_v and K are uniform with depth and constant in time, equation 2.6 is simplified to the diffusion equation:

$$\partial T/\partial t = D \partial^2 T/\partial z^2 \quad (2.7)$$

$$D = K/C_v$$

When employing equation 2.7 it is assumed that variations in soil composition (including water) are more pronounced in the vertical rather than the horizontal direction. Thus a unit cell of soil is hypothesized and separate initial conditions at boundaries within the soil profile are ignored. Van Wijk et al (1963) developed more sophisticated equations to accomodate multi-layered soils in detailed investigations of heat flux. To bring the quantity of energy flow into perspective, the daily cycles of soil heat flux for various months are included in Figure 2.5.

Figure 2.6 graphs imaginary temperature gradients and the corresponding first and second differentials of temperature as a function of depth ($\partial T/\partial z$ and $\partial^2 T/\partial z^2$).

With the boundary conditions (de Vries, 1975; Wierenga, 1969):

$$T(t,o) = T + A_o \ \mathrm{SIN}\ wt \qquad (2.8)$$

$$T(t,\infty) = T$$

the sinusoidal variation of a surface temperature is represented by the equation:

$$T(t,z) = T + A_o e^{-z/d} \sin(wt - z/d) \qquad (2.9)$$

where w = angular frequency
d = damping depth
z = depth
t = time
A_o = amplitude
T = temperature mean

Where d equaled $(2D/w)^2$, the damping depth which can be defined (Cochran et al., 1967) as the measure of the penetration of the diurnal temperature wave into the soil. The diffusivity (D) was determined from (Wierenga, 1969);

$$D = 1/2w(z_2 - z_1)/\Delta t) \qquad (2.10)$$

where Δt represents the time lag of heat flux from z_1 to z_2. T represents the long term mean while A_o is the amplitude of the sine wave, w is the angular frequency, z represents depth and t equals time. These variables and their practical application to subsurface soil temperature estimation is outlined in greater detail in Appendix F.

Coefficients of equation 2.9 are influenced by annual and diurnal cycles of the storage and release of heat (as described by equation 2.1). The amplitude and the depth of penetration of temperature waves into the soil depends on sky conditions and soil texture but it is not influenced significantly by moisture content. For example, in dry soils very little evaporation occurs and thus there is not much energy loss through the latent heat of evaporation. However, this is compensated for by a greater loss of sensible heat. In moist soils the situation is reversed.

de Vries (1975) identified the range of damping depths for the daily temperature variation in sand, loam, and peat soils as 0.080 m to 0.162 m, 0.072 m to 0.119 m, and 0.055 m, respectively. Annual values for these soil types are approximately twenty times the diurnal values.

2.4.3 Heat Transfer by Water

The transport of heat by water in the liquid and vapour phases is the second most important form of heat flux in soils. Water in both phases moves in response to temperature gradients even in the absence of moisture, osmotic, electrical and pressure gradients. For example, experiments conducted in Russia showed that more than 6 cm of soil water moved upward from the soil profile in response to seasonal thermal gradients (Carsel et al., 1969).

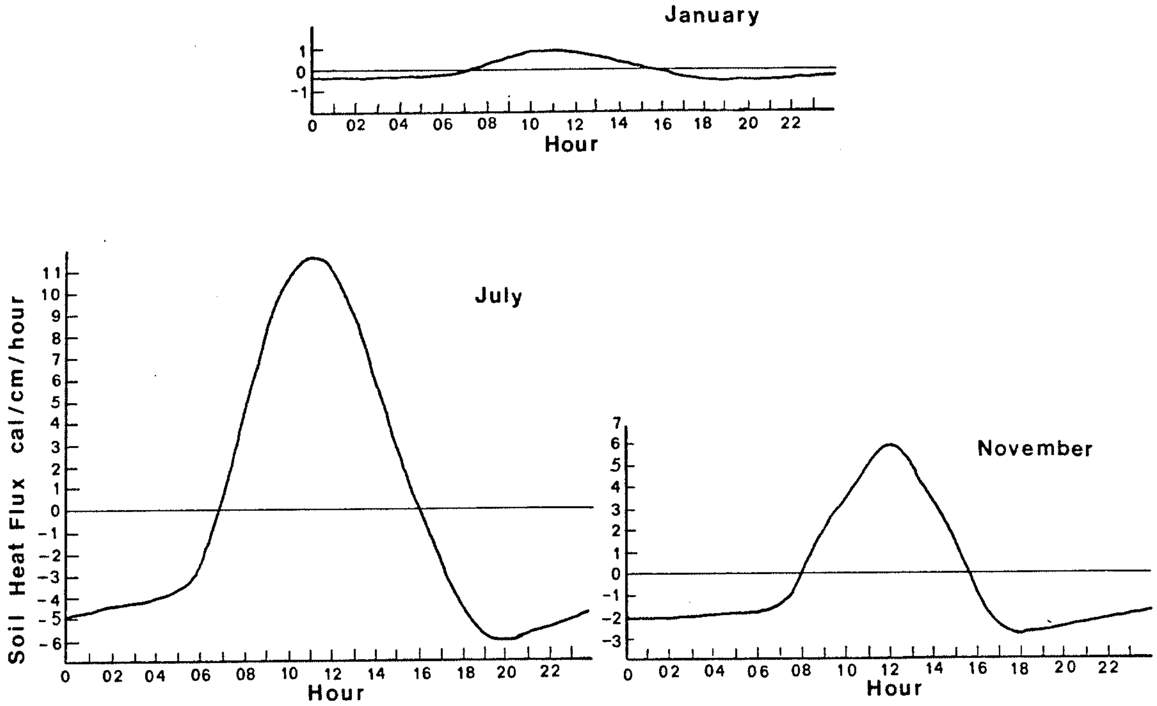


Figure 2.5: Daily Cycle of Heat Flux in Soil for Selected Months of the Year, 1958 (Reproduced from Carson and Moses, 1963)

Table 2.5: Thermal Properties of Soil Minerals, Water, and Air at 10C. (Reproduced from de Vries, 1963).

Substance	K (mcal/cm/sec/C)
Quartz	21
Clay Minerals	7
Organic Matter	0.6
Water	1.37
Ice	5.2
Air	0.06

K = Thermal Conductivity

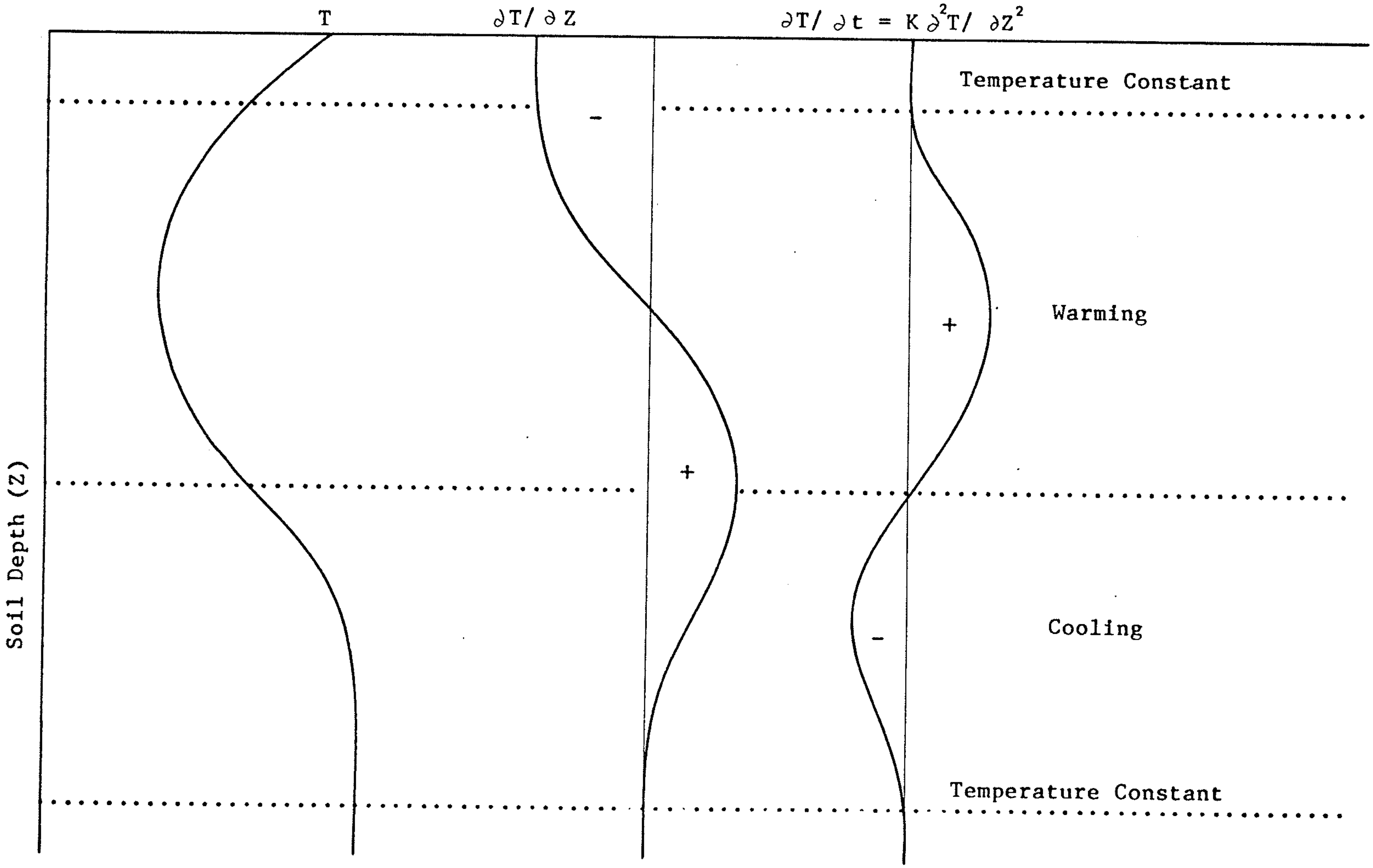


Figure 2.6: Imaginary temperature gradient in soil (left-hand curve), and the corresponding first and second differentials with respect to soil depth.
(Reproduced from Monteith, 1975)

In the vapour phase, moisture transport is primarily a molecular diffusion process where water evaporates in the warmer regions of a soil and condenses in the cooler areas (Cary, 1966; Cary and Taylor, 1962; de Vries, 1966; Taylor and Cavazza, 1954). Although both latent and sensible heat are transported in the vapour phase, the flux of sensible heat is almost negligible (de Vries, 1975; Taylor and Cavazza, 1954).

Liquid flow is usually less important than vapour flow in terms of heat transport. Cary and Taylor (1962b) provided an illustrative example when, from laboratory studies, they calculated that heat flow in the vapour phase was approximately 130 times greater than the quantity of heat transferred by liquid water. However, in certain instances such as intense irrigation, snowmelt, or precipitation, liquid water dramatically influenced soil temperatures. Temperature changes are not necessarily a result of convection but rather the evaporation of water at the soil surface. Therefore, temperature variations are short in duration and most pronounced near the soil surface (Wierenga et al., 1971). The presence of water in soil pores indirectly influences heat flux since it increases the thermal conductivity of pores which subsequently enhances heat transfer by conduction. For example, the thermal conductivity of gas filled pores increased 2 to 20 fold with increasing water content, depending on temperature conditions (de Vries, 1975).

The simultaneous transport of moisture and heat prompted many researchers to model the flow of water vapour through soil (Fritton et al., 1970; Jackson, 1964; Kay and Groenevelt, 1974; Erh et al., 1971; Hanks, 1958; and Cary and Taylor, 1962). Moisture flow is relatively easy to model but vapour flux involves many interrelated variables. For example, vapour diffusion is coupled with evaporation, condensation, the absorption of water molecules on soil surfaces, the transfer of heat from water vapour to soil pore walls (Jackson, 1964), and entropy production (de Groot, 1958). In addition, hysteresis and the influence of soil solutes must be considered (de Vries, 1975).

Before developing equations for any specific case, the rate of change of entropy production is expressed as a function of thermodynamic variables. To determine entropy balance, four fundamental equations are necessary and these involve; (a) the conservation of mass, (b) force (i.e. pressure), (c) energy per unit mass, and (d) Gibbs' equation involving total entropy, energy and chemical potential, and the center of gravity movement. Once entropy production is determined, rate equations (flux of energy and mass) are transformed into expressions which model thermally induced vapour and heat diffusion through the gas phase of a moist soil. Cary and Taylor (1962 a, b) proposed that the following equations represent heat and water flow in the vapour phase:

$$J_v = A_v \Delta \log T + B_v \Delta 1/T \quad (2.11)$$

$$J_e = D_e \Delta \log T + C_e \Delta 1/T \quad (2.12)$$

where J equals flux, T is the absolute temperature, and A, B, C, and D are constants dependent on the system. Subscripts v and e depict water and heat in the gas phase respectively, while "Δt" denotes small differences.

Jackson (1964b) used the equation:

$$q_v = -D_v \partial p / \partial x \quad (2.13)$$

to represent isothermal steady state diffusion of water vapour. Here, q_v is the vapour flux density (g cm^{-2} sec^{-1}), p is the vapour density, x is the distance, and when the equation is applied to a porous medium, D_v is a concentration-dependent vapour diffusion coefficient which includes factors such as porosity, tortuosity, and a coefficient for vapour diffusion in air (i.e. D_v $2p/2\theta$, where θ equaled weight of water per unit volume of porous material).

The influence of gravity on vapour flux was negligible and liquid flow was also unaffected unless the soil was saturated (Jackson, 1964b). Equation 2.13 was modified to account for evaporation, condensation and the transient state, as follows:

$$\partial p/\partial t = \partial/\partial x(D_{v/E(\partial/\partial x)}) + S \qquad (2.14)$$

where E was air filled porosity
S = sorption = (1/E) $(\partial\theta/\partial t)$
x = distance.

Although the equation applies to the transient state, E is assumed to be constant. Equation 2.14 was also utilized to determine liquid flow when p was substituted by θ and a diffusion coefficient for liquid introduced.

With the net diffusion coefficient written as $D_{\theta v}$, the equation most commonly used (Fritton et al., 1970; Jackson, 1964a & b) to represent the total water transfer in a soil system is:

$$\partial\theta/\partial t = \partial/\partial x\ (D_{\theta v}(\partial\theta/\partial x)) \qquad (2.15)$$

Temperature increases due to condensation are insignficant in the long term but they are applicable over short time spans. Diffusivity decreases as water content increases and it does not vary significantly between coarse and fine textured soils (Jackson, 1964a). The soil with the highest diffusivity was medium textured, and therefore pore size distribution rather than texture was the important factor in the vapour flux process.

Hanks (1958) utilized another diffusion equation where the diffusion coefficient was a function of temperature and pressure. However, Hank's equation is not commonly used and it neglects critical variables such as evaporation, condensation, and entropy production.

$$q = -X\ V(DM/RT)(p/p-p_v)(dp_v/dx) \qquad (2.16)$$

where

g = water vapour flow (g cm^{-2} sec^{-1})
D = diffusion coefficients of H_2O vapour in still air
p = total pressure in dynes cm^{-2}
p_v = partial pressure of water vapour
R = Gas constant
T = Temperature (K)
M = Molecular weight of water vapour
x = distance across dry layer
X = Tortuosity factor
V = Volume fraction of air filled voids

2.4.4 Heat Transport in Frozen Soils

In frozen soils moisture and heat flow are more controversial since these phenomena are not yet fully understood. Infiltration and percolation, vapour and liquid transfer in response to thermal gradients, and the lateral flow within the soil pores, are all contemplated as primary mechanisms of moisture transport (de Vries, 1975; Scutz, 1969; Brown, 1966; Willis et al., 1964). There is a general concensus that large volumes of moisture are transported towards and within frozen soils.

For example, Willis et al (1964) recorded a decline of the water table by more than one meter as a result of upward moisture movement in response to a thermal gradient. Studies conducted in areas with very shallow water tables also displayed large fluxes of water to the soil surface (Sartz, 1969). Such observations led to the discovery that lateral flow and percolation of water through the pores of frozen soils occurs on a scale much larger than previously expected.

Due to their thermal properties, frozen soils may propogate themselves as a permafrost region. For example, a dry peat soil has a very low thermal conductivity, but when it is moist or frozen, its heat conduction increases remarkably. Therefore, during the summer a peat soil minimizes heat flux into the soil and in winter it facilitates the conduction of heat away from the ground surface. The net result is that a greater quantity of heat is lost during winter than can be regained throughout the summer.

In terms of modeling, a frozen soil is usually regarded as a two layer system consisting of a frozen and non-frozen portion with individual uniform thermal properties.

2.5 SOIL TEMPERATURE MODELING

2.5.1 Introduction

Literature concerning soil temperature prediction is relatively scarce and many existing models do not account for the damping of temperature with time and depth, or the physical properties of soils such as thermal conductivity. In addition, the conclusions of many macro-scale studies are based on data from surprisingly few recording stations. For example, as few as eight stations distributed across the entire United States were used as the basis for detailed isoline placement (Toy et al., 1978) A more indepth study (Meikle and Treadway, 1979) involved over 100 recording stations from coast to coast in the United States.

The depths at which soil temperatures were recorded varied depending on the study, but temperatures from soils deeper than the 150 cm depth were rarely discussed (Bonham and Fye, 1970; Reimer, 1980; Hasfurther and Burman, 1974; Ouellet, 1973). Soil temperatures were recorded under a variety of surface cover including short grass (Reimer, 1978), wooded areas (Bocock et al., 1977), bare soils (Hadas and Fuchs, 1973), residue and crop cover (Gupta et al., 1981).

Two general types of soil temperature prediction models are identified. Empirical models are based on the statistical relationships between (a) soil temperatures at a given depth, and (b) climatological and soil variables. Physical models are based on the principles of soil heat flux and unlike empirical techniques they are not site specific. In addition, they require surface soil temperatures for the subsequent prediction of subsurface temperatures as a function of time.

2.5.2 Empirical Models

The simplest empirical method of soil temperature prediction involves the addition of several degrees to mean air temperatures. As an example, researchers in the State of New York added 1.8C to the mean annual air temperature to obtain mean annual soil temperature at the 50 cm depth (Vann and Cline, 1975). Differences in elevation were accounted for by adjusting mean annual air temperatures 5.7C for every 300 meters of elevation. Although no statistical technique was employed to measure the accuracy of predicted values, the authors assumed a deviation of 0.9C.

More elaborate empirical models employed the use of regression equations to represent the relationship between climatic variables and observed soil temperatures at a given depth. The number of variables included in regression equations ranged from a single independent variable such as air temperature (Toy et al., 1978) to as many as 21 simple and complex variables (Ouellet, 1973). Climatic parameters commonly utilized in the correlation of soil and air temperatures included maximum and minimum air temperatures, number of rainy days, wind, snowfall, hours of bright sunshine, and certain complex variables such as potential evapotranspiration X rain, or mean maximum air temperature X the number of rainy days (Ouellet, 1973; Bonham and Fry, 1970). On a macroscale, variables were chosen on the basis of their relative availability. Therefore, parameters such as rainfall and sunshine, which are recorded frequently, were more commonly used than variables such as evapotranspiration.

In Ouellet's technique, variables explained 70 to 96 percent of the soil temperature variations, and Bonham and Fye reported a prediction accuracy of 3C for mean annual soil temperature (MAST). In some cases seasonal (Toy et al., 1978) or monthly (Reimer, 1980) regression equations were developed as opposed to a single expression for the entire year.

$$Y = bo + b1X1 + b2X2 + b3X3 \ldots bnXn \quad (2.17)$$

where

Y = dependent variable
X's = independent variables
b's = partial regression coefficient

2.5.3 Physical Models

More recently, physical models based on the principles of heat flow through soil have become prominent (Husfurther and Burman, 1974; Gupta et al., 1981; Bocock et al., 1977; Hadas and Fuchs, 1973; Hanks et al., 1971; Reimer and Shaykewich, 1980). Van Wijk's (1963) and de Vries' (1963) studies of sinusoidal temperature variations in homogenous and layered soils are the basis for most current prediction models. Fouriers series (Equation 2.9) and heat flux equations similar to Equation 2.7 are used to express the steady state flux of heat as a "wave" into the soil as a function of time.

In virtually all physical models the soil temperature at or near the surface is necessary to calculate temperatures at lower depths. Surface soil temperatures can be obtained by several methods. The most direct technique is to measure soil temperature at a depth near the surface (e.g. 1 cm). In the interests of economy and time, some researchers predicted surface soil temperatures from regression equations. This enabled the application of prediction models to a variety of regions as opposed to a specific site. Since air temperature fluctuates considerably on a daily basis, smoothing of climatic data was occasionally used (Hasfurther and Burman, 1974; Reimer and Shaykewich, 1980). Smoothing involved the combination of data from one day before and one day after a given day to obtain the final datum for the date considered.

Once surface soil temperatures have been established, various equations can be adopted to predict subsurface temperatures. Most heat flow models are dependent on the assumption that a soil is homogenous with depth and time. This however, is not strictly true, especially in cultivated soils.

Husfurther and Burman (1974) evaluated the one dimensional heat flow equation:

$$\partial T/\partial t = D(\partial^2 T/\partial z^2) \qquad (2.18)$$

from the boundary condition (Van Wijk, 1963) for periodic temperature variations and this resulted in the equation:

$$T(z,t) = T + \sum_{n=1}^{\infty} TA_{n}\exp((-zn^{1/2})/d)\ \sin(nwt + TOn - zn^{1/2}\ d) \qquad (2.19)$$

which was employed to predict soil temperatures at different depths. Here, TA is the amplitude and TO is a constant selected (by analysis of existing data) to make the term $(nwt + TOn - nz^{1/2}/d)$ greater than 1. Input required for this technique includes maximum and minimum air temperature, and soil temperature on a daily basis.

Both Hasfurther and Burman (1974), and Gupta et al (1981) incorporated a convoluting Fourier series equation which represented the difference between the temperature of the air and soil. The solution to the convoluting sine waves was also the upper boundary condition for the solution of Equation 2.19. With a relationship between soil and air temperatures established by Fourier series, soil temperatures were predicted in advance with as much accuracy as a daily mean air temperature. The predicted values in these studies were usually less than three degrees, and occasionally 5 to 6C from observed values, and accuracy diminished with depth. The observed error was attributed to the fact that the soils were not homogenous. In general, predictions were more accurate when soils were covered with crop residues.

The thermal regimes of soils can also be predicted from field measurements of soil bulk density, water content, and mineral composition (Hadas and Fuchs, 1973). Volumetric heat capacity and thermal conductivity are determined by methods outlined by de Vries (1963). To represent non-steady state heat flow the following equation is utilized:

$$G = -K \partial T/\partial z \qquad (2.20)$$

where G = heat flux density

T = temperature

z = depth.

together with a variation of Equation 2.19 to describe harmonic oscillations of heat content in the soil. Temperature amplitude and thermal conductivity are calculated by elaborate formulas (from de Vries, 1963) too lengthy to describe here. Thermal conductivity was poorly estimated by these methods and the largest discrepancies occurred near the surface. Temperature amplitudes were well predicted in the upper soil layers but accuracy diminished with depth. One would expect the reverse to be true since localized daily temperature events and rapid moisture changes are reduced at lower soil depths. Heat flux density was well predicted.

Chapter III

METHODS AND MATERIALS

3.1 SITES AND DATA COLLECTION

The Manitoba soil survey (MSS) unit initiated site installation and data collection in 1971 throughout Manitoba. Each temperature recording site was equipped with a set of thermocouples inserted at 2.5, 5, 10, 20, 50, 100, and 150 cm soil depths, and selected stations were provided with wells to facilitate the measurement of ground water levels. Thermocouples were inserted vertically and were fastened to thin wooden support stakes by electrical tape. Soil and air temperatures were read from a portable potentiometer which was protected from severe weather by an insulated wooden box. Precipitation, snow cover, and cloud cover were also recorded at each site, but no effort was made to quantify these observations. For example, sky conditions were recorded as clear, partially clear, or overcast, and precipitation was categorized as rainfall or snowfall. The date on which measurements were taken was listed as a day number rather than a calendar day. For example, January 1 was considered to be day 1 and February 4 was labelled day 35. During the winter, measurements were taken approximately once every six weeks. During summer, spring and fall when temperature changes occurred more rapidly, sites where monitored once every four weeks.

Specific sites were chosen to reflect differences in soil temperature as it related to slope, elevation, aspect, latitude, vegetation density, drainage, soil type, soil moisture, surface soil color, and soil texture. Each location was identified by a legal description based on the township and range system.

By 1980 approximately 100 sites were being monitored south of the 57th parallel in Manitoba. The number of years that each site had been in existence ranged from approximately 10 years to less than one year. New sites were continuously added to intensify the network and to replace old sites which, on numerous occasions were destroyed by natural occurring events. For example, in 1980 a set of thermocouples in the Porcupine Hills region were destroyed by fire, and sites near Thompson had been trampled by moose. A majority of the recording stations were installed west of Lake Winnipeg since the area east of the lake is relatively inaccessible. In addition, this eastern area is characterized by extensive peaty soils, areas of deep clay deposits broken by rock outcropping, and thin clay veneers overlying bedrock. Therefore, the installation of soil temperature monitoring sites to this area was not justified. In general, monitored sites were selected from agriculturally productive regions of the province, and vegetated areas representative of the boreal forest of central Manitoba. Certain northern sites were established within, and approaching the permafrost region to enable the characterization of frozen soils.

Since air temperature was not recorded on a daily basis, values for the mean annual air temperature map were obtained from an Environment Canada publication (Canadian Normal Temperatures 1941 - 1970). Information was available for approximately 80 weather stations in Manitoba for the period 1941 - 1970. Air temperature data were required for the correlation of soil temperature and atmospheric measurements.

3.2 CHARACTERIZATION OF SOIL TEMPERATURES

To characterize the data collected up to 1980, a computer program was utilized to calculate meteorological coefficients for 104 recording stations and 7 soil depths simultaneously. Soil temperatures were assumed to be a sine wave function of the time of year for all soil depths. Equation 3.1 was utilized to convert days of the year into angles and to depict annual soil temperatures as a sine wave.

$$\text{Temp} = A + B * \sin(\text{day angle} + \text{alpha}) \qquad (3.1)$$

Day angles were calculated from the equation:

$$N/365 * 2(3.14) \qquad (3.2)$$

where N = the day number.

To evaluate alpha, one must use the equality:

$$\text{Sin}(A + B) = \sin A * \cos B + \sin B * \cos A \qquad (3.3)$$

where A is the day angle, and B is alpha in Equation (3.1). Therefore it is possible to solve for B in the expression, sin(A + B). The first step in calculating B is to find equations of the form:

$$\text{Temp} = C + D \sin A \qquad (3.4)$$

$$\text{Temp} = E + F \cos A \qquad (3.5)$$

Therefore, D = cosB, and F = sinB. Using these two expressions, the value of B (which is equal to alpha in Equation 3.1) was calculated. Having calculated the value of Alpha, a linear regression of temperature on sin(day angle + alpha) was conducted. This yielded the values for A and B in Equation 3.1. Predicted values were then obtained from the derived regression equation and a correlation coefficient was calculated to test the fit between observed and predicted values. Up to ten years of data were combined to obtain a representative sine wave for each soil depth at each site. The best fitting regression equation was then used as the basis for the calculation of the following meteorological variables: mean annual and mean summer soil temperatures ; the dates of occurrence of 0C in the spring and fall; days above 0C; maximum and minimum temperatures and their dates of occurrence; the dates of occurrence of 5C in the spring and fall, days above 5C and degree days above a 5C base; dates of occurrence of 15C in the spring and fall, days above 15C, and degree days above 15C. These values, and the program from which they were derived, are included in Appendices D and B. The values were then submitted to a symap program which graphically displayed the variation of soil temperature at each depth across the province.

3.3 SYMAP ANALYSIS

A Harvard University computer mapping program (1975) was utilized to interpolate the position of isolines for the southern half of Manitoba. Symap interpolation depends on the spatial distribution of data points as determined by nearest neighbour analysis. For example, Equation 3.6 is utilized to calculate the ratio of the distance between observed and expected (or random) data points to determine the distribution pattern of recording stations (Hammond and McCallagh, 1977; Dougenik and Sheehan, 1975).

$$R = D(o)/D(e) \qquad (3.6)$$

where $D(o) = d(i)/N$,
and $D(e) = (A/N)^2/2$.

where R = point distribution coefficient
$D(o)$= mean point distance of the observed distribution
$D(e)$= mean point distance of the expected distribution
$d(i)$= distance from any point to its nearest neighbour
A = the area within the map outline
N = the number of data points.

The calculated value of "R" is then compared to the following critical values;

Type of Distribution	Point Dist. Coefficient
Clustered to random	0.00 - 0.90
Random	0.91 - 1.25
Random to uniform	1.26 - 2.15

A clustered distribution ($R < 0.90$) yields invalid symap interpolation and a uniform ($1.26 < R < 2.15$) distribution is ideal for linear interpolation between data points. Numerous soil temperature sites were omitted from symap analysis since their inclusion resulted in a clustered point distribution. In addition, recording stations with less than five years of data were excluded from symap analysis. For example, if a temperature site with only one summer of data was included as a symap data point, an unrepresentative warm region was portrayed by isolines.

Soil temperature data submitted to the symap program included, (a) seasonal and annual means, (b) degree days above 5 and 15C, and (c) the number of days above 0, 5 and 15C for each depth. After computer maps were obtained for each of the above categories, isolines were transferred to base maps which are included in Appendix C.

3.4 EVALUATION OF REIMER'S MODEL

Obtaining soil temperature measurements from thermocouples is very time consuming and costly. These problems prompted Reimer (1978) to devise a quick and economical set of procedures which permitted the estimation of soil temperatures from meteorological measurements. The study was conducted under forage and zero tillage conditions at the Whiteshell Nuclear Research Establishment near Pinawa, Manitoba.

Linear regression equations were derived to establish the relationship between various meteorological measurements and surface soil temperatures for each month. Reimer discovered that daily maximum and minimum air temperatures and daily hours of bright sunshine were most closely associated with surface soil temperature. For example, Equations 3.7 to 3.10 are the regression equations developed for the months of July, January, June, and August respectively.

$$T = -1.81 + 0.15\,(TMAX) + 0.6\,(TMIN) + 0.15\,(SUN) \qquad (3.7)$$

$$T = -3.14 + 0.20\,(TMAX) + 0.9\,(SUN) \qquad (3.8)$$

$$T = 3.00 + 0.05\,(TMAX) + 0.4\,(TMIN) + 0.2\,(SUN) \qquad (3.9)$$

$$T = -0.26 + 0.15\,(TMAX) + 0.6\,(TMIN) + 0.15\,(SUN) \qquad (3.10)$$

where: TMAX = daily maximum air temperature
TMIN = daily minimum air temperature
SUN = daily hours of bright sunshine
T = the deviation, in degrees C of daily soil temperatures from a monthly mean.

A Fourier series equation, similar to 2.19, was used to represent the annual surface soil temperature wave as a function of the time of year. When applied to surface soil temperatures, the damping and soil depth coefficients were set equal to zero, and one month sections of the resulting curve were utilized to calculate monthly means. Daily mean soil surface temperatures were obtained by using the monthly regression equations to determine the deviation of daily temperatures from a one month section of the Fourier series curve. For example, daily values of "T" were added to the monthly mean to obtain final daily means.

A form of equation 2.19 was also used to calculate daily or annual subsurface soil temperatures.

$$T(z,t) = T + \sum_{n=1}^{\infty} \hat{T}A_n \exp((-zn^{1/2})/d)\ \sin(nwt + T0n - zn^{1/2}/d) \qquad (2.19)$$

For example, for daily estimations, P equaled 24 and A_o equaled the daily mean, and for annual predictions, P equaled 365 while A_o equaled the annual mean. The values of d and w also changed depending on whether one desired an annual or diurnal estimation. In subsurface temperature estimation, z/d was assigned the appropriate soil depth (z) and damping depth (d) values.

To simplify the use of Reimer's Model, the above procedures were incorporated into a FORTRAN/WATFIV computer program. The input required for this program included daily maximum and minimum air temperatures, daily hours of bright sunshine, and the dates on which each measurement was taken. Dates on which measurements were taken were recorded as a day number such that February 2 equaled day number 33. A much more detailed explanation of Reimer's Model and the subsequently derived WATFIV computer program are included in Appendix F.

Reimer's model was tested using data only from those MSS sites which were accompanied by AES stations. These stations included Brandon (62 G 5), Morden (62 G 4), Fort Garry (62 H 4), and Portage La Prairie (62 G 13).

Chapter IV

RESULTS AND DISCUSSION

4.1 CHARACTERIZATION PROGRAM

A computer program (Appendix B) calculated a best fitting sine curve (of soil temperature as a function of the time of the year) for observed data from approximately 100 recording stations at seven different soil depths. A test to determine the degree of association between observed and estimated soil temperatures resulted in an average correlation coefficient (R^2) of 0.90 ($R^2 = 1.0$ denotes a perfect fit). Curves based on insufficient data had substantially lower R^2 values of 0.40 or less, while other sites had R^2 values as high as 0.99. Sites which were represented by curves with a poor correlation coefficient were omitted from further analysis. Approximately 5 years of observations marked the lower limit of the length of record required for reliable soil temperature estimations. Soil sites with fewer data either had low R^2 values or produced irregular isolines when they were applied to the symap program.

In general, curves fit observed data from lower soil depths more accurately than values from the surface. Fluctuating atmospheric conditions caused soil temperatures near the surface to deviate from a sine wave. However, data from the 150 cm depth more closely approximated a periodic function of time. This is illustated in Figure 4.1 where the R^2 values for Morden (site number - 62 G 4) data decrease from 0.91 at the 150 cm depth, to 0.86 at the 5 cm depth.

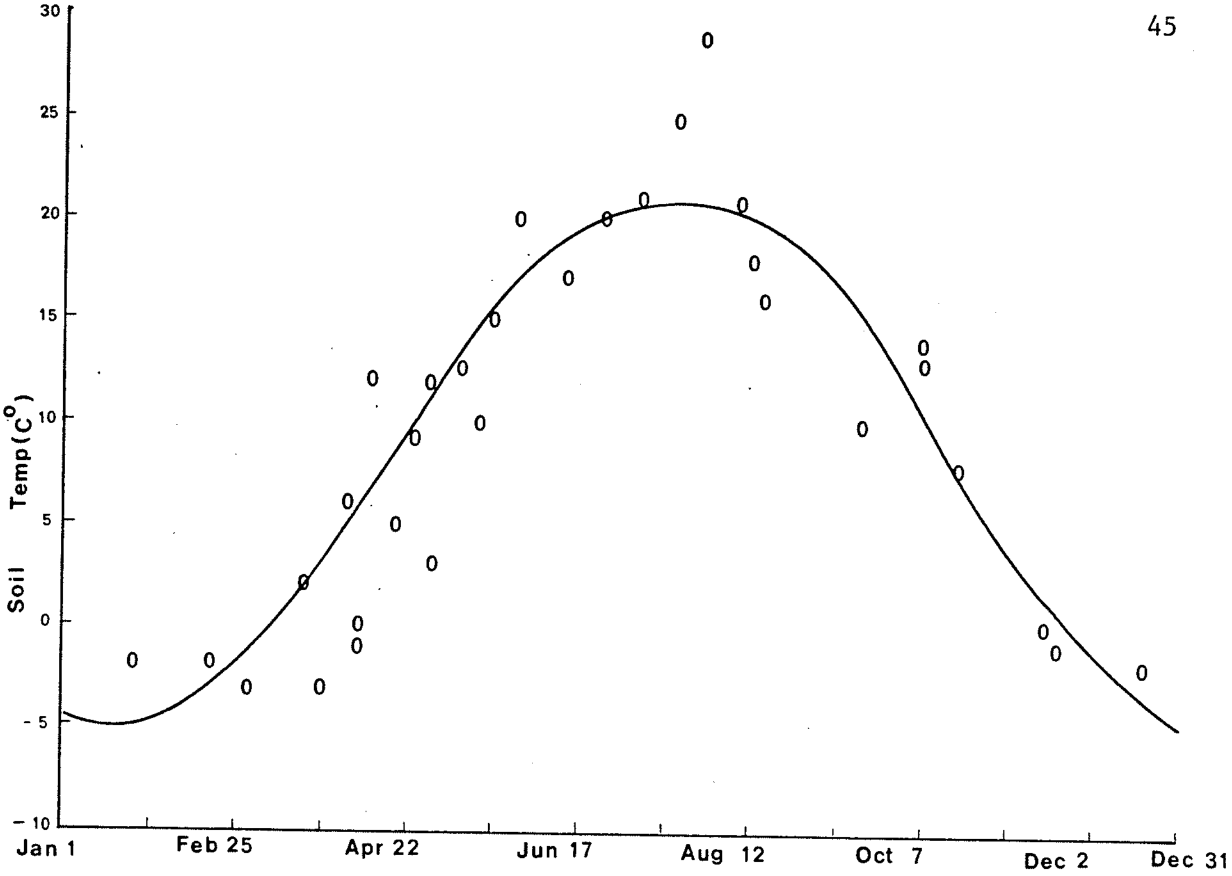


Figure 4.1a: Best Fitting Curve for 8 Years of Observed Data at the 5 cm Soil Depth for Morden, Manitoba.

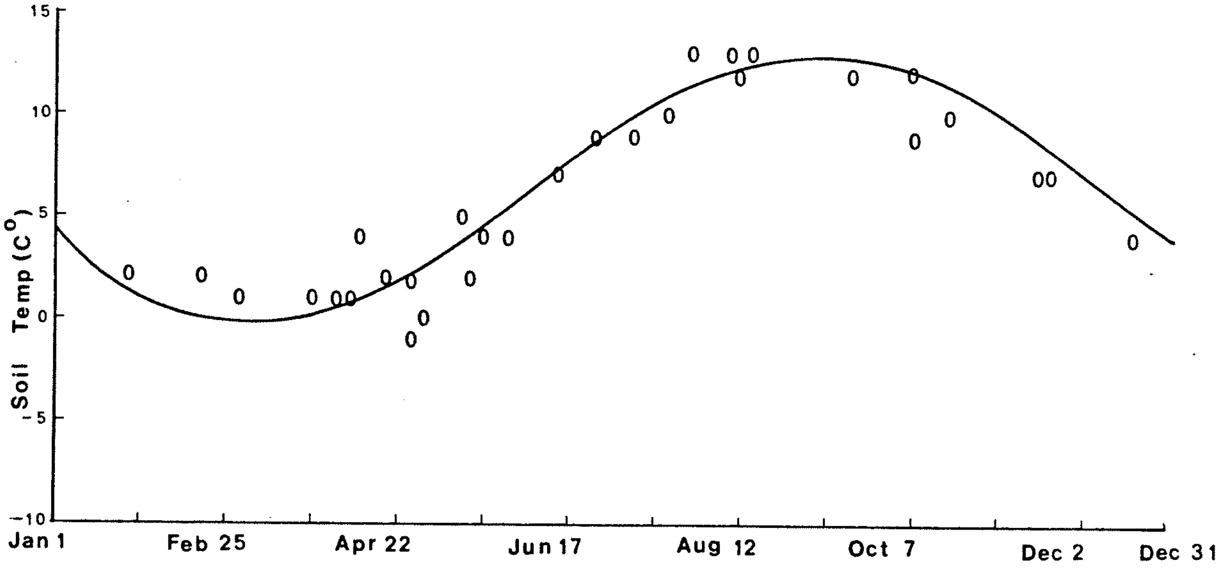


Figure 4.1b: Best Fitting Curve for 8 Years of Observed Data at the 150 cm Soil Depth for Morden, Manitoba.

Therefore, temperature waves characterizing lower soil depths are more reliable than those based on surface data. Since soil temperature maps were produced directly from these values, more validity is attributable to maps composed of data originating from below 20 cm.

4.2 RESOLUTION OF SYMAPS

Map outlines and isolines were printed by the computer using various combinations of symbols selected by the user. By superimposing several different symbols, various tones of gray were produced. Therefore, different shades of gray were used to represent a variety of soil climates. Blank characters between contrasting shaded regions represented isolines which connected points of equal value at intervals defined by the user.

The size of symbols printed by the computer to delineate isolines limited the accuracy of maps. As symaps were reduced in scale, the size of computer symbols remained constant and therefore occupied a greater percentage of the map area. This limited the degree of detail that could be depicted by isolines. This problem was partially compensated for by photographically reducing enlarged versions of the computer printed maps. However, on a 6 by 9 inch map it remained difficult to determine the location of isotherms in regions with densely distributed recording stations.

In addition, map distortion resulted when a map of Manitoba was reproduced by a computer printer which was not capable of plotting curved lines. Additional distortion also occurred when map measurements were rounded off to the nearest 1/10 of an inch (i.e. maps were printed at 10 characters per inch). These factors accounted for a distortion of 3 mm in the 21 cm long symaps. This degree of error is not significant when the maps are utilized to study soil temperature patterns on a provincial scale. However, the comparison of soil temperature data between individual sites is misleading and unrealistic.

4.3 EDITING SYMAPS

Isolines were established from real data and therefore very little human bias was involved in map construction. It was assumed that the distribution of recording stations across a wide variety of landscapes reflected differences in soil temperature as it related to soil type, elevation, latitude, or vegetation cover. However, some editing was required to compensate for stations which had insufficient data. For example, if a recording station was eliminated from the symap, adjacent isolines were adjusted (or smoothed).

4.4 ANALYSIS OF SYMAP ISOLINES

4.4.1 Mean Annual Air Temperature

Mean annual air temperatures range from 3C in southern Manitoba to less than -4C northwest of Thompson. The 2C isoline passes through Brandon (62 G 5) and Winnipeg (at approximately 50 degrees north latitude) and the 0C isoline extends diagonally across Manitoba between 52 and 53 degrees north latitude in the Interlake region. These isolines constitute the basis for the comparison of atmospheric climate and soil temperatures.

Isolines depicting mean annual air temperatures do not coincide with isolines outlining soil temperatures. Mean annual air temperature (Figure C2) is clearly a function of latitude and therefore isolines are aligned in a east to west orientation, decreasing in value towards the north. In general, mean annual air temperatures across the province are 7-10C lower than soil temperatures in the same region.

4.4.2 Mean Annual Soil Temperature

With the exception of damping effects, mean annual soil temperature (MAST) values do not change significantly with depth within soil profiles (Figures C3 to C8). For example, MAST values in southern Manitoba range from 10C at the surface to 7 or 8C at the 150 cm depth. In addition, minimal horizontal (i.e. geographical) temperature variation occurs at the 100 or 150 cm soil depths. This can be attributed to the lack of human and environmental influences. For example, cultivation, irrigation, cropping, and local weather patterns combine to alter heat flux at the soil surface. In contrast, soil at the 150 cm depth is not influenced by diurnal temperature variation or variations of surface crops.

The highest MAST values (8-10C) are located south of Lake Manitoba and extend from Dauphin (62 N 1) to the 49th parallel. The western extent of this belt is near Carberry (62 G 23) where soil type changes from coarse textured Chernozemic Black to coarse textured Regosolic soil and the eastern terminus is near Winnipeg. A few minutes of longditude to the east of Winnipeg, a sharp decline in mean annual soil temperature coincides with a transition of soil type from fine textured Chernozemic Black to Chernozemic Dark Grey and Organic soils. A relatively warm belt (7-8C between 5-10 cm) also stretches between Goodlands (62 F1) and

Boissevain and south to the U.S. border. This area coincides with medium textured Chernozemic Black soils (Figures C3 and C4).

South of Lake Manitoba, the only significantly cool regions are: (a) an elongated area which coincides with higher elevations east of the Escarpment, (b) adjacent to Lake Winnipeg near Gimli (62 I 2) and Winnipeg Beach, and (c) in the southeastern portion of the province dominated by Organic and Luvisolic soil. In these regions, MAST is 5C or less throughout all soil horizons.

Further north, MAST values gradually decrease from approximately 6C in the Interlake region to 1-3C between The Pas (63 F 2) and Thompson. Coolest soils are located slightly north of Ponton (54.5 degrees north latitude) on Organo Cryosol soils, and north of Thompson on fine textured Cryosolic and Organo Cryosol soils.

4.4.3 Mean Summer Soil Temperature

Mean summer soil temperature (MSST) maps were prepared for only the 10, 20 and 50 cm depths (Figures C9 to C11). During the summer (June 1 to August 31) the warmest soils at all depths are south of Lake Manitoba on coarse and fine textured Chernozemic Black soils. In the southern portion of the province MSST decreases rapidly with depth.

Lowest MSST values are depicted (a) in south eastern Manitoba in Organic and Luvisolic soils, (b) southwest of Lake Manitoba near Carberry (62 G 23) in Regosolic soil, (c) near Cowan (63 C 7) in Luvisolic soils, and (d) near The Pas (63 F 2) on Gleyed Eutric Brunisolic soil. Coolest temperatures at each site are at the 50 cm depth ranging from 9C in southern Manitoba to 3C north of Lake Winnipeg.

4.4.4 Days Above OC

Soil temperature at most sites throughout Manitoba is greater than OC for a majority of the year at all soil depths. Exceptions to this are the 100 and 150 cm soil depths in the discontinuous permafrost regions of northern Manitoba. For example, soil sites located at Simonhouse (63 K 1), Mistik Creek (63 K 2), Cranberry (63 K 6), Joey Lake (63 O 1), Orr Lake (64 A 1), and Split Lake (64 A 4) are frozen throughout the year at the 100 and 150 cm depths (Figure C40). Further south in the Interlake region, 150 to 160 frost free days exist at 5 cm below the soil surface (Figure C12). The highest number of frost free days (270) near the surface (5 cm), coincide with fine textured Chernozemic Black soil near Winnipeg. In southern Manitoba the least number of frost free days at the 5 cm depth are experienced in the Riding Mountains and between Brandon (62 G 5) and Glenboro (62 G 7). Days above OC in the Riding Mountains total 230 while near Brandon (62 G 5 - in fine textured Chernozemic Black soil) 240 frost free days exist, and at Glenboro (62 G 7 - in moderately coarse to medium textured Chernozemic soil) 224 days are frost free at a depth of 5 cm.

With the exception of perennially frozen soil sites, the number of frost free days increase as soil depth increases (Figures C12 - C16). For example, at the 150 cm depth most areas south of 52 degrees north latitude experience at least 340 days above OC. Even in northern regions such as Thompson, over 250 days are free of frost at the 150 cm soil depth. The Porcupine Hills region has relatively few frost free days (280) compared to similar soil types at lower elevations.

The increase in frost free days at lower soil depths can be attributed to the damping and insulating effect of overlying soil. At the 20 or 30 cm depth, diurnal temperature variation is damped out and at the 150 cm soil depth much of the annual temperature variation is absent (see Figure 4.1).

4.4.5 Degree Day Accumulations

4.4.5.1 Degree Days Above 5C

Degree days above 5C (DD5C) accumulate at all soil depths throughout the province and they coincide approximately with areas that have high MAST values. The highest number of DD5C accumulate in coarse and fine textured Chernozemic Black surface soils south of Lake Manitoba (Figures C23 to C29). Although degree day accumulations at the surface decline towards the north, areas near The Pas (63 F 2) still accumulate over 1,000 DD5C. However, accumulated DD5C diminish very rapidly with soil depth. For example, south of Lake Manitoba a difference of at least 800 DD5C exists between the soil surface and the 20 cm soil depth. This occurs because summers are not long, or hot enough to significantly increase soil temperatures at depths where seasonal temperature variation is minimal. At the 150 cm soil depth only 200 DD5C accumulate in southern Manitoba, while 25 to 50 DD5C accumulations are characteristic of soils near Thompson and Flin Flon (Appendix D-1).

4.4.5.2 Degree Days Above a 15C Base

The accumulation of a significant number of degree days above a 15C base (DD15C) is limited to southern Manitoba particularly at lower soil depths (Figures C35 to C39). Within 5 cm of the soil surface, DD15C do not accumulate north of Flin Flon. In the vicinity of The Pas (63 F 2) and throughout the Interlake region, 240 DD15C accumulate, while regions west of Lake Manitoba accumulate 450 DD15C. Highest surface accumulations of DD15C correspond to coarse textured Chernozemic Black soil east of Brandon (62 G 5). At the 50 cm soil depth (Figure C37), DD15C are limited to areas surrounding Lavenham and Portage La Prairie which are situated on fine and coarse textured Chernozemic Black soils respectively. At the 150 cm soil depth (Figure C39) accumulations of DD15C are restricted to a small area near Portage La Prairie. The restriction of DD15C to such a small percentage of the province cannot be attributed to one or two individual environmental factors or soil properties. Instead, a combination of soil characteristics, aerial climate, and geographical location, account for the over-all soil climate of this region.

4.4.6 Frozen Soils

There is disagreement among scientists as to where permafrost regions begin. Some researchers have estimated that permafrost boundaries coincide with the 0C mean annual air temperature isotherm (Legget et al., 1961). However, this cannot be strictly true since permafrost should therefore exist south of The Pas (63 F 2) in Manitoba (see Figure C1 and C40). In reality, the southern boundary of continuous permafrost in Manitoba intersects the Northwest Territory border and extends diagonally to Churchill. The discontinuous permafrost boundary sweeps across the province (diagonally) approximately 100 miles south of Thompson near the north end of Lake Winnipeg (Brown, 1970). Most of the maps produced do not extend far enough north to illustrate permanently frozen soil. In addition, the localized frozen soil sites occurring south of the 56th parallel are sparsely distributed and are therefore not portrayed on sy- maps.

Figure C40 displays the locations of frozen soil sites and superimposed isolines depicting mean annual air temperatures and MAST values at the 150 cm depth. The addition of more soil sites near the 54th parallel may more clearly delineate the southern extent of the discontinuous permafrost zone. Existing data suggest that the southern extent of the discontinuous permafrost zone coincides roughly with -1 to -2C mean annual air temperatures.

4.5 THE RELATIONSHIP BETWEEN SOIL PHYSICAL PROPERTIES, THE ENVIRONMENT AND SOIL TEMPERATURE

4.5.1 Introduction

Data from selected soil sites were compared with each other to evaluate the effect of soil physical properties on annual soil temperature characteristics. Individual soil sites were selected to reflect differences in a single independent variable. For example, locations with contrasting textures but similar drainage, slope, latitude, soil subgroup, and vegetation were analysed. Standardization of all conditions at soil sites was very difficult to achieve owing to the multitude of environmental factors to be considered. For example, regional wind patterns, humidity, and vapour pressure influence the evaporation of soil moisture which consequently affects soil temperature. Therefore, the energy budget of a soil near Lake Winnipeg may differ significantly from a site near Morden, even if other variables are similar. As a result, only five or six soil sites could be standardized for each variable (such as drainage or texture).

Upon comparing soil sites which fulfilled the above criteria, several shortcomings became apparent. In particular, insufficient soil moisture data prevented the accurate estimation of soil thermal properties. As an example, a loam and a sandy soil display a wide range of thermal diffusivities depending on their water content. A very moist sandy soil has a much greater thermal diffusivity than a saturated loam soil. However, a saturated loam soil possesses a much higher thermal diffusivity than a relatively drier sandy soil (Figure 4.2).

4.5.2 Soil Texture

4.5.2.1 The Effect of Soil Texture on MAST

With all other variables standardized, the influence of soil texture on various soil temperature characteristics is inconsistent.

In Chernozemic surface soils, MAST values are independent of soil texture but subsurface MAST values increase as particle size increases. Rapid horizontal (i.e. geographical) changes in the surface soil are partially responsible for irregular surface soil temperatures. In particular, water content is an important factor in heat exchange within soil profiles.

In Luvisolic soils, texture has no apparent effect on MAST values. As an example, MAST values for fine textured Luvisolic soil ranges from 2.7C at Wanless (63 K 4), to 5.7C at Sprague (52 E 3) and 5.0C near Jenpeg (63 J 5) at the surface. At the 20 cm depth, the Sprague and Jenpeg soils have MAST values of 4.6C while Wanless has a MAST of 3.3C.

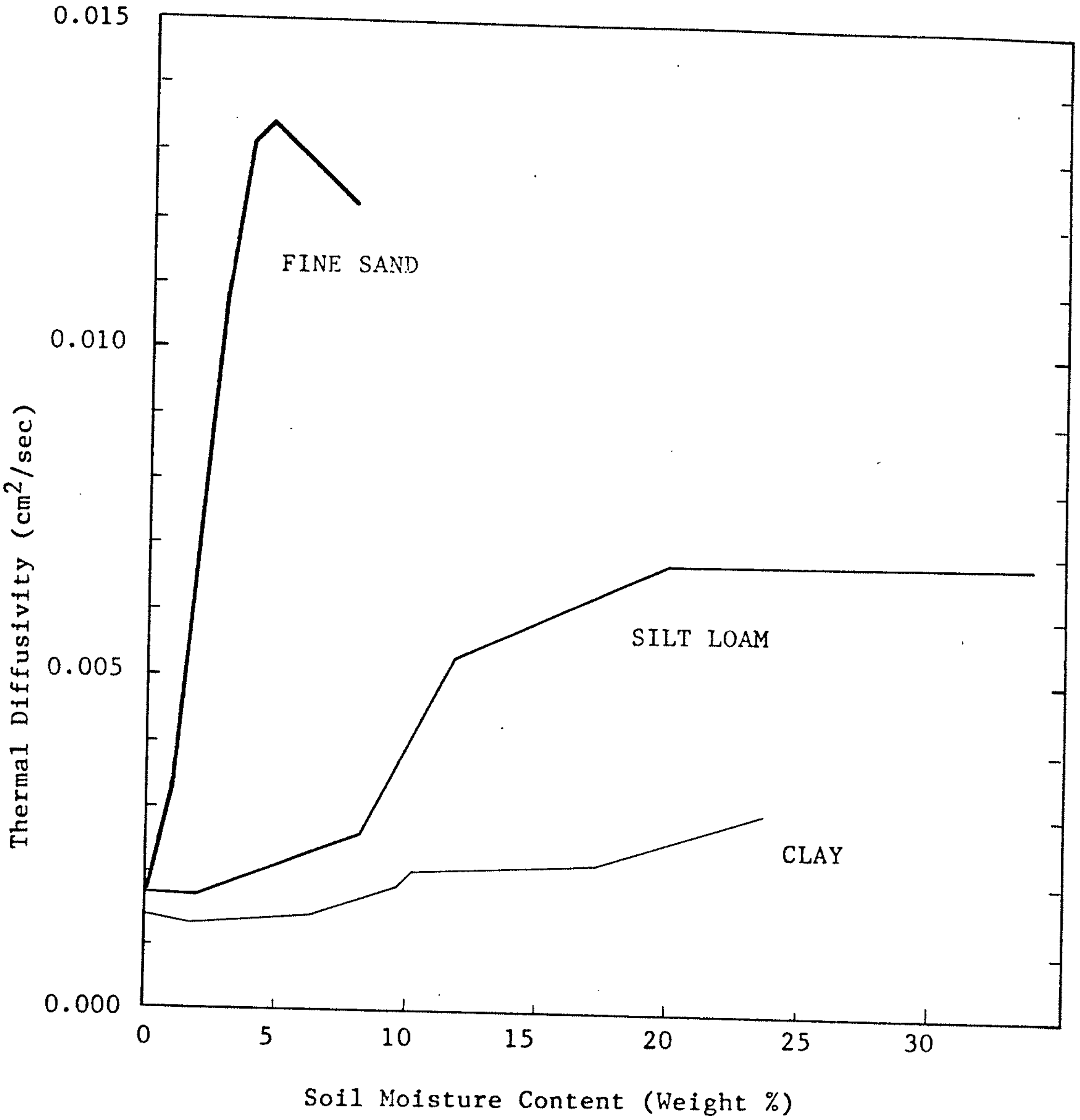


Figure 4.2: Thermal Diffusivity of Three Soils with Different Texture, Related to Moisture Content. (Reproduced from Nakshabandi and Kohnke, 1965).

A coarse textured Luvisol near Cranberry has a MAST of 3.4C, while a medium textured Luvisol in the Porcupine Hills (63 C 3) region also has a MAST of 3.4C (Appendix D).

In Brunisolic soils MAST values increase as particle size decreases. For example, MAST values of 8.6C to 8.4C coincide with fine to medium textured soil, while medium to coarse textured soils have MAST values which range from 2.6C to 5.5C (Mistik Creek, 62 K 2 - Gypsumville, 62 O 2).

4.5.2.2 The Influence of Soil Texture on MSST

With all other variables standardized, soil texture appears to have only minimal influence on MSST. For example, medium textured surface soils at the 20 cm depth near Dauphin (62 N 1) have MSST's of 17.8C, while similar soils near Killarny (62 G 8) have a MSST of over 17.9C, and a fine textured soil at Glenlea (62 H 7) is characterized by a MSST of 17.0C. Subsurface MSST is also unrelated to MSST (Appendix D). However, similar soils at other depthss, and from other sites do not exhibit such consistent temperatures.

By standardizing fewer variables, more relationships between soil texture and MSST become apparent. As an illustration, a well drained coarse textured Regosolic soil near Lavenham (62 G 17) has a MSST of 32.9C at the 2.5 cm soil depth. A second site (62 G 19) several miles away is situated on a Gleysolic silty loam soil and it has a MSST of only 22.7C at the same depth. However, it is uncertain as to whether soil type, drainage, or soil texture accounts for the majority of the influence on MSST.

Similar questions arise concerning soil sites near Miami (62 G 16), St. Claude (62 G 11), Manitou (62 G 15), and Homewood (62 H 9). Fine textured soils near Manitou (62 G 15) and Homewood have significantly lower MSST values than coarser textured soils near Miami (62 G 16) and St. Claude (62 G 11) at all soil depths. Considering the inconsistent influence of soil texture on soil temperature, some consideration should be given to the possible infuence of soil structure on MSST. As an example, soil compaction influences pore size, water content, and therefore soil thermal properties (especially at lower depths).

4.5.2.3 Influence of Texture on Frost Free Days

No direct relationship could be found between texture and the number of frost free days per season at the soil surface. For example, the Fort Garry (62 H 4) and Glenlea (62 H 7) soil sites are both situated on fine textured Chernozemic Black soil. However, the Fort Garry site at the 50 cm depth experiences 52 more frost free days than the Glenlea (62 H 7) site (Appendix D). In addition, the Brandon (62 G 5) site, located on a fine textured Chernozemic Black soil, experiences up to 26 fewer frost free days than similar sites located on medium textured Chernozemic soils. Patterns of subsurface frost free days are equally inconsistent for all soil groups. In most cases, a soil which warms up early in the spring also remains warm for a longer period of time in the autumn. Naturally these soils have the greatest number of frost free days per annum.

4.5.2.4 The Influence of Soil Texture on the Date of Occurrence of OC in the Spring and in the Autumn

Most fine textured surface soils (2.5 cm) warm to OC by March 30 (e.g. Glenlea (62 H 7), Fort Garry (62 H 4), Gypsumville (62 O 2), and Morden (62 G 4)) and coarse textured surface soils (e.g. Cranberry and Mistik Creek (62 K 2)) reach OC during April (Appendix D). There is a great deal of overlap between the dates of occurrence of OC in the two textural classes. However, the former pattern is dominant on symaps since regions characterized by fine textured soils are depicted as having a higher number of frost free days per annum (Figure C12 to C17). However, data in Appendix D show that in many cases fine textured soils reach OC later than coarser textured sites in the spring. For example, coarse and medium textured surface soils at Cranberry, Killarny, and Dauphin (62 N 1), reach OC prior to finer textured surface soils at Fort Garry (62 H 4), Wanless (63 K 4), and Brandon (62 G 5 - Appendix D). In theory, arguments can be provided to support both of these observations.

The availability of soil water determines the amount of energy that can potentially be removed from the soil through the latent heat of evaporation. Small increases in evaporation rates can cause significant changes in soil temperature since it requires over 600 calories to evaporate a gram of water at OC. On a volumetric basis, fine textured soils contain more moisture than coarse textured soils but it is held at higher tensions. Therefore, during the spring, under water saturated conditions, large amounts of moisture may evaporate with more eaze from coarse textured soils. This would result in rapid energy loss and a reduction of soil temperatures. In contrast, moisture would evaporate from finer textured soil at a slower rate and although total energy loss may be greater, it occurs over a longer period of time. Therefore, during short time spans (e.g. 10 days or less), fine textured soils may remain slightly warmer than 0C while coarse textured soil temperatures remain below freezing (even if air temperatures are above 0C - see Oke, 1978).

During less rapid energy loss, coarse textured soils may remain warmer. For example, they have more particle area available for heat conduction and under unsaturated conditions less water is available for evaporation.

The date of occurrence of 0C in the autumn appears to be independent of soil texture. For example, a coarse textured soil at Cranberry cools to 0C on the same date in the fall as a fine textured soil near Wanless (63 K 4 - Appendix D).

4.5.2.5 Soil Texture and Degree Day Accumulations

The accumulation of degree days above 5C (DD5C) is not affected by soil texture in any soil group. For example, in the Luvisolic order subsurface (150 cm) fine textured soil accumulated the highest number of DD5C (572) at one site, (Sprague - 52 E 3) but only 27 DD5C at a similar site (Jenpeg - 63 J 5). Medium textured Luvisols at the same depth accumulated 75 DD5C (63 C 1 -Appendix D).

The highest accumulations of degree days above 15C (DD15C) occur in coarse textured Chernozemic Black soil in southern Manitoba (Portage area 62 G 13 - Figure C38). However, one cannot conclude that soil texture is an important factor in the accumulation of DD15C in Chernozemic soils. For example, other soil or meteorological parameters may contribute significantly to observed soil temperatures.

4.5.3 Drainage

In general, poorly drained Gleysolic soils are cool and they accumulate relatively few degree days above 5C and 15C on an annual basis. In contrast, well drained Chernozemic soils collect a relatively high number of degree days, and they have higher MSST and MAST values, and a longer frost free season. For example, poorly drained soils at Orr Lake (64 A 1) and in the Porcupine Hills (63 C 1) have MAST values of 1.6C and 4.5C respectively, and both sites accumulate fewer than 1,200 DD5C. Well drained Brunisolic soils at Gypsumville (62 O 2) and Dawson Bay (63 C 8) had MAST values in excess of 8C and they accumulated over 1,700 DD5C in a year. However, within each soil type, the relationship between drainage and soil temperature is less discernable. For example, fluctuations in degree day accumulations, MAST, or MSST are not associated with soil drainage. This is apparent in Brunisolic soils at Buffalo Bay (63 G 1) and at Mistik Creek (63 K 2) which have similar drainage characteristics, but MAST values which differ by approximately 3C at the 2.5 cm depth, and 4.3C at the 50 cm depth (Appendix D). However, the number of frost free days below the 100 cm soil depth is influenced by soil drainage patterns. A majority of the poorly drained soil sites (Gleysolic order) are free of frost below the 100 cm depth on an annual basis. In contrast, relatively few well drained sites are frost free 365 days a year.

Since minimum temperatures at the 150 cm soil depth deviate very little from 0C, marginal increases in the soils' energy status may prevent soil freezing. For example, the storage of water in poorly drained soils (or water tables) increases the heat capacity of adjacent soil.

In addition, a relatively warm (unfrozen) water table may prevent freezing temperatures in overlying soil.

4.5.4 Elevation

The majority of Manitoba does not exhibit enough relief to significantly alter soil temperatures. The elevation of central Manitoba does not vary by more than 60 meters for hundreds of kilometers. Since soil temperature decreases 1.5C to 2.0C for every 300 meters of elevation (Carter and Cialkosz, 1980) topography would account for less than 0.5C of the total soil temperature variation. However, there is sufficient relief west of the Escarpment to reflect cooling as a function of altitude. As an example, soil sites located in the Porcupine Hills (Porcupine sites 63C1-5 in Appendix D) are slightly more than 300 meters higher in elevation than stations east of the Escarpment. Mean annual and mean summer soil temperatures at these sites are 1-2C lower than those in the adjacent lowlands, and up to 500 fewer degree days above 5C accumulate at all depths. In addition, 15-20 fewer frost free days exist in the Porcupine Hills (Figures C12 to C17 and Appendix D).

4.5.5 Soil Type

Warmest soils coincide with fine to coarse textured Chernozemic Black soil in southern Manitoba at all soil depths. Brunisolic soils are slightly cooler, they accumulate fewer degree days, and they have shorter growing seasons than the Chernozemic soils. Luvisolic and Gleysolic soils are associated with even less favourable agricultural conditions. Organic soils are also very cool as a result of the insulating properties of entrapped air.

Although each soil group coincides with a certain range of soil temperature, the relationships are not necessarily mutually exclusive. For example, Chernozemic Black surface soils have MAST values which range from approximately 6C to over 10C and frost free seasons which range from 225 to 280 days. Soils from the Brunisolic order are characterized by MAST values which range from approximately 3C to 9C, and frost free periods of 236-260 days. In Gleysolic surface soils, MAST values range from 1C to 5C and fewer than 235 frost free days are common.

A cooling of soil climates is apparent in the gradual progression from warm to cool soil types (Figures C2 to C39 display this pattern). For example, warm Chernozemic soils occupy the southern most portion of the province while Brunisolic and Luvisolic orders occupy the Interlake region, and Glesolic and Organic orders are predominant north of Lake Winnipeg.

4.5.6 Recommendations

Presently the analysis of data is very tedious. Problems originate from an abundance of soil data, a diversity of soil environments, and minor deficiencies in soil site descriptions. Therefore, minor revisions to the existing monitoring network and to the methods of data processing may improve future analysis.

The addition of a few strategically located soil sites would vastly improve the accuracy of symaps. For example, additional soil sites in the Interlake region and north of Lake Manitoba would reduce the clustered nature of existing sites. This would effectively raise the point distribution coefficient for symap analysis by yielding a more uniform station distribution.

In addition, the soil temperature characteristics of regions such as the Winnipeg Beach area, the discontinuous permafrost zone, or the highlands west of the Escarpment, could be better understood with the addition of more sites. For example, additional soil sites north of Lake Manitoba would help define the southern extent of the discontinous permafrost zone.

In northern Manitoba the margin of error associated with soil temperature measurement should be minimized. For example, an alternate method of thermocouple installation, could yield more accurate temperature measurements in nearly frozen soil. Figure 4.3 graphically illustrates an installation technique which reduces the disruption of soil profiles and therefore minimizes modifications to soil thermal properties.

The amount of error associated with existing thermocouples is probably less than 1C. Therefore, it would not be practical to employ an alternate method in southern Manitoba where this degree of error is tolerable.

As well as utilizing existing data more emphasis should be placed on the visual impressions of a site and its local weather patterns. As an example, height and percent of vegetation cover, crop maturity, or irrigation practice may provide useful information during data analysis. Many important aspects of a field station may be over looked by relying on a written description of the site.

The measurement of soil moisture may be beneficial at sites where water content could have a dramatic effect on soil thermal properties.

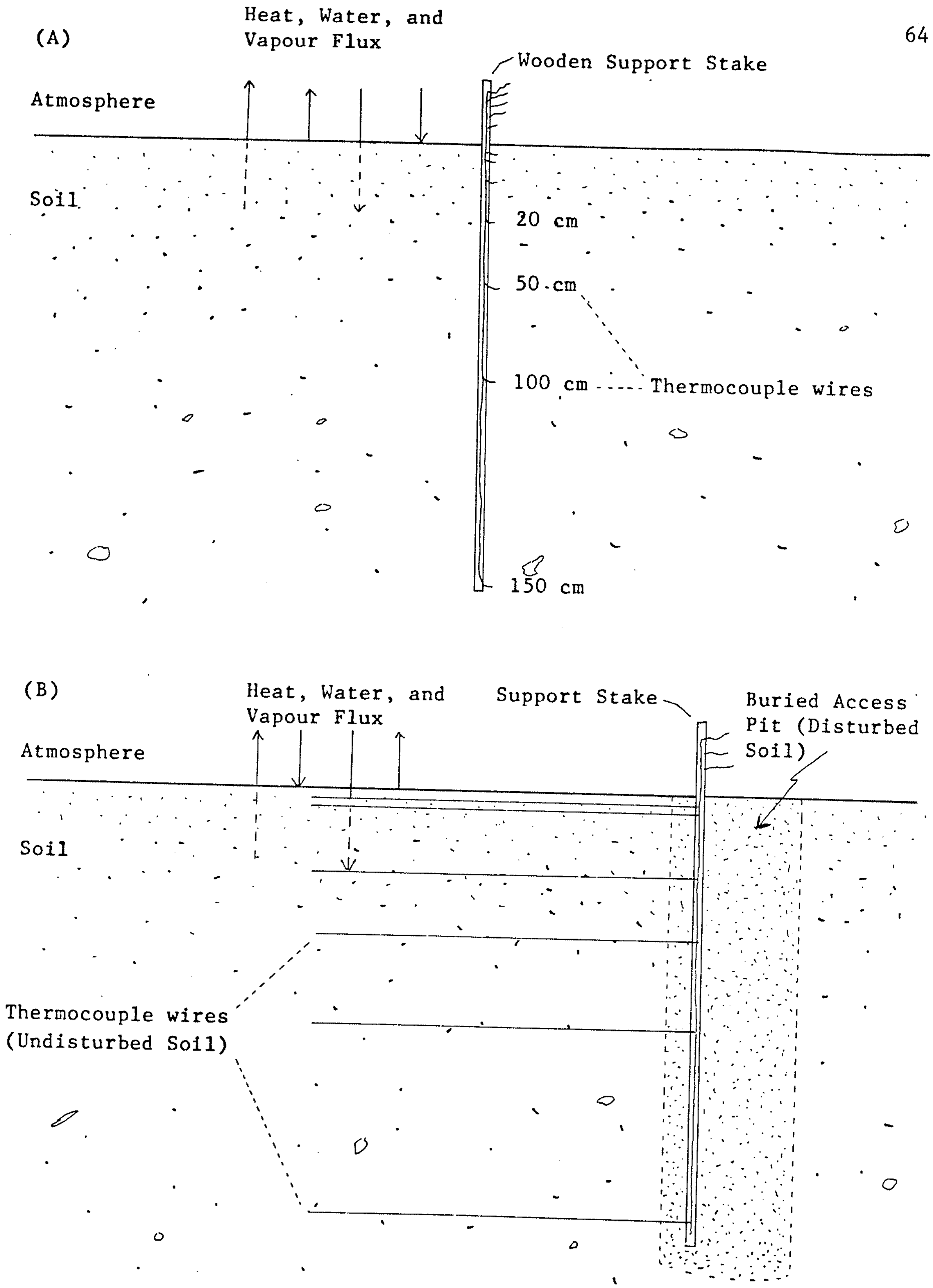


Figure 4.3 : Diagramatic Representation of (A) the Present Method of Thermocouple Installation, and (B) an Alternate Method Which Minimizes Modifications to the Soil Environment at the Point of Soil Temperature Measurement.

In addition, the comparison of individual soil horizons may prove to be more informative than the analysis of an entire soil profile. As an example, a soil profile may fulfill the requirements of a clay, but the particle size, or the percentage of clay in each horizon may vary sufficiently to alter the soil's thermal properties. Therefore, the comparison of individual soil horizons may more clearly illustrate the relationship between soil physical properties and soil temperature. The analysis of soil from between the 20 and 50 cm depths would minimize the effects of the surface environment and subsurface phenomena such as water tables. This would probably eliminate many observed anomalies. In addition, generalizations cannot be made concerning the climate of two different soil profiles on the basis of information from one or two soil horizons. The soil climate of each soil depth must be consideredindividually. For example, MAST at the 2.5 cm depth at East Braintree (loam) and Sprague (52 E 3 - clay) are 7.5C and 5.7C respectively. However, at the 20 cm soil depth their MAST values are within a few tenths of a degree Celcius, and at the 150 cm depth, the MAST at Sprague (52 E 3) is almost 1C warmer than soil at East Braintree (Appendix D).

Owing to the quantity of information available for each soil site, it is impractical to simultaneously correlate the entire data base. A more practical approach would be to analyse data according to categories such as soil texture or soil group. In addition, it is difficult to standardize soil sites or to attribute soil temperature variations to individual variables. The utilization of computers (e.g. statistical analysis) would speed data processing, reduce errors, and eliminate human bias.

For example, in a multiple stepwise regression program, variables are entered or removed one at a time to determine if there is a definite ordering among independent variables. The independent variable which explains the greatest amount of variation in the dependent variable could be identified.

In general it is very difficult to quantify the effect of individual soil physical properties, (such as drainage) based wholly on a large scale field experiment. For example, although numerous trends could be identified between texture and soil temperature, the pattern could rarely be attributed solely to soil texture. In many cases a different soil type, vegetation cover, or a significant difference in geographic location contributed to observed trends. Before valid relationships between soil properties and soil temperature can be obtained, the effects of all variables must be more clearly understood. This may entail a study of the influence of different soil subgroups (developed under different climatic conditions) on soil temperature, and laboratory studies to determine the thermal properties of selected soils.

4.6 TESTING OF REIMER'S SOIL TEMPERATURE ESTIMATION MODEL

To employ Reimer's model one requires hours of bright sunshine, cloud cover data, and maximum and minimum air temperatures on the date of surface soil temperature measurement. The correlation between soil temperatures from MSS sites and meteorological data (from the Atmospheric Environment Service - AES) was very poor. Problems originated from disjointed meteorological data and contrasts between AES and soil temperature recording stations. For example, meteorological measurements at the city of Brandon were initiated at the Canada Department of Agriculture (C.D.A.) experimental sstation by were subsequently transferred to Brandon airport. Similar conditions prevailed near Portage La Prairie. Meteorological data were recorded at the Delta University Field station at the south end of Lake Manitoba, and soil temperatures were recorded approximately 25 miles to the southwest.

Attempts to develop equations to estimate the deviation of soil surface temperature from the monthly mean were not entirely successful. The proportion of the variation in the dependent variable (deviations from the mean) explained by the independent variables (maximum and minimum air temperatures, and sunshine), was also very low ($R^2 = 0.0145$).

Table 4.1: Correlation Matrix Between Meteorological Data and Surface Soil Temperatures (2.5 cm) for Brandon (January, 1974).

	TMAX	TMIN	SUN	SOILT
TMAX	1.000			
TMIN	0.129	1.000		
SUN	-0.004	-0.185	1.000	
SOILT	-0.050	0.041	0.090	1.000

$R^2 = 0.0145$

The estimation equation derived for Brandon (62 G 5) was:

$$T = 0.0044 - 0.0008\ (TMAX) + 0.0025\ (TMIN) + 0.0120\ (SUN) \qquad (4.1)$$

The standard error of this equation was 3.07C, which was too large for the equation to be useful. In other words, coefficients of each variable were too small to reflect daily weather conditions. Therefore, the values of "T", which represent daily deviations of soil temperature from a monthly mean were very low. Consequently, the additions of the values of "T" to the monthly means did not accurately represent daily variations of soil temperatures, but instead they approximated the monthly mean. For example, during April, May, or June, when soil temperatures gradually increase (i.e. upslope of a Fourier curve) temperatures were overestimated at the beginning of each month and underestimated near the completion of each month.

Although Reimer's regression equations were based on data from Pinawa, they provided a more reliable relationship (than MSS data) between atmospheric conditions and soil temperatures. Table 4.2 illustrates the simple correlation coefficients for soil temperatures (1 cm) and meteorological observations for June at Pinawa Manitoba.

Table 4.2: Correlation Coefficients Derived by Reimer for Surface Soil Temperature (1 cm) and Meteorological Measurements at Pinawa, Manitoba.

	SOILT	AIRT	PCPN	TMIN	WNDS	SUN	TMAX
SOILT	1.00						
AIRT	0.97	1.00					
PCPN	-0.02	0.03	1.00				
TMIN	0.95	0.99	0.14	1.00			
WNDS	-0.73	-0.67	0.35	-0.57	1.00		
SUN	0.47	0.46	-0.54	0.34	-0.58	1.00	
TMAX	0.96	0.98	-0.07	0.94	-0.75	0.57	1.00

where SOILT = soil temperature
AIRT = mean monthly air temp.(C)
PCPN = precipitation (mm)
WNDS = wind speed (km/h).

The resulting regression equation for June was:

$$3.0 + 0.05\ (\mathrm{TMAX}) + 0.4\ (\mathrm{TMIN}) + 0.2\ (\mathrm{SUN}) \qquad (4.2)$$

The application of data to Reimer's regression equations resulted in more realistic soil temperature estimations. For example, values of "T" were numerically higher and therefore variations in atmospheric conditions were represented in daily soil temperature estimations. Therefore, Reimer's regression equations for January, June, July, and August, were utilized as the basis for daily soil temperature estimations using available AES meteorological data and MSS soil data for Brandon (62 G 5).

As was originally suspected insufficient weather data, and the inappropriateness of Reimer's regression equations (to MSS sites_ resulted in an ineffective estimation model. In fact, only data from the 2.5 cm soil depth had a correlation coefficient (between observed and estimated data) which was statistically significant (Table 4.3). The R^2 value for data at the 2.5 cm depth (observed values vs. estimated values) was 0.44 which is statistically significant at the 97.5 percent confidence level. Observed and estimated values at the 10 cm soil depth had an R^2 value of only 0.004.

Table 4.3 R SQ, F RATIO and St. Error for Estimated Values.

SOIL DEPTH	R SQR	F RATIO	STANDARD ERROR (Deg. C)
2.5 cm	0.445	8.0	6.0
5.0 cm	0.084	0.9	5.8
10.0 cm	0.004	0.0	6.8

Figure 4.4 illustrates the observed and estimated soil temperatures for June, July, and August of 1974, while Figure 4.5 displays the effect of time lag on soil temperature as a function of depth. Figure 4.5 was utilized to define the point in time on the estimated Fourier curve at which soil temperatures reached the daily mean soil temperature at each depth.

A lack of observed data for January prevented the statistical analysis of estimated values. However, fluctuations in weather conditions are clearly represented in daily soil temperature estimations.

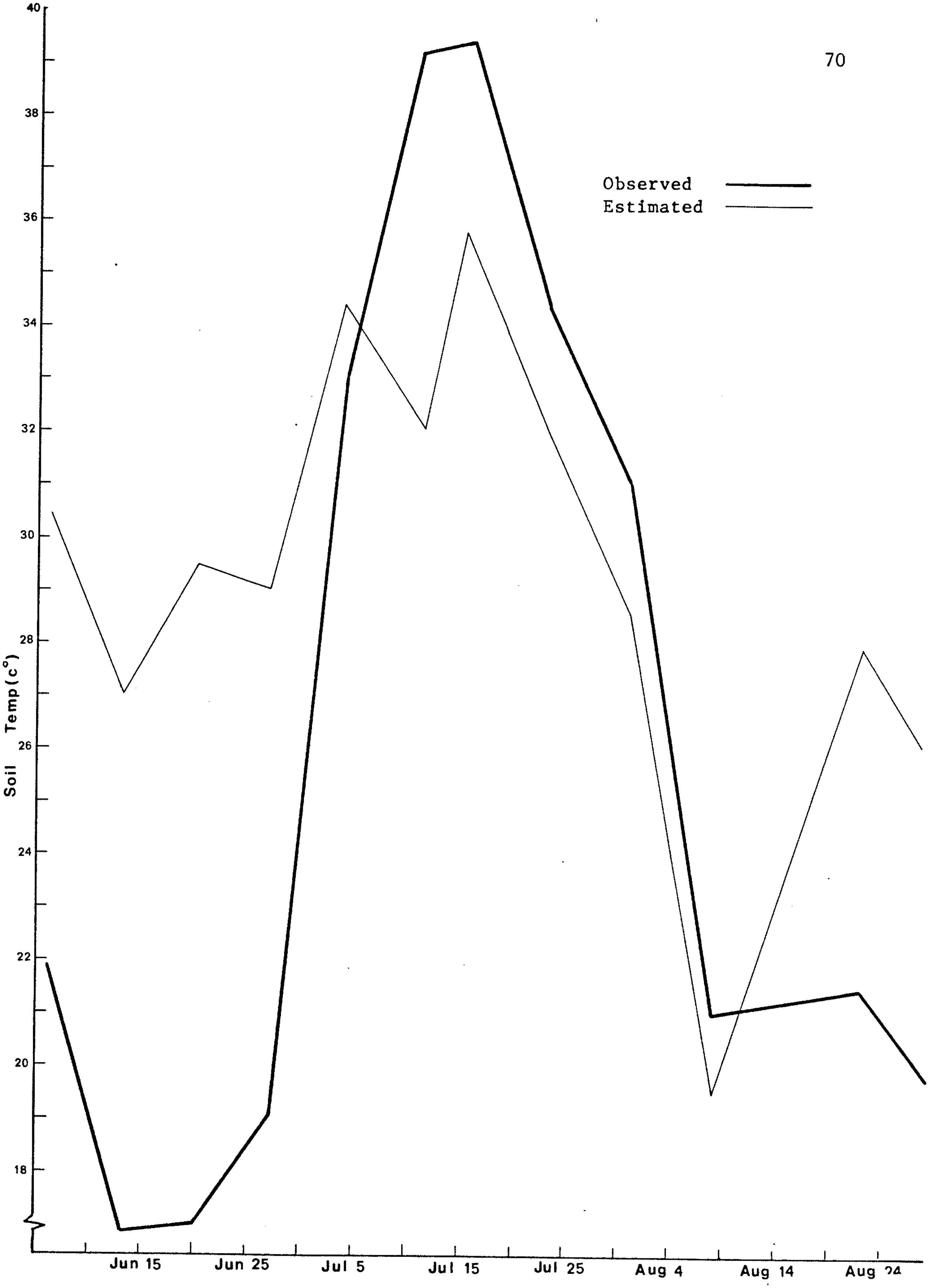
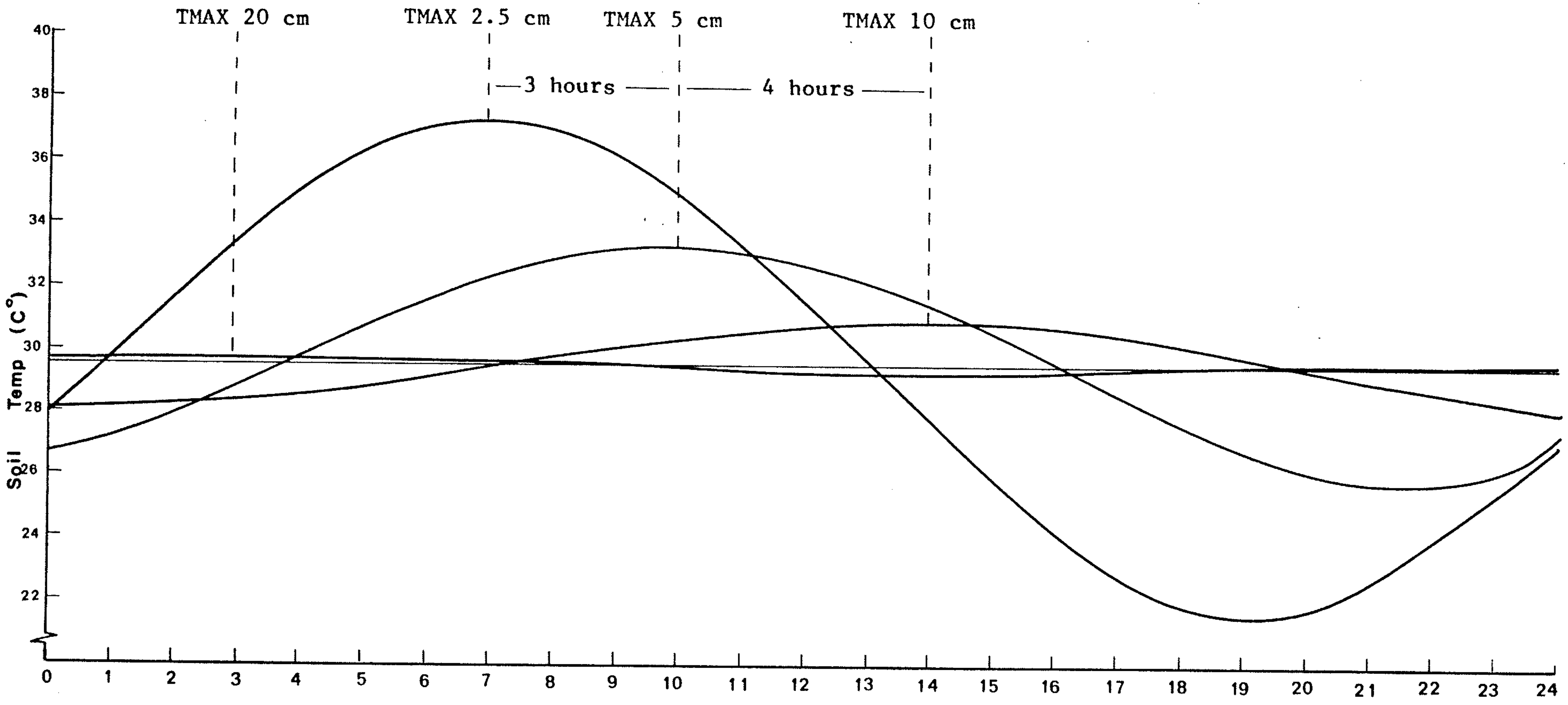


Figure 4.4 : Observed and Estimated Soil Temperatures (at the 2.5 cm depth) for June, July, and August of 1974 at Brandon .



TMAX = Maximum daily soil temperature.

Figure 4.5: Estimated Soil Temperature (from Fourier Curve) for Brandon, Illustrating Damping and Time Lag Effects with Depth on June 1, 1974.

In particular, daily hours of bright sunshine have the major influence on daily soil temperatures (Equation 3.4). In addition, daily amplitudes in January are appropriately reduced to a few tenths of a degree Celcius (Appendix G). It is suspected that actual mean daily soil temperatures would display less day to day variation. For example, estimated daily soil temperatures in June, July, and August, exhibited very little day to day variation.

4.6.1 Sources of Error

It is critical that there is abundant data representing daily weather conditions and that the best possible relationship between atmospheric conditions and soil temperatures is obtained. Numerous aspects of Reimer's model rely on the quantity and quality of meteorological data. Unfortunately, data from the present study do not fulfill the above criteria and therefore the full potential of Reimer's model was not realized. For example, insufficient cloud cover data prevented accurate estimations of daily amplitudes, and hours of bright sunshine did not provide an accurate indication of daily sky conditions (since they were recorded at AES stations several miles from each MSS site). In certain years up to 4 months of sunshine and air temperature data were missing from AES records, and almost every year had at least 1 month of missing data. Therefore, in many cases it was impossible to obtain a statistically significant regression equation to correlate atmospheric data and soil temperatures.

Without accurate weather data it was difficult to determine the time of day at which soil temperatures reached the daily mean. As an example, the first value on an estimated Fourier curve represents the time of day at which soil temperature intersects the daily mean soil temperature. This point (on the curve) is defined by empirical observations and depends on the time of year and on atmospheric conditions. Therefore, soil temperatures may warm to the daily mean more rapidly on a clear sunny summer day as apposed to an overcast day.

In addition, the infrequent measurement of soil temperatures (every 4-6 weeks) did not provide sufficient data to compare predicted and observed values. Although estimated values were calculated for each day of the year, observed values were available for only a few days of each month. An illustrative example is a 3 month period (June, July, and August, 1974) during which soil temperatures were recorded on only 12 days at Brandon (62 G 5). This constitutes a very small data base for statistical analysis.

Some degree of error can be attributed to the assumption that diurnal soil temperature variation can be represented by a sinusoidal wave. Although soil temperatures are a periodic function of the time of day, a dynamic earth atmosphere interface causes surface soils (0-20 cm) to deviate from an ideal curve. For example, on a very hot day soil temperatures may increase more rapidly than the slope of an estimated sine wave. Therefore, a temperature estimated from a Fourier curve may underestimate the actual soil temperature. Similarily, overcast skies, weather fronts, or evaporation, account for irregular soil temperature patterns.

Therefore, the shape of an estimation curve is most critical at the time of day when temperature changes occur most rapidly. In the present study, morning temperatures were usually overestimated particularly during overcast conditions. Estimations were much more accurate for late afternoon periods when soil temperatures are near their maximum. Therefore, amplitude was well estimated but other portions of the curve were less representative of observed soil temperatures. In the final analysis, regression equations failed to approximate variations from a perfect sine wave. Another source of error is the fact that Reimer's regression equations are not necessarily applicable to other soil sites. For example, variations in soil color or soil physical properties will alter the numeric relationship between atmospheric variables and soil temperature.

Chapter V

CONCLUSIONS

Based on the assumption that soil temperature is a periodic function of time, annual soil temperature data was accurately represented by a best fitting sine wave. In general, at least five years of data (with measurements every four weeks) were required to obtain a good correlation between observed and estimated soil temperatures (e.g. $R^2 > 0.80$). Annual soil temperatures at the 100 and 150 cm soil depths were especially well represented by a best fitting "wave". Once curves representing cummulative soil temperatures were obtained, degree days, frost free days, mean annual and mean summer soil temperatures were calculated.

Symaps provided a good summary of the spatial distribution of soil temperature characteristics at different soil depths across a variety of environmental conditions. In particular, they portrayed data in a manner which would be time consuming and tedius to achieve through human analysis. Variations in soil temperature as a result of elevation, latitude, drainage, and general soil type were especially well represented by symaps. To achieve the best possible interpolation between data bases, recording sites were distributed as uniformly as possible. A clustered or random site distribution yielded unreliable linear interpolation between data points.

By standardizing all but one site characteristic, very little correlation was observed between soil physical properties and soil temperatures. However, after considering several soil properties simultaneously, their association with a particular soil temperature range became apparent. For example, well drained, coarse textured soils are generally warmer than poorly drained clay soil.

However, too much data was available to adequately analyze in a study of this scale. Therefore, minor revisions to the data base, and to the methods of analysis (e.g. computer processing) would improve data processing.

Data from the present study were not appropriate to test Reimer's model. Much more atmospheric data is required and meteorological measurements must originate from directly above each soil site. Since daily weather fluctuations determine daily variations in surface soil temperature (1-20 cm), it is extremely important that accurate weather information is available. In addition, regression equations which model the relationship between soil temperature and atmospheric conditions must have the highest possible correlation coefficient. If these conditions are not fulfilled, estimated daily soil temperatures deviate very little from the monthly mean temperature. The most accurate estimations (standard error = 6.0C) were achieved for the 2.5 cm soil depth. In general, amplitude was most accurately estimated but the general shape of the Fourier estimation curve was difficult to establish. It is optimistically assumed that with sufficient data, estimations of daily soil temperatures within 3C of observed values could be calculated. However, the quantity of information required for this degree of accuracy may be time consuming to record and analyse, thereby defeating the original purpose of the estimation model.

BIBLIOGRAPHY

Abdulhadi, R.S. and Chato, J.C. 1978. Flow and Heat Transfer In Convectively Cooled Underground Electrical Cable Systems: Part 2 - Temperature Distributions and Heat Transfer Correlations. J. Heat and Mass Transfer. 100:36-40.

Aitchison, G.D. 1974. Twenty-five Years of Application of Soil Survey Principles In the Practice of Foundation Engineering. IN Developments In Soil Science. (Ed. Simonson, R.W.) Amsterdam: Elsevier Scientific Publishing Company, pp, 99-112.

Alessi, J. and Power, J.F. 1971. Corn Emergence In Relation to Soil Temperature and Seedling Depth. Agron. J. 63:717-719.

Allen, L.H. and Brown, K.W. 1965. Shortwave Radiation In a Corn Crop. Agron. J. 57:575-580.

Baladi, J.Y. and Ayers, D.L. 1981. Transient Heat and Mass Transfer In Soils. International J. Heat and Mass Transfer. 24:449-458.

Bocock, K.L.; Jeffers, J.N.R.; Lindley, D.K.; Adamson, J.K. and Gill, C.A. 1977. Estimating Woodland Soil Temperature from Air Temperature and Other Climatic Variables. Agric. Meteorol. 18:351-372.

Bonham, C.D. and Fye, R.E. 1970. Estimation of Wintertime Soil Temperatures. J. Econ. Entomol. 63:1051-1053.

Bowers, S.A. and Hanks, R.J. 1965. Reflection of Radiant Energy from Soils. Soil Sci. 100:130-138.

Brezel, A.J. and Outcult, S.L. 1973. The Observation and Simulation of Diurnal Evaporation Contrasts In an Alaskan Alpine Pass. J. Applied Meteorol. 12:1134-1143.

Brown, R.J.E. 1966. Relation Between Mean Annual Air and Ground Temperatures In the Permafrost Region of Canada. Proceedings Permafrost International Conference. NAS-NRC Publication 1287.

Brown, R.J.E. 1970. Permafrost In Canada. Toronto:University of Toronto Press.

Bruce, J.P. 1966. Introduction to Hydrometeorology. Oxford:Pergamon Press.

Businger, J.A. 1975. Aerodynamics of Vegetated Surfaces In Heat and Mass Transfer In the Biosphere. (Ed. de Vries and N.H. Afgan). New York: John Wiley & Sons, pp. 139-166.

Carter, Brian J. and Ciolkosz, Edward J. 1980. Soil Temperature Regimes of the Central Appalachians. Soil Sci. Soc. Amer. J. 44:1052-1058.

Carson, J.E. and Moses, H. 1963. The Annual and Diurnal Heat-Exchange Cycles In Upper Layers of Soil. J. Applied Meteorol. 2:397-406.

Cary, J.W. 1966. Soil Moisture Transport Due to Gradients: Practical Aspects. Soil Sci. Soc. Amer. Proc. 30:428-433.

Cary, J.W. and Taylor, S.A. 1962. Thermally Driven Liquid and Vapour Phase Transfer of Water and Energy In Soil. Soil Sci. Soc. Amer. Proc. 26:417-420.

Cary, J.W. and Taylor, S.A. 1962(A). The Interactions of the Simultaneous Diffusion of Heat and Water Vapour. Soil Sci. Soc. Amer. Proc. 26:413-416.

Cary, J.W. and Taylor, S.A. 1962(B). Thermally Driven Liquid and Vapour Phase Transfer of Water and Energy In Soils. Soil Sci. Soc. Amer. Proc. 26:417-420.

Cassel, D.K.; Nielson, D.R. and Biggar, J.W. 1969. Soil Water Movement In Response to Imposed Temperature Gradients. Soil Sci. Soc. Amer. Proc. 33:493-500.

Chang, Jen Hu. 1968. Climate and Agriculture: An Ecological Survey. Chicago: Aldine Publishing Company.

Chato, J.C. and Abdulhadi, R.S. 1978. Flow and Heat Transfer In Convectively Cooled Underground Electric Cable Systems: Part 1 - Velocity Distributions and Pressure Drop Correlations. J. Heat Transfer. 100:30-35.

Cochran, P.; Boersma, H.L. and Youngberg, T. 1967. Thermal Properties of a Pumice Soil. Soil Sci. Soc. Amer. Proc. 31:454-459.

De Groot, S.R. 1958. Thermodynamics of Irreversible Processes. Amsterdam: North Holland Publishing Co.

De Vries, D.A. 1963. Thermal Properties of Soils. IN Physics of the Plant Environment. (Ed. W.R. Van Wijk). Amsterdam: North Holland Publishing Company. pp. 210-235.

De Vries, D.A. 1975. Heat Transfer In Soils. IN Heat and Mass Transfer In the Biosphere. (Ed. de Vries and N.H. Afgan). New York: John Wiley and Sons. pp. 5-28.

De Vries, D.A. and Afgan, N.H. 1975. Heat and Mass Transfer In the Biosphere. Washington D.C.: Scripta Book Co.

Dirksen, C. and Miller, R.D. 1966. Closed System Freezing of Unsaturated Soil. Soil Sci. Soc. Amer. Proc. 30:168-173.

Dougenik, James, A. and Sheehan, David E. 1975. Symaps User's Reference Manual. Laboratory for Computer Graphics and Spatial Analysis. Harvard University, Cambridge, Mass..

Erh, K.T., Nielsen, D.R. and Biggar, J.W. 1971. Two Dimensional Heat Transfer In Porous Media with Steady-state Water Flow. Soil Sci. Soc. Amer. Proc. 35:209-214.

Flint, R.F. and Skinner, B.J. 1974. Physical Geology. New York: John Wiley & Sons, Inc. 38-39.

Franzemerier, D.P. and Pederson, E.J. 1969. Property of Some Soils In the Cumberland Plateau as Related to Slope, Aspect and Position. Soil Sci. Soc. Amer. Proc. 33:755-761.

Fritton, D.D.; Kirkham, Don and Shaw, R.H. 1970. Soil Water Evaporation Isothermal Diffusion and Heat and Water Transfer. Soil Sci. Soc. Amer. Proc. 34:183-189.

Frivik, P.E.; Thorbergsen, E.; Del Giudice, S. and Comini, G. 1977. Thermal Design of Pavement Structures In Seasonal Frost Areas. J. Heat Transfer. 99:533-540.

Geiger, R. 1966. The Climate Near the Ground. Cambridge: Harvard University Press.

Gibson, A.H. 1961. Root Temperature and Symbiotic Nitrogen Fixation. Nature 191:1080-1081.

Groenvelt, P.H and Kay, B.D. 1974. On the Interaction of Water and Heat Transport In Frozen and Unfrozen Soils: II The Liquid Phaze. Soil Sci. Soc. Amer. Proc. 38:400-404.

Gupta, S.C.; Radke, J.K. and Larson, W.E. 1981. Predicting Temperature of Bare and Residue Covered Soils With and Without a Crop. Soil Sci. Soc. Amer. J. 45:405-412.

Hadas, A. and Fuchs, M. 1973. Prediction of the Thermal Regime of Bare Soils. IN Physical Aspects of Soil Water and Salts In Ecosystems. (Ed. A. Hadas). pp. 293-300.

Hammond, R and McCallagh, P.S. Quantitative Techniques In Geography. London: William Clowers and Sons, Ltd..

Hanks, R.J. 1958. Water Vapour Transfer In Dry Soil. Soil Sci. Soc. Amer. Proc. 22:372-374.

Hanks, R.J.; Austin, D.D. and Ondrechen, W.T. 1971. Soil Temperature Estimation by a Numerical Method. Soil Sci. Soc. Amer. Proc. 35:665-667.

Hartog, G. den and Shaw, R.H. 1975. A Field Study of Atmospheric Exchange Processes Within a Vegetative Canopy. IN Heat and Mass Transfer In the Biosphere. (Ed. de Vries and N.H. Afgan). New York: John Wiley & Sons. pp. 299-310.

Hasfurther, V.R. and Burman, R.D. 1974. Soil Temperature Modeling Using Air Temperature as a Driving Mechanism. TRANS. ASAE Gen. Ed (Amer. Soc. Agric. Eng.) 17:78-81.

Jackson, Ray D. 1964(A). Water Vapour Diffusion In Relatively Dry Soil: I Theoretical Considerations and Sorption Experiments. Soil Sci. Soc. Amer. Proc. 28:172-176.

Jackson, Ray D. 1964(B). Water Vapour Diffusion In Relatively Dry Soil: II Steady State Experiments. Soil Sci. Soc. Amer. Proc. 28:467-470.

Jackson, R.D.; Kimbell, B.A.; Reginato, R.J.; Idso, S.B. and Nakayama, F.S. 1975. Heat and Water Transfer In a Natural Soil Environment. IN Heat and Mass Transfer In the Biosphere. (Ed. de Vries and N.H. Afgan). New York: John Wiley & Sons. pp. 67-76.

Jackson, R.D.; Reginato, R.J.; Kimbell, B.A. and Nakayama, F.S. 1974. Diurnal Soil Water Evaporation Comparison of Measured and Calculated Soil Water Fluxes. Soil Sci. Soc. Amer. Proc. 38:861-866.

Joshua, W.D. and de Jong, E. 1973. Moisture Movement Under Temperature Gradients. Can. J. Soil Sci. 53:49-57.

Kaushik, H.D. and Srivastava, A. 1980. Temperature Distribution In Ground; Response Function Technique. International J. Heat and Mass Transfer. 23:903-906.

Kay, B.D. and Groenvelt, P.H. 1974. On the Interaction of Water and Heat Transport In Frozen and Unfrozen Soils: I Basic Theory; The Vapour Phaze. Soil Sci. Soc. Amer. Proc. 38:395-400.

Kuo, T. and Boersma, L. 1971. Soil Water Suction and Root Temperature Effects on Nitrogen Fixation In Soybeans. Agron. J. 63:901-904.

Legg, B. and Monteith, J.L. 1975. Heat and Mass Transfer Within Plant Canopies. IN Heat and Mass Transfer in the Biosphere. (Ed. de Vries and N.H. Afgan). New York: John Wiley & Sons. pp. 167-186.

Mack, A.R. 1973. Soil Temperature and Moisture Conditions In Relation to the Growth and Quality of Field Peas. Can. J. Soil Sci. 53:59-72.

MacLean, A.J. and Donovan, L.S. 1973. Effects of Soil Temperature on Early Growth of Six Single-Cross Corn Hybrids. Can. J. Soil Sci. 53:128-129.

McDale, R.E. and Fosberg, M.A. 1974. Soil Temperatures In Selected Southeastern Idaho Soils. Soil Sci. Soc. Amer. Proc. 38:486-491.

Meikle, R.W. and Treadway, T.R. 1979. A Mathematical Method for Estimating Soil Temperature. Soil Sci. 128:226-242.

Mills, G.F.; Tarnocai, C. and Shaykewich, C.F. 1977. Characteristics and Distribution of Soil Temperature Regimes in Manitoba Canada. Manitoba Soil Science Meeting . U of M Unpublished Paper. pp. 56-76.

Monteith, J.L. 1959. The Reflection of Shortwave Radiation by Vegetation. Quart. J. Roy. Meteorol. Soc. 85:

Monteith, J.L. and Szeicz, G. 1961. The Radiation Balance of Bare Soil and Vegetation. Quart. J. Roy. Meteorol. Soc. 87:159-170.

Mueller, D. 1970. Soil Temperature Regimes In a Forested Area of the Northern Rockies. Soil Sci. 109:40-47.

Musselman, R.L. 1978. Effect of Elevated Pipeline on Moss Covered Ground Temperature. J. Heat and Mass Transfer. 100:363-367.

Nakshabandi, G.A. and Kohnke, H. 1965. Thermal Conductivity and Diffusivity of Soils as Related to Moisture Tension and Other Physical Properties. Agric. Meteorol. 2:271-279.

Nerpin, S.V. 1975. Thermodynamic and Rheological Peculiarities of Soil Water and Their Role In Energy and Mass Transfer. IN Heat and Mass Transfer In the Biosphere. (Ed. de Vries and N.H. Afgan). New York: John Wiley & Sons. pp. 46-66.

Norman, J.M. 1975. Radiative Transfer In Vegetation. IN Heat and Mass Transfer In the Biosphere. (Ed. de Vries and N.H. Afgan). New York: John Wiley & Sons. pp. 187-206.

Oke, T.R. 1978. Boundary Layer Climates. London England: William Cloves and Sons Limited.

Ouellet, C.D. 1973. Macroclimate Model for Estimating Monthly Soil Temperatures Under Short Grass Cover In Canada. Can. J. Soil Sci. 53:263-274.

Pate, J.S. 1961. Temperature Characteristics of Bacterial Variation In legume Symbiosis. Nature. 192:637-639.

Penner, E. 1970. Thermal Conductivity of Frozen Soils. Can. J. Earth Sci. 7:982-987.

Philip, J.R. 1975. Water Movement In Soil. IN Heat and Mass Transfer In the Biosphere. (Ed. de Vries and N.H. Afgan). New York: John Wiley & Sons. pp. 29-48.

Reimer, A. 1978. Soil Temperature Estimation from Meteorological Measurements. MSc Thesis. University of Manitoba, Department of Soil Science.

Reimer, A. and Shaykewich, C.F. 1980. Estimation of Manitoba Soil Temperatures from Atmospheric Meteorological Measurements. Can. J. Soil Sci. 60:299-309.

Ripley, E. and Sangier, B. 1975. Energy and Mass Exchange In a Native Grassland In Saskatchewan. IN Heat and Mass Transfer In the Biosphere. (Ed. de Vries and N.H. Afgan). New York: John Wiley & Sons. pp. 311-326.

Ross, J. and Nilson, T. 1975. Radiation Exchange In Plant Canopies. IN Heat and Mass Transfer In the Biosphere. (Ed. de Vries and N.H. Afgan). New York: John Wiley & Sons. pp. 327-336.

Rykbost, K.A.; Boersma, L.; Jarman, G.D. 1976. Soil Temperature Increases Induced by Subsurface Line Heat Sources. Agron. J. 68:94-99.

Sartz, Richard. 1969. Soil Water Movement as Affected by Deep Freezing. Soil Sci. Soc. Amer. Proc. 33:333-337.

Sellers, W.D. 1965. Physical Climatology. Chicago: University of Chicago Press.

Slegel, D.L. and Davis, L.R. 1977. Transient Heat and Mass Transfer In Soils In the Vicinity of Heated Porous Pipes. J. Heat Transfer. 99:541-546.

Strahler, Arthur N. 1975. Physical Geography 4th ed. New York: John Wiley & Sons, Inc.

Stanhill, G.; Hofstede, G.H. and Kalma. 1966. Radiation Balance of Natural and Agric. Vegetation. Quart. J. Roy. Meteorol. Soc. 92:

Swinbank, W.C. 1963. Longwave Radiation from Clear Skys. Quart. J. Roy. Meteorol. Soc. 89:

Taylor, Sterling. 1972. Physical Edaphology. San Francisco: W.H. Freeman and Company.

Taylor, S.A. and Cavozza, L. 1954. The Movement of Soil Moisture In Response to Temperature Gradients. Soil Sci. Soc. Amer. Proc. 18:451-358

Toy, Terrence; Kuhaida, Andrew and Munson, Brian. 1978. The Prediction of Mean Monthly Temperature from Mean Monthly Air Temperature. Soil Sci. 126:181-189.

Trewartha, Glenn T. 1968. An Introduction to Climate. New York: McGraw-Hill Book Company.

Van Wijk, W.R. 1963. General Temperature Variations In a Homogeneous Soil. IN Physics of the Plant Environment. (Ed. W.R. Van Wijk). Amsterdam: North Holland Publishing Company. pp. 144-169.

Van Wijk, W.R. 1963. Sinusoidal Temperature Variation In a Layered Soil. IN Physics of the Plant Environment. (Ed. W.R. Van Wijk). Amsterdam: North Holland Publishing Company. pp. 171-206.

Van Wijk, W.R. and de Vries, D.A. 1963. Periodic Temperature Variations In a Homogeneous Soil. IN Physics of the Plant Environment. (Ed. W.R. Van Wijk). Amsterdam: North Holland Publishing Company. pp. 102-140.

Vann, J.R. and Cline, M.G. 1975. Estimating the Mean Annual Soil Temperature of Areas Correlated as the Same Soil Series Where Both Elevation and Latitude Vary. J. Soil Water Cons. 30:85-87.

Vincent, J.M. 1965. Environmental factors In the Fixation of Nitrogen by the Legume. IN Soil Nitrogen. (Ed. Bartholomew, W.V. and F. Clark). ASA Monograph 10.

Walker, John M. 1969. One Degree Increments In Soil Temperature Affect Maize Seedling Behavior. Soil Sci. Soc. Amer. Proc. 33:729-736.

Watts, W.R. 1975. Air and Soil Temperature Differences In Controlled Environments as a Consequence of High Radiant Flux Densities and of Day/Night Temperature Changes. Plant Soil. 42:299-303.

Weber, D.F. and Miller, V.L. 1972. Effect of Soil Temperature on Rhizobium Japonium Serogroup Distribution in Soyabean Modules. Agron. J. 64:796-798.

Westcot, D.W. and Wierenga, P.J. 1974. Transfer of Heat by Conduction and Vapour Movement In a Closed Soil System. Soil Sci. Soc. Amer. Proc. 38:9-14.

Wierenga, P.J. and de Wit, C.T. 1970. Simulation of Heat Transfer In Soils. Soil Sci. Soc. Amer. Proc. 34:845-848.

Wierenga, P.J.; Hagan, R.M. and Gregory, E.J. 1971. Effects of Irrigation Water Temperature on Soil Temperature. Agron. J. 63:33-36.

Wiesner, C.J. 1970. Hydrometeorology. London: Chapman and Hall Ltd..

Appendix A

LIST OF COMMONLY USED SYMBOLS AND ABBREVIATIONS

Abbreviations

MAST = Mean annual soil temperature

MSST = Mean summer soil temperature

DD5C = Degree days above a 5C base

DD15C= Degree days above a 15C base

MSS = Manitoba soil survey (soil site)

TMAX = Maximum daily air temperature

TMIN = Minimum daily air temperature

SUN = Daily hours of bright sunshine

Symbols

A_o = wave amplitude

B.D. = Bulk density

C_v = Heat capacity

C_w = Specific heat capacity of water

D = Damping depth

E = Evaporation

J = Flux of gas, fluid, or heat

K = Thermal conductivety

$K\uparrow$ = Reflected shortwave radiation

K^* = Net shortwave radiation

$K\downarrow$ = Incoming shortwave radiation

$L\downarrow$ = Incoming longwave radiation
$L\uparrow$ = Longwave radiation emitted by a surface
L^* = Net longwave radiation
P = Precipitation
p = Vapour density
Q_e = Turbulent latent heat flux density
Q_h = Turbulent sensible heat flux density
ΔQ_p = The net rate of biochemical heat storage
Q_g = Subsurface heat flux density
Q_r = Rate of energy supply due to rainfall.
ΔQ_s = Net rate of physical heat storage
Q^* = Net all wave flux density
q_v = Vapour flux
S = Sorption
T = Temperature
$\bar{T}$ = Temperature mean
t = Time
V = Denotes the volume fraction of a substance
W = Weight factor for a substance
w = Angular frequency
X = Distance
Z = Soil depth

μ = Microns
Σ = Summation notation
θ = Volumetric water content

Less frequently used symbols are defined as they appear In the text of the thesis.

Appendix B

SOIL TEMPERATURE CHARACTERIZATION (ESTIMATION) PROGRAM

```
//GEOGRAPH JOB ´0075,SIN,98,T=40,L=15,I=50,F=31´,´J KRPAN´,MSGLEVEL=1
/*TSO SOIL
//  EXEC WATFIV,SIZE=896K
//GO.SYSIN DD *
$JOB WATFIV KRPAN,NOEXT
C
C
C      THIS PROGRAM ESTIMATES MEAN DAILY SOILTEMPERATURES AND ANNUAL
C      TEMP. WAVES  FROM METEORLOGICAL DATA AND MONTHLY
C      REGRESSION EQUATIONS
C
C
C      VARIABLES:
C      YR             =YEAR IN WHICH READING WERE TAKEN.
C      DATE           =THE DAY NUMBER ON WHICH READINGS WERE TAKEN.
C                      I.E., JAN. 1 =DAY1 AND FEB. 1 = DAY32
C      TMAX           =DAILY MAXIMUM AIR TEMP.
C      TMIN           =DAILY MINIMUM AIR TEMP.
C      SUN            =DAILY HOURS OF BRIGHT SUNSHINE.
C      AMP            =AMP CONDITION ON DAY OF MEASUREMENT.
C      T1,T2...T12    =SURFACE SOIL TEMP. DEVIATION FROM A
C                      MONTHLY MEAN.
C      TJAN,TFEB ETC  =MEAN SOILTEMPS FOR EACH MONTH.
C      TEMP           =DAILY SOILTEMPS FOR A FOURIER CURVE.
C      FJANT,FFEBT    =FINAL DAILY SOILTEMPS FOR EACH MONTH.
C      DTC(K,I)       =DAILY TEMPERATURE CURVES, K=DAY,I=HOUR
C      ATC(K,I)       =ANNUAL TEMP. CURVES, K=YEAR,I=DAY.
C      Z              =SOIL DEPTH.
C      TYEAR          =MEAN DAILY SOIL TEMPS FOR ONE YEAR.
C      I,J,K,JK,N     =INCRIMENT VARIABLES
C
C
      DIMENSION YR(367),DATE(367),TMAX(367),TMIN(367),SUN(367),
     /          AMP(366),ADATE(366),AMAX(366),AMIN(366),ASUN(366)
     /          ,ASKY(366),T1(365),T2(365),T3(365),T4(365),T5(365),
     /          T6(365),T7(365),T8(365),T9(365),T10(365),T11(365)
     /          ,TEMP(365),SKY(367),T12(365)
      DIMENSION TYEAR(365),DTC5(365,24),TEM(365)
     /          ,DTC20(365,24),DTC10(365,24),DTC50(365,24),DTC25(365
     /          ,24),DTC100(365,24),DTC150(365,24),ATC(150,365)
     /         ,TM25(365),TM5(365),TM10(365),TM20(365),TM50(365)
     /         ,TM150(365),TM100(365)
      REAL BLANK/´   ´/
C
C
C      THIS SECTION OF THE PROGRAM READS IN DATA,  STORES IT IN THE
C      APPROPRIATE ARRAY AND ADJUSTS DAY NUMBERS TO COMPENSATE FOR
C      LEAP YEARS.
C
C
      DO 83 J=1,365
1     READ(5,2,END=3) TMAX(J),TMIN(J),SUN(J),SKY(J),DATE(J),YR(J)
83    CONTINUE
3     CONTINUE
```

```
      K=1
      I=0
      WHILE(K.LE.J) DO
       IF(AMOD(YR(K),4.).EQ.0) THEN DO
        I=I + DATE(K)
        WHILE(I.LE.366) DO
         ADATE(I)=DATE(I+1)
         AMAX(I)=TMAX(I+1)
         AMIN(I)=TMIN(I+1)
         ASUN(I)=SUN(I+1)
         ASKY(I)=SKY(I+1)
C
         DATE(I)=0
         TMAX(I)=0
         TMIN(I)=0
         SUN(I)=0
         SKY(I)=0
C
         DATE(I)=ADATE(I)
         TMAX(I)=AMAX(I)
         TMIN(I)=AMIN(I)
         SUN(I)=ASUN(I)
         SKY(I)=ASKY(I)
C
         I=I+1
         K=K+1
        END WHILE
         I=I-366
        K=K-1
       ELSE DO
        K=J+1
       END IF
      END WHILE
C
C
C      THIS PORTION OF THE PROGRAM SMOOTHS METEEOROLOGICAL DATA
C      ACCORDING TO A MOVING 3 DAY FILTERING FUNCTION.
C
C
      J=365
      DO 42 I=1,J
       IF(I.LE.(J-2)) THEN DO
        TMIN(I)=TMIN(I)* 0.25
        TMIN(I+1)=TMIN(I+1)* 0.50
        TMIN(I+2)=TMIN(I+2)* 0.25
        TMIN(I+1)=TMIN (I+1)+TMIN(I)+TMIN(I+2)
       ELSE DO
        TMIN(I)=TMIN(I) * 4.0
        TMIN(J)=TMIN(J) * 4.0
       END IF
42    CONTINUE
C
C
      DO 43 I=1,J
```

```
        IF(I.LE.(J-2)) THEN DO
          TMAX(I)=TMAX(I)* 0.25
         TMAX(I+1)=TMAX(I+1) * 0.50
         TMAX(I+2)=TMAX(I+2) * 0.25
         TMAX(I+1)=TMAX(I+1) + TMAX(I) + TMAX(I+2)
        ELSE DO
         TMAX(I)=TMAX(I) * 4
         TMAX(J)=TMAX(J) * 4.0
        END IF
43      CONTINUE
C
C
C       THIS PORTION OF THE PROGRAM SOLVES THE PREVIOUSLY DERIVED
C       REGRESSION EQUATIONS TO OBTAIN PREDICTED SOIL SURFACE
C       TEMPS.  EACH MONTH IS REPRESENTED BY A UNIQUE REGRESSION
C       EQUATION AND PREDICTED VALUES REPRESENT THE DEVIATION OF
C       A SOIL TEMP. FROM A LONG TERM MEAN.
C
C
        DO 4 I=1,J
         IF(DATE(I).GE.1.AND.DATE(I).LE.31) GO TO 5
         IF(DATE(I).GE.1.AND.DATE(I).LE.59) GO TO 6
         IF(DATE(I).GE.60.AND.DATE(I).LE.90) GO TO 7
         IF(DATE(I).GE.91.AND.DATE(I).LE.120) GO TO 8
         IF(DATE(I).GE.121.AND.DATE(I).LE.151) GO TO 9
         IF(DATE(I).GE.152.AND.DATE(I).LE.181) GO TO 10
         IF(DATE(I).GE.181.AND.DATE(I).LE.212) GO TO 11
         IF(DATE(I).GE.213.AND.DATE(I).LE.243) GO TO 12
         IF(DATE(I).GE.244.AND.DATE(I).LE.273) GO TO 13
         IF(DATE(I).GE.274.AND.DATE(I).LE.304) GO TO 14
         IF(DATE(I).GE.305.AND.DATE(I).LE.334) GO TO 15
         IF(DATE(I).GE.335.AND.DATE(I).LE.365) GO TO 16
C
C
5       T1(I)=-3.14 + 0.2*TMAX(I)+0.9*SUN(I)
6       T2(I)=0.9777-0.0033*TMAX(I)+0.0542*TMIN(I)+0.0298*SUN(I)
7       T3(I)=0.8744-0.0000*TMAX(I)+0.0809*TMIN(I)+0.0365*SUN(I)
8       T4(I)=0.4009+0.0073*TMAX(I)+0.2852*TMIN(I)+0.0394*SUN(I)
9       T5(I)=-1.5548+0.0117*TMAX(I)+0.2252*TMIN(I)+0.0247*SUN(I)
10      T6(I)= 3.0+0.05*TMAX(I)+0.4*TMIN(I)+0.2*SUN(I)
11      T7(I)=-1.81+0.15*TMAX(I)+0.6*TMIN(I)+0.15*SUN(I)
12      T8(I)=-0.26+0.15*TMAX(I)+0.6*TMIN(I)+0.15*SUN(I)
13      T9(I)=-2.1343+0.0923*TMAX(I)+0.1630*TMIN(I)-0.0369*SUN(I)
14      T10(I)=-0.3484+0.0246*TMAX(I)+0.1768*TMIN(I)+0.0635*SUN(I)
15      T11(I)=1.2140+0.0213*TMAX(I)+0.1585*TMIN(I)+0.0977*SUN(I)
16      T12(I)=-0.1199+0.0214*TMAX(I)-0.0137*TMIN(I)+0.0099*SUN(I)
4       CONTINUE
C
C
C       AN ANNUAL CURVE MUST NOW BE CALCULATED FOR THE SITE IN
C       QUESTION FROM A FOURIER CURVE .
C
        DO 17 I=1,365
         TEM(I)=9.0 + 18.0 *SIN(6.28*I/365)
```

```
17     CONTINUE
C
C
C      SINCE DAY ONE ON THE ABOVE CURVE REPRESENTS APRIL 13
C      TEMP(I) MUST BE ADJUSTED SO THAT JAN 1 = DAY 1.
C
C
       DO 98 I=1,102
        TEMP(I)=TEM(I+263)
98     CONTINUE
C
       DO 97 I=103,365
        TEMP(I)=TEM(I-102)
97     CONTINUE
C
C      THE FOLLOWING PORTION OF THIS PROGRAM CALCULATES A
C      MONTHLY MEAN FOR EACH MONTH.
C
C
       TJAN=TFEB=TMAR=TAPRIL=TMAY=TJUN=TJUL=TAUG=TSEP=TOCT=TNOV=TDEC=0
C
       DO 18 I=1,31
        TJAN=TJAN+TEMP(I)
18     CONTINUE
       TJAN=TJAN/31
C
       DO 19 I=32,59
        TFEB=TFEB+TEMP(I)
19     CONTINUE
       TFEB=TFEB/28
C
       DO 20 I=60,90
        TMAR=TMAR+TEMP(I)
20     CONTINUE
       TMAR=TMAR/31
C
       DO 21 I=91,120
        TAPRIL=TAPRIL+TEMP(I)
21     CONTINUE
       TAPRIL=TAPRIL/30
C
       DO 22 I=121,151
        TMAY=TMAY+TEMP(I)
22     CONTINUE
       TMAY=TMAY/31
C
       DO 23 I=152,181
        TJUN=TJUN+TEMP(I)
23     CONTINUE
       TJUN=TJUN/30
C
       DO 24 I=182,212
        TJUL=TJUL+TEMP(I)
24     CONTINUE
```

```
      TJUL=TJUL/30
C
      DO 25 I=213,243
       TAUG=TAUG+TEMP(I)
25    CONTINUE
      TAUG=TAUG/31
C
      DO 26 I=244,273
       TSEP=TSEP+TEMP(I)
26    CONTINUE
      TSEP=TSEP/30
C
      DO 27 I=274,304
       TOCT=TOCT+TEMP(I)
27    CONTINUE
      TOCT=TOCT/31
C
      DO 28 I=305,334
       TNOV=TNOV+TEMP(I)
 28    CONTINUE
      TNOV=TNOV/30
C
      DO 29 I=335,365
       TDEC=TDEC+TEMP(I)
29    CONTINUE
      TDEC=TDEC/31
C
C     THIS SECTION OF THE PROGRAM DETERMINES WHAT THE AMPLITUDE
C     WILL BE FOR DAILY TEMP CURVES DEPENDING ON THE TIME OF
C     YEAR AND SKY CONDITIONS.
C
      DO 101 I=1,365
       IF(DATE(I).GE.121.AND.DATE(I).LE.243) THEN DO
        IF(SKY(I).EQ.0) AMP(I)=10.0
        IF(SKY(I).EQ.1) AMP(I)=1.5
        IF(SKY(I).EQ.2.OR.SKY(I).EQ.3.OR.SKY(I).EQ.4)THEN DO
         IF(DATE(I).GE.121.AND.DATE(I).LE.151) AMP(I)=TMAY
         IF(DATE(I).GE.152.AND.DATE(I).LE.181) AMP(I)=TJUN
         IF(DATE(I).GE.182.AND.DATE(I).LE.212) AMP(I)=TJUL
         IF(DATE(I).GE.213.AND.DATE(I).LE.243) AMP(I)=TAUG
        ELSE DO
        END IF
       ELSE DO
        IF(DATE(I).GE.91.AND.DATE(I).LE.120.OR.DATE(I).GE.244
     /  .AND.DATE(I).LE.304) THEN DO
         IF(SKY(I).EQ. 0) AMP(I)= 5.0
         IF(SKY(I).GE.1.AND.SKY(I).LE.4) THEN DO
          IF(DATE(I).GE.244.AND.DATE(I).LE.273) AMP(I)=TSEP
          IF(DATE(I).GE.274.AND.DATE(I).LE.304) AMP(I)=TOCT
          IF(DATE(I).GE.91.AND.DATE(I).LE.120) AMP(I)=TAPRIL
         ELSE DO
         END IF
        ELSE DO
        END IF
```

```
       END IF
      IF(DATE(I).GE.305.AND.DATE(I).LE.365) AMP(I)=0.1
       IF(DATE(I).GE.1.AND.DATE(I).LE.90) AMP(I)=0.1
101   CONTINUE
C
C     THE FOLLOWING CALCULATIONS ADD THE APPROPRIATE DEVIATIONS
C     TO THE MONTHLY MEANS TO OBTAIN DAILY MEANS.
C
C
      DO 30 I=1,31
       TYEAR(I)=TJAN+T1(I)
30    CONTINUE
C
      DO 31 I=32,59
       TYEAR(I)=TFEB+T2(I)
31    CONTINUE
C
      DO 32 I=60,90
       TYEAR(I)=TMAR+T3(I)
32    CONTINUE
C
      DO 33 I=91,120
       TYEAR(I)=TAPRIL+T4(I)
33    CONTINUE
C
      DO 34 I=121,151
       TYEAR(I)=TMAY +T5(I)
34    CONTINUE
C
      DO 35 I=152,181
       TYEAR(I)=TJUN+T6(I)
35    CONTINUE
C
      DO 36 I=182,212
       TYEAR(I)=TJUL+T7(I)
36    CONTINUE
C
      DO 37 I=213,243
       TYEAR(I)=TAUG+T8(I)
37    CONTINUE
C
      DO 38 I=244,273
       TYEAR(I)=TSEP+T9(I)
38    CONTINUE
C
      DO 39 I=274,304
       TYEAR(I)=TOCT+T10(I)
39    CONTINUE
C
      DO 40 I=305,334
       TYEAR(I)=TNOV+T11(I)
40    CONTINUE
C
      DO 41 I=335,365
```

```
        TYEAR(I)=TDEC+T12(I)
 41    CONTINUE
 C
 C     USING THE DAILY SOIL SURFACE MEANS, SUBSURFACE DAILY
 C     CURVES ARE CALCULATED USING FOURIER SERIES AND THE BEST
 C     AVAILABLE THERMAL PROPERTIES OF THE SOIL.
 C
 C     T=A + B(EXP -Z/D) SIN(6.28*T/P-Z/D)
 C
 C     THE VALUE OF D  WAS CALCULATED BY MEASURING THE TIME LAG
 C     IN SECONDS BETWEEN TEMP. CURVES FROM TWO DIFFERENT SOIL
 C     DEPTHS, AND APPLYING THE INFORMATION TO THE FOLLOWING
 C     FORMULA.
 C
 C                 D = 1/2W(Z2-Z1/DELTA T)
 C
 C     A MEAN DAILY VALUE IS ALSO CALCULATED FROM HOURLY
 C     VALUES ESTIMATED BY THE PROGRAM.
 C
       DO 79 K=1,365
        TM25(K)=TM5(K)=TM10(K)=TM20(K)=TM50(K)=TM100(K)=TM150(K)=0
 79    CONTINUE
 C
       Z=2.5
       DO 46 K=1,365
        DO 47 I=1,24
         ZZ=-0.25
        DTC25(K,I)=TYEAR(K)+AMP(K)*EXP(ZZ)*SIN(6.28*I/24-Z/10.0)
        TM25(K)=TM25(K)+DTC25(K,I)
 47     CONTINUE
        TM25(K)=TM25(K)/24
 46    CONTINUE
 C
       Z=Z+2.5
       DO 48 K=1,365
        DO 49 I=1,24
         ZZ1=Z/(-10.0)
        DTC5(K,I)=TYEAR(K)+AMP(K)*EXP(ZZ1)*SIN(6.28*I/24-Z/10.0)
        TM5(K)=TM5(K)+DTC5(K,I)
 49     CONTINUE
         TM5(K)=TM5(K)/24
 48    CONTINUE
       Z=Z+5
       DO 50 K=1,365
        DO 51 I=1,24
         ZZ2=Z/(-10.0)
         DTC10(K,I)=TYEAR(K)+AMP(K)*EXP(ZZ2)*SIN(6.28*I/24-
      /              Z/10.0)
        TM10(K)=TM10(K)+DTC10(K,I)
 51        CONTINUE
        TM10(K)=TM10(K)/24
 50      CONTINUE
 C
       Z=Z+10
```

```
      DO 52 K=1,365
       DO 53 I=1,24
        ZZ3=Z/(-10.0)
        DTC20(K,I)=TYEAR(K)+AMP(K)*EXP(ZZ3)*SIN(6.28*I/24-
     /             Z/(10.0) )
       TM20(K)=TM20(K)+DTC20(K,I)
53     CONTINUE
       TM20(K)=TM20(K)/24
52    CONTINUE
C
      Z=Z+30
      DO 54 K=1,365
       DO 55 I=1,24
        ZZ4=Z/(-10.0)
        DTC50(K,I)=TYEAR(K)+AMP(K)*EXP(ZZ4)*SIN(6.28*I/24-
     /             Z/(10.0) )
       TM50(K)=TM50(K)+DTC50(K,I)
55     CONTINUE
       TM50(K)=TM50(K)/24
54    CONTINUE
C
      Z=Z+50
      DO 56 K=1,365
       DO 57 I=1,24
        ZZ5=Z/(-10.0)
        DTC100(K,I)=TYEAR(K)+AMP(K)*EXP(ZZ5)*SIN(6.28*I/24-
     /              Z/(10.0) )
       TM100(K)=TM100(K)+DTC100(K,I)
57     CONTINUE
       TM100(K)=TM100(K)/24
56    CONTINUE
C
      Z=Z+50
      DO 58 K=1,365
       DO 59 I=1,24
        ZZ6=Z/(-10.0)
        DTC150(K,I)=TYEAR(K)+AMP(K)*EXP(ZZ6)*SIN(6.28*I/24-
     /              Z/(10.0) )
       TM150(K)=TM150(K)+DTC150(K,I)
59     CONTINUE
       TM150(K)=TM150(K)/24
58    CONTINUE
C
C     THE FOLLOWING SECTION OF THE PROGRAM IS USED TO CALCULATE
C     SUBSOIL ANNUAL WAVES
C
C
      DO 60 IZ=50,150,50
       DO 61 I=1,365
        ATC(IZ,I)=9.0+18.*EXP(-IZ/175.0)*SIN(6.28*I/365-IZ/175.0)
61     CONTINUE
60    CONTINUE
2     FORMAT(' ',T4,F6.2,1X,F6.2,1X,F5.1,1X,F4.1,1X,F4.0,1X,F5.0)
C
```

```
C      THIS SECTION OF THE PROGRAM PRINTS OUT DAILY TEMPERATURE
C      CURVES INTO A TABLE.  DAILY TEMPERATURE CURVES IN THE
C      TABLES ARE COMPOSED OF HOURLY VALUES.
C
       ICOUNT = 0
       PRINT 71
       PRINT, '  '
       DO 70 K=1,351,14
        ICOUNT=ICOUNT + 1
        PRINT 72,K,K+1,K+2,K+3,K+4,K+5,K+6,K+7,K+8,K+9,K+10,
     /          K+11,K+12,K+13
       PRINT, '  '
        DO 73 I=1,24
         PRINT 74, DTC25(K,I),DTC25(K+1,I),DTC25(K+2,I),DTC25(K+3,I)
     /             ,DTC25(K+4,I),DTC25(K+5,I),DTC25(K+6,I),
     /             DTC25(K+7,I),DTC25(K+8,I),DTC25(K+9,I),
     /             DTC25(K+10,I),DTC25(K+11,I),DTC25(K+12,I),
     /             DTC25(K+13,I)
73      CONTINUE
        PRINT 75,TM25(K),TM25(K+1),TM25(K+2),TM25(K+3),TM25(K+4),TM25
     /           (K+5),
     /          TM25(K+6),TM25(K+7),TM25(K+8),TM25(K+9),TM25(K+10),
     /          TM25(K+11),TM25(K+12),TM25(K+13)
        IF(ICOUNT.GT. 1) THEN DO
         IF(MOD (ICOUNT,2).EQ. 0) THEN DO
          PRINT 71
         END IF
        END IF
70     CONTINUE
C
71     FORMAT('1',40X,'TABLE OF DAILY TEMPERATURE CURVE DATA.')
72     FORMAT('0',T2,14('DAY ',I3,1X))
74     FORMAT(' ',T2,14(F7.3,1X))
75     FORMAT('0',T2,14('M=',F6.2))
C
       ICOUNT=ICOUNT-ICOUNT
C
       PRINT 71
       PRINT, '  '
       DO 200 K=1,351,14
        ICOUNT=ICOUNT + 1
        PRINT 72,K,K+1,K+2,K+3,K+4,K+5,K+6,K+7,K+8,K+9,K+10,
     /          K+11,K+12,K+13
       PRINT, '  '
        DO 201 I=1,24
         PRINT 74, DTC10(K,I),DTC10(K+1,I),DTC10(K+2,I),DTC10(K+3,I)
     /             ,DTC10(K+4,I),DTC10(K+5,I),DTC10(K+6,I),
     /             DTC10(K+7,I),DTC10(K+8,I),DTC10(K+9,I),
     /             DTC10(K+10,I),DTC10(K+11,I),DTC10(K+12,I),
     /             DTC10(K+13,I)
201     CONTINUE
        PRINT 75,TM10(K),TM10(K+1),TM10(K+2),TM10(K+3),TM10(K+4),TM10
     /           (K+5),
     /          TM10(K+6),TM10(K+7),TM10(K+8),TM10(K+9),TM10(K+10),
```

```
     /          TM10(K+11),TM10(K+12),TM10(K+13)
       IF(ICOUNT.GT. 1) THEN DO
        IF(MOD (ICOUNT,2).EQ. 0) THEN DO
         PRINT 71
        END IF
       END IF
200    CONTINUE
C
C
      ICOUNT=ICOUNT-ICOUNT
      ICOUNT=ICOUNT-ICOUNT
      PRINT 71
      PRINT, ' '
      DO 202 K=1,351,14
       ICOUNT=ICOUNT + 1
       PRINT 72,K,K+1,K+2,K+3,K+4,K+5,K+6,K+7,K+8,K+9,K+10,
     /         K+11,K+12,K+13
      PRINT, ' '
       DO 203 I=1,24
        PRINT 74, DTC20(K,I),DTC20(K+1,I),DTC20(K+2,I),DTC20(K+3,I)
     /            ,DTC20(K+4,I),DTC20(K+5,I),DTC20(K+6,I),
     /            DTC20(K+7,I),DTC20(K+8,I),DTC20(K+9,I),
     /            DTC20(K+10,I),DTC20(K+11,I),DTC20(K+12,I),
     /            DTC20(K+13,I)
203     CONTINUE
       PRINT 75,TM20(K),TM20(K+1),TM20(K+2),TM20(K+3),TM20(K+4),TM20
     /           (K+5),
     /          TM20(K+6),TM20(K+7),TM20(K+8),TM20(K+9),TM20(K+10),
     /          TM20(K+11),TM20(K+12),TM20(K+13)
       IF(ICOUNT.GT. 1) THEN DO
        IF(MOD (ICOUNT,2).EQ. 0) THEN DO
         PRINT 71
        END IF
       END IF
202    CONTINUE
C
C
      ICOUNT=ICOUNT-ICOUNT
      PRINT 71
      PRINT, ' '
      DO 204 K=1,351,14
       ICOUNT=ICOUNT + 1
       PRINT 72,K,K+1,K+2,K+3,K+4,K+5,K+6,K+7,K+8,K+9,K+10,
     /         K+11,K+12,K+13
      PRINT, ' '
       DO 205 I=1,24
        PRINT 74, DTC50(K,I),DTC50(K+1,I),DTC50(K+2,I),DTC50(K+3,I)
     /            ,DTC50(K+4,I),DTC50(K+5,I),DTC50(K+6,I),
     /            DTC50(K+7,I),DTC50(K+8,I),DTC50(K+9,I),
     /            DTC50(K+10,I),DTC50(K+11,I),DTC50(K+12,I),
     /            DTC50(K+13,I)
205     CONTINUE
       PRINT 75,TM50(K),TM50(K+1),TM50(K+2),TM50(K+3),TM50(K+4),TM50
     /           (K+5),
```

```
     /          TM50(K+6),TM50(K+7),TM50(K+8),TM50(K+9),TM50(K+10),
     /          TM50(K+11),TM50(K+12),TM50(K+13)
       IF(ICOUNT.GT. 1) THEN DO
        IF(MOD (ICOUNT,2).EQ. 0) THEN DO
         PRINT 71
        END IF
       END IF
204    CONTINUE
C
C
      ICOUNT=ICOUNT-ICOUNT
      PRINT 71
      PRINT, ' '
      DO 206 K=1,351,14
       ICOUNT=ICOUNT + 1
       PRINT 72,K,K+1,K+2,K+3,K+4,K+5,K+6,K+7,K+8,K+9,K+10,
     /         K+11,K+12,K+13
      PRINT, ' '
       DO 207 I=1,24
        PRINT 74, DTC100(K,I),DTC100(K+1,I),DTC100(K+2,I),DTC100(K+3,I)
     /            ,DTC100(K+4,I),DTC100(K+5,I),DTC100(K+6,I),
     /            DTC100(K+7,I),DTC100(K+8,I),DTC100(K+9,I),
     /            DTC100(K+10,I),DTC100(K+11,I),DTC100(K+12,I),
     /            DTC100(K+13,I)
207     CONTINUE
       PRINT 75,TM100(K),TM100(K+1),TM100(K+2),TM100(K+3),TM100(K+4),
     /           TM100(K+5),
     /          TM100(K+6),TM100(K+7),TM100(K+8),TM100(K+9),TM100(K+10),
     /          TM100(K+11),TM100(K+12),TM100(K+13)
       IF(ICOUNT.GT. 1) THEN DO
        IF(MOD (ICOUNT,2).EQ. 0) THEN DO
         PRINT 71
        END IF
       END IF
206    CONTINUE
C
C
      ICOUNT=ICOUNT-ICOUNT
      PRINT 71
      PRINT, ' '
      DO 208 K=1,351,14
       ICOUNT=ICOUNT + 1
       PRINT 72,K,K+1,K+2,K+3,K+4,K+5,K+6,K+7,K+8,K+9,K+10,
     /         K+11,K+12,K+13
      PRINT, ' '
       DO 209 I=1,24
        PRINT 74, DTC150(K,I),DTC150(K+1,I),DTC150(K+2,I),DTC150(K+3,I)
     /            ,DTC150(K+4,I),DTC150(K+5,I),DTC150(K+6,I),
     /            DTC150(K+7,I),DTC150(K+8,I),DTC150(K+9,I),
     /            DTC150(K+10,I),DTC150(K+11,I),DTC150(K+12,I),
     /            DTC150(K+13,I)
209     CONTINUE
       PRINT 75,TM150(K),TM150(K+1),TM150(K+2),TM150(K+3),TM150(K+4),
     /           TM150(K+5).
```

```
     /          TM150(K+6),TM150(K+7),TM150(K+8),TM150(K+9),TM150(K+10),
     /          TM150(K+11),TM150(K+12),TM150(K+13)
       IF(ICOUNT.GT. 1) THEN DO
        IF(MOD (ICOUNT,2).EQ. 0) THEN DO
         PRINT 71
        END IF
       END IF
208    CONTINUE
C
      ICOUNT=ICOUNT-ICOUNT
C     THIS SECTION OF THE PROGRAM PRINTS OUT THE ANNUAL
C     SOIL TEMPERATURE CURVE DATA.
C
      STOP
      END
$ENTRY
```

Appendix C

SOIL TEMPERATURE MAPS

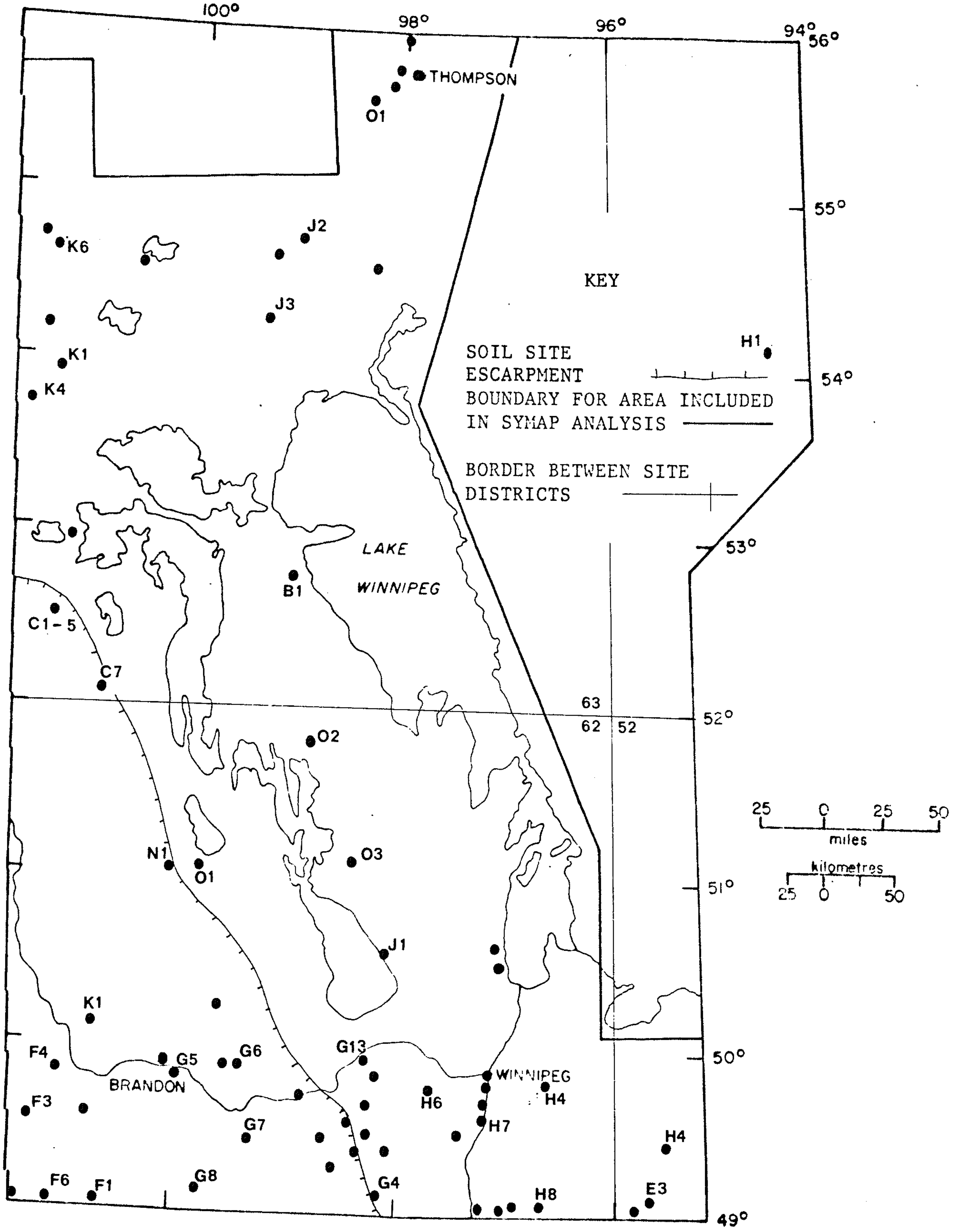


Figure C1: Distribution of Recording Stations in Manitoba.

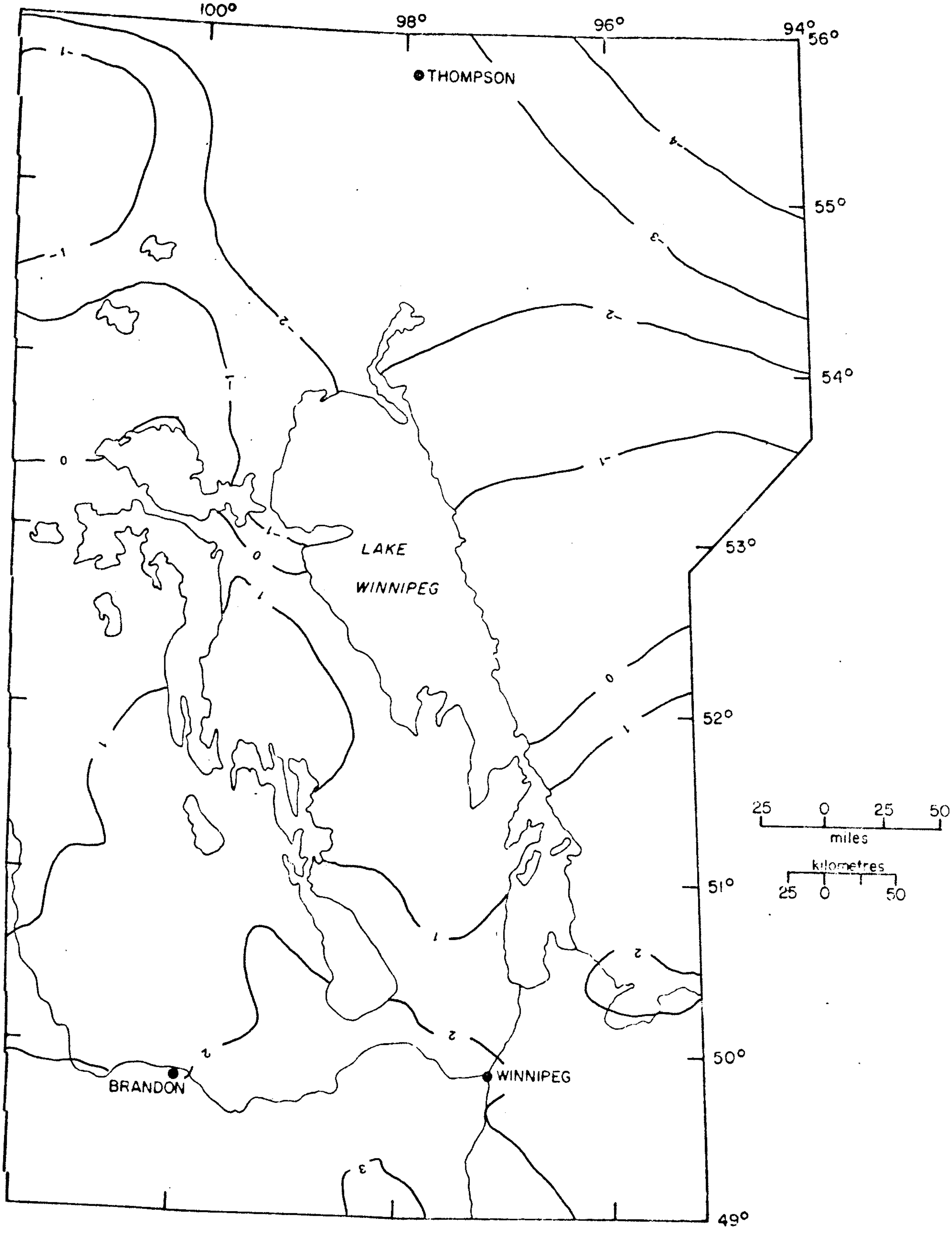


Figure C2: Mean Annual Air Temperature. Isoline Int. = 1C

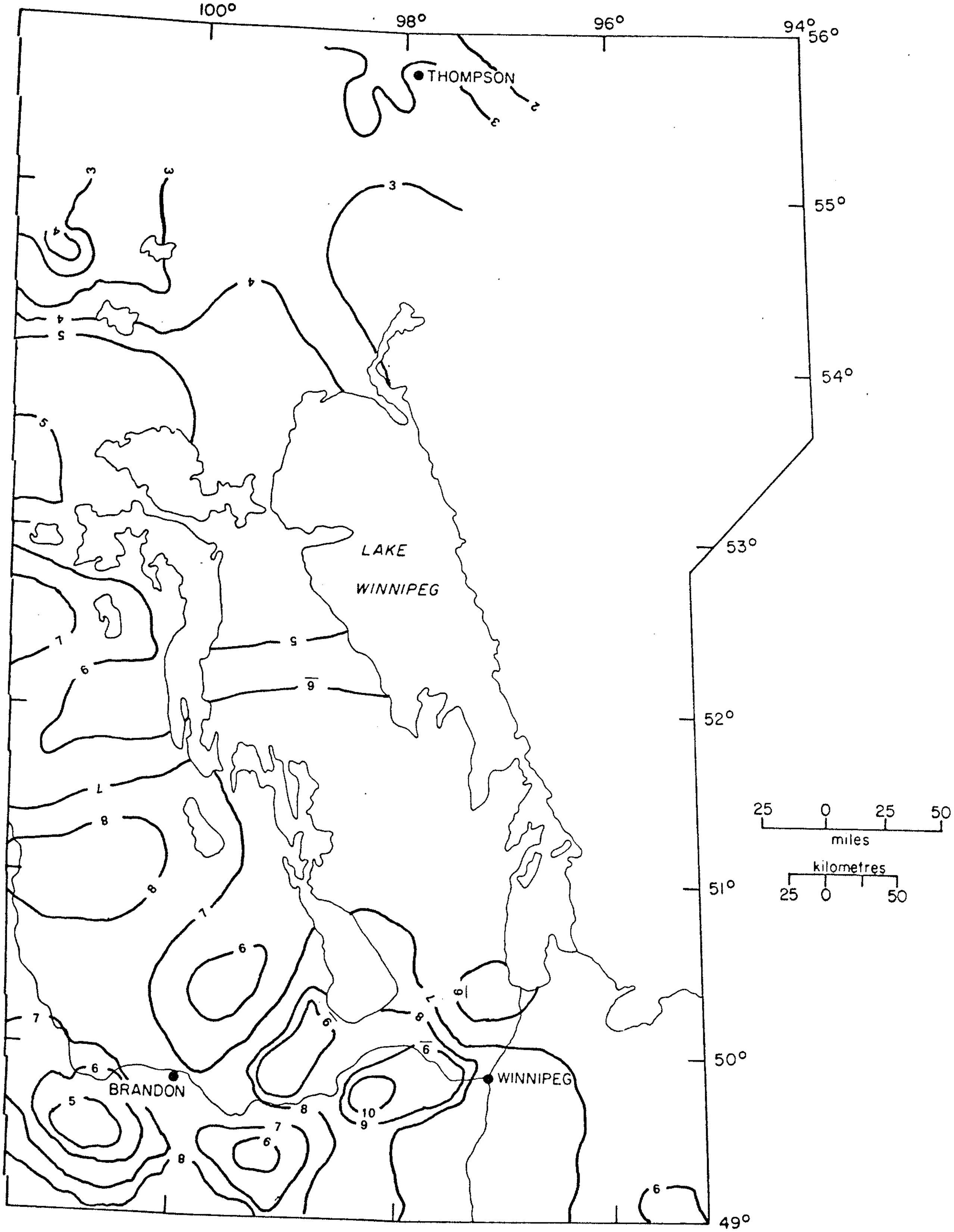


Figure C3: Mean Annual Soil Temperature at the 5 cm Depth.

Isoline Int. = 1C

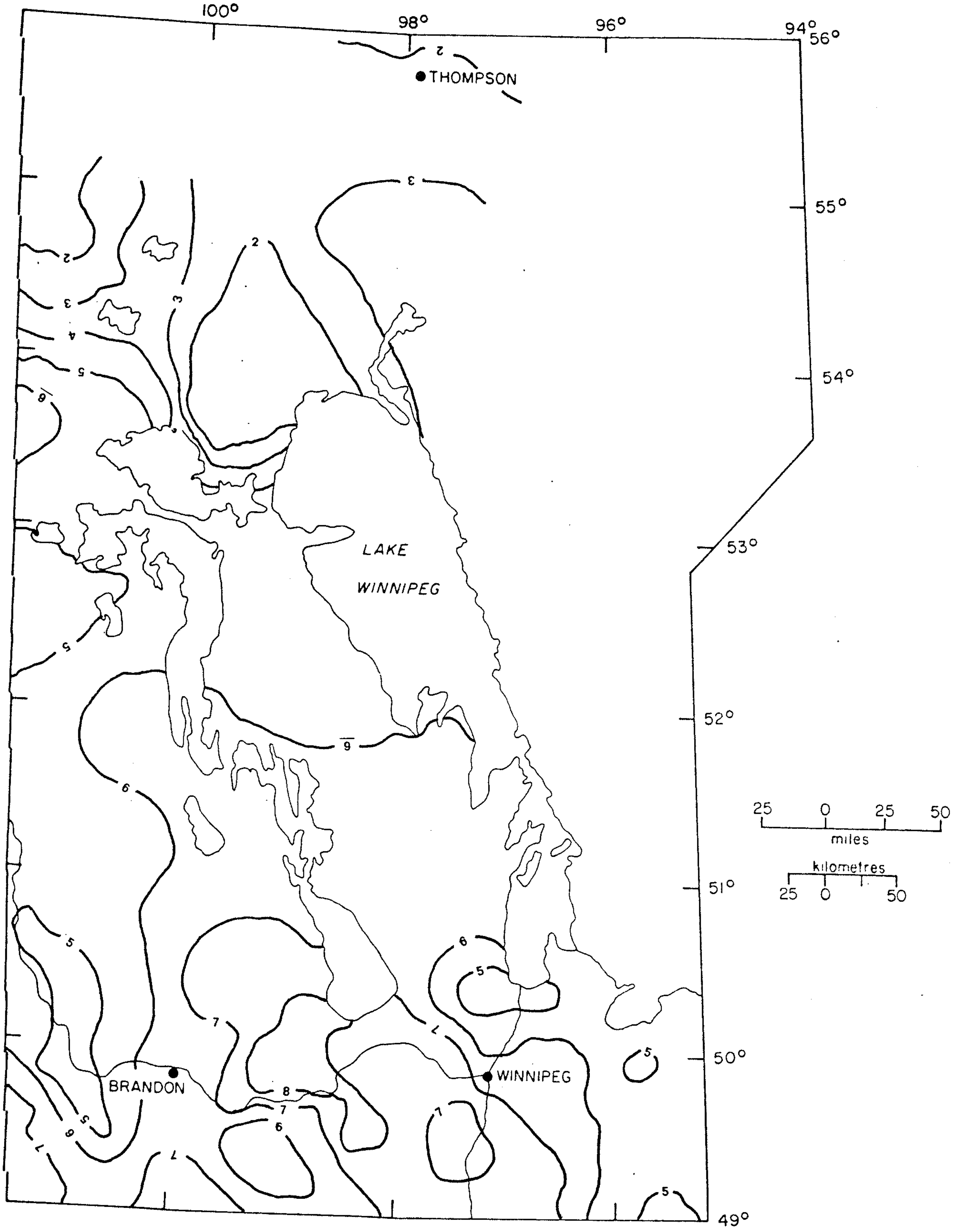


Figure C4: Mean Annual Soil Temperature at the 10 cm Depth.

Isoline Int. = 1C

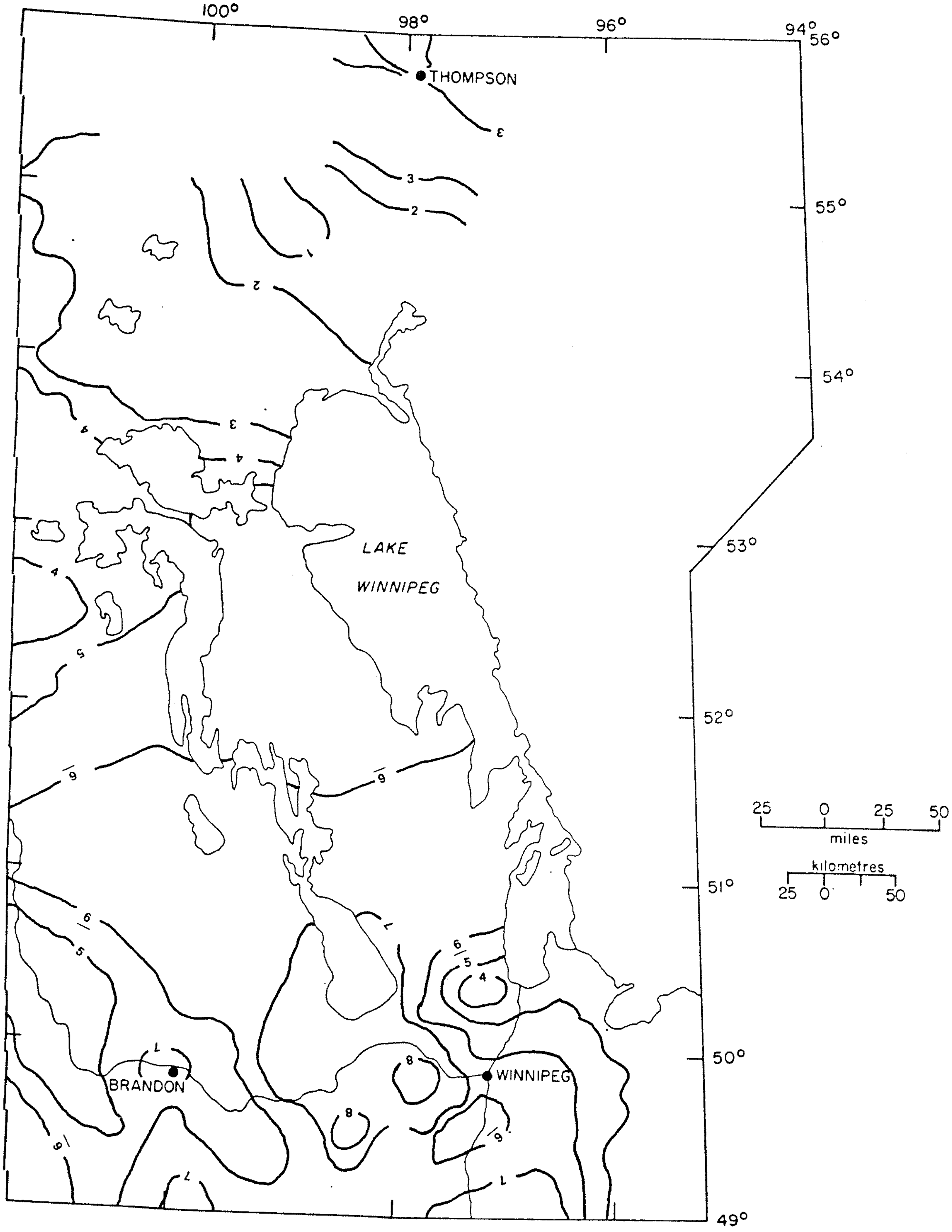


Figure C5: Mean Annual Soil Temperature at the 20 cm Depth.

Isoline Int. = 1C

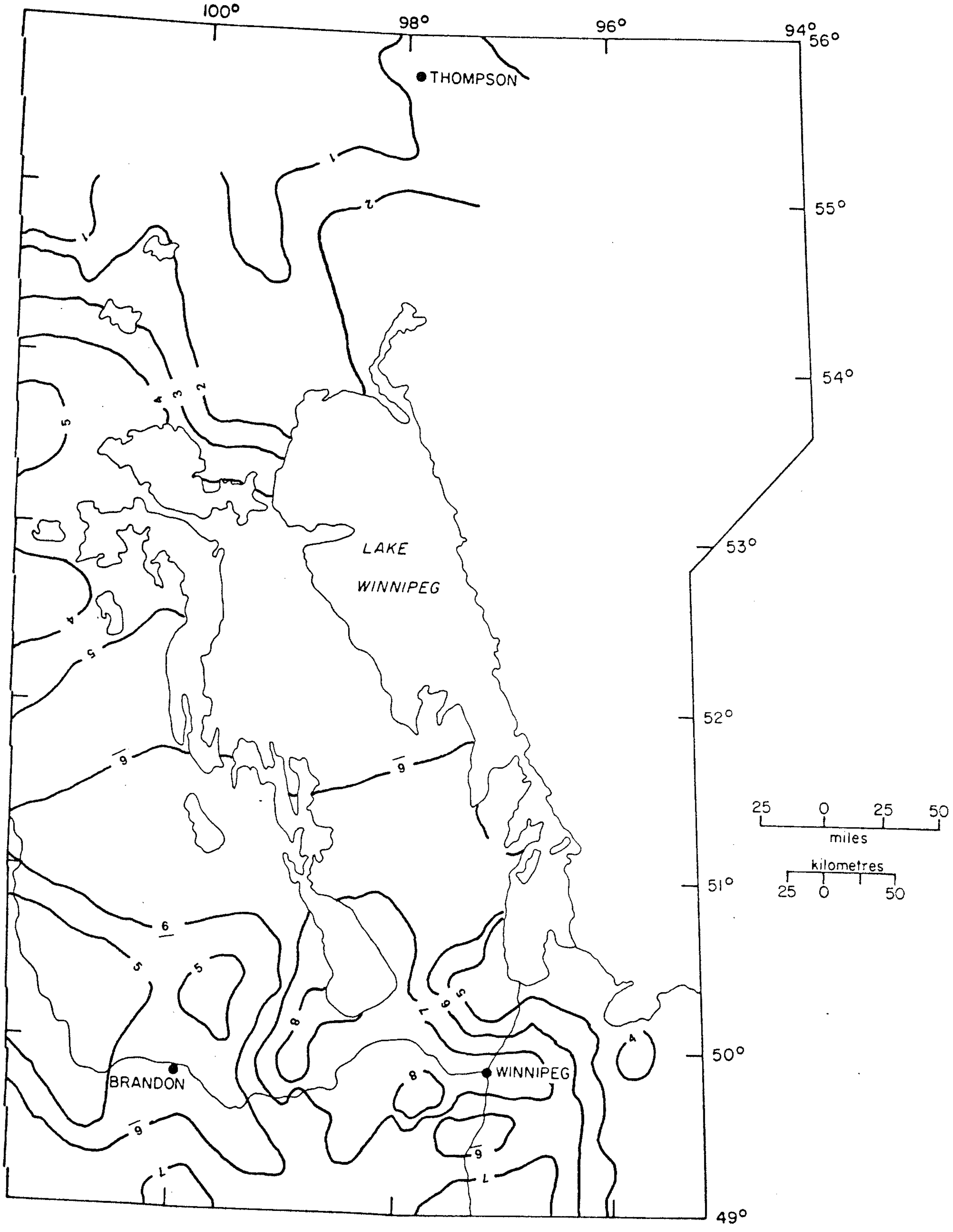


Figure C6: Mean Annual Soil Temperature at the 50 cm Depth.

Isoline Int. = 1C

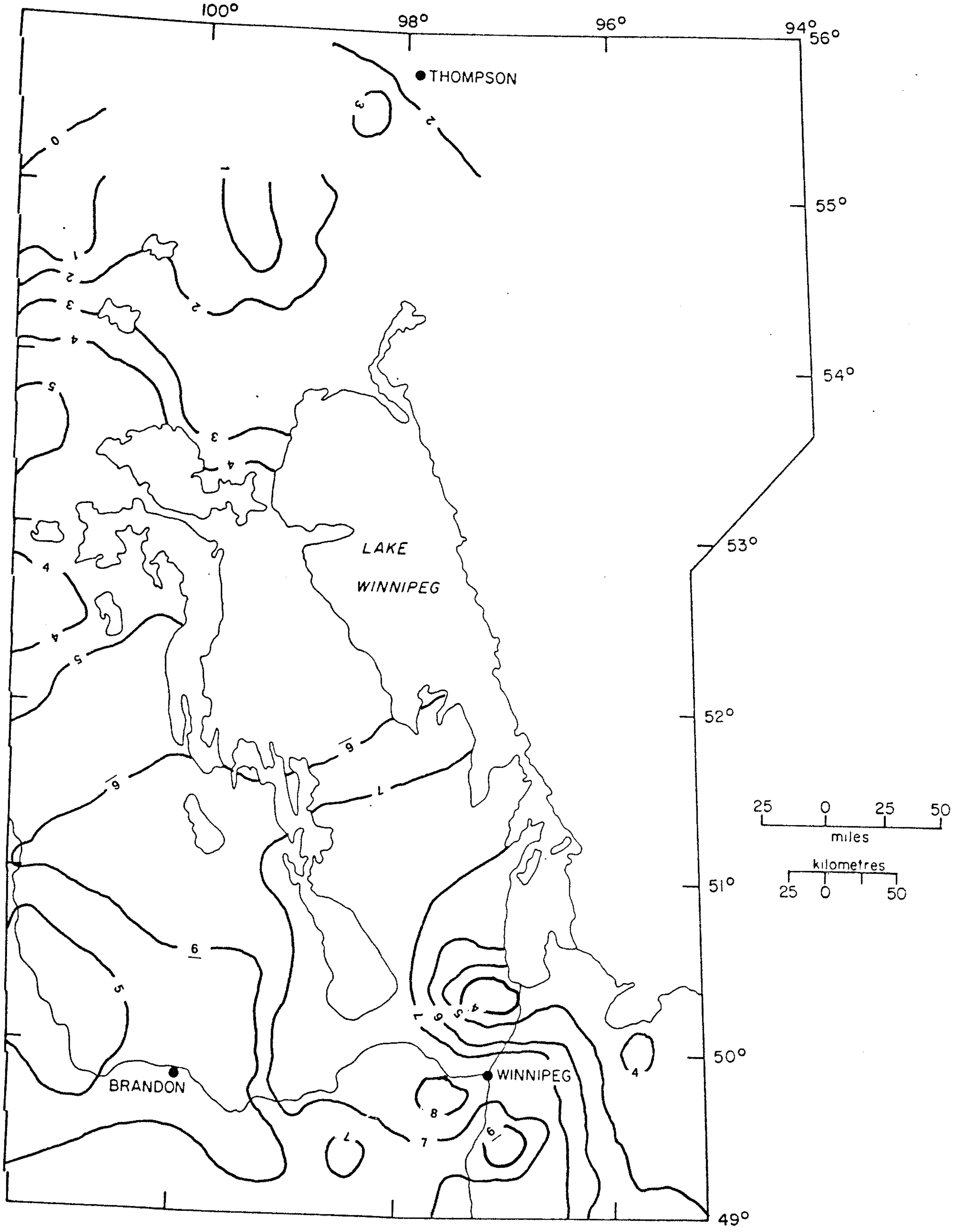


Figure C7: Mean Annual Soil Temperature at the 100 cm Depth.

Isoline Int. = 1C

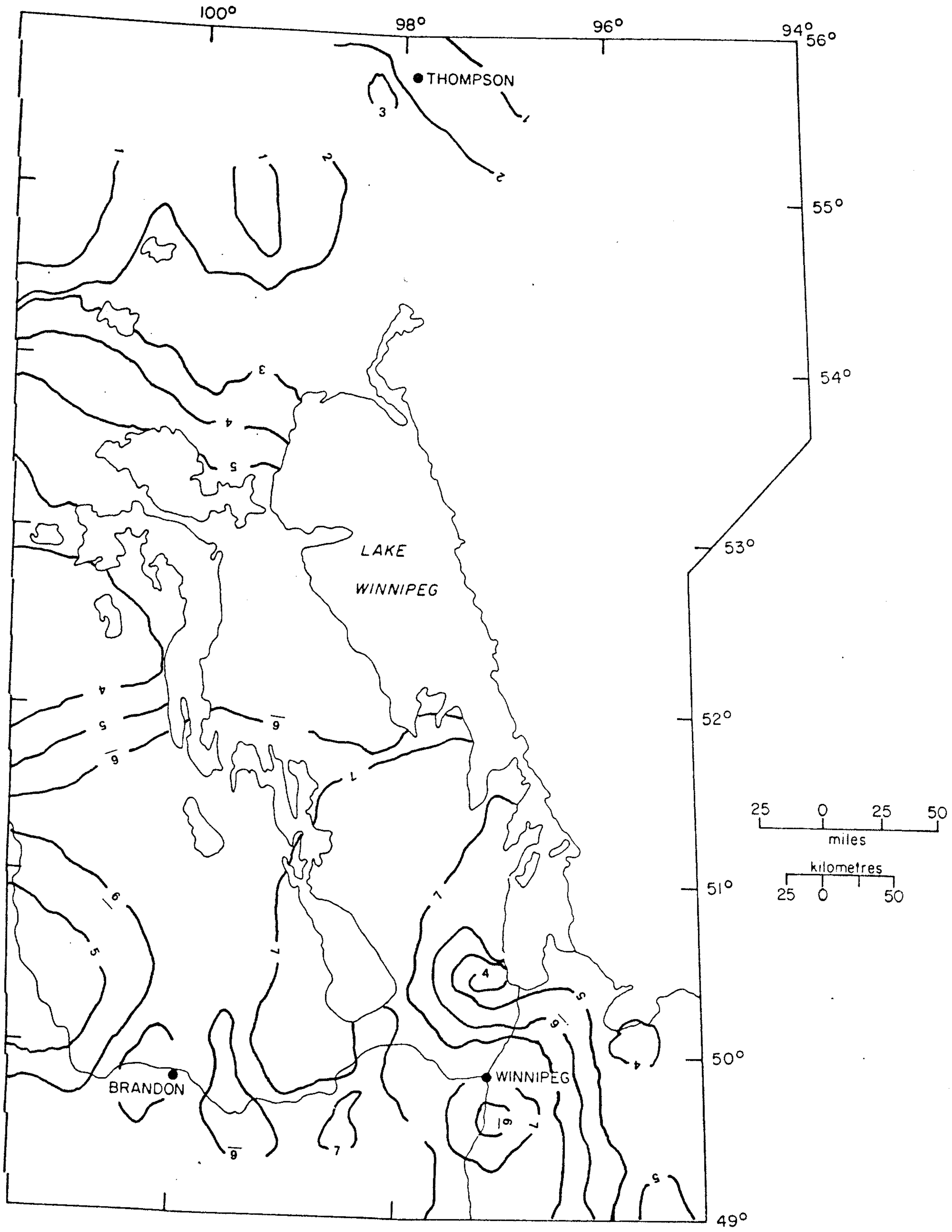


Figure C8: Mean Annual Soil Temperature at the 150 cm Depth.

Isoline Int. = 1C

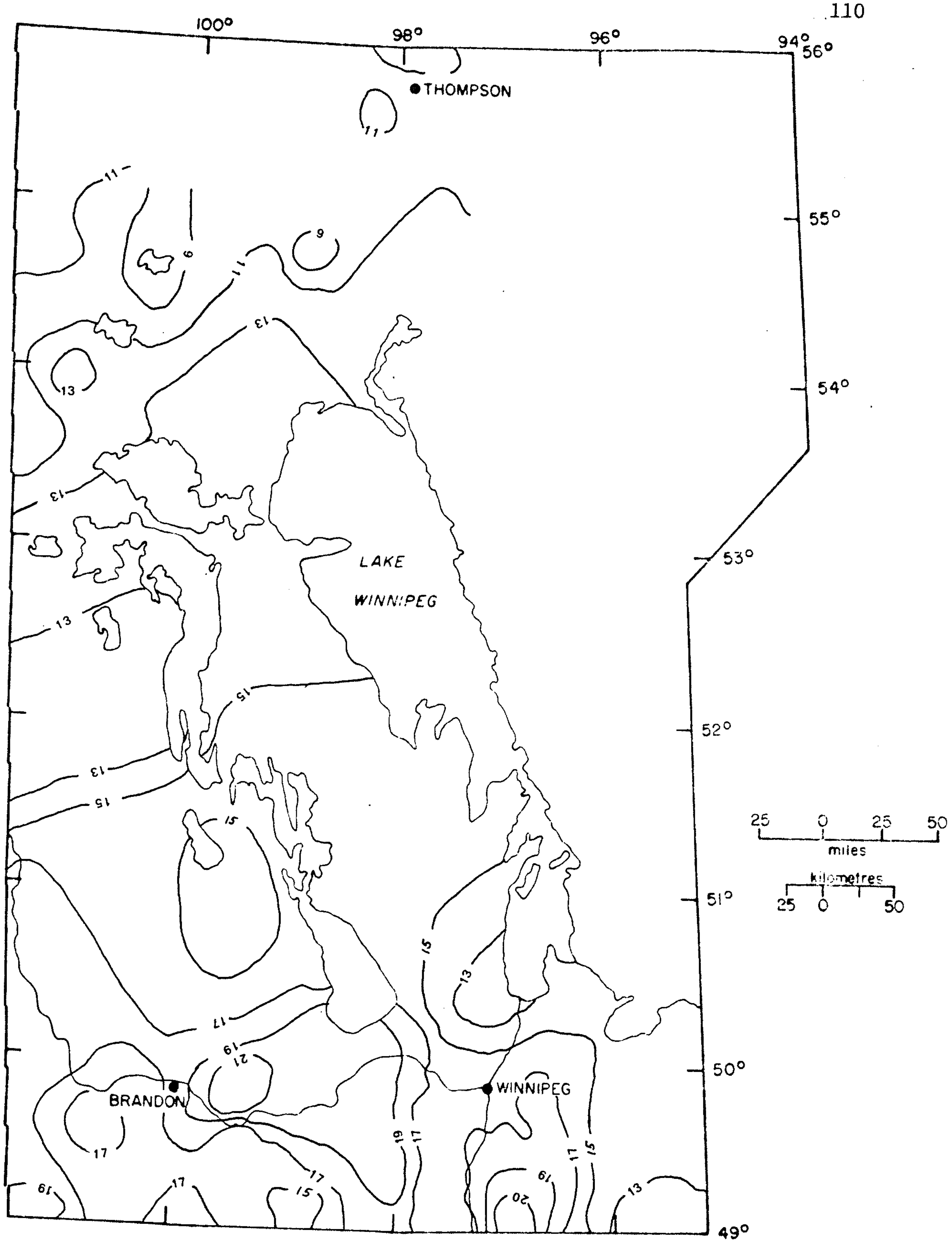


Figure C9: Mean Summer Temperature at 10 cm.
Isoline Int. = 2C.

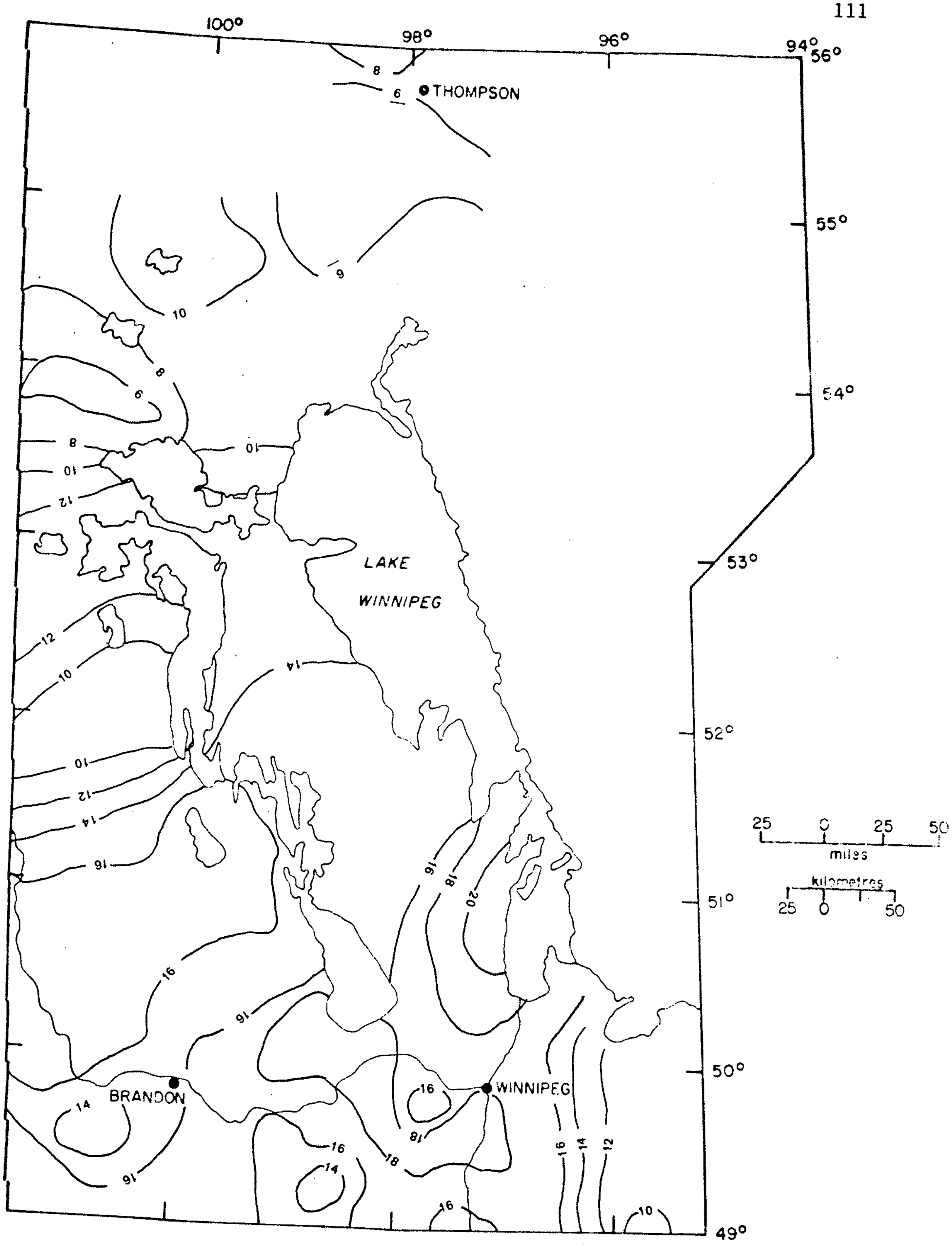


Figure C10: Mean Summer Temperature at 20 cm.
Isoline Int. = 2C.

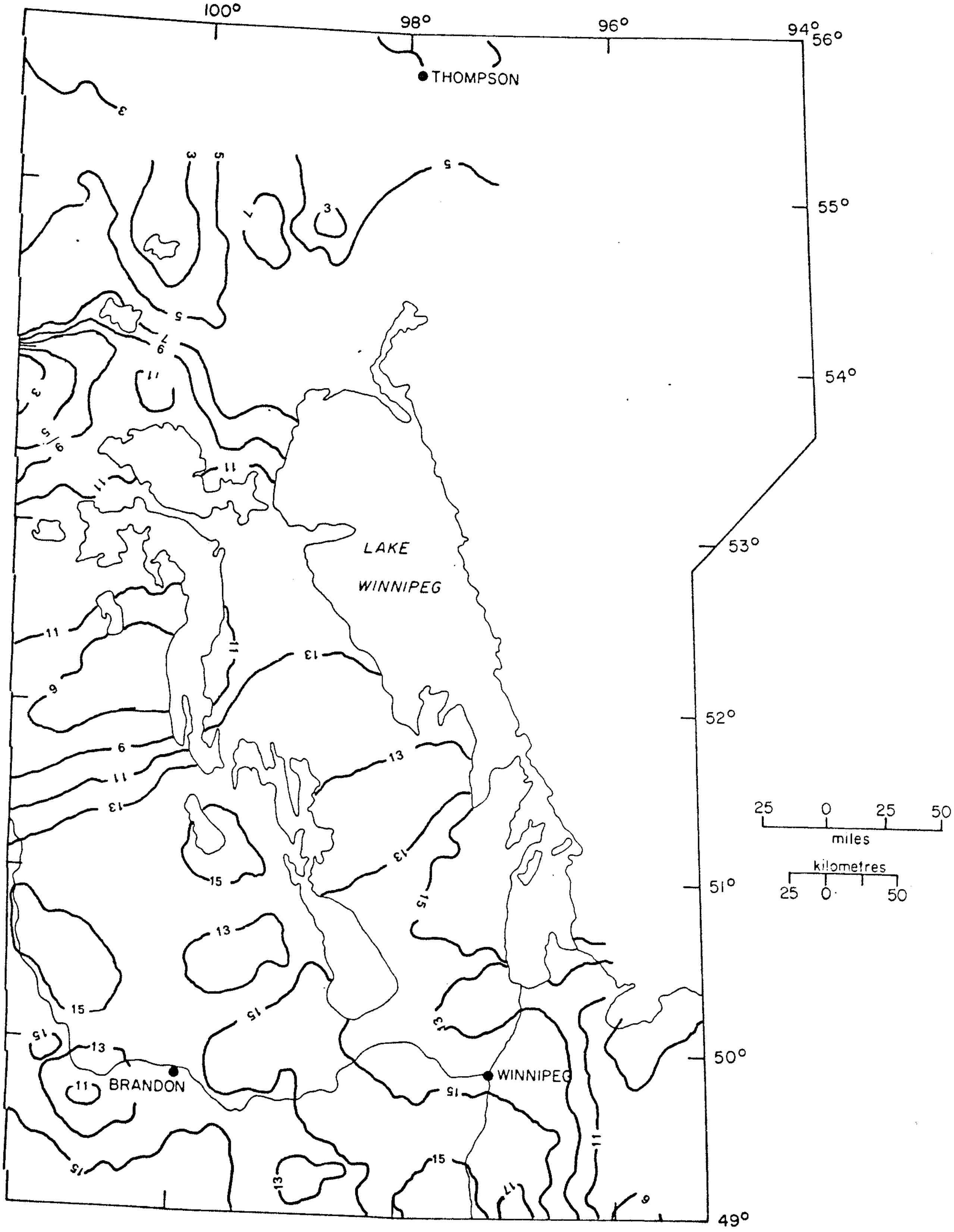


Figure C11: Mean Summer Soil Temperature at the 50 cm Depth.

Isoline Int. = 2C

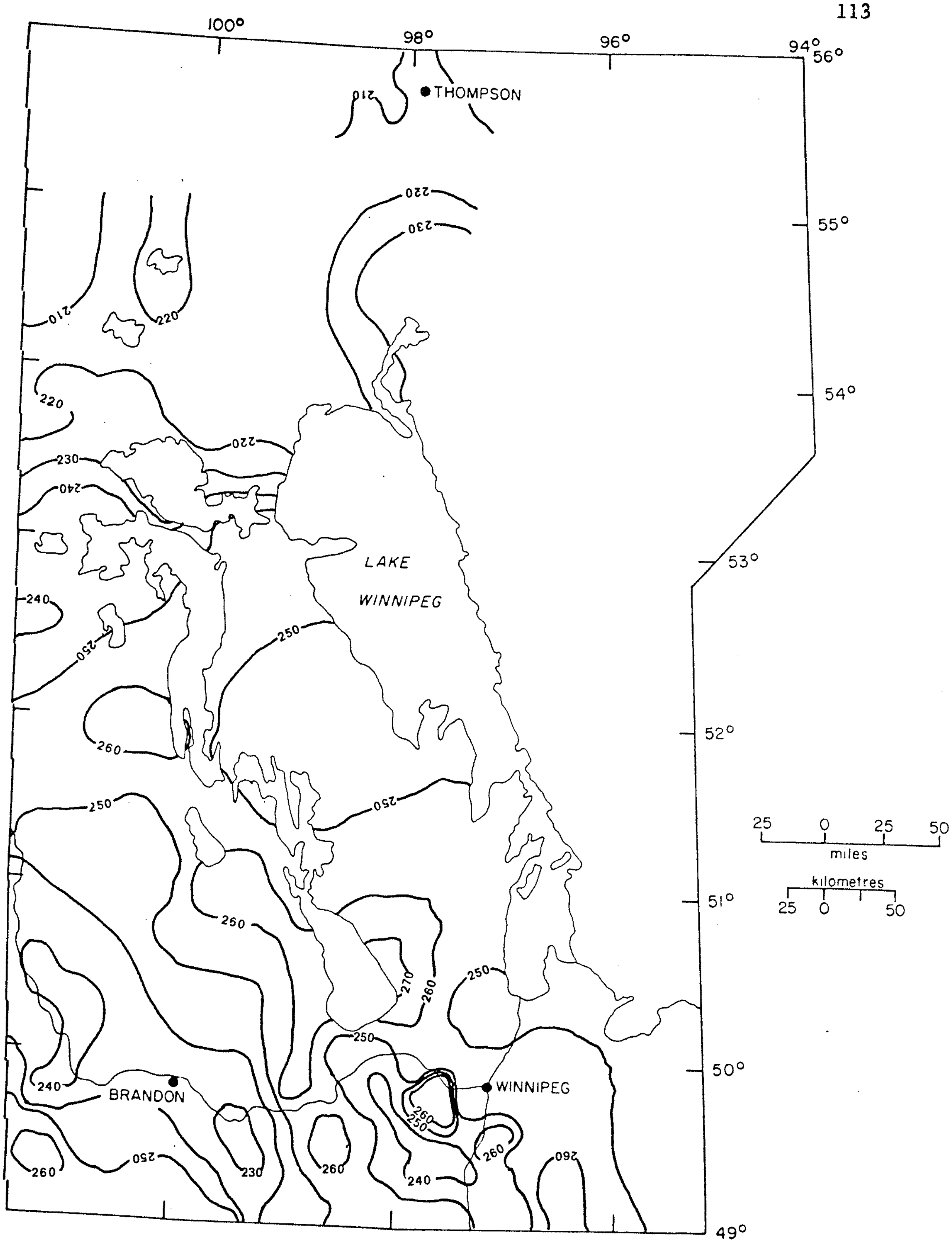


Figure C12 : Days Above 0C at the 5 cm Depth.

Isoline Int. = 10

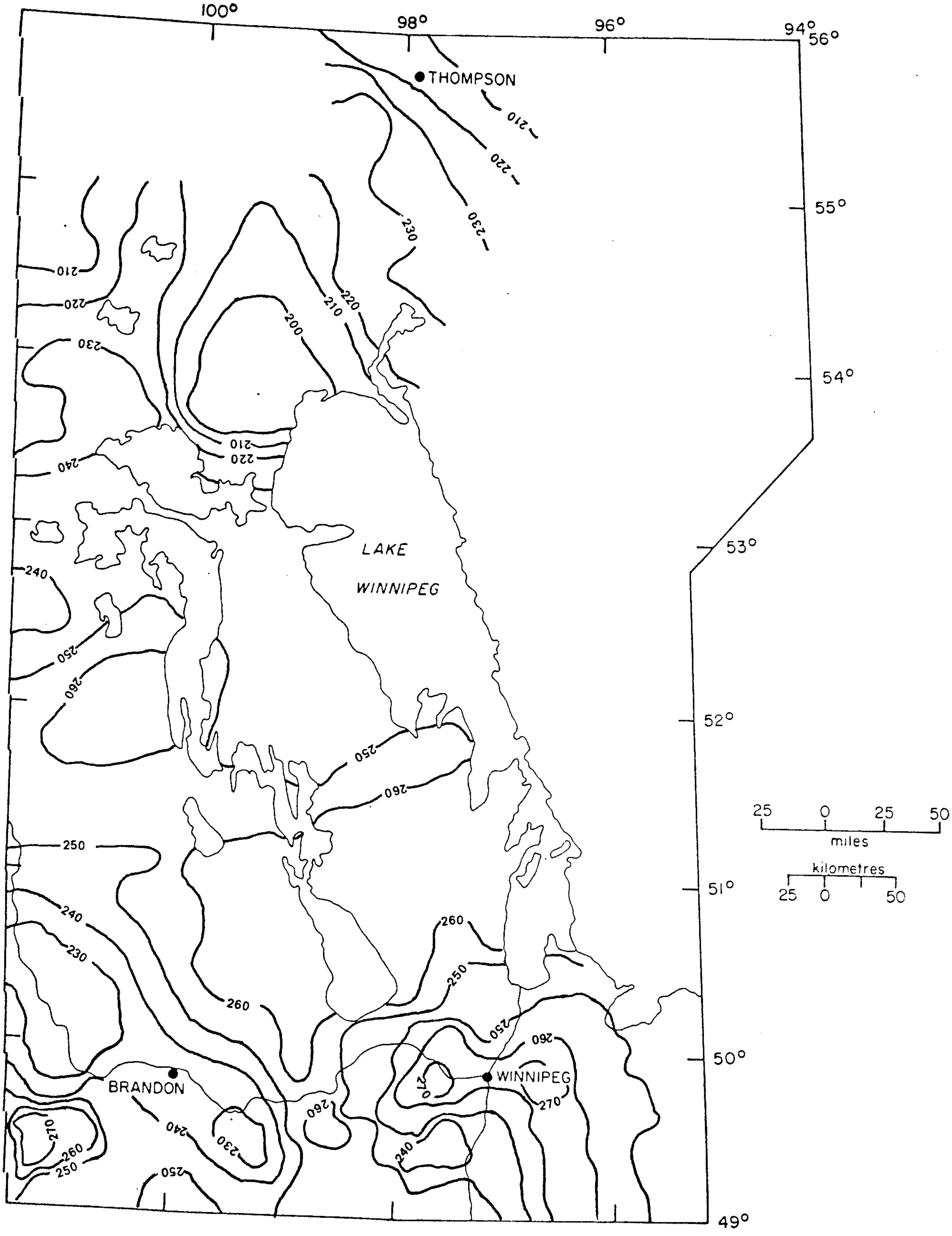


Figure C13 : Days Above 0C at the 10 cm Depth.

Isoline Int. = 10

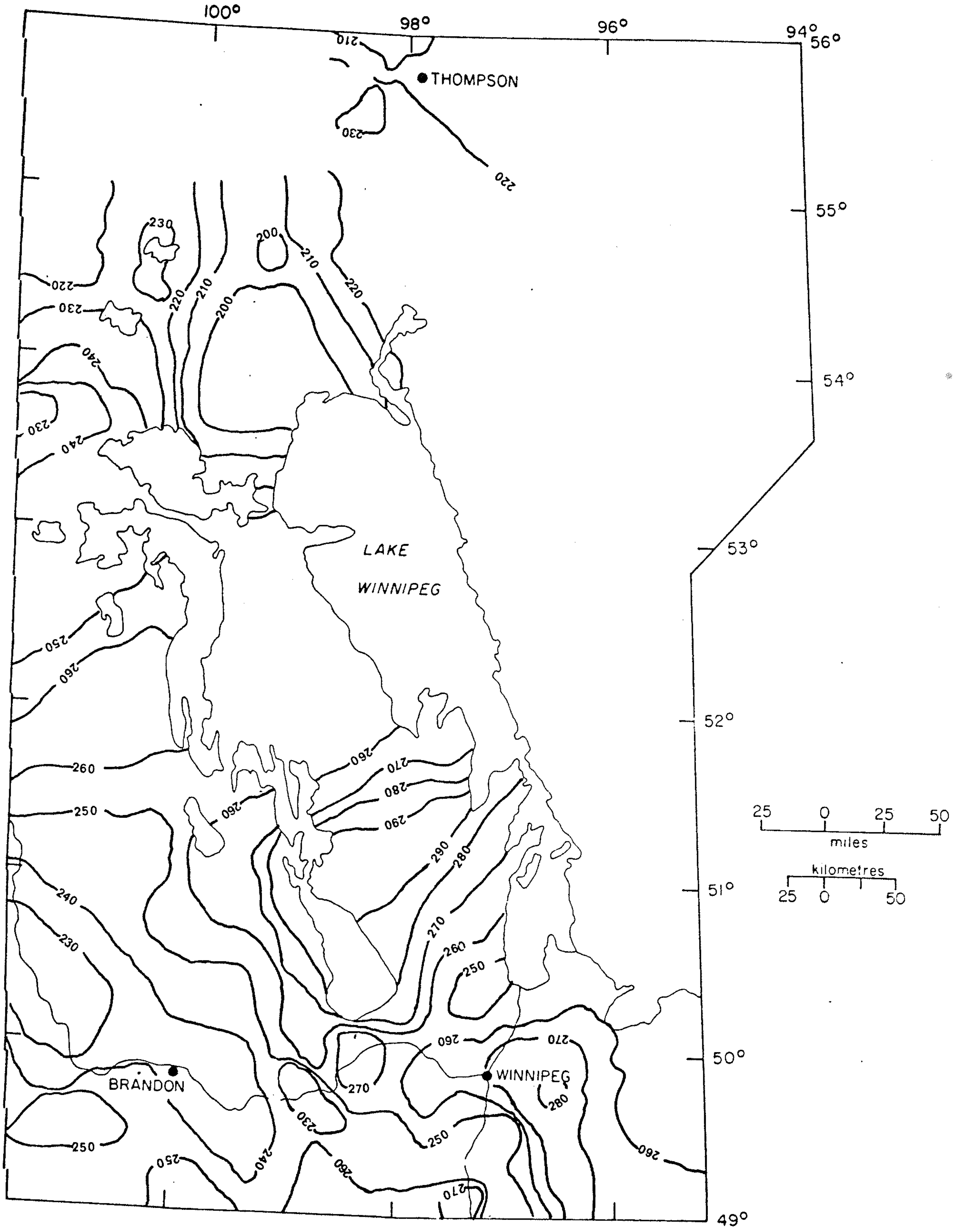


Figure C14 : Days Above OC at the 20 cm Depth.

Isoline Int. = 10

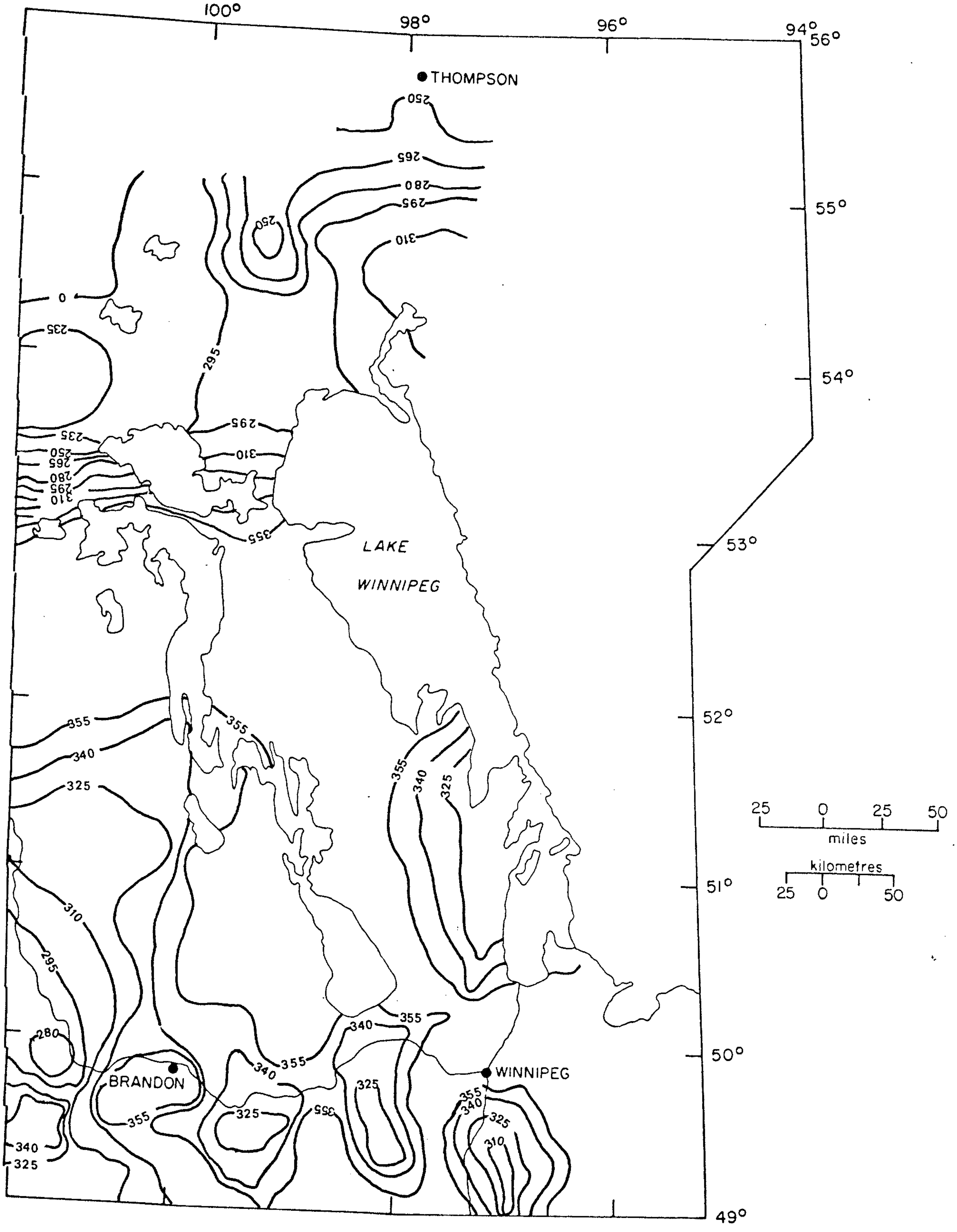


Figure C15 : Days Above 0C at the 50 cm Depth.

Isoline Int. = 15

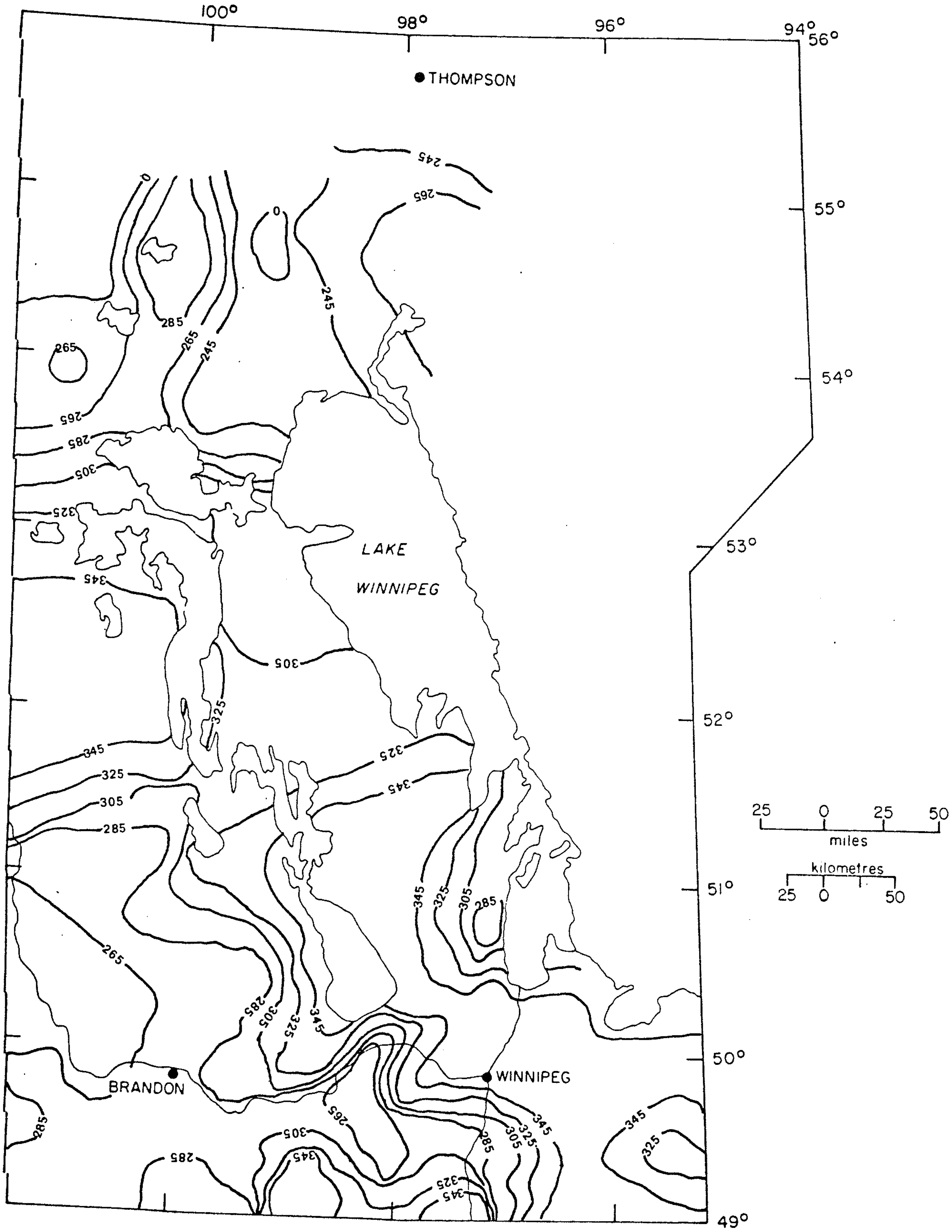


Figure C16 : Days Above 0C at the 100 cm Depth.

Isoline Int. = 20

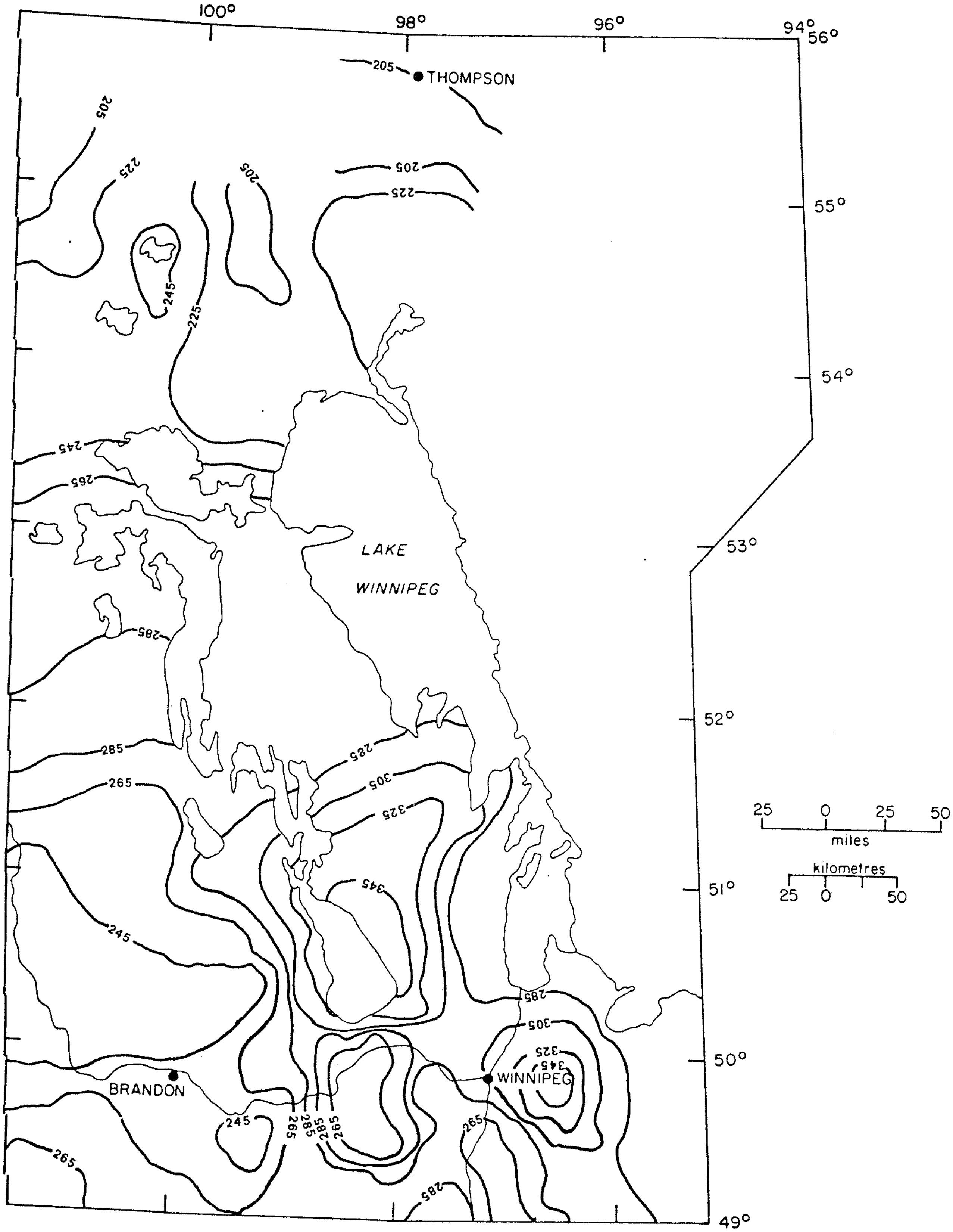


Figure C17 : Days Above 0C at the 150 cm Depth.

Isoline Int. = 20

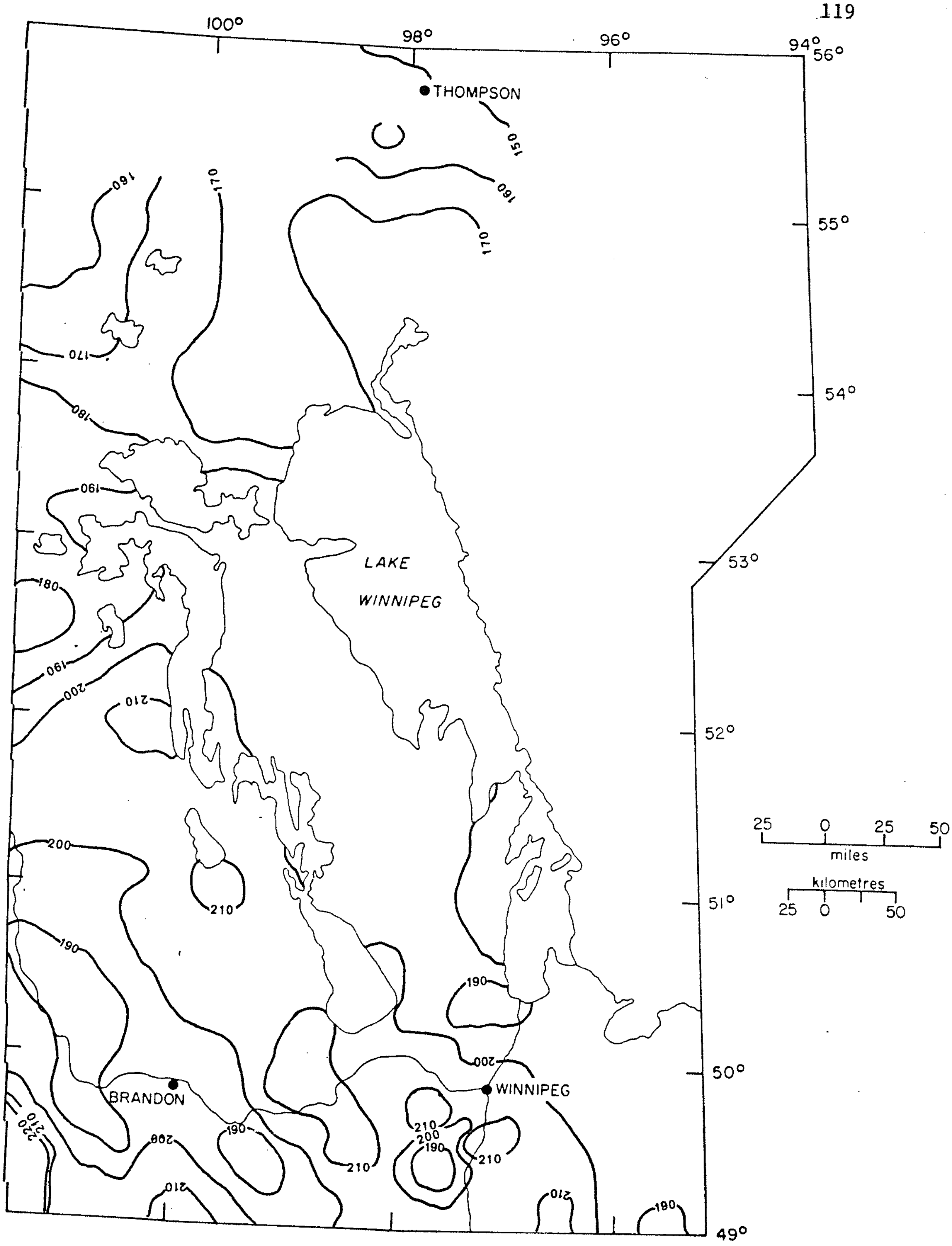


Figure C18 : Days Above 5C at the 5 cm Depth.

Isoline Int. = 10

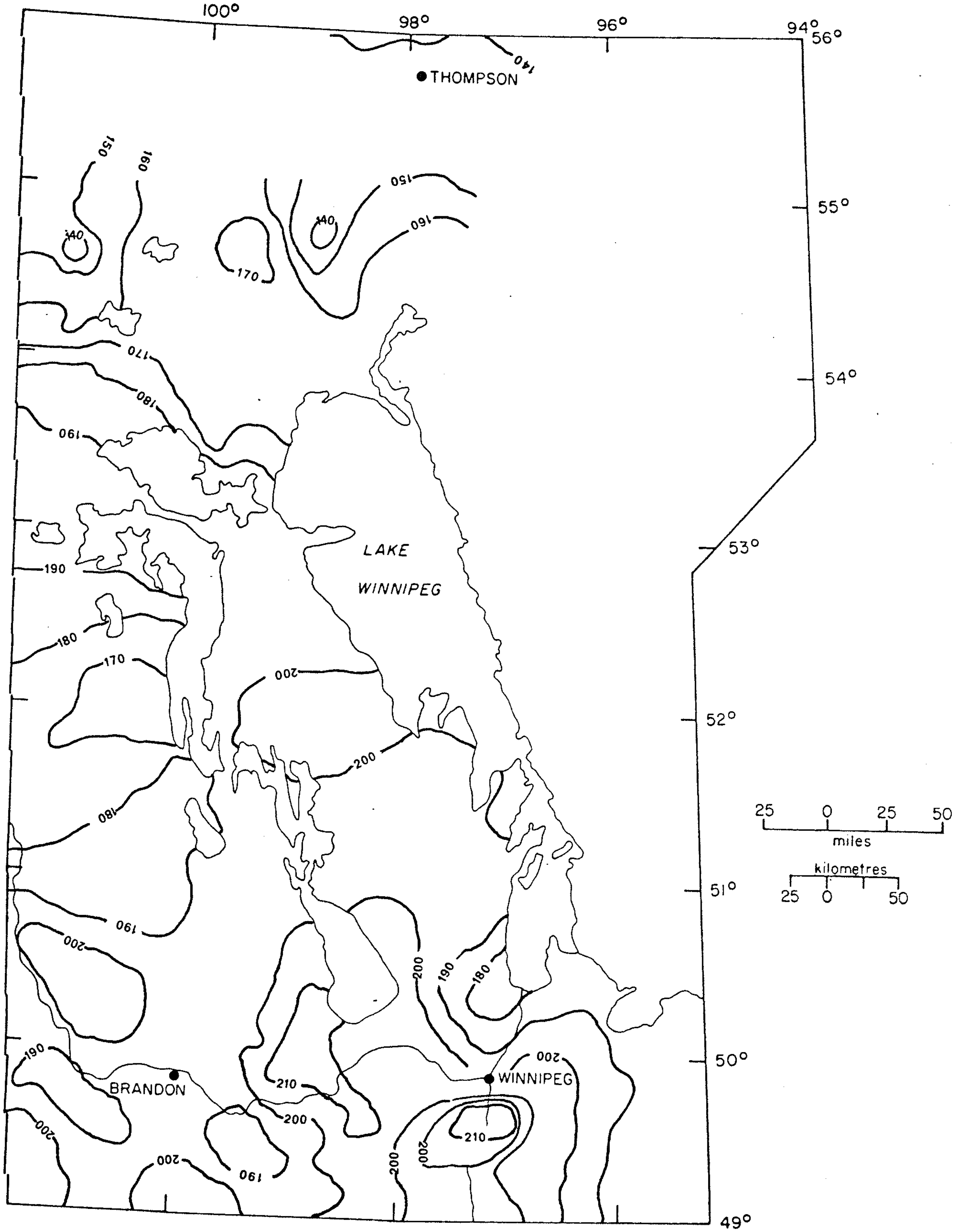


Figure C19 : Days Above 5C at the 10 cm Depth.

Isoline Int. = 10

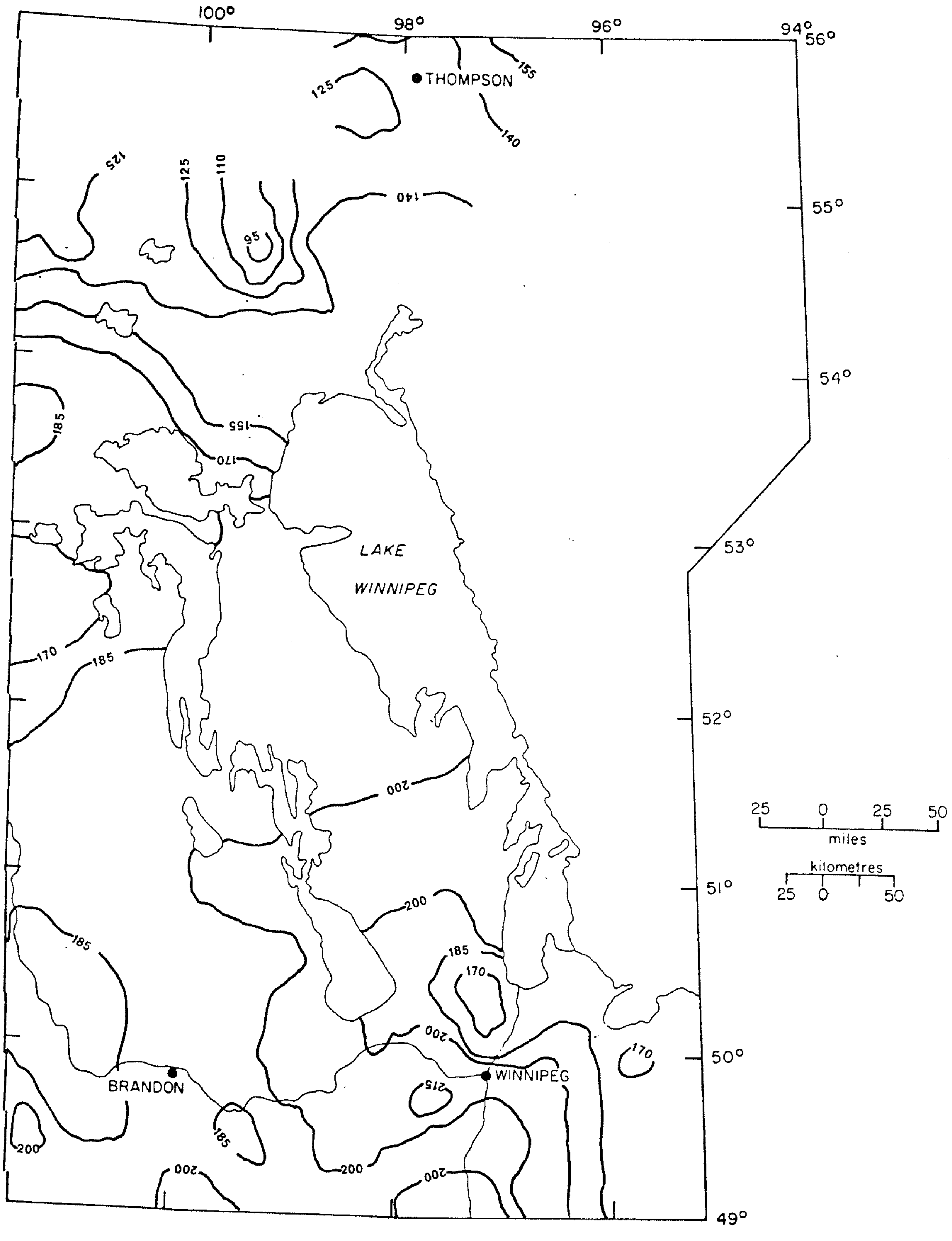


Figure C20 : Days Above 5C at the 20 cm Depth.

Isoline Int. = 15

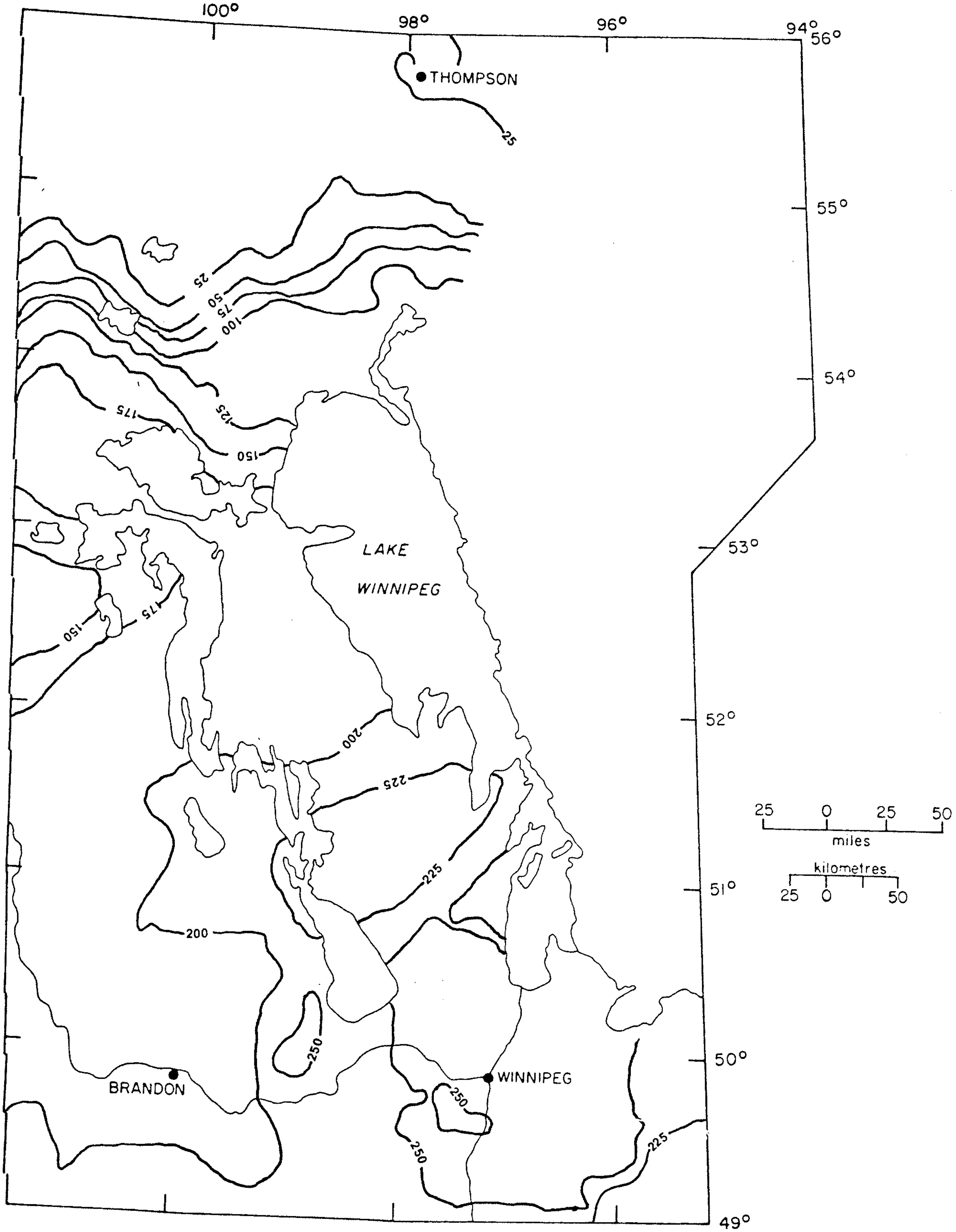


Figure C21 : Days Above 5c at the 100 cm Depth.

Isoline Int. = 25

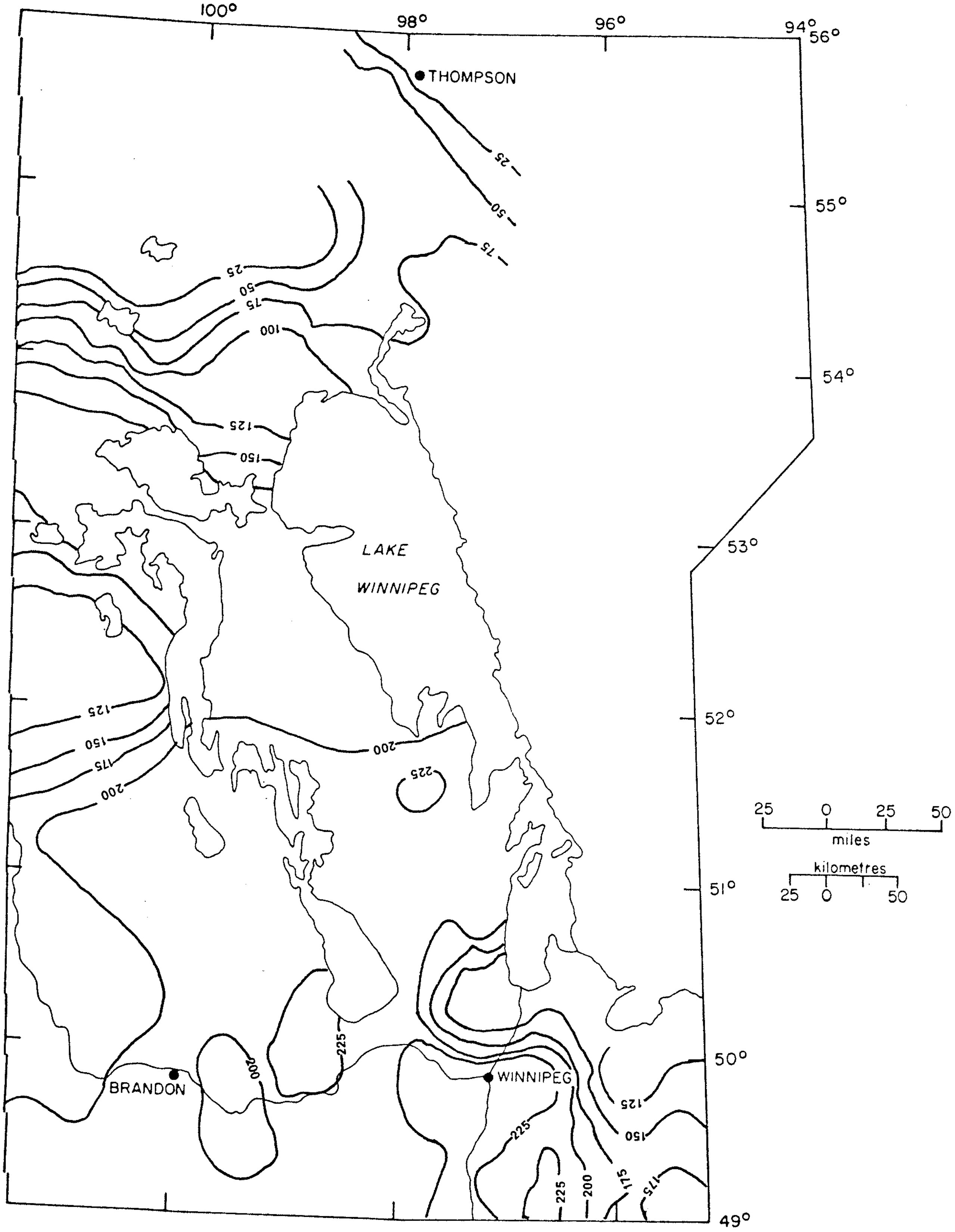


Figure C22 : Days Above 5C at the 150 cm Depth.

Isoline Int. = 25

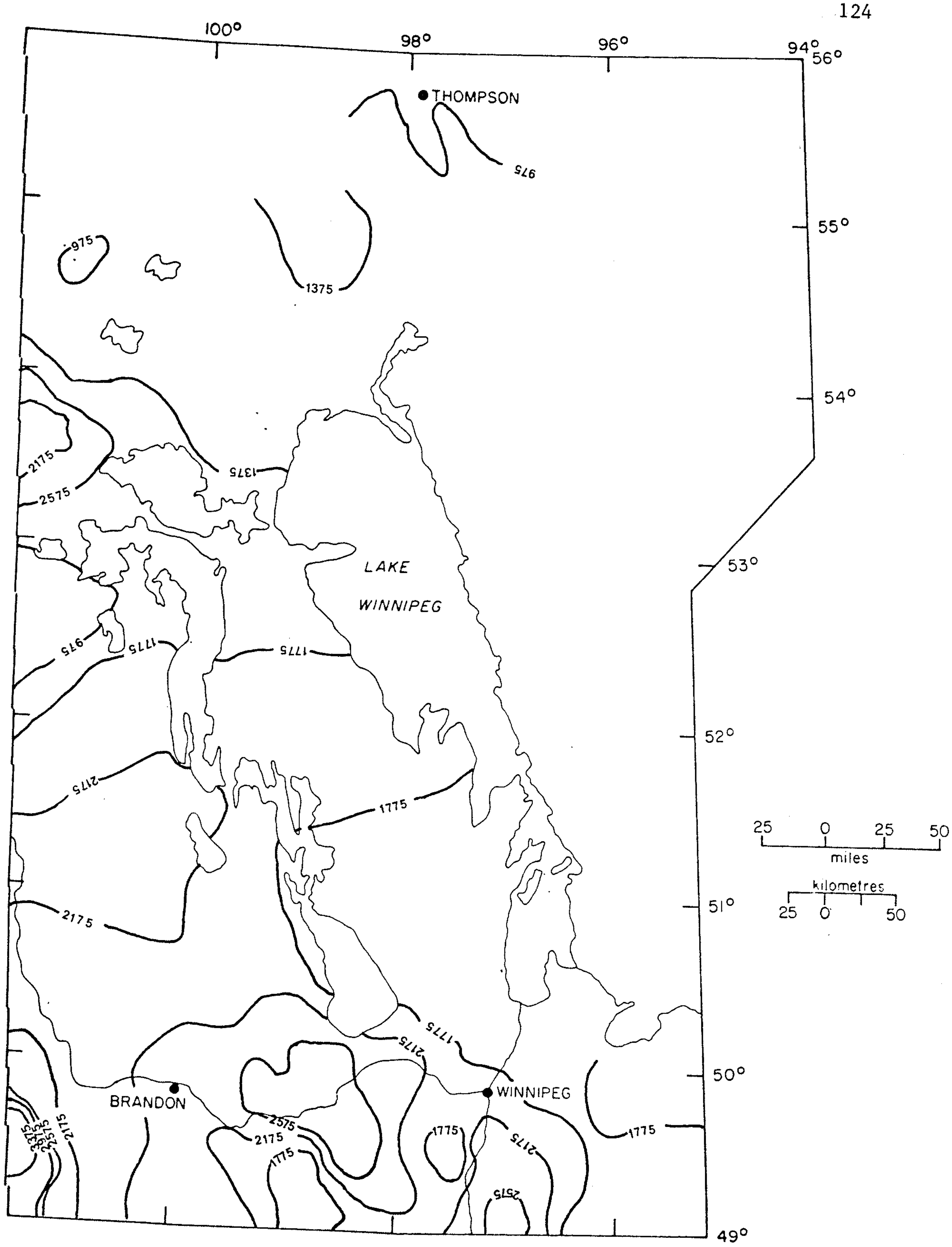


Figure C23 : Degree Days Above 5C at the 5 cm Depth

Isoline Int. = 400

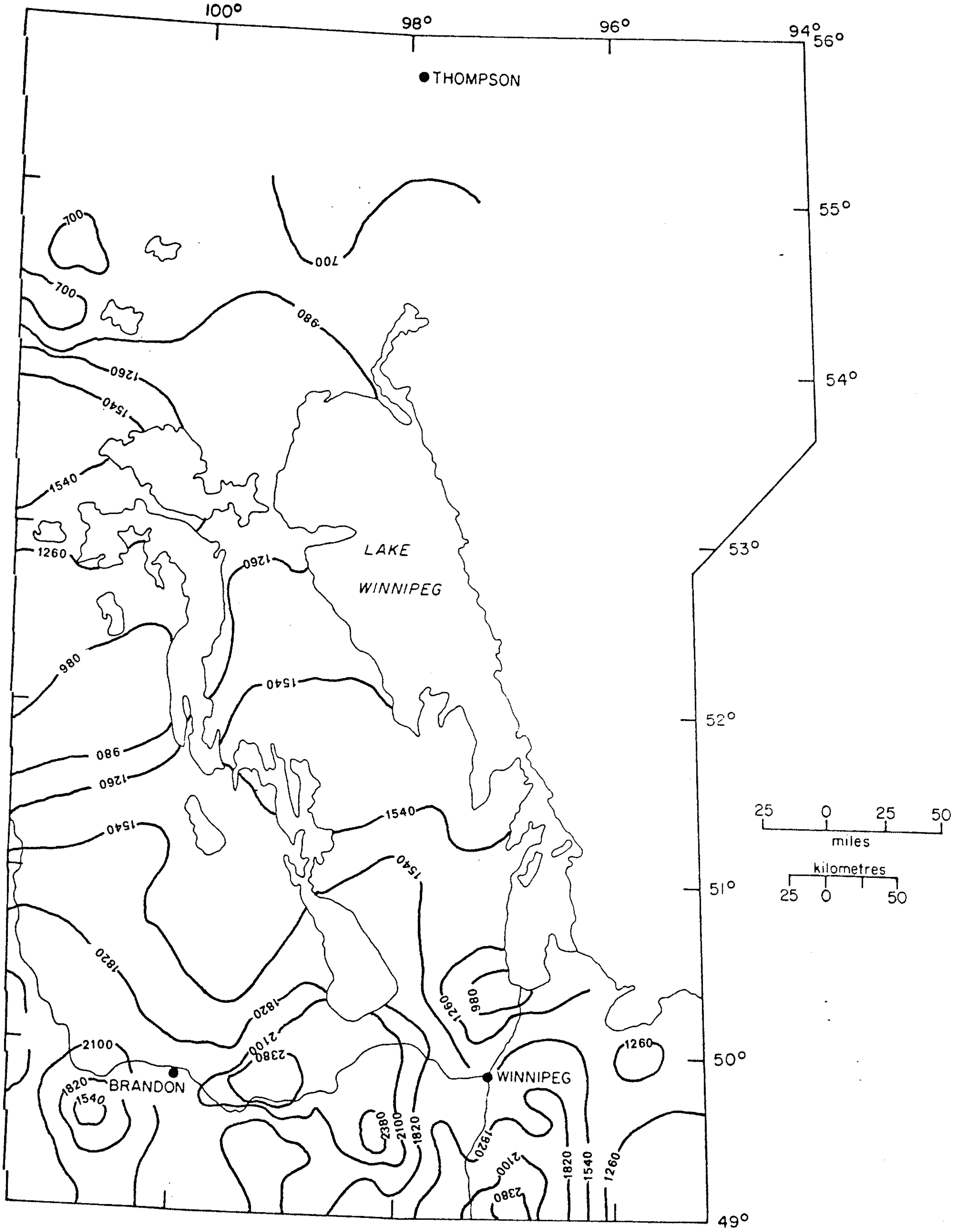


Figure C24 : Degree Days Above 5C at the 10C Depth.

Isoline Int. = 280

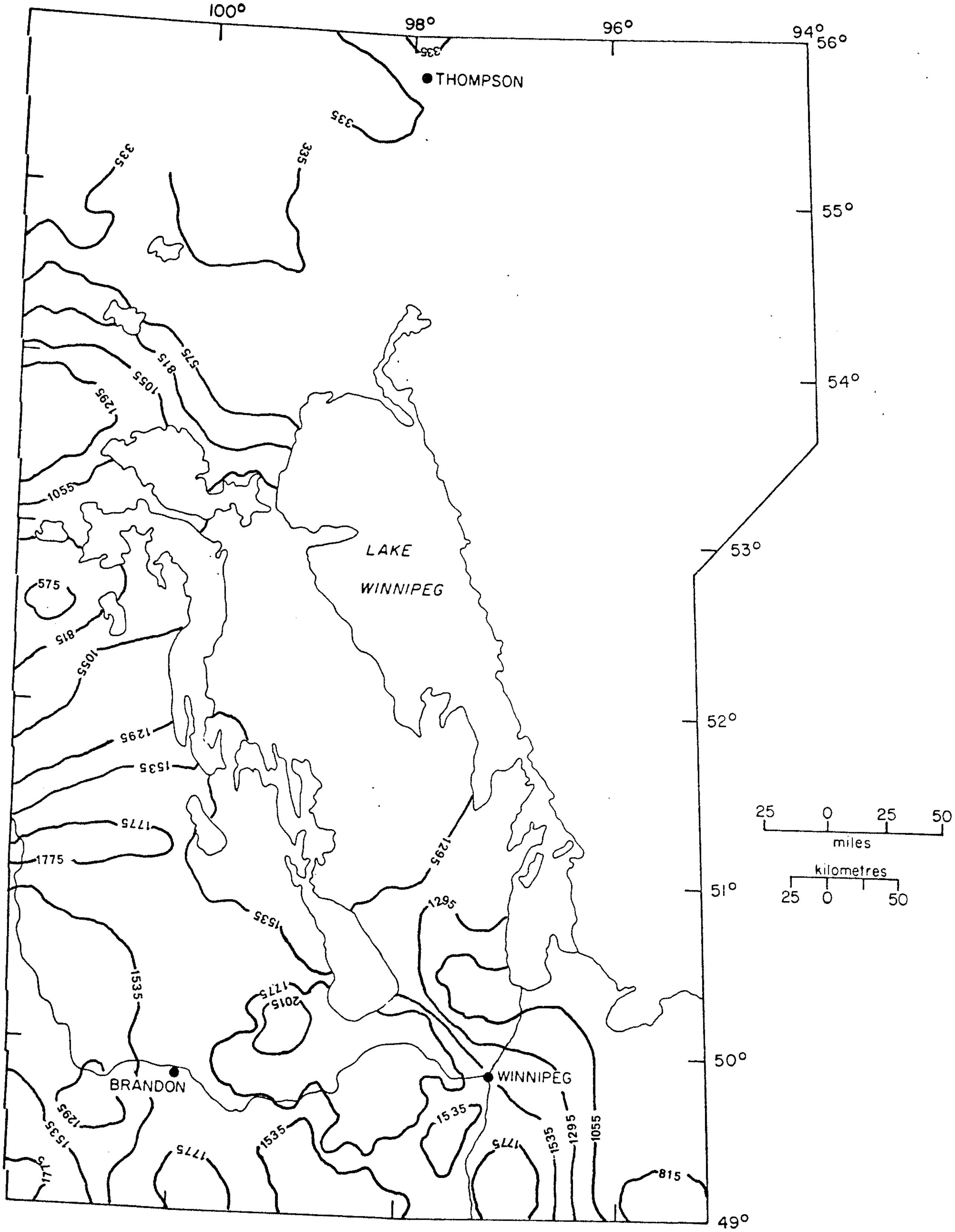


Figure C25: Degree Days Above 5C at the 20 cm Depth.

Isoline Int. = 240

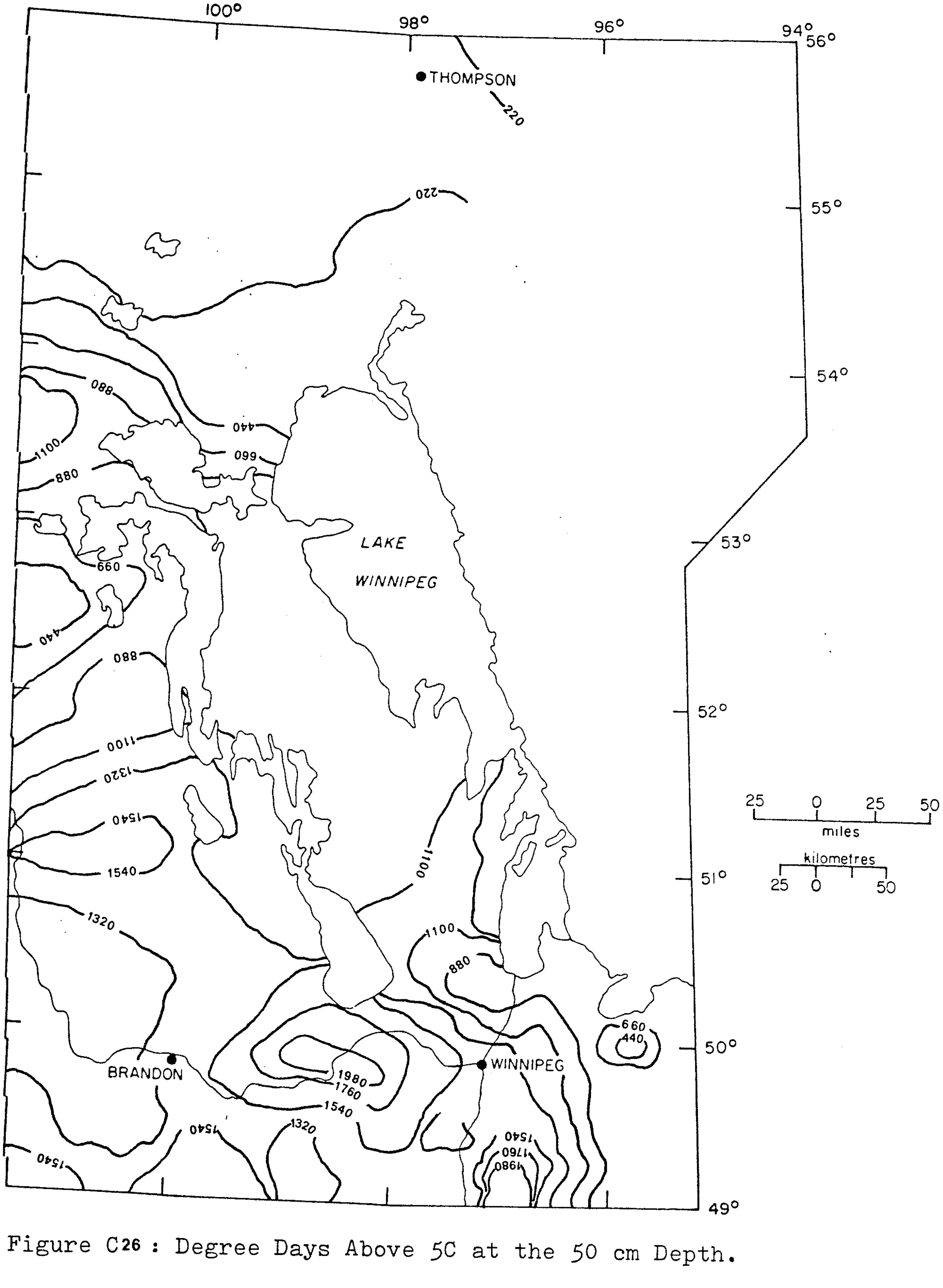


Figure C26 : Degree Days Above 5C at the 50 cm Depth.

Isoline Int. = 220

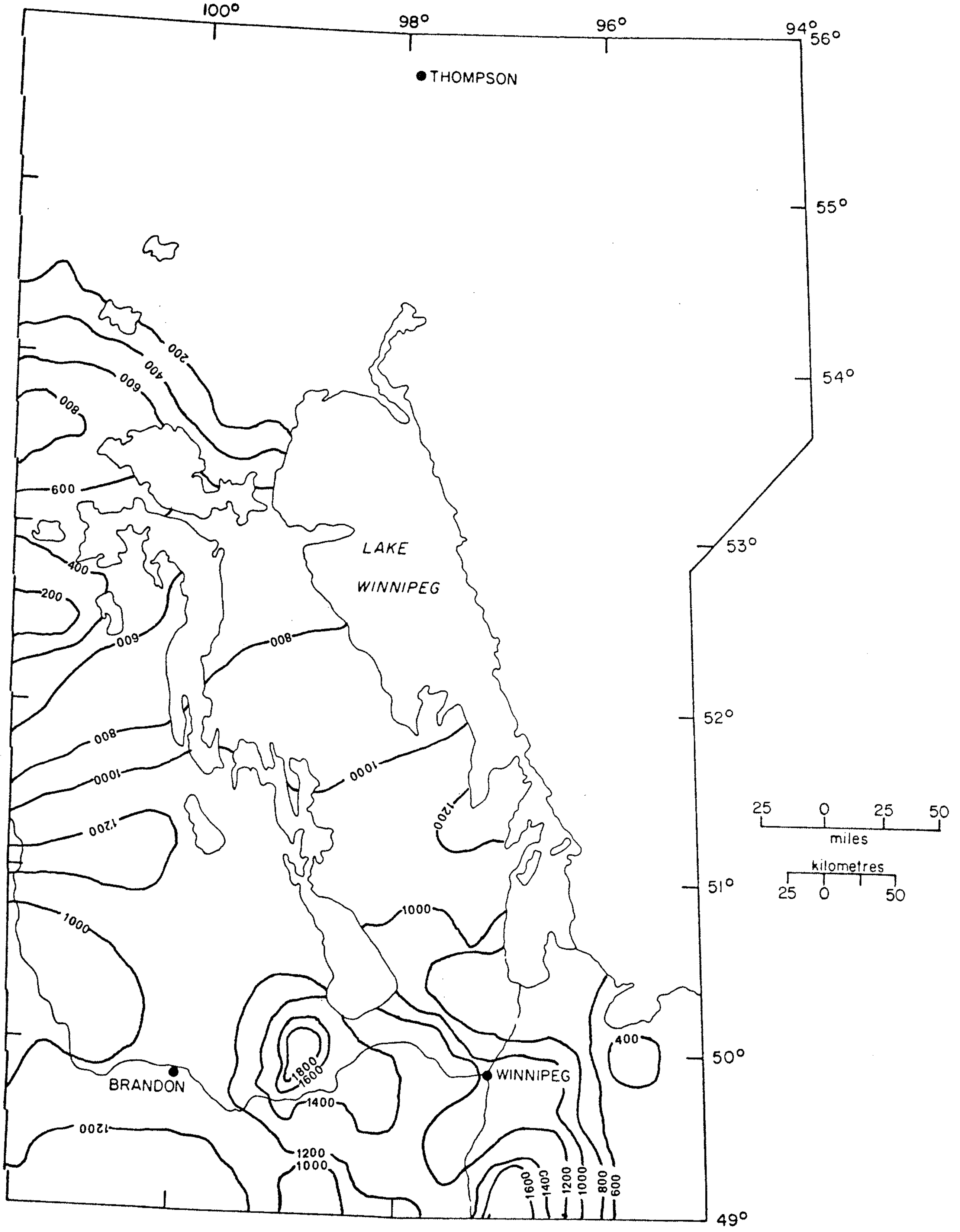


Figure C27 : Degree Days Above 5C at the 100 cm Depth.

Isoline Int. = 200

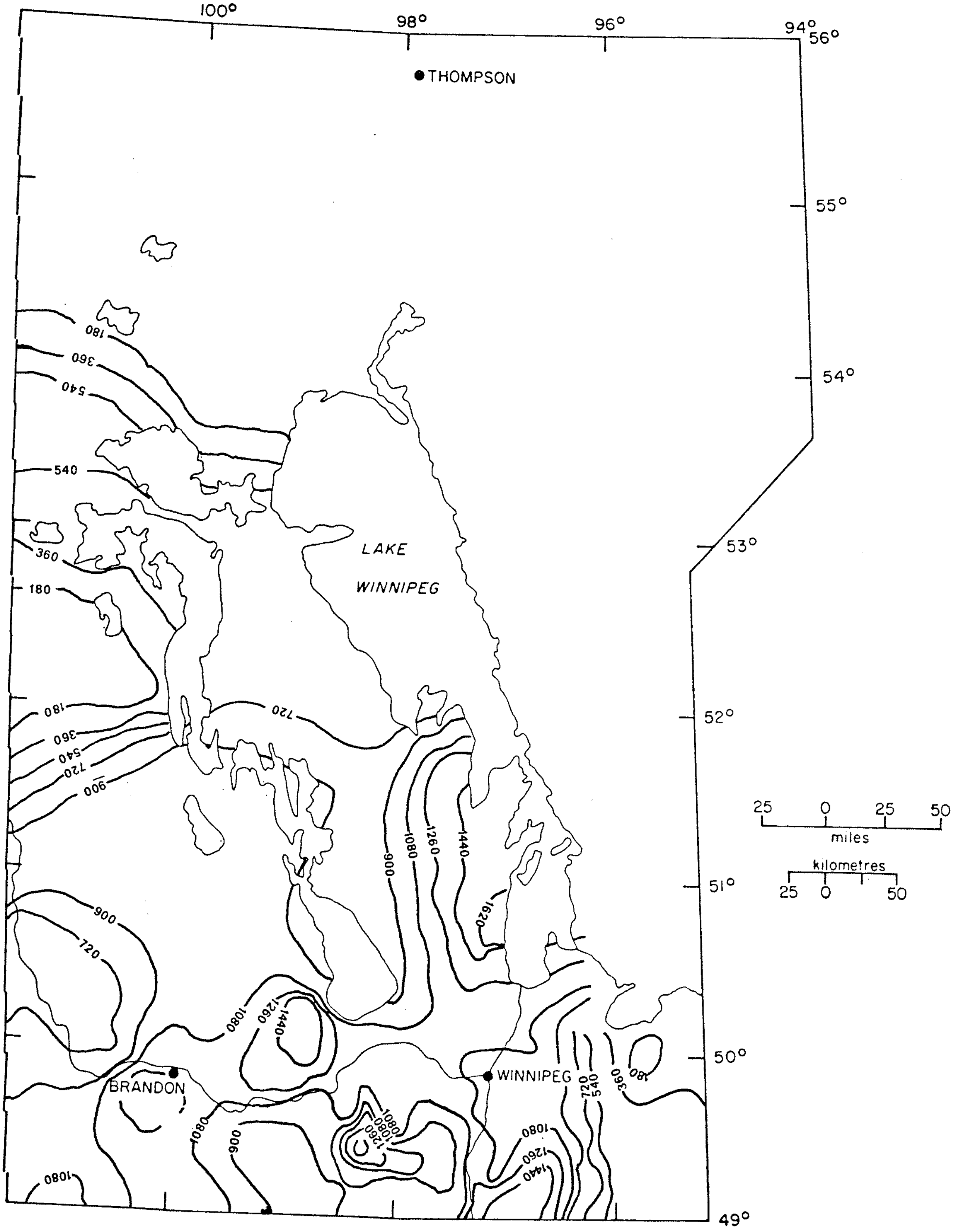


Figure C28 : Degree Days Above 5C at the 150 cm Depth.

Isoline Int. = 180

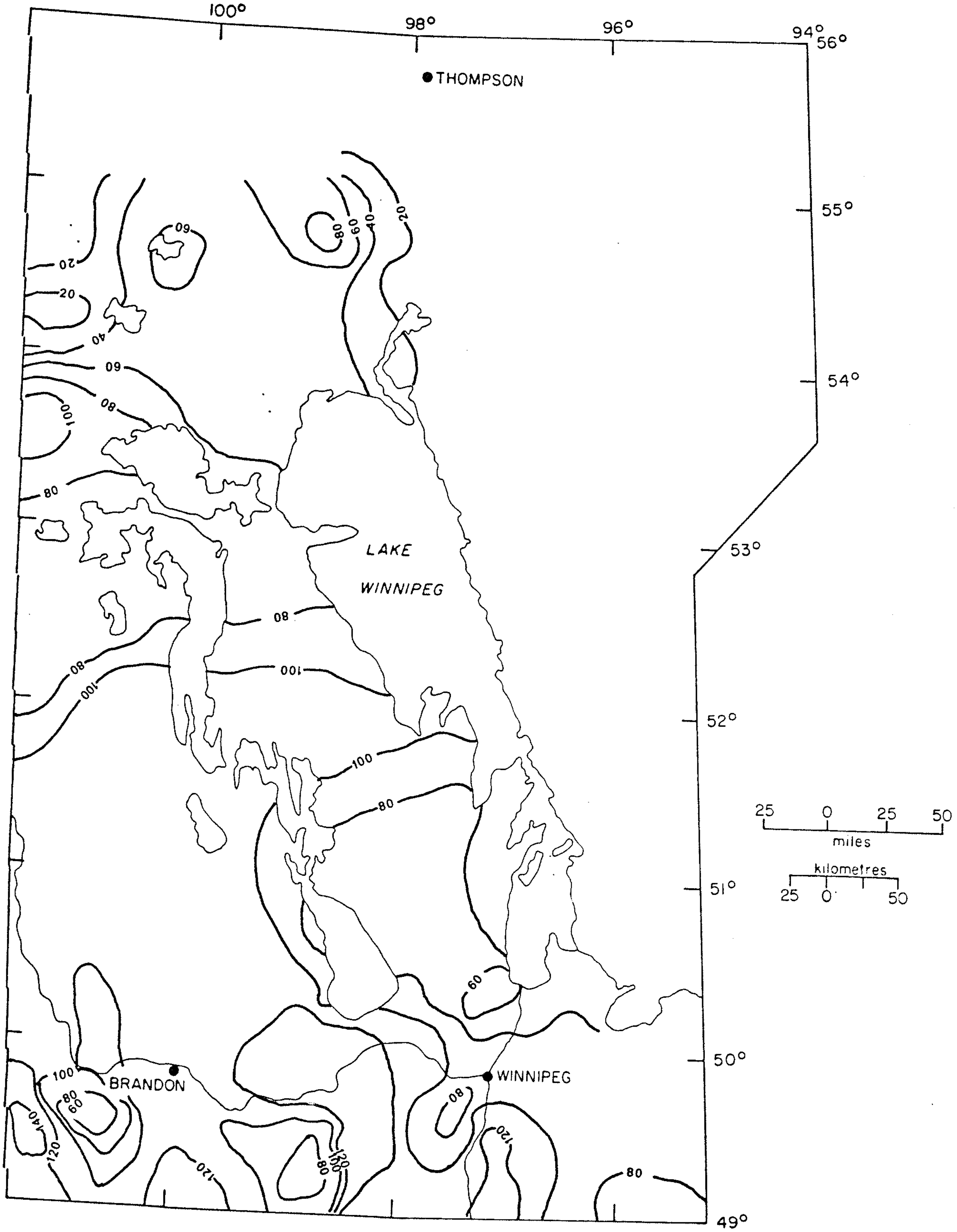


Figure C29 : Days Above 15C at the 5 cm Depth.

Isoline Int. = 20

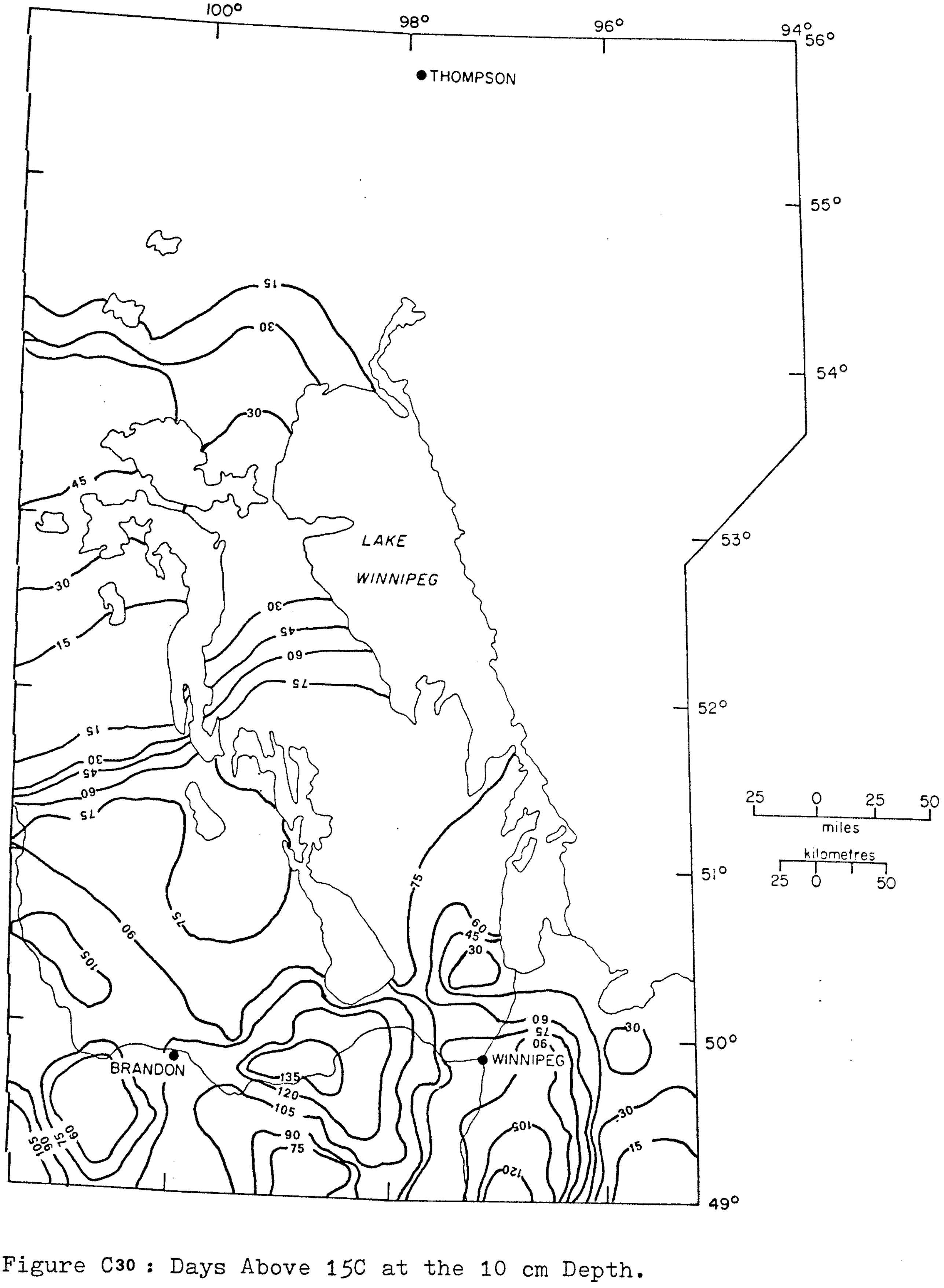


Figure C30 : Days Above 15C at the 10 cm Depth.

Isoline Int. = 15

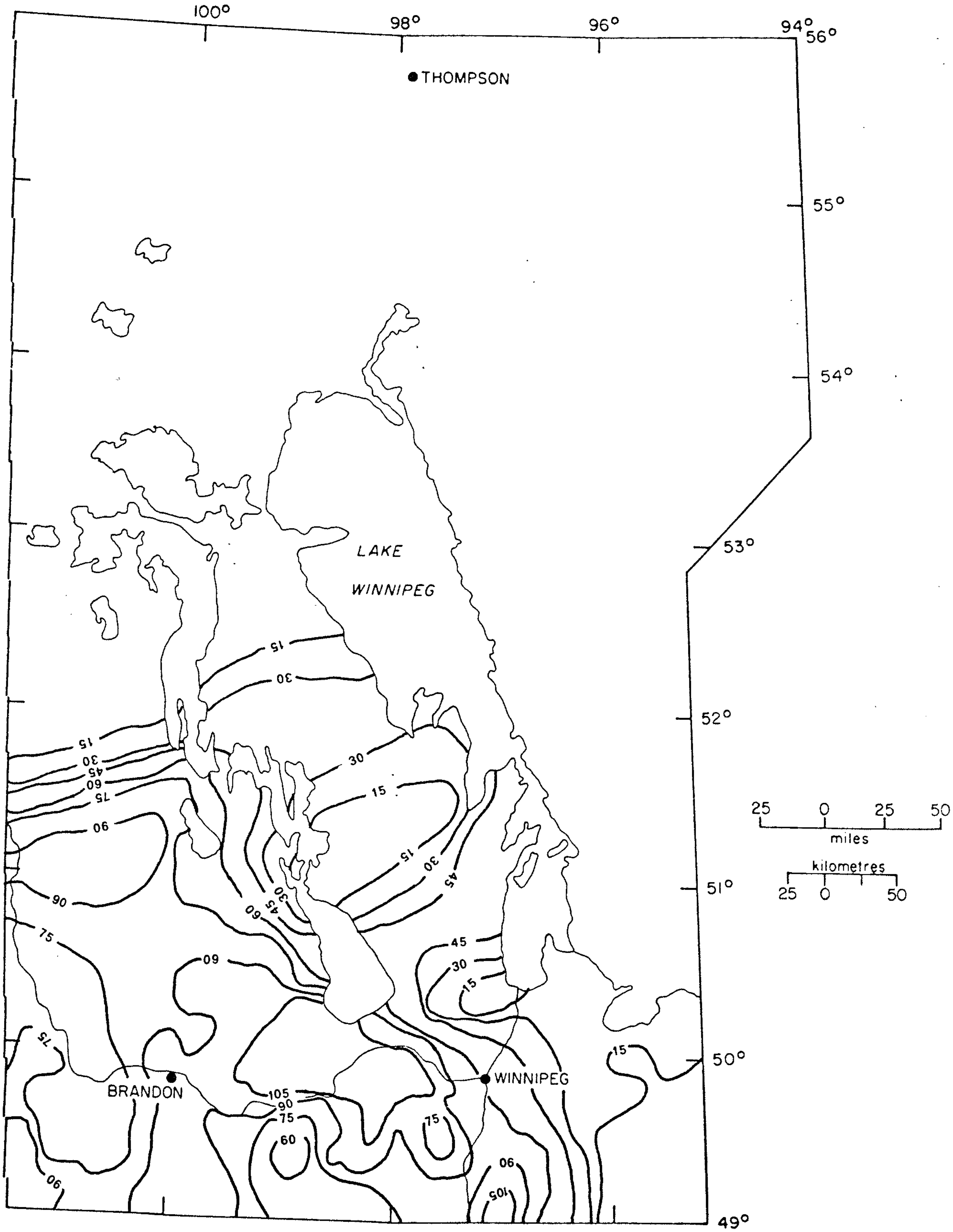


Figure C31: Days Above 15C at the 20 cm Depth.

Isoline Int. = 15

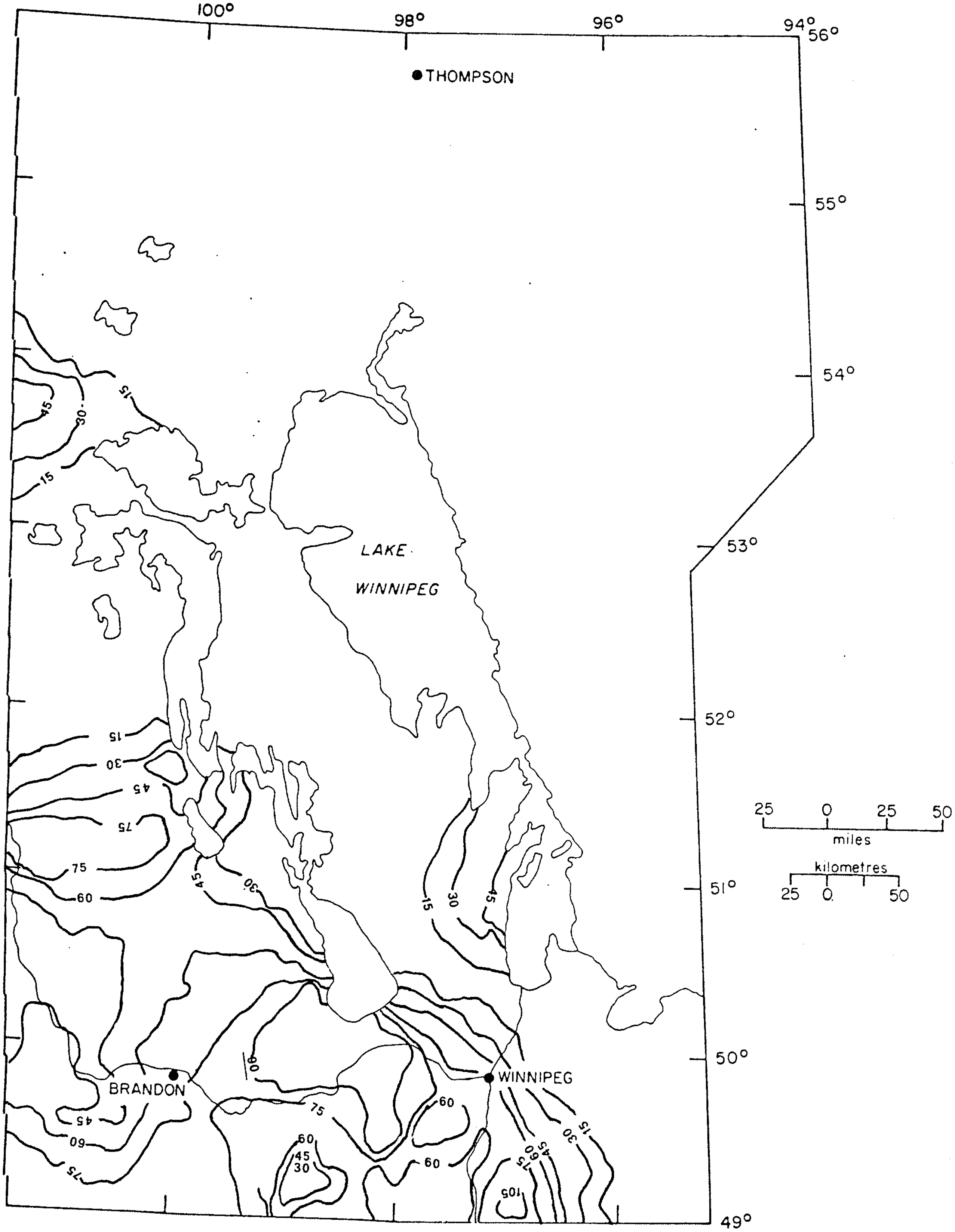


Figure C32 : Days Above 15C at the 50 cm Depth.

Isoline Int. = 15

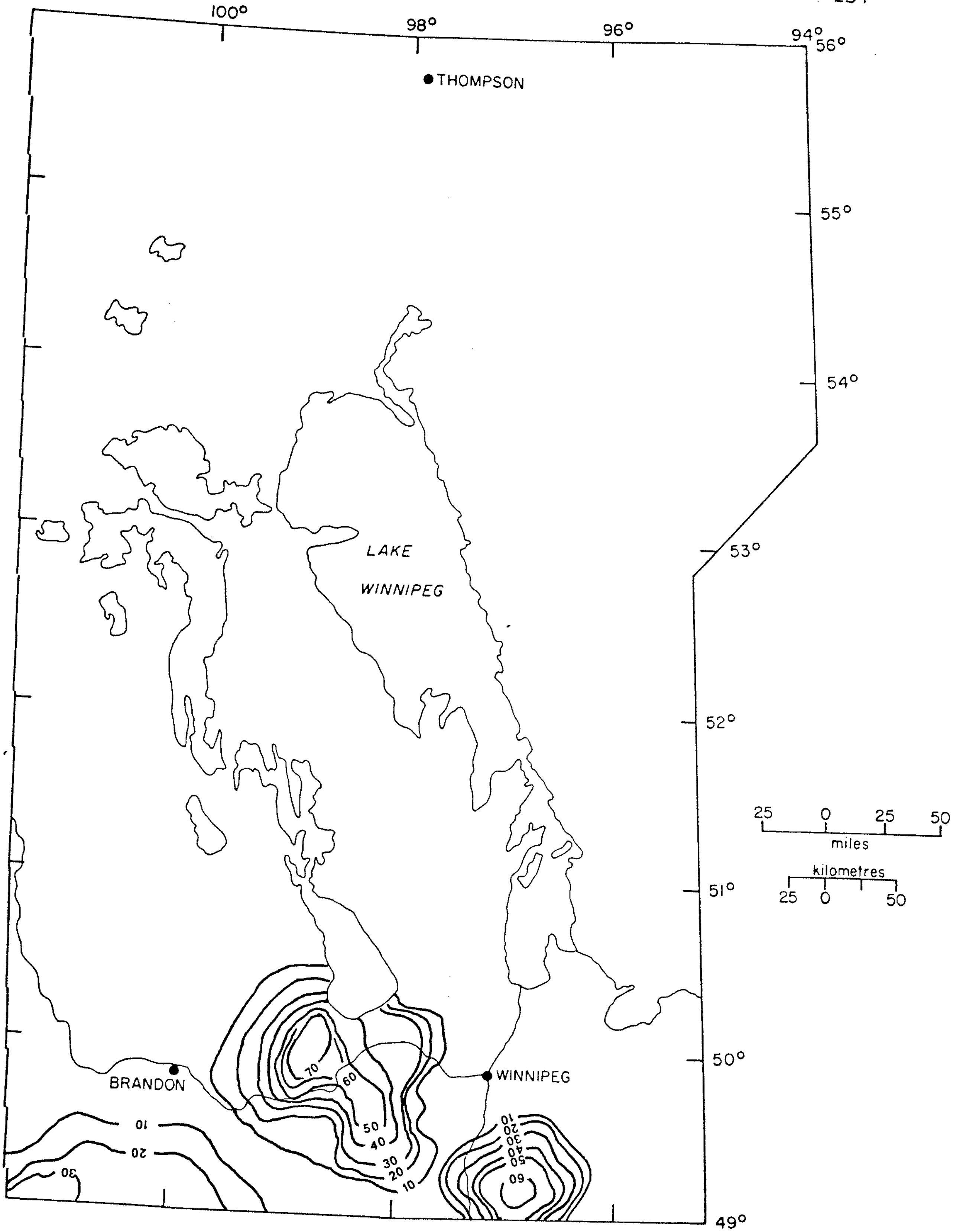


Figure C33 : Days Above 15C at the 100 cm Depth.

Isoline Int. = 10

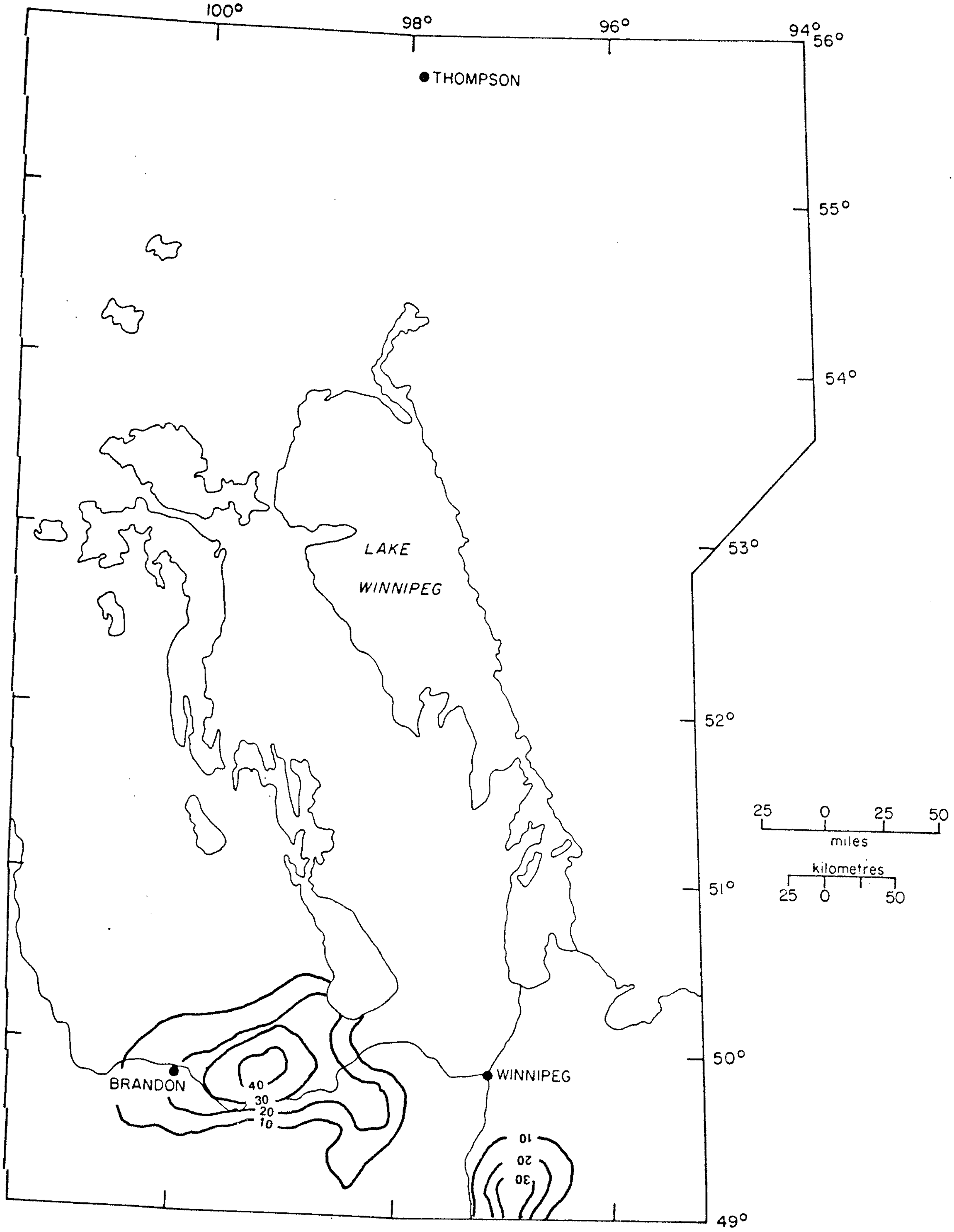


Figure C34 : Days Above 15C at the 150 cm Depth.

Isoline Int. = 10

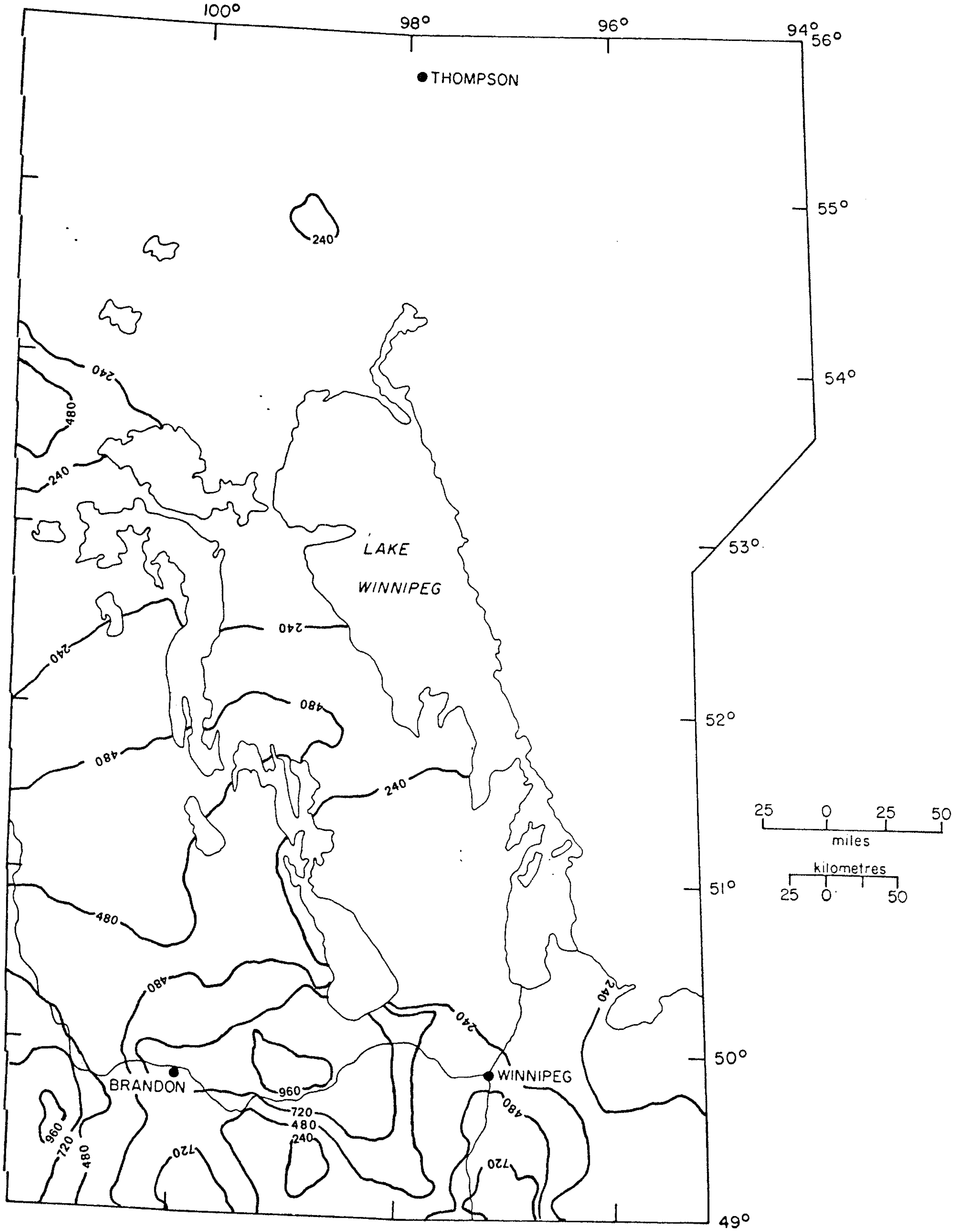


Figure C35 : Degree Days Above 15C at the 5 cm Depth.

Isoline Int. = 240

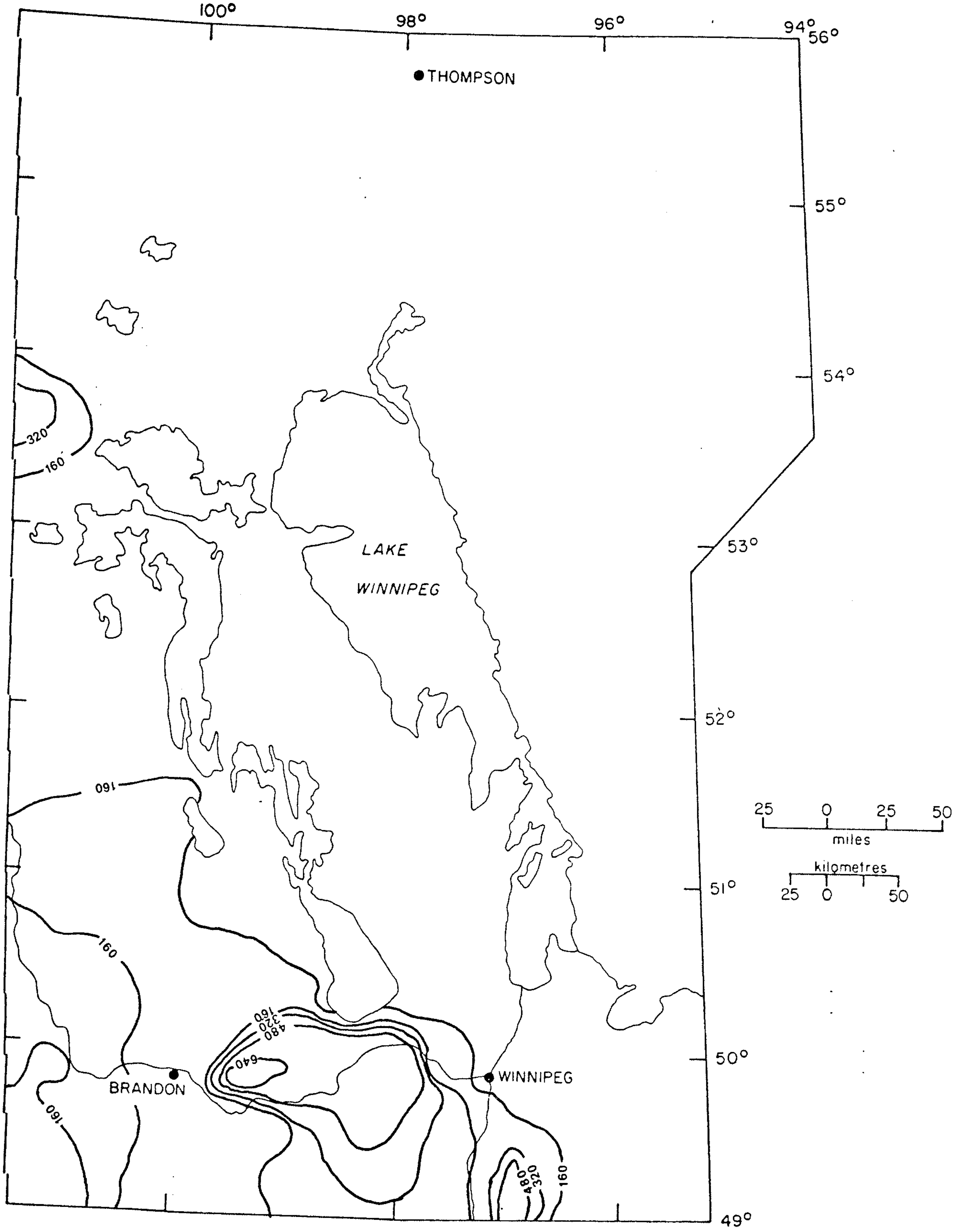


Figure C36 : Degree Days Above 15C at the 20 cm Depth.

Isoline Int. = 160

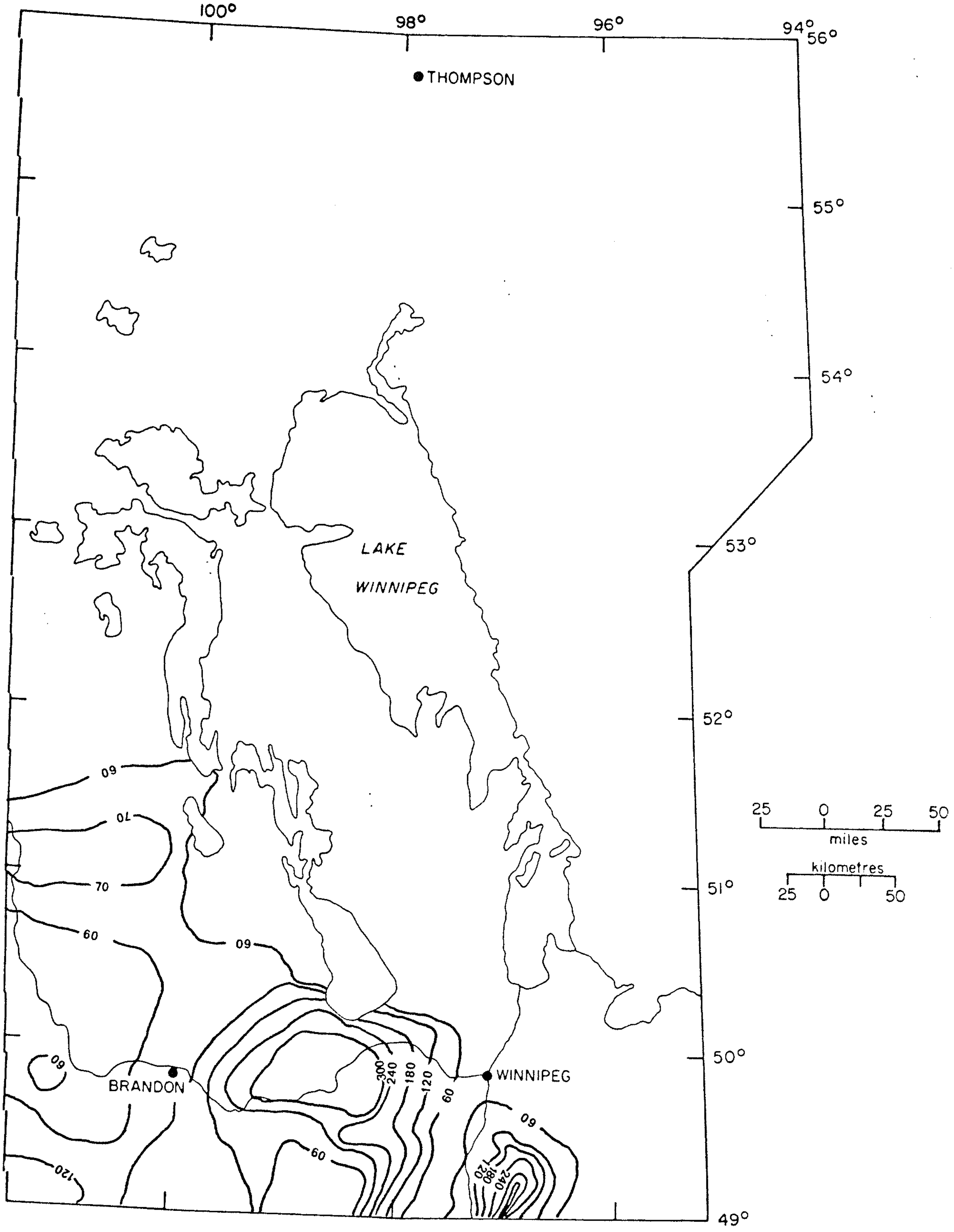


Figure C37 : Degree Days Above 15C at the 50 cm Depth.

Isoline Int. = 10

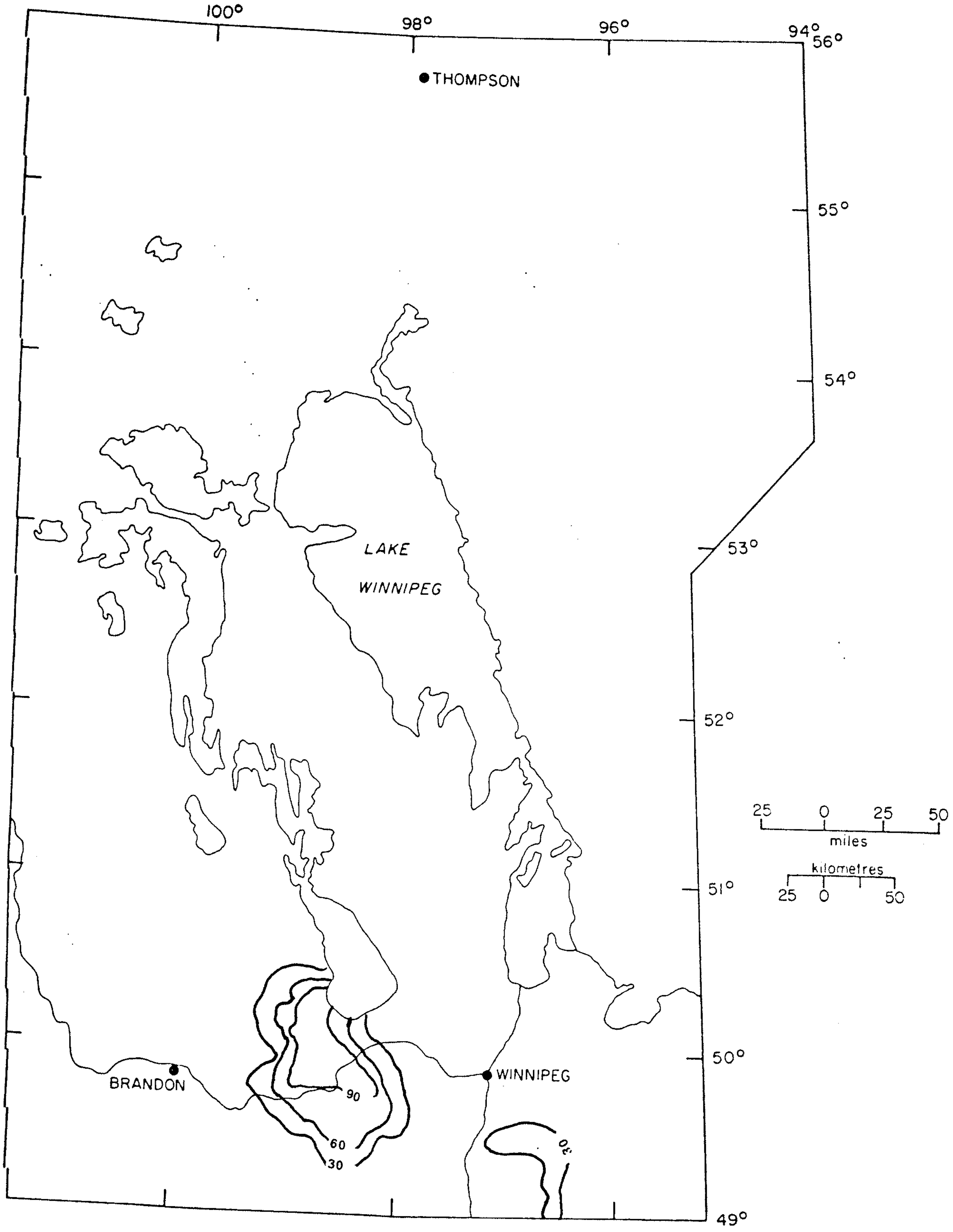


Figure C38 : Degree Days Above 15C at the 100 cm Depth.

Isoline Int. = 30

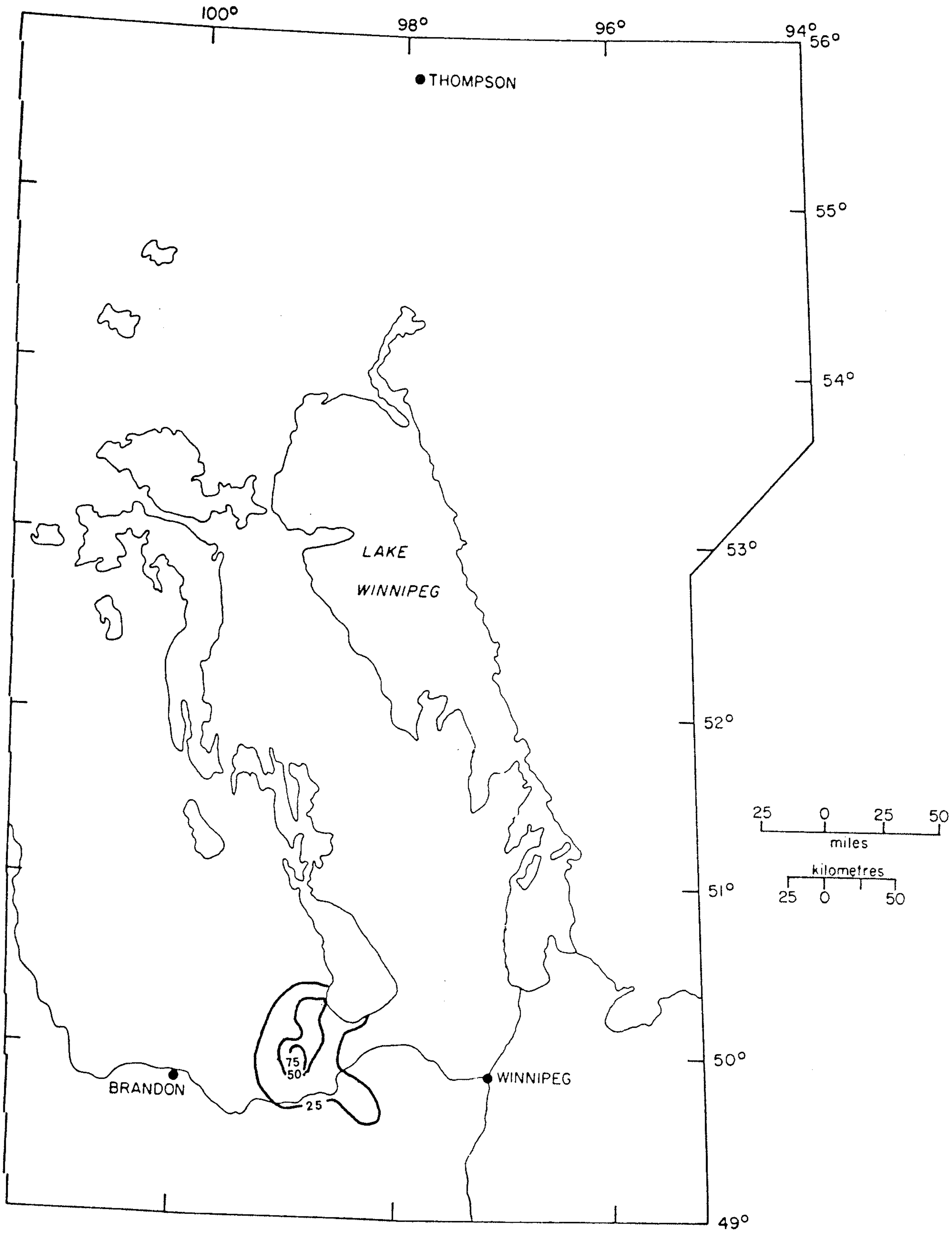


Figure C39 : Degree Days Above 15C at the 150 cm Depth.

Isoline Int. = 25

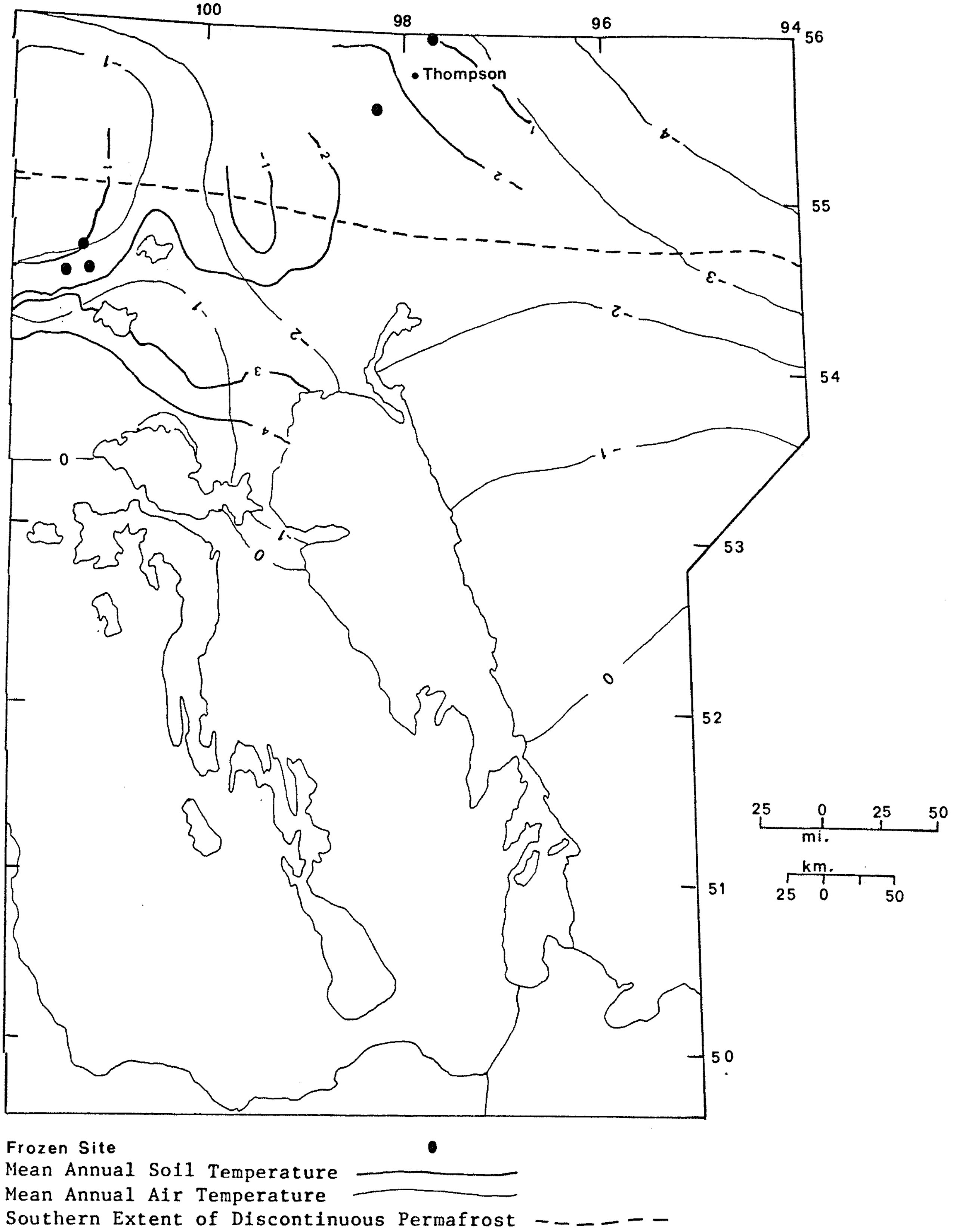


Figure C40 : Map Showing the Southern Extent of the Discontinuous Permafrost Zone, with Superimposed Isolines Depicting Mean Annual Air Temperatures and MAST.

Appendix D

TABLE OF ESTIMATED SOIL TEMPERATURES

Appendix D contains the values from the computer program outlined in Appendix B. The first two columns of the table list site names and soil depths while the remaining columns contain soil temperature characteristics. Site numbers are also listed so that the approximate location of recording stations can be located on Figure C1. In Figure C1, selected sites have been labeled with station numbers to define the general area of each series of station identification codes. For example, station 52 E3 (Sprague (52 E 3)) is located in the lower right hand portion of Figure C1. Therefore, the first row in the table on page B2 refers to Whitemouth's soil temperature characteristics for the 2.5 cm soil depth. Column three lists the MAST (6.8C) while the following two columns list the dates of occurrence of the MAST in the spring and the autumn. The sixth column contains MSST values (June 1 - August 31) and the next two columns list the dates of occurrence of 0C in the spring and in the winter. Column nine contains the number of days above 0C (frost free) per year, while the following four columns list maximum and minimum soil temperatures and their dates of occurrence. Columns fourteen and fifteen list the dates of occurrence of 5C and columns sixteen and seventeen contain the number of days above 5C and the number of degree days above 5C. The following two columns contain the dates of occurrence of 15C. The last four columns list the number of days above 15C and the number of degree days above 15C. Dates of occurrence are listed as day numbers from January 1, and the symbol "U", denotes an undefined value.

Table D-2 serves as a cross reference for soil temperature site information. For example, site names, location and selected soil physical properties are listed for each site. Sites marked with an "*" have insufficient data for analysis.

Table D-1: Site Names and Descriptions

Site No.	Name	Location sec twp rge	Elev. m asl	Soil Name	Subgroup	Tex.	Drain.
52E 1	Whitemouth 1	NE22 11 12E	290	Baynham	Ty.M	Org.	I-D
52E 2	Whitemouth 2	NE22 11 12E	290	Baynham	Ty.M	Org.	I-D
52E 3	Sprague	NC33 1 14E	340	Arnes	O.GL	C	NW-W
52E 4	East Braintree	SW 4 6 15E	325	MacArthur	O.GL	L	NW
52E 5	South Junction	SW21 1 13E	335	Baynham	Ty.M	Org	P
62F 1	Goodlands	NW15 2 24W	495	Waskada	O.Bl	L	W
62F 2	Lyleton	SE16 1 28W	455	Cameron	O.Bl	L	W-MW
62F 3	Tilston	NE20 5 29W	470	Medora	O.Bl	L	W
62F 4	Virden 1	SW23 10 28W	500	Medora	O.Bl	L	W-I
62F 5	Virden 2	NE16 11 26W	450	Oxbow	O.Bl	L	MW
62F 6	Waskada	SE 4 2 26W	450	Beresford	O.Bl	CL	W
62F 7	Sinclair 1	NW22 7 28W	487	Medora	Ca.Bl	L	MW
62F 8	Sinclair 2	NW22 7 28W	485	Coatstone	GlR.Bl	L	I
62F 9	Sinclair 3	NW22 7 28W	483	Tilston	H.LG	L	P
62G 4	Morden	NE 4 2 5W	320	Horndean	Gl.Bl	CL	I
62G 5	Brandon	NE28 10 19W	380	Agnew	Gl.Bl	L	I
62G 6	Carberry	NE11 11 15W	395	Wellwood	O.Bl	L	I
62G 7	Glenboro	SW 2 7 14W	380	Glenboro	O.Bl	SL	W
62G 8	Killarney	SE29 3 17W	490	Waskada	O.Bl	L	W
62G 9	Graysville	SW19 6 5W	290	Willowcrest	GlCa.Bl	LS	MW-I
62G10	Carmen	NE13 6 5W	265	Neuenberg	GlR.B	L	I-P
62G11	St. Claude	NE 3 8 7W	305	Almasippi	Assoc.	SL	I-P
62G12	Haywood	SW25 8 6W	290	Almasippi	Assoc.	SL	I-P
62G13	Portage-Elm Rd.	NW13 11 6W	260	Gervais	GlCu.R	L	MW-I
62G14	Notre Dame	NE14 7 9W	460	Pembina	O.GL	L	W
62G15	Manitou	NW 2 4 8W	495	Brundis	O.Bl	CL	W
62G16	Miami	NW29 5 6W		Reinland		lvfs	
62G17	Lavenham 1	SW 2 10 10W		Shilox		FS	
62G18	Lavenham 2	NW11 10 10W		Halstead		VFSL	
62G19	Lavenham 3	EC22 10 10W		Lelant		SL	

Table D-1: Site Names and Descriptions

Site No.	Name	Location			Elev.	Soil Name	Subgroup	Tex.	Drain.
		sec	twp	rge	m asl				
62G20	Lavenham 4	NE27	10	10W		Almasippi		LS	
62G21	Lavenham 5	NE35	10	10W		Lelant		LFS	
62G22	Lavenham 6	WC15	11	10W		Reinland		LFS	
62G23	Carberry 2	SW17	11	14W		Wellwood		L	
62H 1	Letellier	NC15	2	2E		Emerson		SiCL	
62H 2	Altona	SE24	2	2W		Altona		VFSCL	
62H 3	Altona	SW 5	11	7		Fairford		L	
62H 4	Fort Garry	NW28	9	3E		Fort Garry		C	
62H 5	Menisino	SE 1	2	10E		Vassar		S	
62H 6	Starbuck	SE27	9	1W		Red River		C	
62H 7	Glenlea Corn	RL 9	8	3E		Red River		C	
62H 8	Stuartburn	NE17	2	7E		Inwood		L	
62H 9	Homewood	NE26	6	4W		Sperling			
62H10	Domain 1	SE29	7	1E		Red River			
62H11	Domain 2	SE29	7	1E		Osborne			
62I 1	Winnipeg Beach	WC23	17	4E		Inwood			
62I 2	Gimli	NC29	19	4E		Lakeland			
62I 3	Hnausa	EC 5	22	5E		St. Norbert			
62J 1	Lundar	NE11	19	5W	250	Isafold	R.Bl	L	W
62J 2	Neepawa	NW21	15	15W	380	Carroll	O.Bl	CL	MW-I
62K 1	Hamiota 1	SW23	13	24W	500	Newdale	O.Bl	L	W
62K 2	Hamiota 2	NE11	14	23		Newdale		L	
62K 3	Hamiota 3	NE11	14	23		Newdale		L	
62K 4	Hamiota 4	NE30	13	23		Newdale		L	
62K 5	Hamiota 5	NE30	13	23		Newdale		L	
62K 6	Hamiota 6	NE30	13	23		Newdale		L	
62K 7	Hamiota 7	NE30	13	23		Newdale		L	
62N 1	Dauphin A.	NE16	24	19W	325	Edwards	GlCu.R	L	MW

Table D-1: Site Names and Descriptions

Site No.	Name	Location			Elev.	Soil Name	Subgroup	Tex.	Drain.
		sec	twp	rge	m asl				
620 1	Ochre River	SC 7	24	16W	275	Fairford	E.EB	L	MW
620 2	Gypsumville	C 12	33	10W	265	Fairford	E.EB	L	MW
620 3	Ashern	SC11	25	7W	245	Fairford	E.EB	L	MW
63B 1	Devils Lake	SW14	43	11W	245	Cedar Lake	O.Gl	C	W-MW
63C 1	Porcupine 1	SW31	40	26W	667	Sinnott	R.HG	L	P
63C 2	Porcupine 2	SW31	40	26W	668	Tee Lake	Gl.GL	L	I
63C 3	Porcupine 3	SW31	40	26W	670	Waitville	O.GL	L	W
63C 4	Porcupine 4	SW31	40	26W	668	Tee Lake	Gl.GL	L	MW-I
63C 5	Porcupine 5	SW31	40	26W	667	Tee Lake	Gl.GL	L	I
63C 6	Dawson Bay 1	SE21	46	25W	260	Atikameg	E.EB	L	W
63C 7	Cowan	SW20	36	23W	350	Garson	O.GL	L	W-MW
63C 8	Dawson Bay 2	SE21	46	25W	260	Atikameg	E.EB	L	W
63C 9	Porcupine	NE13	41	27W		Waitville		L	
63F 1	LeSann Farm	36	54	28					
63F 2	The Pas Moraine	SW34	57	26		Chiter			
63G 1	Buffalo Bay	SW32	52	13W	275	Limestone	E.EB	L	W
63J 1	Ponton	NW28	65	12W	260	Kiski	GR.Gl	C	P
63J 2	Kiski Creek	7	66	10W	230	Sipiwesk	O.Gl	C	W
63J 3	Minago River	22	60	12W	245	Sipiwesk	O.Gl	C	W
63J 4	Jenpeg 1	7	64	4W	220	Wabowden	So.Gl	C	W
63J 5	Jenpeg 2	7	64	4W	218	Wabowden	So.Gl	C	W
63J 6	Jenpeg 3	7	64	4W	217	Roe Lake	Gl.Gl	C	I
63K 1	Simonhouse	SE31	63	26W	290	Nekik Lake	M.OC	Org.	I-W
63K 2	Mistik Creek 1	NE25	65	28W	305	Nekik Lake	M.OC	Org.	I
63K 3	Mistik Creek 2	NE25	65	28W	305	Fay Lake	E Dy B	SL	W
63K 4	Wanless	SE24	60	27W	275	Wabowden	Sz.GL	C	W

Table D-1: Site Names and Descriptions

Site No.	Name	Location sec twp rge	Elev. m asl	Soil Name	Subgroup	Tex.	Drain.
63K 5	Cranberry 1	SE 7 64 26W	295	Egg Lake	O.GL	L	W
63K 6	Cranberry 2	NE 6 64 26W	290	Nekik Lake	M.OC	Org.	I-W
63K 7	Reed Lake	C30 64 20W	290	Hargrave	Ty.M	Org.	I-P
63O 1	Joey Lake	NW 3 75 5W	230	Nekik Lake	M.OC	Org.	I-P
63O 2	Ospwagan Lake	C32 75 4W	220	Sipiwesk	O.GL	C	W
63P 5	Split Lake Rd. 1						
63P 6	Split Lake Rd. 2						
63P 7	Horse Stable Rd. 1						
63P 8	Horse Stable Rd. 2						
63P 9	Birch Tree North 1						
63P10	Birch Tree North 2						
63P11	Birch Tree South 1						
63P12	Birch Tree South 2						
64A1	Orr Lake 1	NE19 81 3E E		Arnot Siding			
64A2	Orr Lake 2	NE19 81 3E C		Monk Siding			
64A3	Orr Lake 3	NE19 81 3E W		Brannigan Cr.			

Subgroup (soil) Classification

O.GL	Orthic Gray Luvisol
O.Bl	Orthic Black
Gl.Bl	Gleyed Black
GlCu.R	Gleyed Cumulic Regosol
GlCa.Bl	Gleyed Calcareous Black
E.EB	Eluviated Eutric Brunisol
R.HG	Rego Humic Gleysol
R.Bl	Rego Black
Sz.GL	Solonetzic Gray Luvisol
Gl.GL	Gleyed Gray Luvisol
CrR.Gl	Cryic Rego Gleysol
Ty.M	Typic Mesisol
E.DyB	Eluviated Dystric Brunisol
M.OC	Mesic Organic Cryosol
GlSz.Bl	Gleyed Solonetzic Black

Drainage

W	Well
I	Imperfect
P	Poor
MW	Moderately well
I-P	Imperfect to poor

Texture

Org.	Organic Soil
L	Loam
C	Clay
CL	Clay Loam
S	Sand
LS	Loamy Sand
SL	Sandy Loam

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
WHITEMOUTH 1	2.5	6.8	103.	286.	20.1	75.	313.	238.	21.6	194.	-8.0	12.	96.	293.	197.	2065.	137.	252.	114.	497.
	5	6.4	106.	290.	17.9	77.	321.	244.	19.3	199.	-6.4	17.	101.	297.	196.	1762.	150.	248.	97.	273.
	10	5.0	119.	302.	13.3	86.	334.	248.	14.5	210.	-4.4	28.	119.	302.	183.	1102.	UUUU	UUUU	UUUU	UUUUU
52 E1	20	4.0	137.	319.	9.3	100.	356.	256.	10.8	228.	-2.8	45.	145.	311.	166.	622.	UUUU	UUUU	UUUU	UUUUU
	50	3.2	158.	341.	5.8	113.	21.	273.	7.8	230.	-1.4	67.	181.	318.	137.	253.	UUUU	UUUU	UUUU	UUUUU
	100	3.1	182.	364.	3.8	90.	90.	365.	6.2	273.	0.0	90.	220.	326.	106.	83.	UUUU	UUUU	UUUU	UUUUU
	150	2.9	205.	388.	2.7	114.	114.	365.	4.9	297.	1.0	114.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
WHITEMOUTH 2	2.5	7.6	110.	292.	19.5	74.	328.	253.	20.9	201.	-5.7	19.	98.	304.	205.	2050.	144.	258.	114.	440.
	5	7.1	112.	295.	18.0	76.	331.	255.	19.3	204.	-5.0	21.	102.	305.	203.	1818.	153.	254.	100.	281.
	10	6.4	118.	301.	16.3	83.	336.	253.	17.6	210.	-4.8	27.	111.	308.	197.	1571.	169.	250.	81.	141.
52 E2	20	5.9	128.	310.	13.9	89.	349.	260.	15.5	219.	-3.7	37.	122.	316.	194.	1269.	200.	238.	38.	13.
	50	6.3	141.	323.	11.9	82.	17.	301.	13.8	232.	-1.1	49.	130.	334.	204.	1127.	UUUU	UUUU	UUUU	UUUUU
	100	6.2	164.	346.	8.7	72.	72.	365.	11.3	255.	1.2	72.	149.	360.	211.	827.	UUUU	UUUU	UUUU	UUUUU
	150	6.1	187.	369.	6.6	96.	96.	365.	9.4	278.	2.8	96.	168.	388.	220.	596.	UUUU	UUUU	UUUU	UUUUU
SPRAGUE	2.5	5.7	115.	298.	17.5	90.	323.	234.	19.0	206.	-7.7	24.	112.	300.	188.	1675.	160.	253.	92.	245.
	5	5.3	119.	301.	15.9	92.	328.	235.	17.4	210.	-6.8	27.	117.	303.	186.	1464.	173.	247.	75.	119.
	10	4.8	125.	307.	13.2	95.	337.	242.	14.6	216.	-5.0	33.	126.	306.	180.	1108.	UUUU	UUUU	UUUU	UUUUU
52 E3	20	4.6	131.	313.	9.9	86.	358.	272.	11.1	222.	-2.0	39.	134.	309.	175.	688.	UUUU	UUUU	UUUU	UUUUU
	50	5.0	142.	325.	9.9	94.	8.	280.	11.8	234.	-1.7	51.	142.	325.	183.	785.	UUUU	UUUU	UUUU	UUUUU
	100	5.4	151.	334.	8.7	60.	60.	365.	10.6	243.	0.1	60.	147.	338.	190.	678.	UUUU	UUUU	UUUU	UUUUU
	150	5.4	161.	343.	7.6	70.	70.	365.	9.7	252.	1.1	70.	156.	349.	193.	572.	UUUU	UUUU	UUUU	UUUUU
EAST BRAINTR	2.5	7.5	109.	291.	19.7	75.	325.	250.	21.1	200.	-6.2	17.	98.	302.	204.	2057.	143.	257.	114.	455.
	5	6.4	114.	296.	17.1	81.	329.	248.	18.4	205.	-5.6	22.	107.	303.	196.	1667.	160.	250.	90.	205.
52 E4	10	5.3	121.	303.	13.8	87.	336.	249.	15.1	212.	-4.5	29.	119.	305.	186.	1194.	204.	219.	15.	1.
	20	4.8	127.	310.	11.5	91.	346.	256.	12.8	219.	-3.3	36.	129.	308.	179.	693.	UUUU	UUUU	UUUU	UUUUU
	50	4.7	137.	319.	10.0	91.	365.	273.	11.5	228.	-2.0	46.	139.	317.	178.	738.	UUUU	UUUU	UUUU	UUUUU
	100	4.8	150.	332.	8.2	84.	33.	314.	10.0	241.	-0.5	58.	152.	330.	177.	570.	UUUU	UUUU	UUUU	UUUUU
	150	4.7	160.	343.	6.9	69.	69.	365.	8.9	252.	0.5	69.	165.	339.	174.	436.	UUUU	UUUU	UUUU	UUUUU
SOUTH JUNCTI	2.5	7.3	113.	296.	17.8	75.	335.	260.	19.1	205.	-4.5	22.	102.	307.	205.	1823.	155.	255.	100.	273.
	5	6.4	119.	301.	15.6	80.	340.	260.	16.9	210.	-4.0	27.	111.	309.	198.	1489.	174.	245.	71.	89.
	10	5.2	130.	313.	12.1	92.	351.	259.	13.6	222.	-3.3	39.	129.	314.	185.	1009.	UUUU	UUUU	UUUU	UUUUU
52 E5	20	4.6	143.	325.	9.7	102.	2.	265.	11.6	234.	-2.4	52.	146.	322.	176.	745.	UUUU	UUUU	UUUU	UUUUU
	50	4.5	156.	338.	7.7	99.	30.	296.	9.9	247.	-0.9	65.	161.	333.	172.	543.	UUUU	UUUU	UUUU	UUUUU
	100	4.6	174.	356.	5.8	82.	82.	365.	6.1	265.	1.0	82.	181.	349.	168.	333.	UUUU	UUUU	UUUU	UUUUU
	150	4.4	191.	373.	4.6	100.	100.	365.	6.6	282.	2.3	100.	206.	358.	152.	159.	UUUU	UUUU	UUUU	UUUUU
GOODLANDS	2.5	7.9	97.	279.	20.4	62.	314.	253.	21.9	188.	-6.1	6.	85.	292.	207.	2197.	128.	249.	121.	548.
	5	7.3	99.	282.	19.1	65.	316.	251.	20.6	191.	-5.9	8.	89.	292.	203.	1986.	135.	246.	111.	403.
	10	6.3	109.	291.	17.2	77.	323.	246.	18.4	200.	-5.9	18.	103.	297.	195.	165[illegible]	156.	245.	89.	200.
62 F1	20	5.5	117.	299.	16.1	89.	327.	238.	17.5	208.	-6.5	26.	114.	302.	188.	1487.	170.	246.	76.	126.
	50	6.7	130.	313.	15.2	89.	354.	265.	17.0	222.	-3.6	39.	120.	322.	202.	1527.	185.	258.	74.	98.
	100	6.4	155.	338.	11.6	108.	20.	277.	15.2	247.	-2.4	64.	146.	347.	201.	1290.	234.	254.	25.	3.
	150	6.0	171.	354.	8.8	114.	46.	296.	13.3	263.	-1.2	80.	163.	362.	199.	1036.	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
LYLETON	2.5	10.3	106.	288.	26.4	70.	324.	254.	28.2	197.	-7.6	15.	88.	306.	218.	3146.	121.	273.	152.	1299.
	5	9.5	107.	289.	24.4	71.	325.	254.	26.0	198.	-7.0	16.	91.	306.	215.	2821.	126.	270.	143.	1028.
	10	7.9	107.	290.	19.6	70.	327.	258.	20.9	199.	-5.2	16.	94.	303.	208.	2072.	141.	256.	115.	443.
62 F2	20	6.7	115.	297.	17.9	82.	330.	248.	19.3	206.	-5.8	23.	107.	305.	199.	1792.	156.	255.	99.	281.
	50	6.7	124.	306.	16.3	87.	343.	255.	18.0	215.	-4.7	33.	115.	315.	200.	1635.	172.	258.	86.	171.
	100	6.5	138.	321.	13.2	90.	4.	278.	15.3	230.	-2.3	47.	129.	330.	202.	1302.	216.	243.	28.	5.
	150	6.1	151.	333.	10.0	59.	59.	365.	12.2	242.	0.0	59.	140.	344.	204.	917.	UUUU	UUUU	UUUU	UUUUU
TILSTON	2.5	9.0	104.	286.	24.4	71.	318.	247.	26.2	195.	-8.2	12.	90.	302.	210.	2779.	124.	265.	141.	1022.
	5	8.2	105.	288.	22.3	73.	320.	247.	23.9	197.	-7.4	14.	93.	300.	207.	2454.	131.	262.	131.	760.
	10	7.1	108.	290.	19.3	76.	322.	246.	20.7	199.	-6.6	16.	99.	299.	200.	1983.	144.	254.	110.	415.
	20	6.3	113.	296.	17.2	81.	327.	246.	18.6	204.	-5.9	22.	107.	302.	195.	1672.	159.	250.	91.	213.
62 F3	50	6.6	128.	311.	15.4	89.	350.	261.	17.1	219.	-4.0	37.	119.	319.	200.	1528.	182.	257.	75.	105.
	100	5.7	147.	329.	11.6	105.	6.	266.	14.3	238.	-2.9	55.	142.	334.	192.	1131.	UUUU	UUUU	UUUU	UUUUU
	150	5.5	166.	348.	8.8	115.	34.	284.	12.7	257.	-1.7	75.	161.	353.	191.	937.	UUUU	UUUU	UUUU	UUUUU
VIRDEN 1	2.5	8.2	97.	279.	21.4	63.	314.	251.	23.0	188.	-6.6	6.	84.	292.	208.	2346.	125.	252.	127.	664.
	5	7.4	98.	280.	19.8	65.	313.	248.	21.3	189.	-6.5	6.	87.	290.	203.	2087.	131.	247.	116.	481.
	10	6.2	103.	285.	17.0	71.	317.	246.	18.2	194.	-5.8	12.	97.	291.	194.	1626.	151.	238.	87.	186.
62 F4	20	5.7	111.	293.	15.6	79.	324.	245.	16.8	202.	-5.4	19.	107.	297.	190.	1415.	169.	235.	66.	77.
	50	5.5	128.	311.	13.2	91.	347.	256.	14.8	220.	-3.8	37.	125.	314.	189.	1172.	UUUU	UUUU	UUUU	UUUUU
	100	5.3	152.	335.	9.9	105.	17.	277.	12.6	243.	-2.0	61.	150.	337.	187.	902.	UUUU	UUUU	UUUU	UUUUU
	150	5.0	169.	352.	7.3	104.	53.	314.	10.6	261.	-0.5	78.	169.	352.	184.	658.	UUUU	UUUU	UUUU	UUUUU
VIRDEN 2	2.5	6.4	103.	286.	25.3	85.	304.	219.	27.5	194.	-14.6	12.	99.	290.	190.	2713.	127.	261.	134.	1088.
	5	6.2	97.	280.	21.0	75.	302.	227.	22.8	189.	-10.5	6.	93.	284.	191.	2149.	130.	247.	117.	599.
	10	4.9	105.	283.	19.7	88.	305.	217.	21.4	197.	-11.6	14.	106.	287.	182.	1896.	144.	249.	106.	444.
62 F5	20	4.0	106.	289.	17.0	90.	305.	215.	18.5	198.	-10.4	15.	110.	285.	175.	1506.	157.	239.	82.	139.
	50	4.1	116.	299.	15.1	97.	318.	222.	16.6	208.	-3.3	25.	120.	295.	174.	1291.	178.	237.	59.	62.
	100	4.6	146.	328.	11.3	117.	357.	240.	14.2	237.	-5.1	54.	148.	326.	173.	1049.	UUUU	UUUU	UUUU	UUUUU
	150	4.9	167.	350.	8.1	125.	28.	268.	12.2	259.	-2.4	76.	168.	349.	181.	837.	UUUU	UUUU	UUUU	UUUUU
WASKADA	2.5	9.5	101.	284.	23.1	62.	324.	262.	24.6	193.	-5.6	10.	84.	302.	213.	2664.	123.	262.	139.	875.
	5	8.5	103.	286.	21.8	68.	322.	254.	23.3	195.	-6.3	12.	89.	300.	211.	2413.	130.	260.	130.	705.
	10	7.2	108.	290.	19.8	77.	322.	245.	21.2	199.	-6.9	17.	99.	299.	201.	2146.	142.	256.	114.	462.
62 F6	20	6.5	114.	297.	18.0	84.	328.	244.	19.4	206.	-6.4	23.	107.	304.	196.	1788.	156.	255.	99.	269.
	50	6.6	124.	307.	16.3	89.	342.	254.	18.0	216.	-4.9	33.	116.	315.	199.	1631.	172.	259.	86.	173.
	100	6.4	140.	322.	13.2	95.	2.	272.	15.5	231.	-2.8	48.	131.	331.	200.	1328.	211.	251.	40.	14.
	150	6.4	152.	335.	11.0	90.	32.	308.	13.8	243.	-0.9	61.	141.	346.	206.	1131.	UUUU	UUUU	UUUU	UUUUU
SINCLAIR1	2.5	10.4	99.	282.	23.8	54.	326.	272.	25.4	190.	-4.6	8.	78.	303.	226.	2848.	117.	264.	146.	988.
	5	15.0	93.	275.	32.8	45.	323.	279.	35.3	184.	-5.4	2.	63.	300.	242.	4472.	93.	275.	182.	2356.
	10	8.6	103.	285.	19.0	54.	334.	280.	20.2	194.	-2.9	11.	84.	304.	220.	2075.	136.	251.	115.	392.
62 F7	20	7.1	108.	291.	17.4	70.	329.	259.	18.6	200.	-4.5	17.	98.	311.	214.	1744.	152.	247.	95.	227.
	50	6.9	120.	303.	15.3	74.	348.	274.	16.6	211.	-2.8	29.	109.	314.	205.	1493.	178.	245.	67.	71.
	100	6.5	136.	319.	12.4	76.	14.	303.	14.1	228.	-1.0	45.	124.	331.	206.	1180.	UUUU	UUUU	UUUU	UUUUU
	150	6.7	148.	330.	10.8	56.	57.	365.	12.9	239.	0.5	57.	132.	345.	215.	1054.	UUUU	UUUU	UUUU	UUUUU
SINCLAIR2	2.5	12.7	105.	287.	28.5	58.	334.	276.	30.3	196.	-5.0	13.	78.	313.	235.	3647.	112.	279.	167.	1542.
	5	10.3	107.	290.	23.7	62.	334.	272.	25.2	199.	-4.5	16.	86.	311.	225.	2813.	126.	271.	145.	959.
	10	9.3	109.	292.	21.4	65.	336.	270.	22.8	201.	-4.2	18.	91.	311.	220.	2426.	135.	256.	131.	665.
62 F8	20	8.5	113.	296.	19.5	69.	340.	271.	20.8	205.	-3.8	22.	96.	313.	216.	2130.	146.	263.	118.	450.
	50	8.3	118.	300.	17.8	66.	352.	286.	19.1	209.	-2.4	25.	99.	313.	219.	1914.	157.	261.	134.	279.
	100	7.9	129.	312.	15.0	59.	16.	322.	16.5	220.	-0.6	38.	106.	332.	224.	1583.	166.	255.	69.	67.
	150	7.8	137.	319.	13.0	45.	45.	365.	14.5	228.	1.0	45.	112.	344.	232.	1362.	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS	T.	DAY	T.	DAY	DATE 5C		DAYS	DEGREE	DATE 15C		DAYS	DEG.
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER	ABOVE 0 C	MAX		MIN		SPRING	FALL	ABOVE 5 C	DAYS 5 C	SPRING	FALL	ABOVE 15 C	DAYS 15 C
SINCLAIR3	2.5	11.0	101.	283.	26.7	61.	323.	262.	28.5	192.	-6.5	10.	80.	304.	223.	3251.	114.	270.	156.	1358.
	5	11.1	95.	278.	24.5	47.	326.	279.	26.2	187.	-4.0	4.	71.	302.	231.	3019.	110.	263.	152.	1105.
	10	9.5	95.	273.	20.5	45.	328.	283.	22.0	187.	-3.0	4.	74.	299.	225.	2362.	122.	251.	129.	587.
62 F9	20	8.2	100.	283.	17.5	48.	335.	287.	18.6	191.	-2.3	9.	82.	300.	218.	1842.	142.	241.	99.	233.
	50	7.6	112.	294.	14.7	38.	3.	330.	15.6	203.	-0.4	21.	92.	314.	221.	1451.	181.	225.	44.	17.
	100	7.2	127.	309.	12.9	36.	36.	365.	14.0	218.	0.5	36.	107.	329.	222.	1232.	UUUU	UUUU	UUUU	UUUUU
	150	7.2	142.	324.	11.1	50.	50.	365.	12.6	233.	1.9	50.	116.	349.	233.	1085.	UUUU	UUUU	UUUU	UUUUU
MORDEN	2.5	9.1	111.	293.	21.9	70.	334.	263.	23.4	202.	-5.1	20.	94.	310.	217.	2486.	135.	269.	133.	731.
	5	8.0	115.	297.	19.5	76.	336.	260.	20.9	206.	-4.9	23.	101.	311.	210.	2089.	148.	264.	116.	449.
	10	7.0	120.	302.	17.0	82.	341.	259.	18.4	211.	-4.5	29.	110.	313.	203.	1714.	165.	257.	92.	210.
62 G4	20	6.4	127.	309.	15.2	88.	348.	260.	16.9	218.	-4.0	35.	118.	317.	199.	1490.	182.	253.	71.	89.
	50	6.7	138.	321.	13.6	90.	4.	279.	15.7	229.	-2.4	47.	127.	331.	204.	1380.	206.	253.	47.	24.
	100	6.7	155.	337.	11.0	83.	44.	325.	13.9	246.	-0.4	64.	141.	351.	211.	1173.	UUUU	UUUU	UUUU	UUUUU
	150	6.6	170.	353.	8.9	79.	79.	365.	12.4	262.	0.8	79.	154.	369.	215.	988.	UUUU	UUUU	UUUU	UUUUU
BRANDON	2.5	8.4	106.	288.	23.8	76.	318.	242.	25.5	197.	-8.8	15.	94.	300.	205.	2648.	129.	265.	136.	936.
	5	7.6	106.	288.	22.1	77.	317.	240.	23.8	197.	-8.5	15.	96.	298.	201.	2383.	133.	261.	127.	731.
	10	6.5	109.	291.	19.4	82.	318.	237.	20.8	200.	-7.9	18.	103.	297.	194.	1948.	146.	254.	109.	418.
62 G5	20	6.1	114.	297.	17.5	86.	326.	240.	19.0	206.	-6.7	23.	109.	302.	193.	1704.	159.	253.	94.	246.
	50	5.9	128.	310.	15.1	95.	343.	248.	16.9	219.	-5.1	37.	123.	315.	192.	1445.	184.	254.	69.	87.
	100	5.6	152.	335.	10.9	110.	11.	266.	14.1	243.	-2.9	61.	148.	339.	191.	1098.	UUUU	UUUU	UUUU	UUUUU
	150	7.7	196.	378.	7.8	104.	104.	365.	15.1	287.	0.2	104.	174.	399.	225.	1404.	278.	296.	18.	1.
CARBERRY	2.5	6.8	96.	279.	20.8	70.	305.	235.	22.6	187.	-8.9	5.	89.	285.	196.	2180.	128.	247.	119.	593.
	5	5.8	100.	283.	19.2	77.	306.	229.	20.7	191.	-9.1	9.	97.	286.	189.	1883.	139.	244.	105.	396.
	10	5.0	102.	284.	16.2	78.	309.	231.	17.4	193.	-7.4	11.	102.	285.	183.	1448.	156.	230.	74.	123.
62 G23	20	4.6	107.	289.	16.1	85.	311.	225.	17.4	198.	-8.2	16.	109.	287.	179.	1419.	162.	234.	72.	112.
	50	4.5	119.	301.	14.9	96.	324.	228.	16.4	210.	-7.3	28.	121.	299.	178.	1297.	181.	239.	57.	54.
	100	4.5	142.	324.	11.6	114.	352.	239.	14.2	233.	-5.2	51.	145.	321.	177.	1042.	UUUU	UUUU	UUUU	UUUUU
	150	4.9	162.	344.	8.8	120.	21.	266.	12.4	253.	-2.5	70.	162.	344.	181.	855.	UUUU	UUUU	UUUU	UUUUU
GLENBORO	2.5	5.8	103.	285.	20.3	81.	307.	225.	22.0	194.	-10.3	11.	100.	288.	188.	2028.	138.	255.	112.	512.
	5	5.4	104.	287.	19.1	83.	308.	224.	20.6	196.	-9.9	13.	103.	288.	185.	1843.	144.	247.	103.	383.
	10	5.0	108.	290.	17.7	86.	311.	225.	19.1	199.	-9.1	16.	108.	290.	183.	1641.	153.	244.	91.	247.
62 G7	20	5.0	113.	295.	17.0	91.	318.	227.	18.4	204.	-8.4	22.	113.	295.	182.	1560.	162.	247.	85.	192.
	50	5.4	123.	306.	15.3	95.	333.	238.	17.0	214.	-6.3	32.	121.	307.	186.	1417.	180.	249.	69.	96.
	100	5.4	148.	332.	11.3	109.	4.	261.	14.1	239.	-3.3	56.	145.	333.	186.	1091.	UUUU	UUUU	UUUU	UUUUU
	150	5.5	171.	354.	8.0	113.	47.	300.	12.0	263.	-1.0	80.	167.	353.	191.	847.	UUUU	UUUU	UUUU	UUUUU
KILLARNEY	2.5	12.1	110.	292.	28.2	67.	335.	268.	30.0	201.	-5.9	18.	86.	315.	229.	3542.	119.	282.	163.	1581.
	5	9.0	113.	296.	22.5	76.	333.	257.	24.1	205.	-6.1	22.	96.	311.	214.	2551.	137.	272.	135.	802.
	10	7.8	116.	299.	19.8	81.	334.	253.	21.4	207.	-5.9	25.	104.	310.	206.	2122.	149.	266.	117.	493.
62 G8	20	7.2	119.	301.	17.9	82.	338.	256.	19.4	210.	-5.0	27.	108.	312.	204.	1846.	159.	261.	102.	297.
	50	7.2	126.	308.	16.4	84.	350.	267.	18.1	217.	-3.7	35.	114.	320.	206.	1689.	172.	262.	89.	180.
	100	6.8	138.	321.	13.2	84.	10.	291.	15.2	230.	-1.6	47.	126.	333.	207.	1322.	217.	241.	24.	3.
	150	6.6	148.	330.	11.3	75.	33.	328.	13.6	239.	-0.4	56.	134.	344.	210.	1125.	UUUU	UUUU	UUUU	UUUUU
GRAYSVILLE	2.5	9.6	111.	294.	23.8	74.	332.	258.	25.4	203.	-6.3	20.	94.	311.	217.	2757.	132.	274.	142.	963.
	5	8.7	114.	296.	22.0	78.	332.	255.	23.6	205.	-6.3	23.	99.	311.	211.	2461.	139.	271.	132.	740.
62 G9	10	8.2	117.	299.	20.6	81.	335.	255.	22.2	208.	-5.9	25.	103.	312.	209.	2250.	146.	270.	123.	590.
	20	7.2	122.	304.	18.1	86.	339.	253.	19.8	213.	-5.4	30.	111.	314.	203.	1892.	163.	265.	115.	333.
	50	7.2	133.	316.	15.9	90.	359.	268.	18.0	224.	-3.5	42.	121.	326.	207.	1688.	187.	269.	89.	177.
	100	6.9	152.	335.	12.2	98.	24.	292.	15.4	244.	-1.6	61.	139.	343.	208.	1351.	227.	260.	34.	8.
	150	6.6	164.	347.	10.1	100.	46.	311.	14.0	256.	-0.8	73.	152.	360.	208.	1174.	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH CM	SOIL TEMPERATURE MEAN FOR YEAR	SOIL TEMPERATURE SPRING	SOIL TEMPERATURE FALL	SOIL TEMPERATURE MEAN SUMMER	DATE CC SPRING	DATE CC FALL OR WINTER	DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C SPRING	DATE 5C FALL	DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C SPRING	DATE 15C FALL	DAYS ABOVE 15 C	DEG. DAYS 15 C
CARMAN	25	8.4	115.	298.	23.0	84.	329.	245.	24.9	206.	-8.0	24.	103.	310.	207.	2580.	139.	274.	135.	866.
	5	7.9	117.	299.	21.9	86.	329.	243.	23.7	208.	-7.9	25.	106.	310.	204.	2401.	144.	272.	128.	732.
	10	7.2	119.	302.	20.0	89.	332.	243.	21.9	210.	-7.4	28.	110.	310.	200.	2128.	152.	269.	117.	528.
62 G10	20	6.5	123.	306.	18.1	94.	335.	241.	20.0	214.	-6.9	32.	116.	312.	196.	1855.	163.	266.	103.	340.
	50	6.4	132.	315.	16.1	100.	347.	243.	18.4	224.	-5.6	41.	125.	321.	196.	1659.	179.	268.	90.	201.
	100	6.2	146.	328.	12.9	105.	4.	264.	15.8	237.	-3.4	55.	139.	336.	197.	1348.	213.	261.	49.	27.
	150	6.1	160.	342.	10.2	107.	30.	289.	13.8	251.	-1.6	69.	152.	351.	199.	1098.	UUUU	UUUU	UUUU	UUUUU
STE CLAUDE	25	10.1	96.	273.	24.5	56.	317.	261.	26.3	187.	-6.1	4.	77.	297.	220.	2914.	113.	260.	147.	1080.
	5	9.8	96.	279.	23.5	56.	319.	263.	25.2	188.	-5.6	5.	78.	297.	219.	2761.	116.	259.	143.	949.
	10	9.1	98.	281.	21.7	57.	322.	264.	23.3	190.	-5.0	7.	81.	298.	217.	2468.	123.	256.	133.	714.
62 G11	20	8.4	105.	287.	19.8	62.	329.	267.	21.1	196.	-4.2	13.	89.	303.	214.	2149.	136.	255.	119.	473.
	50	7.5	123.	306.	17.3	81.	348.	267.	18.9	214.	-3.9	32.	110.	319.	209.	1623.	165.	264.	109.	259.
	100	6.9	142.	324.	13.8	94.	7.	278.	16.4	233.	-2.5	50.	130.	336.	206.	1474.	201.	265.	64.	59.
	150	6.8	152.	335.	11.5	83.	38.	320.	14.2	243.	-0.5	61.	137.	349.	212.	1222.	UUUU	UUUU	UUUU	UUUUU
STE CLAUDE	25	10.8	109.	292.	26.6	71.	330.	258.	28.5	201.	-6.9	18.	90.	311.	221.	3219.	124.	278.	154.	1343.
	5	9.2	110.	293.	23.2	74.	329.	256.	24.9	202.	-6.5	19.	94.	309.	214.	2654.	132.	271.	138.	888.
	10	8.5	111.	294.	20.8	73.	332.	259.	22.3	203.	-5.4	20.	97.	308.	212.	2290.	140.	265.	125.	597.
62 G11	20	7.9	116.	298.	18.8	75.	339.	264.	20.2	207.	-4.3	24.	102.	312.	211.	2001.	151.	262.	111.	378.
	50	8.4	122.	304.	17.9	71.	356.	285.	19.3	213.	-2.5	31.	103.	323.	219.	1957.	159.	267.	107.	306.
	100	8.6	135.	317.	15.3	44.	44.	365.	17.1	226.	0.0	44.	110.	343.	233.	1735.	184.	268.	84.	117.
	150	8.6	145.	328.	13.5	54.	54.	365.	15.6	236.	1.6	54.	114.	359.	245.	1574.	213.	260.	47.	18.
HAYWOOD	25	9.9	101.	284.	25.9	67.	318.	251.	27.8	193.	-8.0	10.	85.	300.	215.	3053.	118.	267.	149.	1234.
	5	8.9	104.	286.	23.8	71.	319.	248.	25.5	195.	-7.7	13.	90.	300.	210.	2686.	126.	264.	138.	942.
	10	7.5	109.	291.	20.9	78.	322.	244.	22.4	200.	-7.4	18.	99.	301.	202.	2213.	139.	261.	121.	587.
62 G12	20	6.7	117.	299.	18.6	86.	330.	243.	20.2	208.	-6.7	26.	109.	307.	198.	1896.	155.	261.	106.	362.
	50	6.9	125.	308.	17.5	91.	342.	251.	19.4	216.	-5.5	34.	116.	317.	201.	1819.	166.	267.	101.	291.
	100	7.0	133.	316.	15.9	94.	355.	261.	18.2	225.	-4.2	42.	123.	326.	203.	1684.	180.	269.	90.	189.
	150	7.1	142.	325.	14.0	93.	9.	281.	16.6	234.	-2.4	51.	129.	338.	209.	1514.	200.	268.	68.	72.
PORTAGE-ELM	25	7.1	100.	282.	22.8	76.	306.	231.	24.7	191.	-10.5	9.	93.	289.	196.	2438.	127.	255.	128.	808.
	5	6.7	101.	284.	21.6	77.	308.	230.	23.3	193.	-10.0	10.	96.	290.	194.	2252.	132.	253.	122.	665.
	10	6.3	105.	287.	20.0	80.	312.	232.	21.5	196.	-8.9	13.	100.	292.	193.	2012.	140.	252.	112.	477.
62 G13	20	6.2	111.	293.	18.0	83.	321.	239.	19.4	202.	-7.1	20.	106.	298.	193.	1755.	153.	251.	97.	282.
	50	6.7	124.	306.	16.6	88.	342.	254.	18.3	215.	-4.9	32.	115.	315.	199.	1668.	170.	260.	89.	193.
	100	6.7	142.	324.	13.2	93.	9.	281.	15.6	233.	-2.2	51.	131.	335.	204.	1558.	212.	254.	42.	16.
	150	6.6	160.	342.	10.2	83.	54.	336.	13.4	251.	-0.2	69.	146.	356.	210.	1096.	UUUU	UUUU	UUUU	UUUUU
NOTRE DAME	25	7.0	107.	290.	17.6	70.	327.	256.	18.8	199.	-4.8	16.	98.	300.	202.	1751.	151.	246.	95.	237.
	5	6.9	110.	293.	16.2	68.	335.	266.	17.3	202.	-3.5	19.	100.	303.	204.	1572.	162.	241.	78.	119.
	10	6.4	118.	300.	14.7	75.	343.	268.	15.9	209.	-3.1	27.	109.	309.	199.	1370.	184.	235.	51.	30.
62 G14	20	6.3	125.	307.	13.6	78.	354.	276.	14.9	216.	-2.4	33.	116.	316.	199.	1245.	UUUU	UUUU	UUUU	UUUUU
	50	6.3	134.	316.	12.3	77.	8.	297.	13.9	225.	-1.3	43.	124.	326.	203.	1132.	UUUU	UUUU	UUUU	UUUUU
	100	6.3	149.	332.	10.2	58.	58.	365.	12.2	241.	0.3	53.	137.	345.	208.	941.	UUUU	UUUU	UUUU	UUUUU
	150	6.2	152.	334.	9.8	60.	61.	365.	11.9	243.	0.4	61.	140.	345.	206.	897.	UUUU	UUUU	UUUU	UUUUU
MANITOU	25	6.4	111.	293.	18.0	80.	324.	243.	19.3	202.	-6.5	20.	104.	300.	195.	1766.	153.	251.	98.	278.
	5	6.3	113.	295.	16.9	81.	328.	247.	18.2	204.	-5.7	22.	107.	302.	195.	1623.	161.	246.	87.	182.
	10	6.2	115.	297.	15.9	80.	332.	253.	17.1	206.	-4.7	23.	108.	304.	195.	1499.	169.	243.	74.	104.
62 G15	20	6.4	119.	301.	15.3	79.	342.	263.	16.5	211.	-3.7	28.	111.	310.	199.	1444.	178.	242.	64.	64.
	50	6.3	127.	310.	13.4	80.	358.	278.	14.8	219.	-2.3	36.	119.	318.	200.	1235.	UUUU	UUUU	UUUU	UUUUU
	100	6.3	141.	324.	10.8	50.	59.	365.	12.4	233.	0.1	51.	129.	336.	207.	965.	UUUU	UUUU	UUUU	UUUUU
	150	6.5	152.	334.	9.3	60.	61.	365.	11.0	243.	1.9	61.	133.	355.	222.	825.	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
LETTELIER	2.5	9.5	115.	297.	22.2	72.	339.	267.	23.8	206.	-4.8	23.	96.	316.	220.	2563.	138.	274.	136.	780.
	5	8.1	117.	299.	20.0	79.	337.	258.	21.6	208.	-5.3	26.	103.	313.	210.	2179.	148.	268.	120.	520.
	10	7.5	117.	299.	18.0	77.	339.	263.	19.4	208.	-4.3	26.	104.	312.	208.	1869.	156.	260.	103.	296.
62 H1	20	7.2	119.	302.	16.1	74.	348.	274.	17.4	211.	-3.0	28.	107.	315.	208.	1618.	170.	251.	82.	130.
	50	7.3	126.	309.	14.7	70.	365.	294.	16.1	218.	-1.6	35.	111.	324.	212.	1474.	188.	247.	59.	43.
	100	7.2	141.	323.	12.2	50.	50.	365.	14.0	232.	0.4	50.	121.	343.	221.	1233.	UUUU	UUUU	UUUU	UUUUU
	150	7.1	155.	338.	10.0	64.	64.	365.	11.9	246.	2.3	64.	129.	364.	235.	1001.	UUUU	UUUU	UUUU	UUUUU
ANOLA 1972	2.5	7.5	110.	293.	18.5	73.	331.	258.	19.8	202.	-4.8	19.	99.	305.	206.	1909.	149.	255.	106.	332.
	5	6.8	115.	293.	16.9	78.	335.	259.	18.1	207.	-4.5	24.	106.	307.	201.	1665.	162.	251.	89.	184.
	10	6.6	123.	305.	14.9	79.	350.	271.	16.2	214.	-3.0	32.	113.	315.	202.	1428.	185.	244.	59.	48.
62 H3	20	6.9	126.	309.	14.2	72.	363.	292.	15.5	218.	-1.7	35.	113.	322.	209.	1375.	197.	237.	40.	14.
	50	7.3	134.	316.	12.9	42.	43.	365.	14.4	225.	0.2	43.	115.	335.	220.	1281.	UUUU	UUUU	UUUU	UUUUU
	100	7.4	145.	327.	11.3	54.	54.	365.	13.0	236.	1.7	54.	120.	353.	233.	1151.	UUUU	UUUU	UUUU	UUUUU
	150	7.4	156.	339.	10.2	65.	65.	365.	12.2	248.	2.6	65.	126.	370.	244.	1070.	UUUU	UUUU	UUUU	UUUUU
FORT GARRY	2.5	8.0	105.	287.	20.4	69.	323.	255.	21.8	196.	-5.8	14.	92.	300.	208.	2189.	136.	256.	121.	535.
	5	7.3	111.	293.	18.4	74.	330.	256.	19.7	202.	-5.0	20.	100.	304.	205.	1885.	150.	254.	104.	321.
	10	7.0	117.	299.	17.0	78.	338.	261.	18.3	208.	-4.3	25.	106.	310.	203.	1703.	162.	254.	91.	199.
62 H4	20	6.8	124.	307.	15.6	83.	349.	266.	17.1	216.	-3.5	33.	114.	317.	203.	1545.	179.	253.	76.	106.
	50	6.9	135.	318.	13.9	83.	4.	286.	15.7	226.	-2.0	44.	123.	330.	207.	1398.	202.	250.	48.	24.
	100	6.9	152.	334.	11.2	67.	54.	353.	13.8	243.	-0.0	61.	136.	350.	214.	1177.	UUUU	UUUU	UUUU	UUUUU
	150	6.8	166.	348.	9.3	74.	74.	365.	12.3	257.	1.4	74.	146.	368.	223.	1002.	UUUU	UUUU	UUUU	UUUUU
STARBUCK CBC	2.5	8.1	111.	294.	18.9	69.	336.	267.	20.2	202.	-4.0	20.	96.	308.	212.	2015.	146.	258.	112.	380.
	5	7.9	112.	294.	18.4	68.	337.	269.	19.7	203.	-3.8	20.	97.	309.	212.	1944.	149.	257.	107.	331.
	10	8.1	112.	294.	18.0	65.	341.	276.	19.2	203.	-3.1	21.	96.	311.	215.	1903.	151.	255.	104.	288.
62 H6	20	8.8	114.	295.	18.2	56.	354.	298.	19.3	205.	-1.7	23.	92.	318.	225.	1995.	151.	260.	109.	309.
	50	8.2	125.	307.	15.6	54.	13.	324.	16.9	216.	-0.5	33.	103.	329.	226.	1656.	177.	254.	77.	95.
	100	7.8	141.	324.	12.6	50.	50.	365.	14.3	232.	1.3	50.	115.	349.	234.	1341.	UUUU	UUUU	UUUU	UUUUU
	150	7.7	162.	344.	10.2	70.	70.	365.	12.6	253.	2.9	70.	127.	379.	253.	1155.	UUUU	UUUU	UUUU	UUUUU
GLENLEA CORN	2.5	11.0	98.	280.	24.5	51.	327.	277.	26.1	189.	-4.2	7.	74.	304.	230.	2992.	113.	265.	151.	1089.
	5	9.3	104.	286.	22.5	64.	326.	261.	24.1	195.	-5.5	12.	87.	303.	217.	2570.	127.	263.	136.	803.
	10	7.3	113.	295.	19.3	79.	328.	249.	20.7	204.	-6.2	21.	103.	305.	202.	2003.	148.	259.	111.	420.
62 H7	20	5.7	123.	305.	17.0	97.	331.	234.	18.9	214.	-7.5	32.	120.	309.	189.	1659.	169.	260.	91.	232.
	50	5.1	139.	321.	14.3	113.	346.	233.	17.2	230.	-7.0	47.	138.	322.	184.	1429.	194.	266.	72.	106.
	100	4.9	161.	344.	9.9	130.	9.	244.	14.6	253.	-4.8	70.	162.	343.	181.	1105.	UUUU	UUUU	UUUU	UUUUU
	150	4.9	179.	362.	7.1	140.	36.	261.	12.8	270.	-2.9	68.	179.	361.	182.	906.	UUUU	UUUU	UUUU	UUUUU
STUARTBURNE	2.5	8.7	105.	287.	20.0	61.	332.	271.	21.3	196.	-3.9	14.	88.	305.	217.	2201.	135.	257.	122.	499.
	5	7.9	106.	288.	18.1	61.	333.	272.	19.3	197.	-3.4	15.	91.	303.	213.	1896.	145.	249.	104.	292.
	10	7.3	108.	291.	16.7	63.	336.	273.	17.8	200.	-3.1	17.	95.	304.	209.	1666.	156.	243.	86.	157.
62 H8	20	7.2	112.	295.	15.7	63.	344.	281.	16.7	204.	-2.4	21.	99.	306.	209.	1530.	168.	239.	70.	79.
	50	7.3	120.	302.	14.7	60.	362.	302.	15.8	211.	-1.2	29.	104.	318.	214.	1441.	186.	236.	50.	26.
	100	7.6	135.	317.	13.0	43.	43.	365.	14.5	226.	0.7	43.	112.	339.	227.	1323.	UUUU	UUUU	UUUU	UUUUU
	150	7.7	145.	327.	12.0	53.	53.	365.	13.9	236.	1.5	53.	119.	353.	234.	1277.	UUUU	UUUU	UUUU	UUUUU
LUNDAR 1971	2.5	6.9	113.	296.	16.6	73.	336.	263.	17.8	205.	-3.9	22.	103.	306.	203.	1638.	162.	247.	85.	159.
	5	6.8	113.	296.	16.4	74.	335.	262.	17.6	203.	-4.0	22.	104.	306.	202.	1600.	154.	246.	92.	140.
	10	6.3	116.	299.	16.0	81.	334.	253.	17.3	207.	-4.8	25.	109.	305.	196.	1519.	169.	245.	76.	115.
62 J1	20	6.3	121.	303.	14.8	80.	344.	264.	16.0	212.	-3.5	29.	113.	311.	198.	1379.	185.	239.	54.	38.
	50	6.4	133.	316.	12.3	72.	12.	305.	13.8	225.	-1.0	42.	122.	327.	205.	1132.	UUUU	UUUU	UUUU	UUUUU
	100	6.4	142.	324.	10.7	51.	51.	365.	12.3	233.	0.4	51.	120.	330.	210.	958.	UUUU	UUUU	UUUU	UUUUU
	150	6.5	157.	340.	8.9	66.	65.	365.	10.8	249.	2.1	66.	137.	359.	222.	805.	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS. 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
NEWTON 1977	2.5	9.5	114.	297.	25.3	82.	329.	248.	27.3	206.	-8.4	23.	100.	312.	212.	2957.	133.	279.	146.	1165.
	5	8.8	115.	297.	23.6	82.	330.	248.	25.5	206.	-7.8	23.	101.	311.	210.	2683.	137.	275.	138.	940.
	10	8.3	117.	300.	21.6	84.	333.	250.	23.4	209.	-6.9	26.	105.	312.	208.	2453.	144.	273.	129.	711.
62 G13	20	7.8	121.	304.	19.7	86.	339.	253.	21.5	213.	-5.9	30.	109.	315.	206.	2143.	153.	272.	118.	508.
	50	7.7	132.	315.	17.4	92.	355.	263.	19.7	223.	-4.3	41.	119.	328.	209.	1926.	170.	277.	107.	332.
	100	7.0	149.	332.	13.1	98.	18.	284.	16.2	241.	-2.1	58.	136.	345.	209.	1468.	210.	271.	61.	50.
	150	7.0	157.	339.	10.8	65.	65.	365.	13.7	248.	0.3	65.	139.	357.	218.	1177.	UUUU	UUUU	UUUU	UUUUU
MIAMI 1977	2.5	11.0	113.	295.	26.7	73.	335.	261.	28.6	204.	-6.6	21.	92.	316.	223.	3270.	126.	282.	156.	1375.
	5	10.0	115.	297.	24.2	75.	337.	262.	26.0	206.	-5.9	24.	96.	316.	220.	2863.	133.	279.	146.	1034.
	10	8.2	121.	303.	20.6	85.	339.	254.	22.5	212.	-6.0	30.	107.	317.	209.	2293.	149.	275.	125.	614.
62 G16	20	7.8	126.	303.	18.7	88.	346.	259.	20.7	217.	-5.0	35.	113.	321.	208.	2044.	160.	274.	114.	422.
	50	7.8	133.	315.	16.6	86.	362.	275.	18.7	224.	-3.1	41.	117.	330.	213.	1827.	174.	273.	99.	244.
	100	7.8	145.	327.	14.1	83.	23.	305.	16.8	236.	-1.2	53.	126.	346.	220.	1611.	198.	273.	75.	90.
	150	7.9	153.	336.	12.3	62.	62.	365.	15.2	245.	0.5	62.	130.	359.	229.	1440.	231.	258.	27.	3.
HOMEWOOD	2.5	8.5	109.	291.	22.9	76.	324.	248.	24.6	200.	-7.5	17.	96.	304.	208.	2555.	133.	267.	134.	837.
	5	8.9	105.	283.	23.3	67.	317.	250.	25.0	192.	-7.2	9.	86.	297.	211.	2632.	123.	260.	137.	889.
	10	8.3	115.	297.	21.9	81.	330.	249.	23.7	206.	-7.1	23.	102.	310.	208.	2429.	141.	271.	130.	735.
62 H9	20	2.5	162.	344.	6.7	143.	363.	220.	10.6	253.	-5.5	70.	180.	326.	146.	527.	UUUU	UUUU	UUUU	UUUUU
	50	1.1	199.	381.	0.9	188.	27.	205.	6.7	290.	-4.6	108.	243.	337.	93.	106.	UUUU	UUUU	UUUU	UUUUU
	100	1.3	218.	401.	-0.7	206.	48.	207.	7.4	310.	-4.9	127.	257.	363.	106.	166.	UUUU	UUUU	UUUU	UUUUU
	150	2.2	222.	405.	-0.3	202.	60.	223.	8.5	314.	-4.2	131.	249.	378.	129.	296.	UUUU	UUUU	UUUU	UUUUU
DOMAIN 1 77	2.5	4.8	110.	292.	18.8	92.	311.	219.	20.4	201.	-10.8	19.	111.	292.	181.	1775.	151.	251.	100.	353.
	5	4.7	114.	297.	16.9	94.	317.	223.	18.4	205.	-9.1	23.	115.	295.	180.	1540.	163.	247.	84.	190.
	10	5.0	119.	301.	15.8	95.	326.	231.	17.4	210.	-7.3	28.	119.	301.	183.	1436.	174.	245.	73.	114.
62 H10	20	5.6	126.	309.	14.2	92.	343.	250.	15.8	218.	-4.6	35.	123.	312.	189.	1292.	195.	240.	45.	23.
	50	5.9	147.	330.	11.4	99.	12.	278.	14.0	238.	-2.2	56.	140.	336.	196.	1116.	UUUU	UUUU	UUUU	UUUUU
	100	6.9	164.	347.	9.8	73.	73.	365.	13.0	256.	0.7	73.	146.	365.	218.	1085.	UUUU	UUUU	UUUU	UUUUU
	150	7.4	164.	347.	10.4	73.	73.	365.	13.7	256.	1.1	73.	142.	370.	228.	1223.	UUUU	UUUU	UUUU	UUUUU
DOMAIN 2 77	2.5	2.7	128.	310.	19.1	120.	318.	199.	22.3	219.	-16.9	36.	134.	303.	169.	1876.	167.	271.	104.	499.
	5	4.8	120.	303.	20.4	105.	319.	214.	22.8	212.	-13.1	29.	121.	302.	181.	2054.	155.	268.	112.	573.
	10	5.7	120.	303.	21.0	101.	322.	221.	23.3	212.	-11.8	29.	118.	305.	187.	2174.	153.	270.	118.	638.
62 H11	20	6.1	119.	302.	20.4	97.	324.	227.	22.4	210.	-10.2	28.	115.	305.	190.	2101.	153.	268.	115.	561.
	50	7.8	126.	309.	17.6	84.	351.	267.	19.5	217.	-3.9	35.	112.	322.	210.	1905.	165.	270.	105.	310.
	100	7.7	134.	316.	13.3	43.	43.	365.	14.7	225.	0.6	43.	111.	339.	227.	1366.	UUUU	UUUU	UUUU	UUUUU
	150	7.2	136.	318.	10.7	45.	45.	365.	11.6	227.	2.7	45.	106.	348.	242.	982.	UUUU	UUUU	UUUU	UUUUU
WPG. BEACH	2.5	6.2	105.	288.	17.0	74.	319.	245.	18.2	197.	-5.9	14.	100.	293.	194.	1619.	153.	240.	87.	184.
	5	5.3	104.	286.	15.3	75.	315.	240.	16.4	195.	-5.8	13.	102.	288.	186.	1348.	165.	225.	59.	56.
	10	4.0	104.	286.	12.1	77.	313.	236.	13.0	195.	-5.0	13.	110.	283.	173.	876.	UUUU	UUUU	UUUU	UUUUU
62 I 1	20	2.8	101.	283.	10.0	80.	304.	225.	10.8	192.	-5.1	10.	117.	257.	150.	563.	UUUU	UUUU	UUUU	UUUUU
	50	3.2	100.	282.	9.5	72.	310.	239.	10.2	191.	-3.8	8.	115.	267.	153.	518.	UUUU	UUUU	UUUU	UUUUU
	100	2.5	92.	275.	6.6	60.	307.	247.	7.2	183.	-2.2	1.	125.	242.	117.	169.	UUUU	UUUU	UUUU	UUUUU
	150	3.1	96.	278.	5.2	4.	4.	365.	5.5	187.	0.6	4.	149.	225.	76.	26.	UUUU	UUUU	UUUU	UUUUU
WELL# 1	2.5	6.9	118.	301.	19.7	89.	329.	240.	21.5	210.	-7.6	27.	111.	308.	198.	2056.	152.	266.	114.	484.
	5	5.9	111.	293.	18.7	86.	318.	233.	20.2	202.	-8.3	27.	107.	297.	190.	1629.	151.	253.	102.	348.
	10	5.0	113.	295.	16.3	89.	319.	230.	17.7	204.	-7.6	22.	113.	296.	183.	1481.	166.	243.	77.	139.
62 K2	20	5.0	119.	302.	14.7	92.	329.	237.	16.1	211.	-6.1	28.	120.	302.	182.	1283.	185.	237.	52.	38.
	50	4.9	129.	311.	12.7	97.	343.	247.	14.3	220.	-4.5	38.	129.	311.	182.	1081.	UUUU	UUUU	UUUU	UUUUU
	100	4.7	143.	325.	10.2	104.	364.	260.	12.3	234.	-2.9	51.	145.	323.	178.	827.	UUUU	UUUU	UUUU	UUUUU
	150	5.0	151.	334.	9.1	100.	20.	284.	11.5	243.	-1.5	60.	151.	334.	182.	756.	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE CC		DAYS ABOVE C C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
ORR LAKE GLE 64 A3	2.5	7.8	99.	282.	20.3	64.	316.	252.	21.8	190.	-6.1	8.	87.	293.	206.	2171.	130.	250.	120.	532.
	5	5.0	110.	293.	17.1	88.	315.	227.	18.5	202.	-8.5	19.	110.	293.	182.	1566.	159.	244.	85.	196.
	10	3.9	118.	300.	13.6	97.	321.	224.	15.0	209.	-7.2	26.	123.	294.	171.	1090.	UUUU	UUUU	UUUU	UUUUU
	20	1.1	132.	314.	7.2	123.	323.	199.	8.7	223.	-6.5	40.	163.	283.	119.	288.	UUUU	UUUU	UUUU	UUUUU
	50	-0.1	142.	325.	2.3	145.	323.	178.	3.2	234.	-3.4	51.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	100	-0.2	149.	331.	0.8	158.	322.	164.	1.3	240.	-1.8	58.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	-0.1	130.	312.	0.6	UUUU	UUUU	UUUU	0.7	221.	-0.8	38.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
SPLIT LAKE 64 A4	2.5	0.6	116.	299.	12.9	114.	301.	188.	14.5	208.	-13.2	25.	135.	280.	145.	893.	UUUU	UUUU	UUUU	UUUUU
	5	1.0	120.	303.	11.0	115.	308.	193.	12.5	212.	-10.5	29.	141.	282.	141.	690.	UUUU	UUUU	UUUU	UUUUU
	10	1.4	127.	309.	8.9	118.	318.	200.	10.3	218.	-7.6	35.	151.	285.	134.	465.	UUUU	UUUU	UUUU	UUUUU
	20	1.5	131.	314.	6.7	118.	327.	209.	7.9	223.	-4.9	40.	165.	280.	115.	216.	UUUU	UUUU	UUUU	UUUUU
	50	1.0	132.	314.	4.1	117.	329.	212.	4.9	223.	-2.9	46.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	100	0.8	147.	329.	2.3	123.	353.	229.	3.0	238.	-1.3	56.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	0.8	129.	312.	2.0	99.	342.	243.	2.3	221.	-0.8	38.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
SPLIT LAKE 64 A5	2.5	3.8	123.	305.	13.8	103.	324.	221.	15.4	214.	-7.9	31.	129.	299.	170.	1140.	198.	230.	32.	9.
	5	4.4	118.	309.	15.8	98.	320.	222.	17.4	209.	-8.7	27.	121.	297.	177.	1402.	173.	245.	72.	114.
	10	3.5	132.	315.	11.6	112.	335.	223.	13.6	224.	-6.6	41.	141.	306.	165.	907.	UUUU	UUUU	UUUU	UUUUU
	20	2.5	137.	319.	7.1	112.	344.	232.	8.5	228.	-3.6	46.	162.	294.	132.	334.	UUUU	UUUU	UUUU	UUUUU
	50	1.4	150.	333.	3.3	122.	362.	240.	4.3	242.	-1.5	59.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	100	1.1	150.	333.	1.9	82.	35.	318.	2.3	241.	-0.1	59.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	0.8	232.	415.	0.8	UUUU	UUUU	UUUU	0.9	324.	0.8	141.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
LAVENHAM 62 G17	2.5	12.0	120.	302.	32.9	89.	333.	244.	36.0	211.	-11.9	28.	102.	319.	217.	4189.	127.	295.	168.	2264.
	5	10.4	119.	301.	29.1	89.	331.	242.	31.8	210.	-11.0	28.	104.	315.	212.	3548.	131.	289.	157.	1700.
	10	8.8	118.	300.	25.1	89.	329.	240.	27.3	209.	-9.8	27.	106.	312.	206.	2887.	138.	280.	143.	1140.
	20	7.5	119.	302.	20.8	89.	332.	242.	22.7	211.	-7.8	28.	110.	311.	201.	2246.	149.	272.	122.	618.
	50	7.7	122.	304.	18.7	84.	342.	259.	20.5	213.	-5.0	31.	109.	317.	208.	2017.	157.	269.	112.	434.
	100	8.1	129.	311.	16.5	75.	364.	289.	18.3	222.	-2.1	37.	111.	329.	218.	1801.	172.	268.	96.	237.
	150	8.1	134.	316.	15.0	60.	24.	329.	16.7	225.	-0.4	42.	112.	338.	226.	1638.	188.	262.	75.	85.
LAVENHAM(2) 62 G18	2.5	10.9	116.	299.	25.7	75.	340.	264.	27.7	208.	-6.0	25.	95.	319.	224.	3147.	131.	284.	154.	1269.
	5	9.3	115.	297.	22.3	75.	337.	262.	24.0	206.	-5.4	24.	98.	315.	217.	2562.	138.	274.	136.	794.
	10	8.1	115.	297.	19.7	76.	336.	260.	21.2	206.	-5.0	23.	101.	311.	210.	2128.	147.	265.	118.	476.
	20	7.3	116.	298.	17.9	77.	336.	259.	19.3	207.	-4.6	24.	104.	309.	205.	1841.	156.	257.	101.	285.
	50	7.8	120.	303.	16.7	70.	353.	283.	18.0	211.	-2.4	29.	104.	319.	215.	1746.	165.	257.	92.	184.
	100	8.2	129.	311.	14.6	37.	37.	365.	16.0	220.	0.4	37.	104.	335.	231.	1561.	191.	249.	58.	38.
	150	8.1	133.	316.	13.0	42.	42.	365.	14.3	225.	1.9	42.	103.	346.	243.	1374.	UUUU	UUUU	UUUU	UUUUU
LAVENHAM(3) 62 G19	2.5	9.7	123.	305.	22.7	82.	346.	263.	24.8	214.	-5.4	32.	105.	324.	219.	2699.	144.	285.	141.	898.
	5	9.3	122.	305.	21.7	81.	346.	264.	23.7	214.	-5.1	31.	105.	323.	218.	2541.	146.	281.	135.	770.
	10	8.1	121.	304.	18.6	79.	346.	263.	20.2	213.	-4.0	30.	106.	319.	213.	2025.	156.	269.	112.	386.
	20	7.6	120.	303.	16.7	73.	350.	277.	18.0	212.	-2.8	29.	106.	317.	212.	1724.	166.	257.	91.	132.
	50	7.5	124.	307.	15.4	69.	362.	294.	16.7	216.	-1.7	33.	108.	323.	215.	1569.	179.	252.	72.	82.
	100	7.6	132.	314.	13.9	56.	25.	334.	15.4	223.	-0.3	41.	113.	334.	221.	1425.	205.	241.	36.	9.
	150	7.4	139.	322.	12.7	48.	48.	365.	14.4	230.	0.4	48.	118.	342.	224.	1302.	UUUU	UUUU	UUUU	UUUUU
LAVENHAM(4) 62 G20	2.5	11.8	120.	303.	30.0	85.	338.	252.	32.7	212.	-9.1	29.	101.	322.	221.	3808.	129.	294.	165.	1380.
	5	10.8	121.	303.	27.3	85.	339.	254.	29.7	212.	-8.1	29.	102.	321.	219.	3373.	133.	290.	157.	1491.
	10	9.6	121.	303.	23.7	84.	340.	256.	25.8	212.	-6.6	30.	104.	320.	216.	2674.	141.	284.	143.	[illegible]
	20	8.4	123.	306.	20.1	84.	344.	260.	22.1	214.	-5.2	32.	108.	320.	212.	2264.	152.	276.	124.	574.
	50	9.0	124.	307.	19.2	75.	356.	281.	21.0	216.	-3.0	33.	105.	327.	222.	2203.	155.	276.	122.	477.
	100	9.0	135.	317.	16.7	66.	21.	319.	18.8	226.	-0.8	44.	110.	342.	232.	1964.	173.	279.	106.	262.
	150	9.0	142.	325.	14.9	51.	51.	365.	17.1	233.	0.8	51.	112.	354.	242.	1785.	191.	276.	85.	119.

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
LAVENHAM(5)	2.5	8.5	128.	310.	19.7	89.	350.	261.	21.9	219.	-5.0	37.	113.	326.	213.	2252.	157.	281.	124.	562.
	5	5.3	141.	324.	8.4	50.	50.	365.	9.5	233.	1.2	50.	136.	329.	192.	544.	UUUU	UUUU	UUUU	UUUUU
	10	6.7	137.	319.	14.0	91.	365.	273.	16.2	228.	-2.8	46.	126.	330.	203.	1434.	198.	258.	59.	48.
62 G21	20	7.2	126.	308.	17.5	89.	345.	256.	19.4	217.	-5.0	35.	115.	319.	203.	1845.	166.	268.	102.	297.
	50	6.5	129.	311.	15.6	92.	348.	256.	17.5	220.	-4.5	38.	121.	319.	198.	1559.	181.	260.	79.	129.
	100	6.7	147.	329.	12.0	87.	24.	302.	14.4	238.	-1.1	55.	134.	342.	208.	1229.	UUUU	UUUU	UUUU	UUUUU
	150	6.8	152.	335.	11.0	61.	61.	365.	13.6	244.	0.0	61.	137.	351.	214.	1141.	UUUU	UUUU	UUUU	UUUUU
LAVENHAM(6)	2.5	8.9	119.	301.	20.6	76.	344.	268.	22.2	210.	-4.4	28.	101.	319.	217.	2333.	146.	274.	127.	602.
	5	8.5	119.	301.	19.8	76.	343.	267.	21.3	210.	-4.3	27.	102.	317.	215.	2191.	149.	270.	121.	502.
	10	8.2	119.	301.	18.8	75.	344.	269.	20.3	210.	-3.9	27.	103.	317.	214.	2043.	153.	267.	113.	395.
62 G22	20	8.1	118.	301.	18.1	73.	346.	273.	19.5	209.	-3.4	27.	102.	316.	214.	1934.	156.	263.	107.	314.
	50	8.2	126.	309.	16.6	70.	365.	295.	18.2	218.	-1.8	35.	107.	328.	221.	1803.	170.	265.	95.	199.
	100	8.3	136.	318.	14.7	44.	44.	365.	16.4	227.	0.2	44.	111.	343.	232.	1632.	192.	262.	70.	67.
	150	8.3	142.	325.	13.0	51.	51.	365.	14.8	234.	1.8	51.	112.	356.	244.	1455.	UUUU	UUUU	UUUU	UUUUU
CARBERRY(2)	2.5	10.5	104.	286.	30.7	75.	315.	239.	33.0	195.	-12.0	13.	89.	301.	211.	3703.	115.	275.	159.	1849.
	5	8.7	108.	290.	26.8	82.	316.	234.	28.9	199.	-11.4	17.	97.	301.	204.	3059.	126.	272.	146.	1308.
	10	9.2	104.	287.	27.5	77.	314.	237.	29.6	196.	-11.2	13.	92.	299.	207.	3188.	121.	270.	149.	1409.
62 G23	20	6.8	112.	295.	21.6	87.	319.	232.	23.4	203.	-9.8	21.	106.	301.	195.	2268.	142.	265.	122.	671.
	50	6.6	125.	307.	18.6	96.	335.	239.	20.7	216.	-7.5	33.	118.	314.	195.	1933.	162.	270.	108.	401.
	100	5.9	147.	329.	12.3	107.	4.	262.	15.3	238.	-3.5	56.	141.	335.	194.	1263.	223.	253.	29.	6.
	150	6.6	138.	320.	15.7	104.	354.	250.	18.6	229.	-5.4	47.	130.	328.	198.	1695.	183.	275.	92.	217.
WOODMORE	2.5	7.7	112.	295.	26.0	89.	317.	228.	26.1	203.	-12.7	21.	104.	302.	198.	2693.	133.	273.	140.	1198.
	5	8.1	118.	300.	26.4	95.	324.	229.	28.9	209.	-12.7	27.	109.	309.	200.	3009.	138.	281.	143.	1291.
	10	7.7	121.	303.	24.4	97.	327.	231.	26.9	212.	-11.5	29.	112.	311.	199.	2743.	143.	280.	137.	1058.
62 H12	20	7.2	122.	304.	21.8	96.	330.	234.	24.1	213.	-9.6	30.	114.	312.	198.	2385.	149.	276.	127.	754.
	50	7.4	128.	311.	19.5	97.	342.	245.	21.9	220.	-7.1	37.	119.	321.	202.	2147.	160.	279.	118.	535.
	100	7.8	146.	329.	15.5	101.	9.	273.	19.0	237.	-3.3	55.	131.	343.	212.	1853.	187.	288.	101.	264.
	150	7.9	164.	346.	12.5	104.	41.	302.	17.2	255.	-1.3	72.	145.	365.	220.	1671.	214.	296.	82.	121.
WPG BEACH	2.5	8.7	110.	293.	18.8	59.	344.	286.	20.0	202.	-2.5	19.	91.	312.	222.	2064.	145.	259.	114.	373.
	5	8.2	112.	294.	17.4	57.	349.	291.	18.5	203.	-2.0	20.	93.	313.	220.	1848.	154.	252.	99.	225.
	10	7.5	114.	296.	15.2	52.	357.	305.	16.1	205.	-1.1	22.	96.	313.	217.	1498.	175.	234.	59.	43.
62 I 1	20	7.4	117.	299.	14.4	49.	2.	318.	15.4	208.	-0.6	20.	100.	317.	217.	1402.	191.	226.	35.	9.
	50	7.7	126.	308.	13.9	34.	35.	365.	15.0	217.	0.4	35.	104.	330.	226.	1403.	211.	223.	11.	0.
	100	7.8	139.	322.	12.2	48.	48.	365.	13.7	231.	1.9	48.	111.	351.	240.	1275.	UUUU	UUUU	UUUU	UUUUU
	150	8.0	150.	333.	11.1	59.	59.	365.	12.9	241.	3.1	59.	112.	370.	258.	1218.	UUUU	UUUU	UUUU	UUUUU
GIMLI LAKE	2.5	6.7	122.	304.	16.7	86.	341.	255.	18.2	213.	-4.8	31.	113.	313.	200.	1669.	169.	258.	89.	192.
	5	6.6	122.	305.	16.2	85.	342.	257.	17.7	213.	-4.5	31.	114.	313.	200.	1599.	172.	255.	83.	149.
	10	6.3	125.	307.	14.9	86.	346.	260.	16.4	216.	-3.8	34.	117.	315.	197.	1418.	165.	247.	82.	57.
62 I 2	20	6.6	129.	311.	14.7	86.	354.	269.	16.4	220.	-3.1	33.	119.	321.	202.	1443.	169.	251.	82.	56.
	50	6.9	138.	321.	13.6	86.	7.	280.	15.7	229.	-2.0	47.	126.	333.	207.	1392.	206.	253.	47.	22.
	100	7.0	151.	333.	11.5	59.	59.	365.	14.0	242.	0.0	59.	133.	350.	217.	1214.	UUUU	UUUU	UUUU	UUUUU
	150	7.1	160.	343.	10.3	69.	69.	365.	13.1	251.	1.2	69.	139.	364.	225.	1123.	UUUU	UUUU	UUUU	UUUUU
ST-NORBERT	2.5	7.3	120.	302.	18.4	84.	338.	253.	20.1	211.	-3.5	29.	109.	313.	203.	1926.	157.	265.	107.	356.
	5	7.0	123.	305.	17.4	87.	341.	254.	19.1	214.	-5.1	31.	113.	315.	202.	1788.	165.	263.	98.	264.
	10	6.7	125.	303.	16.2	87.	346.	259.	17.9	217.	-4.4	34.	116.	317.	201.	1625.	174.	259.	85.	161.
	20	6.8	130.	312.	15.2	88.	354.	266.	17.0	221.	-3.5	38.	120.	322.	203.	1535.	184.	256.	75.	101.
	50	7.1	138.	321.	13.8	84.	10.	290.	15.9	229.	-1.8	47.	124.	334.	210.	1434.	203.	256.	53.	32.
	100	7.2	149.	332.	11.7	58.	58.	365.	14.0	241.	0.4	53.	130.	351.	221.	1234.	UUUU	UUUU	UUUU	UUUUU
	150	7.6	158.	340.	10.3	67.	67.	365.	12.5	249.	2.6	67.	126.	372.	246.	1113.	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
NEEPAWA	2.5	7.9	100.	283.	21.0	67.	316.	248.	22.6	192.	-6.8	9.	89.	294.	205.	2268.	130.	253.	124.	614.
	5	7.4	98.	281.	19.8	66.	313.	248.	21.3	190.	-6.5	7.	88.	291.	203.	2073.	132.	247.	115.	472.
62 J2	10	7.5	92.	274.	18.1	53.	314.	261.	19.6	183.	-4.5	1.	80.	287.	207.	1894.	131.	236.	105.	315.
	20	6.5	97.	280.	17.3	65.	313.	248.	18.7	189.	-5.7	6.	90.	287.	197.	1700.	142.	235.	93.	225.
	50	4.9	116.	298.	15.4	91.	323.	232.	16.8	207.	-6.9	25.	116.	298.	182.	1363.	175.	239.	64.	75.
	100	5.8	151.	333.	11.3	108.	11.	268.	14.4	242.	-2.8	60.	146.	339.	193.	1151.	UUUU	UUUU	UUUU	UUUUU
	150	6.4	179.	362.	8.1	88.	88.	365.	12.7	271.	0.0	88.	167.	374.	208.	998.	UUUU	UUUU	UUUU	UUUUU
HAMIOTA	2.5	6.4	95.	278.	20.0	71.	302.	232.	21.8	187.	-9.1	4.	90.	283.	193.	2054.	130.	243.	114.	510.
	5	5.7	98.	280.	18.8	75.	303.	229.	20.4	189.	-9.0	6.	95.	283.	188.	1834.	138.	240.	103.	363.
62 K1	10	4.9	102.	284.	17.0	80.	306.	226.	18.4	193.	-8.5	11.	102.	284.	182.	1553.	151.	235.	84.	189.
	20	4.8	107.	289.	16.0	84.	312.	228.	17.3	198.	-7.7	16.	108.	283.	181.	1411.	163.	233.	71.	106.
	50	4.5	124.	306.	13.5	98.	332.	234.	15.1	215.	-6.0	32.	126.	303.	177.	1138.	209.	221.	12.	0.
	100	4.7	159.	342.	8.9	121.	14.	258.	12.4	250.	-3.1	63.	162.	339.	178.	842.	UUUU	UUUU	UUUU	UUUUU
	150	4.7	184.	367.	5.8	126.	60.	299.	10.2	275.	-0.9	93.	187.	363.	176.	589.	UUUU	UUUU	UUUU	UUUUU
DAUPHIN A	2.5	8.9	108.	290.	23.9	75.	322.	247.	25.6	199.	-7.9	16.	94.	304.	210.	2710.	129.	268.	139.	963.
	5	7.6	110.	293.	21.2	80.	323.	243.	22.8	201.	-7.6	19.	100.	302.	202.	2266.	140.	263.	123.	629.
62 N1	10	5.8	126.	309.	14.8	92.	342.	250.	16.5	218.	-4.8	35.	122.	313.	192.	1390.	187.	248.	61.	59.
	20	6.5	119.	302.	17.8	88.	333.	244.	19.4	211.	-6.4	28.	112.	309.	190.	1784.	161.	260.	99.	286.
	50	6.3	130.	312.	15.7	96.	346.	251.	17.7	221.	-5.1	39.	123.	319.	196.	1572.	180.	262.	82.	146.
	100	6.1	143.	325.	12.5	98.	5.	272.	14.9	234.	-2.7	51.	135.	332.	197.	1233.	UUUU	UUUU	UUUU	UUUUU
	150	6.1	152.	334.	10.3	86.	35.	314.	12.8	243.	-0.6	61.	142.	344.	201.	990.	UUUU	UUUU	UUUU	UUUUU
OCHRE RIVER	2.5	9.5	103.	285.	22.6	62.	327.	265.	24.1	195.	-5.1	12.	85.	304.	219.	2599.	126.	263.	138.	814.
	5	8.2	109.	291.	19.4	68.	332.	264.	20.7	200.	-4.4	17.	94.	306.	212.	2083.	142.	258.	116.	434.
62 01	10	6.8	115.	298.	16.5	76.	337.	261.	17.7	207.	-4.1	24.	106.	308.	202.	1615.	165.	248.	84.	150.
	20	6.5	120.	303.	15.0	78.	345.	267.	16.3	212.	-3.2	29.	111.	312.	201.	1430.	181.	242.	61.	53.
	50	6.6	129.	312.	13.6	77.	364.	287.	15.0	220.	-1.8	38.	116.	323.	205.	1292.	214.	226.	12.	0.
	100	6.6	140.	323.	11.7	63.	35.	337.	13.5	232.	-0.2	49.	126.	337.	211.	1117.	UUUU	UUUU	UUUU	UUUUU
	150	6.6	150.	332.	10.2	59.	59.	365.	12.2	241.	1.0	59.	133.	349.	216.	968.	UUUU	UUUU	UUUU	UUUUU
GYPSUMVILLE	2.5	8.6	113.	296.	21.1	74.	334.	260.	22.6	205.	-5.3	22.	98.	311.	213.	2338.	141.	268.	127.	629.
	5	7.2	113.	296.	19.9	83.	326.	244.	21.4	205.	-7.1	22.	104.	305.	205.	2075.	147.	262.	115.	486.
62 02	10	6.0	117.	300.	16.2	86.	332.	246.	17.5	209.	-5.5	26.	112.	305.	193.	1527.	169.	248.	78.	131.
	20	5.6	121.	304.	14.3	86.	339.	252.	15.6	213.	-4.3	30.	117.	307.	193.	1276.	192.	233.	40.	16.
	50	5.7	132.	315.	12.2	86.	360.	274.	13.7	223.	-2.3	41.	127.	320.	193.	1064.	UUUU	UUUU	UUUU	UUUUU
	100	5.8	140.	323.	10.6	76.	22.	311.	12.3	232.	-0.7	49.	133.	330.	197.	906.	UUUU	UUUU	UUUU	UUUUU
	150	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
ASHERN 1971	2.5	6.7	115.	293.	17.7	82.	331.	248.	19.2	207.	-5.8	24.	107.	306.	198.	1773.	158.	256.	98.	268.
	5	6.4	118.	301.	15.9	82.	337.	255.	17.2	210.	-4.5	27.	111.	305.	197.	1518.	172.	247.	75.	139.
62 03	10	6.1	121.	303.	14.0	76.	346.	268.	15.2	212.	-3.0	29.	113.	310.	197.	1266.	200.	224.	24.	3.
	20	6.5	127.	310.	13.1	69.	3.	299.	14.3	219.	-1.2	36.	116.	322.	206.	1205.	UUUU	UUUU	UUUU	UUUUU
	50	6.4	133.	316.	11.7	55.	29.	339.	13.0	225.	-0.2	42.	121.	328.	208.	1039.	UUUU	UUUU	UUUU	UUUUU
	100	7.8	128.	311.	12.1	37.	37.	365.	12.9	22[illegible].	2.8	37.	94.	345.	251.	1201.	UUUU	UUUU	UUUU	UUUUU
	150	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
DEVILS LAKE	2.5	6.7	116.	298.	18.5	85.	329.	243.	20.1	207.	-6.7	25.	109.	305.	197.	1875.	155.	259.	105.	349.
	5	6.2	120.	302.	16.1	86.	336.	251.	17.5	211.	-5.0	29.	113.	309.	195.	1543.	172.	251.	79.	132.
63 B1	10	5.3	124.	307.	13.9	92.	339.	247.	15.3	215.	-4.8	33.	122.	306.	185.	1222.	200.	231.	34.	7.
	20	5.3	128.	311.	12.9	93.	346.	253.	14.5	220.	-3.9	37.	127.	312.	186.	1121.	UUUU	UUUU	UUUU	UUUUU
	50	5.3	138.	321.	11.3	95.	364.	269.	13.2	229.	-2.5	47.	136.	323.	187.	969.	UUUU	UUUU	UUUU	UUUUU
	100	5.2	149.	332.	9.3	91.	25.	299.	11.5	241.	-1.0	58.	147.	334.	187.	765.	UUUU	UUUU	UUUU	UUUUU
	150	5.3	159.	341.	8.0	68.	68.	365.	10.3	250.	0.4	68.	155.	345.	190.	637.	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS ABOVE	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE	DEGREE DAYS	DATE 15C		DAYS ABOVE	DEG. DAYS
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER	0 C					SPRING	FALL	5 C	5 C	SPRING	FALL	15 C	15 C
PORCUPINE 1	2.5	4.5	114.	296.	13.8	88.	322.	234.	14.9	205.	-5.9	22.	116.	293.	177.	1119.	UUUU	UUUU	UUUU	UUUUU
	5	4.4	117.	300.	12.9	89.	327.	239.	14.0	208.	-5.2	26.	121.	296.	175.	1008.	UUUU	UUUU	UUUU	UUUUU
63 C1	10	4.0	123.	305.	11.7	97.	332.	235.	13.0	214.	-5.1	32.	130.	299.	169.	869.	UUUU	UUUU	UUUU	UUUUU
	20	3.3	134.	316.	8.8	105.	345.	240.	10.2	225.	-3.7	43.	148.	302.	154.	520.	UUUU	UUUU	UUUU	UUUUU
	50	3.2	151.	333.	6.1	104.	15.	276.	7.8	242.	-1.3	60.	174.	310.	136.	244.	UUUU	UUUU	UUUU	UUUUU
	100	3.3	161.	344.	5.0	76.	64.	353.	6.6	253.	-0.0	70.	192.	313.	121.	129.	UUUU	UUUU	UUUU	UUUUU
	150	3.4	173.	356.	4.3	82.	82.	365.	6.1	265.	0.7	82.	211.	318.	107.	75.	UUUU	UUUU	UUUU	UUUUU
PORCUPINE 2	2.5	4.1	115.	297.	14.0	93.	319.	226.	15.2	206.	-7.1	23.	119.	292.	173.	1131.	194.	217.	23.	3.
	5	4.0	118.	301.	12.8	95.	324.	229.	14.1	209.	-6.1	27.	124.	295.	171.	990.	UUUU	UUUU	UUUU	UUUUU
	10	3.7	123.	306.	10.4	95.	334.	239.	11.5	215.	-4.2	32.	133.	296.	163.	682.	UUUU	UUUU	UUUU	UUUUU
63 C2	20	3.2	131.	314.	8.2	99.	346.	247.	9.3	222.	-2.9	40.	148.	296.	148.	414.	UUUU	UUUU	UUUU	UUUUU
	50	3.1	145.	327.	6.5	103.	4.	267.	7.9	236.	-1.6	54.	168.	304.	136.	255.	UUUU	UUUU	UUUU	UUUUU
	100	3.2	157.	340.	5.3	99.	33.	299.	7.0	249.	-0.6	66.	187.	311.	124.	159.	UUUU	UUUU	UUUU	UUUUU
	150	3.2	168.	351.	4.5	77.	77.	365.	6.2	259.	0.2	77.	205.	314.	109.	88.	UUUU	UUUU	UUUU	UUUUU
PORCUPINE 3	2.5	4.5	107.	293.	14.3	83.	314.	231.	15.4	199.	-6.5	16.	110.	287.	177.	1181.	182.	215.	33.	10.
	5	4.1	110.	293.	12.8	85.	318.	233.	13.8	202.	-5.7	19.	116.	287.	172.	972.	UUUU	UUUU	UUUU	UUUUU
	10	3.8	119.	302.	10.9	91.	331.	239.	11.9	211.	-4.3	28.	128.	293.	165.	732.	UUUU	UUUU	UUUU	UUUUU
63 C3	20	3.2	126.	308.	9.6	100.	334.	234.	10.7	217.	-4.3	35.	140.	294.	155.	572.	UUUU	UUUU	UUUU	UUUUU
	50	3.4	139.	322.	8.0	104.	357.	254.	9.4	231.	-2.5	48.	155.	307.	152.	436.	UUUU	UUUU	UUUU	UUUUU
	100	3.3	155.	337.	6.1	109.	19.	275.	8.0	246.	-1.3	64.	176.	316.	140.	275.	UUUU	UUUU	UUUU	UUUUU
	150	3.4	166.	349.	5.1	100.	50.	315.	7.1	258.	-0.3	75.	192.	322.	130.	177.	UUUU	UUUU	UUUU	UUUUU
PORCUPINE 4	2.5	4.9	103.	286.	15.6	79.	310.	231.	16.9	195.	-7.2	12.	104.	285.	181.	1369.	162.	227.	65.	81.
	5	4.7	105.	288.	14.6	80.	313.	233.	15.7	197.	-6.4	14.	107.	286.	179.	1226.	175.	219.	42.	21.
63 C4	10	3.8	117.	303.	11.1	89.	328.	239.	12.1	208.	-4.4	26.	125.	291.	166.	758.	UUUU	UUUU	UUUU	UUUUU
	20	3.1	129.	312.	8.5	100.	341.	240.	9.6	221.	-3.4	38.	146.	295.	148.	444.	UUUU	UUUU	UUUU	UUUUU
	50	3.2	147.	329.	6.6	106.	6.	265.	8.2	238.	-1.7	56.	168.	308.	140.	287.	UUUU	UUUU	UUUU	UUUUU
	100	3.2	162.	345.	5.1	106.	36.	295.	7.1	254.	-0.7	71.	191.	317.	126.	171.	UUUU	UUUU	UUUU	UUUUU
	150	3.2	174.	357.	4.3	83.	83.	365.	6.3	265.	0.2	83.	210.	321.	111.	93.	UUUU	UUUU	UUUU	UUUUU
PORCUPINE 5	2.5	4.2	112.	295.	13.7	89.	318.	229.	14.9	204.	-6.5	21.	117.	291.	174.	1096.	UUUU	UUUU	UUUU	UUUUU
	5	4.0	119.	301.	12.1	93.	327.	234.	13.2	210.	-5.3	28.	125.	295.	169.	893.	UUUU	UUUU	UUUU	UUUUU
63 C5	10	3.5	125.	303.	10.1	98.	336.	238.	11.2	217.	-4.2	34.	137.	297.	160.	644.	UUUU	UUUU	UUUU	UUUUU
	20	3.4	139.	322.	7.9	104.	358.	254.	9.4	231.	-2.5	48.	155.	306.	151.	427.	UUUU	UUUU	UUUU	UUUUU
	50	3.2	151.	334.	6.0	105.	15.	276.	7.6	242.	-1.3	67.	175.	309.	134.	229.	UUUU	UUUU	UUUU	UUUUU
	100	3.2	166.	349.	4.8	99.	51.	318.	6.7	258.	-0.3	73.	198.	317.	119.	129.	UUUU	UUUU	UUUU	UUUUU
	150	3.2	177.	359.	4.0	86.	86.	365.	6.0	268.	0.4	86.	216.	318.	102.	64.	UUUU	UUUU	UUUU	UUUUU
DAWSON BAY 1	2.5	8.4	109.	292.	22.0	75.	326.	251.	23.5	201.	-6.7	18.	96.	305.	209.	2423.	135.	265.	130.	723.
	5	7.9	110.	292.	20.7	76.	327.	251.	22.1	201.	-6.3	19.	98.	304.	207.	2221.	146.	262.	122.	570.
	10	6.9	114.	296.	17.2	77.	333.	257.	18.5	205.	-4.7	23.	104.	306.	202.	1718.	159.	251.	93.	216.
63 C6	20	5.8	122.	304.	14.0	83.	343.	259.	15.3	213.	-3.7	30.	117.	309.	193.	1257.	198.	228.	30.	6.
	50	5.5	135.	317.	11.3	85.	2.	281.	12.9	226.	-1.8	43.	130.	321.	191.	949.	UUUU	UUUU	UUUU	UUUUU
	100	5.4	146.	323.	9.5	80.	29.	314.	11.3	237.	-0.6	55.	142.	332.	190.	757.	UUUU	UUUU	UUUU	UUUUU
	150	5.5	154.	337.	8.2	63.	63.	365.	10.0	246.	0.9	63.	149.	342.	194.	618.	UUUU	UUUU	UUUU	UUUUU
COWAN	2.5	8.2	103.	286.	20.2	65.	324.	259.	21.6	195.	-5.2	12.	89.	300.	210.	2184.	134.	255.	120.	520.
	5	7.7	106.	288.	18.9	67.	327.	260.	20.2	197.	-4.8	14.	93.	301.	208.	1982.	142.	252.	110.	377.
	10	6.0	116.	298.	14.3	75.	339.	263.	15.4	217.	-3.4	25.	110.	305.	195.	1281.	196.	224.	33.	9.
63 C7	20	5.6	122.	304.	12.9	80.	346.	266.	14.0	213.	-2.9	30.	118.	308.	190.	1091.	UUUU	UUUU	UUUU	UUUUU
	50	5.6	132.	314.	11.3	77.	3.	291.	12.6	223.	-1.4	47.	126.	319.	193.	926.	UUUU	UUUU	UUUU	UUUUU
	100	5.6	146.	323.	9.3	54.	54.	365.	11.0	237.	0.2	54.	140.	334.	194.	732.	UUUU	UUUU	UUUU	UUUUU
	150	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUUUUUUU		UUUU	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
REED LAKE	2.5	4.7	115.	297.	17.2	95.	317.	223.	18.8	206.	-9.3	23.	116.	296.	180.	1585.	162.	250.	87.	218.
	5	4.3	116.	299.	15.4	96.	319.	223.	16.9	208.	-8.2	25.	120.	296.	176.	1334.	176.	240.	64.	79.
63 K7	10	3.4	121.	303.	11.7	100.	324.	224.	13.0	212.	-6.3	30.	131.	294.	163.	840.	UUUU	UUUU	UUUU	UUUUU
	20	2.6	133.	316.	7.7	108.	340.	232.	9.0	224.	-3.7	42.	155.	293.	138.	357.	UUUU	UUUU	UUUU	UUUUU
	50	2.1	156.	338.	4.3	123.	6.	249.	5.9	247.	-1.8	64.	206.	288.	82.	50.	UUUU	UUUU	UUUU	UUUUU
	100	2.1	168.	350.	3.0	97.	56.	324.	4.3	259.	-0.1	77.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	2.2	179.	362.	2.4	88.	88.	365.	3.2	271.	1.1	88.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
JOEY LAKE	2.5	2.6	113.	295.	14.4	101.	307.	206.	15.8	204.	-10.5	21.	123.	285.	162.	1121.	184.	224.	40.	21.
	5	2.8	114.	296.	13.4	100.	310.	211.	14.7	205.	-9.0	22.	124.	285.	161.	1004.	UUUU	UUUU	UUUU	UUUUU
63 01	10	2.2	123.	306.	10.2	110.	319.	209.	11.6	215.	-7.3	32.	141.	288.	147.	627.	UUUU	UUUU	UUUU	UUUUU
	20	1.4	135.	317.	7.2	123.	328.	205.	8.7	226.	-5.9	43.	164.	287.	123.	298.	UUUU	UUUU	UUUU	UUUUU
	50	0.1	153.	336.	1.7	150.	339.	190.	2.6	244.	-2.3	62.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	100	0.2	145.	328.	0.5	UUUU	UUUU	UUUU	0.6	237.	-0.3	54.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	0.1	147.	330.	0.4	UUUU	UUUU	UUUU	0.6	239.	-0.3	56.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
OSPWAGON	2.5	2.0	114.	296.	12.8	104.	306.	202.	14.1	205.	-10.1	23.	128.	282.	154.	905.	UUUU	UUUU	UUUU	UUUUU
	5	2.3	116.	298.	11.9	104.	310.	207.	13.2	207.	-8.7	25.	131.	284.	153.	610.	UUUU	UUUU	UUUU	UUUUU
63 02	10	2.0	121.	304.	9.6	109.	317.	208.	10.8	213.	-6.9	30.	142.	284.	142.	532.	UUUU	UUUU	UUUU	UUUUU
	20	3.2	135.	318.	4.4	44.	44.	365.	4.8	227.	1.6	44.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	50	1.8	149.	332.	4.8	126.	354.	228.	6.3	240.	-2.8	58.	195.	286.	91.	79.	UUUU	UUUU	UUUU	UUUUU
	100	1.5	166.	349.	2.7	129.	20.	256.	4.1	257.	-1.1	75.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	1.4	169.	351.	2.2	119.	36.	281.	3.3	260.	-0.5	77.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
ARMAND LESAN	2.5	5.1	106.	288.	23.2	91.	303.	212.	25.3	197.	-15.0	15.	105.	289.	183.	2363.	136.	258.	123.	825.
	5	5.7	107.	289.	22.6	89.	307.	218.	24.5	198.	-13.2	16.	105.	291.	187.	2307.	137.	259.	122.	756.
63 F1	10	6.2	108.	290.	22.1	87.	311.	224.	23.9	199.	-11.6	16.	104.	294.	190.	2276.	133.	260.	122.	708.
	20	5.8	118.	300.	18.9	95.	323.	228.	20.7	209.	-9.2	26.	115.	303.	188.	1860.	156.	261.	105.	396.
	50	5.2	133.	315.	14.2	104.	343.	239.	16.4	224.	-6.0	41.	131.	316.	185.	1343.	194.	253.	59.	56.
	100	5.2	153.	335.	10.0	110.	13.	268.	12.9	244.	-2.6	62.	151.	337.	185.	936.	UUUU	UUUU	UUUU	UUUUU
	150	5.0	169.	352.	7.3	108.	48.	305.	10.7	261.	-0.7	78.	169.	351.	182.	662.	UUUU	UUUU	UUUU	UUUUU
THE PAS MORA	2.5	4.1	118.	300.	15.7	99.	319.	219.	17.3	209.	-9.1	27.	122.	296.	175.	1372.	174.	244.	69.	105.
	5	4.2	119.	301.	15.2	98.	321.	223.	16.7	210.	-8.3	27.	122.	297.	175.	1315.	179.	241.	62.	71.
63 F2	10	5.0	121.	304.	14.4	93.	332.	239.	15.8	213.	-5.8	30.	121.	304.	183.	1259.	190.	235.	46.	25.
	20	4.6	133.	316.	11.6	101.	347.	246.	13.3	224.	-4.2	42.	136.	313.	177.	937.	UUUU	UUUU	UUUU	UUUUU
	50	4.3	142.	325.	9.6	105.	362.	256.	11.6	234.	-3.0	51.	148.	319.	172.	726.	UUUU	UUUU	UUUU	UUUUU
	100	4.4	150.	333.	8.2	103.	15.	277.	10.4	242.	-1.6	59.	156.	327.	170.	564.	UUUU	UUUU	UUUU	UUUUU
	150	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUUUUUUU		UUUU	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
MENISENO	2.5	-2.1	97.	279.	25.8	101.	275.	175.	29.3	188.	-33.6	6.	110.	266.	156.	2450.	130.	246.	116.	1087.
	5	-2.8	97.	280.	25.1	102.	274.	172.	28.5	189.	-34.2	6.	112.	265.	153.	2331.	132.	244.	112.	997.
62 H5	10	-2.8	96.	279.	22.9	102.	273.	171.	26.1	188.	-31.8	5.	112.	263.	151.	2060.	135.	240.	105.	771.
	20	2.3	91.	274.	19.9	84.	280.	196.	22.5	133.	-17.8	6.	99.	266.	167.	1877.	131.	234.	104.	511.
	50	-5.6	105.	287.	19.4	116.	275.	159.	22.3	196.	-33.5	13.	127.	264.	137.	1540.	153.	239.	86.	411.
	100	0.5	125.	307.	16.6	123.	309.	185.	19.5	216.	-18.5	34.	139.	294.	155.	1449.	175.	257.	82.	243.
	150	9.2	165.	348.	13.1	74.	74.	365.	17.6	256.	0.7	74.	135.	377.	242.	1865.	209.	303.	94.	163.
DAUPHIN	2.5	6.0	97.	280.	20.7	76.	301.	226.	22.5	189.	-10.5	5.	94.	283.	189.	2105.	131.	246.	115.	569.
	5	5.1	99.	281.	20.1	81.	299.	218.	21.9	190.	-11.7	8.	99.	282.	183.	1968.	136.	245.	109.	493.
	10	4.2	106.	289.	17.5	89.	306.	216.	19.0	196.	-10.5	15.	109.	286.	177.	1562.	154.	241.	88.	233.
	20	3.5	115.	298.	17.3	102.	311.	209.	19.1	207.	-12.1	24.	121.	292.	171.	1543.	163.	249.	86.	230.
	50	4.6	126.	303.	15.5	104.	330.	225.	17.5	217.	-3.2	35.	128.	307.	179.	1427.	181.	254.	73.	121.
	100	6.6	158.	341.	11.1	103.	31.	293.	14.7	249.	-1.5	67.	146.	352.	205.	1250.	UUUU	UUUU	UUUU	UUUUU
	150	6.8	176.	353.	8.8	84.	84.	365.	13.0	267.	0.5	84.	159.	375.	216.	1079.	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH CM	SOIL TEMPERATURE				DATE CC		DAYS ABOVE C C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
		MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
DAWSON BAY 2	2.5	6.4	109.	291.	17.4	77.	323.	247.	18.7	200.	-5.8	17.	102.	298.	196.	1694.	154.	246.	92.	224.
	5	5.8	112.	294.	15.9	80.	326.	246.	17.1	203.	-5.4	20.	107.	298.	191.	1460.	167.	239.	71.	98.
	10	5.3	120.	303.	13.7	87.	336.	249.	14.9	211.	-4.4	29.	118.	304.	186.	1171.	UUUU	UUUU	UUUU	UUUUU
63 C8	20	4.7	130.	312.	11.6	96.	347.	251.	13.2	221.	-3.8	39.	132.	310.	178.	929.	UUUU	UUUU	UUUU	UUUUU
	50	4.8	142.	324.	9.8	97.	4.	272.	11.6	233.	-2.1	50.	144.	322.	179.	753.	UUUU	UUUU	UUUU	UUUUU
	100	4.8	157.	339.	7.7	86.	45.	324.	9.9	248.	-0.3	66.	159.	337.	178.	558.	UUUU	UUUU	UUUU	UUUUU
	150	5.1	163.	346.	7.1	72.	72.	365.	9.2	255.	1.0	72.	162.	347.	184.	490.	UUUU	UUUU	UUUU	UUUUU
BUFFALO BAY	2.5	5.5	114.	297.	16.3	87.	324.	236.	17.7	206.	-6.8	23.	112.	299.	187.	1510.	166.	245.	79.	142.
	5	5.3	118.	301.	14.6	88.	331.	243.	16.1	209.	-5.4	27.	116.	302.	186.	1311.	183.	235.	52.	37.
	10	4.6	127.	310.	11.4	93.	344.	252.	12.8	219.	-3.6	36.	130.	307.	177.	877.	UUUU	UUUU	UUUU	UUUUU
62 G1	20	4.5	133.	315.	10.4	95.	354.	259.	11.8	224.	-2.9	42.	137.	311.	175.	765.	UUUU	UUUU	UUUU	UUUUU
	50	4.6	142.	325.	9.2	97.	5.	274.	11.0	234.	-1.9	51.	146.	321.	175.	670.	UUUU	UUUU	UUUU	UUUUU
	100	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUUU	UUUUU	UUUU	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUUU	UUUUU	UUUU	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
PONTON	2.5	3.6	113.	295.	17.0	99.	310.	211.	18.6	204.	-11.4	22.	118.	290.	172.	1502.	163.	245.	83.	199.
	5	3.3	115.	298.	14.7	101.	313.	212.	16.2	207.	-9.7	24.	123.	290.	167.	1204.	181.	232.	51.	41.
	10	1.9	123.	305.	9.2	110.	319.	209.	10.4	214.	-6.6	32.	145.	284.	139.	489.	UUUU	UUUU	UUUU	UUUUU
63 J1	20	0.9	131.	313.	5.6	122.	322.	200.	6.6	222.	-4.9	39.	177.	266.	89.	95.	UUUU	UUUU	UUUU	UUUUU
	50	0.2	146.	329.	1.9	143.	333.	190.	2.6	238.	-2.3	55.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	100	0.2	146.	323.	1.0	135.	340.	205.	1.4	237.	-1.0	55.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	0.3	138.	320.	0.9	115.	343.	228.	1.1	229.	-0.5	46.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
KISKI CREEK	2.5	4.0	109.	292.	19.0	95.	306.	211.	20.8	201.	-12.7	18.	113.	289.	176.	1772.	151.	250.	99.	377.
	5	3.8	111.	293.	18.2	97.	307.	210.	19.9	202.	-12.2	20.	115.	289.	174.	1659.	155.	249.	93.	301.
	10	3.0	119.	301.	13.9	105.	315.	210.	15.4	210.	-9.5	28.	129.	292.	163.	1095.	195.	225.	30.	8.
63 J2	20	2.3	129.	312.	9.1	113.	328.	214.	10.5	221.	-6.0	38.	149.	292.	143.	516.	UUUU	UUUU	UUUU	UUUUU
	50	2.0	145.	328.	5.8	124.	349.	226.	7.4	237.	-3.5	54.	179.	293.	114.	181.	UUUU	UUUU	UUUU	UUUUU
	100	1.9	164.	347.	3.4	128.	18.	255.	5.1	256.	-1.3	73.	238.	273.	35.	3.	UUUU	UUUU	UUUU	UUUUU
	150	1.7	178.	361.	2.3	124.	50.	292.	3.9	270.	-0.4	87.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
MINAGO RIVER	2.5	3.3	114.	297.	16.2	101.	310.	209.	17.8	206.	-11.2	23.	121.	290.	169.	1387.	169.	242.	73.	136.
	5	3.3	116.	299.	14.7	102.	314.	212.	16.2	208.	-9.7	25.	124.	291.	167.	1198.	183.	233.	50.	40.
	10	3.1	122.	305.	12.0	105.	322.	217.	13.5	213.	-7.4	31.	133.	294.	161.	676.	UUUU	UUUU	UUUU	UUUUU
63 J3	20	2.7	136.	318.	8.8	115.	339.	224.	10.5	227.	-5.1	45.	153.	301.	148.	531.	UUUU	UUUU	UUUU	UUUUU
	50	2.9	150.	332.	6.7	121.	362.	241.	8.8	241.	-3.1	59.	171.	311.	140.	343.	UUUU	UUUU	UUUU	UUUUU
	100	2.9	165.	347.	5.0	122.	25.	268.	7.2	256.	-1.4	73.	194.	318.	124.	182.	UUUU	UUUU	UUUU	UUUUU
	150	3.0	177.	360.	4.1	114.	57.	308.	6.5	268.	-0.4	86.	212.	324.	112.	103.	UUUU	UUUU	UUUU	UUUUU
JENPEG 1	2.5	5.0	108.	290.	16.0	83.	315.	232.	17.2	199.	-7.2	17.	108.	290.	183.	1423.	163.	235.	71.	106.
	5	4.5	114.	296.	14.0	88.	322.	234.	15.1	205.	-6.0	23.	117.	294.	177.	1147.	196.	214.	18.	1.
	10	3.5	122.	304.	11.1	99.	328.	229.	12.3	213.	-5.4	31.	132.	294.	162.	764.	UUUU	UUUU	UUUU	UUUUU
63 J4	20	2.8	129.	312.	8.9	106.	335.	229.	10.2	221.	-4.5	38.	147.	294.	148.	493.	UUUU	UUUU	UUUU	UUUUU
	50	2.7	148.	330.	6.3	118.	360.	242.	8.1	239.	-2.8	57.	174.	305.	131.	268.	UUUU	UUUU	UUUU	UUUUU
	100	2.7	174.	357.	4.0	130.	36.	271.	6.6	266.	-1.2	83.	211.	320.	108.	112.	UUUU	UUUU	UUUU	UUUUU
	150	2.6	189.	371.	3.0	124.	71.	312.	5.6	280.	-0.3	97.	243.	316.	73.	27.	UUUU	UUUU	UUUU	UUUUU
JENPEG 2	2.5	4.2	115.	293.	13.4	91.	322.	231.	14.6	207.	-6.2	24.	120.	294.	174.	1066.	UUUU	UUUU	UUUU	UUUUU
	5	3.9	120.	303.	12.0	95.	328.	234.	13.2	212.	-5.3	29.	127.	296.	169.	893.	UUUU	UUUU	UUUU	UUUUU
	10	3.0	131.	313.	9.3	108.	336.	229.	10.7	222.	-4.7	[illegible]	146.	298.	152.	564.	UUUU	UUUU	UUUU	UUUUU
63 J5	20	2.8	137.	320.	8.1	113.	344.	231.	9.6	229.	-4.1	46.	156.	300.	144.	433.	UUUU	UUUU	UUUU	UUUUU
	50	2.5	157.	340.	5.5	129.	3.	239.	7.7	249.	-2.8	66.	186.	311.	124.	223.	UUUU	UUUU	UUUU	UUUUU
	100	2.7	180.	363.	3.8	137.	41.	269.	6.7	271.	-1.3	89.	215.	327.	112.	123.	UUUU	UUUU	UUUU	UUUUU
	150	2.8	191.	374.	3.1	114.	86.	337.	5.7	283.	-0.1	100.	240.	324.	84.	40.	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
JENPEG 3	2.5	5.0	110.	293.	15.9	86.	317.	231.	17.2	202.	-7.2	19.	111.	293.	182.	1414.	166.	237.	70.	102.
	5	4.6	115.	297.	14.1	89.	323.	234.	15.3	206.	-6.1	24.	117.	295.	178.	1166.	193.	219.	26.	5.
	10	3.6	123.	305.	11.1	98.	330.	232.	12.3	214.	-5.2	32.	132.	296.	164.	774.	UUUU	UUUU	UUUU	UUUUU
63 J6	20	3.0	133.	315.	8.4	107.	342.	235.	9.7	224.	-3.8	42.	151.	298.	147.	452.	UUUU	UUUU	UUUU	UUUUU
	50	2.9	155.	337.	6.1	120.	7.	252.	8.2	246.	-2.3	63.	178.	314.	135.	279.	UUUU	UUUU	UUUU	UUUUU
	100	2.8	175.	357.	4.2	131.	36.	270.	6.9	266.	-1.3	84.	208.	324.	116.	143.	UUUU	UUUU	UUUU	UUUUU
	150	2.8	189.	371.	3.2	117.	77.	325.	5.8	280.	-0.2	97.	236.	324.	83.	48.	UUUU	UUUU	UUUU	UUUUU
SIMONHOUSE	2.5	2.3	105.	288.	17.0	97.	296.	199.	18.6	197.	-13.9	14.	115.	278.	163.	1430.	157.	236.	79.	188.
	5	2.3	106.	289.	15.8	97.	298.	201.	17.4	198.	-12.7	15.	117.	279.	162.	1286.	165.	231.	66.	103.
	10	2.0	109.	292.	12.2	99.	302.	203.	13.4	201.	-9.4	18.	125.	276.	152.	823.	UUUU	UUUU	UUUU	UUUUU
63 K1	20	1.6	122.	304.	7.4	108.	318.	210.	8.4	213.	-5.2	30.	152.	273.	121.	266.	UUUU	UUUU	UUUU	UUUUU
	50	0.6	142.	324.	2.0	120.	346.	225.	2.4	233.	-1.2	51.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	100	0.3	139.	322.	0.6	UUUU	UUUU	UUUU	0.7	231.	-0.1	48.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	0.2	125.	308.	0.5	UUUU	UUUU	UUUU	0.6	217.	-0.1	34.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
MISTIK CREEK 1	2.5	2.6	108.	290.	15.8	97.	300.	203.	17.3	199.	-12.2	16.	117.	281.	163.	1293.	166.	232.	66.	101.
	5	2.3	110.	292.	13.6	99.	303.	204.	14.9	201.	-10.3	18.	122.	280.	158.	1009.	UUUU	UUUU	UUUU	UUUUU
	10	1.9	116.	293.	9.7	103.	311.	208.	10.7	207.	-6.9	25.	136.	278.	141.	526.	UUUU	UUUU	UUUU	UUUUU
63 K2	20	1.8	119.	302.	7.4	102.	318.	216.	8.2	210.	-4.6	28.	150.	271.	121.	252.	UUUU	UUUU	UUUU	UUUUU
	50	0.3	139.	322.	1.6	127.	334.	207.	2.0	231.	-1.3	48.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	100	-0.1	122.	305.	0.5	UUUU	UUUU	UUUU	0.6	213.	-0.7	31.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	-0.0	137.	319.	0.5	UUUU	UUUU	UUUU	0.6	228.	-0.6	46.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
MISTIK CREEK 2	2.5	3.8	113.	295.	15.0	95.	314.	219.	16.3	204.	-8.6	22.	118.	290.	172.	1243.	177.	231.	54.	46.
	5	3.6	117.	299.	13.3	97.	318.	221.	14.5	208.	-7.4	25.	124.	291.	167.	1025.	UUUU	UUUU	UUUU	UUUUU
	10	3.4	120.	303.	11.9	99.	324.	225.	13.2	211.	-6.3	29.	129.	293.	164.	860.	UUUU	UUUU	UUUU	UUUUU
63 K3	20	3.5	123.	305.	11.5	101.	327.	227.	12.8	214.	-5.9	32.	132.	296.	164.	824.	UUUU	UUUU	UUUU	UUUUU
	50	3.7	128.	311.	10.5	101.	338.	237.	11.9	220.	-4.5	37.	137.	301.	164.	730.	UUUU	UUUU	UUUU	UUUUU
	100	3.6	137.	319.	8.5	102.	355.	253.	10.0	228.	-2.7	46.	150.	307.	157.	507.	UUUU	UUUU	UUUU	UUUUU
	150	3.8	144.	327.	3.8	53.	53.	365.	3.8	236.	3.8	53.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
WANLESS 197	2.5	2.7	110.	293.	14.7	98.	304.	206.	16.1	202.	-10.7	19.	120.	283.	162.	1160.	178.	225.	47.	35.
	5	2.9	113.	295.	13.6	99.	309.	210.	15.0	204.	-9.2	22.	123.	285.	162.	1038.	UUUU	UUUU	UUUU	UUUUU
	10	3.0	122.	304.	11.7	104.	322.	218.	13.1	213.	-7.0	30.	133.	293.	161.	830.	UUUU	UUUU	UUUU	UUUUU
63 K4	20	3.3	132.	314.	10.1	108.	338.	229.	11.7	223.	-5.1	41.	144.	302.	159.	683.	UUUU	UUUU	UUUU	UUUUU
	50	3.4	148.	330.	7.7	116.	362.	247.	9.8	239.	-3.0	57.	163.	315.	152.	470.	UUUU	UUUU	UUUU	UUUUU
	100	3.4	169.	352.	5.3	122.	34.	277.	8.0	260.	-1.3	76.	190.	331.	141.	273.	UUUU	UUUU	UUUU	UUUUU
	150	3.3	182.	364.	4.1	108.	73.	331.	6.8	273.	-0.2	91.	211.	335.	124.	145.	UUUU	UUUU	UUUU	UUUUU
CRANBERRY 1	2.5	3.2	108.	291.	13.3	94.	304.	210.	16.7	199.	-10.4	17.	116.	283.	167.	1253.	170.	229.	59.	66.
	5	3.3	112.	294.	13.7	95.	311.	215.	15.0	203.	-8.5	21.	120.	285.	165.	1059.	UUUU	UUUU	UUUU	UUUUU
	10	3.3	117.	300.	12.2	98.	319.	221.	13.4	209.	-6.8	26.	127.	289.	162.	873.	UUUU	UUUU	UUUU	UUUUU
63 K5	20	3.4	123.	305.	11.4	101.	327.	226.	12.8	214.	-5.9	32.	133.	296.	163.	813.	UUUU	UUUU	UUUU	UUUUU
	50	3.6	133.	315.	9.3	102.	346.	244.	10.7	224.	-3.5	42.	144.	304.	160.	59[illegible].	UUUU	UUUU	UUUU	UUUUU
	100	3.6	147.	329.	7.2	103.	7.	269.	8.8	238.	-1.7	55.	162.	313.	151.	374.	UUUU	UUUU	UUUU	UUUUU
	150	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUU	UUUUUUUUU		UUUU	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
CRANBERRY 2	2.5	1.5	114.	297.	14.2	108.	303.	195.	15.8	206.	-12.7	23.	129.	283.	154.	1[illegible]7[illegible].	187.	225.	38.	19.
	5	1.3	117.	299.	12.2	110.	305.	195.	13.7	208.	-11.0	25.	134.	282.	147.	829.	UUUU	UUUU	UUUU	UUUUU
	10	1.1	122.	304.	8.8	114.	312.	197.	10.0	213.	-7.7	31.	148.	273.	137.	422.	UUUU	UUUU	UUUU	UUUUU
63 K6	20	0.7	129.	312.	6.4	124.	318.	194.	7.6	221.	-6.3	38.	169.	273.	104.	179.	UUUU	UUUU	UUUU	UUUUU
	50	-0.0	149.	331.	1.5	150.	331.	181.	2.3	24[illegible].	-2.3	57.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	100	-0.1	126.	303.	0.2	UUUU	UUUU	UUUU	0.3	217.	-0.5	35.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	-0.0	93.	276.	0.1	UUUU	UUUU	UUUU	0.2	185.	-0.2	2.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH CM	SOIL TEMPERATURE MEAN FOR YEAR	SOIL TEMPERATURE SPRING	SOIL TEMPERATURE FALL	SOIL TEMPERATURE MEAN SUMMER	DATE 0C SPRING	DATE 0C FALL OR WINTER	DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C SPRING	DATE 5C FALL	DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C SPRING	DATE 15C FALL	DAYS ABOVE 15 C	DEG. DAYS 15 C
WELL # 3	2.5	4.6	120.	302.	14.8	96.	326.	230.	16.2	211.	-7.0	28.	122.	303.	179.	1282.	184.	238.	54.	45.
	5	4.6	121.	304.	14.6	97.	328.	231.	16.1	212.	-6.9	30.	123.	302.	179.	1266.	187.	239.	51.	38.
	10	4.3	123.	305.	13.6	99.	329.	229.	15.1	214.	-6.6	32.	127.	301.	175.	1128.	206.	222.	16.	1.
62 K3	20	4.8	126.	308.	13.5	98.	336.	238.	15.1	217.	-5.6	35.	127.	307.	180.	1154.	210.	224.	13.	1.
	50	5.4	132.	314.	12.3	93.	354.	261.	13.9	223.	-3.2	41.	130.	317.	187.	1063.	UUUU	UUUU	UUUU	UUUUU
	100	5.5	137.	319.	11.0	85.	6.	287.	12.6	228.	-1.6	46.	132.	324.	191.	925.	UUUU	UUUU	UUUU	UUUUU
	150	5.6	138.	320.	9.9	58.	35.	343.	11.3	229.	-0.1	47.	132.	326.	194.	770.	UUUU	UUUU	UUUU	UUUUU
WELL # 7	2.5	7.7	127.	309.	22.8	101.	335.	234.	25.7	218.	-10.2	35.	118.	318.	200.	2609.	151.	285.	134.	933.
	5	6.9	126.	308.	20.9	101.	333.	232.	23.5	217.	-9.7	34.	119.	315.	196.	2289.	155.	279.	123.	665.
	10	6.2	126.	308.	18.9	102.	333.	231.	21.3	217.	-9.0	35.	122.	313.	191.	1974.	162.	272.	110.	453.
62 K4	20	5.8	129.	311.	17.1	103.	337.	234.	19.5	220.	-7.9	38.	125.	315.	189.	1741.	172.	269.	97.	267.
	50	5.8	133.	315.	15.4	103.	345.	242.	17.7	224.	-6.0	41.	129.	319.	191.	1534.	184.	264.	80.	142.
	100	5.7	144.	326.	12.4	106.	364.	259.	15.1	235.	-3.7	53.	140.	331.	191.	1218.	229.	241.	13.	0.
	150	6.0	152.	334.	11.3	105.	16.	276.	14.4	243.	-2.3	61.	145.	341.	197.	1162.	UUUU	UUUU	UUUU	UUUUU
WELL # 8	2.5	7.5	128.	311.	21.7	101.	337.	236.	24.5	219.	-9.5	37.	119.	319.	200.	2460.	154.	284.	130.	807.
	5	6.4	129.	311.	20.0	105.	335.	230.	22.8	220.	-9.9	38.	124.	317.	193.	2175.	161.	280.	119.	608.
	10	5.7	130.	313.	18.3	108.	335.	226.	21.0	222.	-9.7	39.	128.	315.	188.	1912.	168.	275.	107.	424.
62 K5	20	4.8	131.	314.	16.6	112.	334.	222.	19.3	223.	-9.7	40.	132.	313.	181.	1652.	177.	269.	92.	262.
	50	3.8	143.	325.	12.7	125.	343.	219.	16.1	234.	-8.6	52.	149.	320.	171.	1216.	209.	259.	50.	36.
	100	3.5	158.	341.	8.6	136.	364.	228.	12.7	250.	-5.6	67.	168.	331.	163.	805.	UUUU	UUUU	UUUU	UUUUU
	150	3.9	166.	349.	7.4	136.	14.	244.	11.7	258.	-3.9	75.	175.	341.	166.	711.	UUUU	UUUU	UUUU	UUUUU
WELL # 9	2.5	6.9	123.	306.	21.9	99.	329.	230.	24.3	214.	-10.6	32.	117.	312.	195.	2385.	151.	277.	126.	771.
	5	6.4	123.	306.	20.8	101.	329.	228.	23.2	215.	-10.3	32.	118.	311.	193.	2216.	155.	275.	120.	643.
	10	5.9	124.	306.	19.5	101.	329.	227.	21.7	215.	-9.9	32.	120.	310.	189.	2011.	159.	271.	111.	493.
62 K6	20	5.5	124.	306.	17.7	101.	329.	228.	19.8	215.	-8.8	33.	122.	313.	186.	1746.	166.	264.	98.	306.
	50	4.9	135.	318.	14.8	112.	341.	229.	17.5	227.	-7.7	44.	136.	317.	182.	1444.	189.	264.	74.	122.
	100	4.4	154.	337.	10.4	128.	363.	235.	14.4	246.	-5.7	63.	158.	333.	175.	1055.	UUUU	UUUU	UUUU	UUUUU
	150	4.3	166.	349.	8.2	135.	15.	244.	12.8	258.	-4.2	75.	171.	344.	173.	864.	UUUU	UUUU	UUUU	UUUUU
WELL # 10	2.5	6.8	131.	313.	15.6	91.	353.	261.	17.6	222.	-4.0	40.	121.	323.	202.	1599.	181.	263.	82.	141.
	5	5.8	130.	313.	13.8	94.	349.	255.	15.6	222.	-4.1	39.	126.	317.	192.	1286.	201.	242.	41.	16.
	10	5.4	131.	313.	13.5	98.	346.	249.	15.3	222.	-4.6	40.	129.	315.	187.	1225.	207.	237.	30.	6.
62 K7	20	4.3	133.	315.	12.8	109.	339.	230.	14.9	224.	-6.4	42.	137.	311.	175.	1110.	UUUU	UUUU	UUUU	UUUUU
	50	4.9	145.	327.	10.5	107.	0.	259.	12.9	236.	-3.1	54.	146.	327.	181.	910.	UUUU	UUUU	UUUU	UUUUU
	100	5.2	155.	338.	9.0	99.	29.	295.	11.6	247.	-1.1	64.	153.	340.	187.	784.	UUUU	UUUU	UUUU	UUUUU
	150	5.4	162.	345.	8.1	71.	71.	365.	10.7	253.	0.2	71.	157.	349.	192.	692.	UUUU	UUUU	UUUU	UUUUU
JACK PINE	2.5	1.8	122.	305.	11.0	112.	314.	202.	12.5	213.	-9.0	31.	140.	287.	147.	717.	UUUU	UUUU	UUUU	UUUUU
	5	1.6	125.	307.	9.8	115.	317.	202.	11.3	216.	-8.0	34.	146.	287.	141.	576.	UUUU	UUUU	UUUU	UUUUU
	10	1.0	129.	312.	7.9	122.	319.	197.	9.4	221.	-7.4	38.	158.	283.	125.	358.	UUUU	UUUU	UUUU	UUUUU
63 P8	20	1.0	132.	314.	7.2	124.	322.	198.	8.6	223.	-6.5	40.	164.	282.	118.	277.	UUUU	UUUU	UUUU	UUUUU
	50	0.8	139.	322.	4.6	130.	331.	201.	5.9	231.	-4.3	43.	196.	265.	69.	41.	UUUU	UUUU	UUUU	UUUUU
	100	1.0	150.	333.	2.6	128.	355.	228.	3.5	242.	-1.6	59.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	0.9	161.	344.	1.5	93.	47.	319.	2.0	253.	-0.1	70.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
E STABLE R	2.5	0.0	120.	303.	7.8	120.	303.	183.	8.9	212.	-8.9	29.	155.	269.	114.	294.	UUUU	UUUU	UUUU	UUUUU
	5	0.2	122.	305.	7.6	121.	306.	185.	8.7	214.	-8.4	31.	157.	270.	113.	277.	UUUU	UUUU	UUUU	UUUUU
	10	0.3	124.	307.	7.0	122.	309.	187.	6.1	216.	-7.5	33.	162.	269.	107.	219.	UUUU	UUUU	UUUU	UUUUU
63 P7	20	0.9	134.	317.	6.0	126.	325.	199.	7.3	226.	-5.5	43.	175.	277.	102.	150.	UUUU	UUUU	UUUU	UUUUU
	50	0.6	139.	321.	4.0	131.	329.	198.	5.1	230.	-3.9	48.	219.	242.	23.	1.	UUUU	UUUU	UUUU	UUUUU
	100	0.5	148.	330.	1.7	133.	344.	211.	2.4	239.	-1.4	56.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	0.6	147.	329.	1.5	117.	359.	242.	1.9	238.	-0.6	56.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU

D-2: Parameters Derived from Analysis of Soil Temperature Data

SITE	DEPTH	SOIL TEMPERATURE				DATE 0C		DAYS ABOVE 0 C	T. MAX	DAY	T. MIN	DAY	DATE 5C		DAYS ABOVE 5 C	DEGREE DAYS 5 C	DATE 15C		DAYS ABOVE 15 C	DEG. DAYS 15 C
	CM	MEAN FOR YEAR	SPRING	FALL	MEAN SUMMER	SPRING	FALL OR WINTER						SPRING	FALL			SPRING	FALL		
HORSE STABLE 2	25	1.6	128.	311.	8.2	117.	322.	205.	9.5	223.	-6.4	37.	154.	285.	131.	387.	UUUU	UUUU	UUUU	UUUUU
	5	1.6	129.	312.	8.0	117.	323.	206.	9.3	223.	-6.2	38.	156.	285.	129.	364.	UUUU	UUUU	UUUU	UUUUU
	10	1.2	131.	313.	6.9	121.	323.	202.	8.2	222.	-5.8	39.	164.	279.	115.	238.	UUUU	UUUU	UUUU	UUUUU
63 P8	20	1.2	135.	318.	6.2	124.	328.	204.	7.6	226.	-5.2	44.	172.	281.	109.	187.	UUUU	UUUU	UUUU	UUUUU
	50	1.0	141.	324.	4.3	126.	337.	209.	5.4	233.	-3.4	50.	207.	258.	51.	15.	UUUU	UUUU	UUUU	UUUUU
	100	0.7	144.	326.	2.5	126.	344.	218.	3.2	235.	-1.7	52.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	0.8	132.	315.	2.3	105.	341.	236.	2.6	224.	-1.0	41.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
BIRCHTREE	25	0.1	113.	296.	12.4	113.	296.	183.	14.0	205.	-13.9	22.	134.	275.	141.	817.	UUUU	UUUU	UUUU	UUUUU
	5	0.6	121.	303.	10.5	118.	306.	189.	12.0	212.	-10.8	29.	144.	280.	136.	620.	UUUU	UUUU	UUUU	UUUUU
	10	0.8	128.	311.	8.6	124.	315.	192.	10.2	220.	-8.7	37.	155.	284.	128.	437.	UUUU	UUUU	UUUU	UUUUU
63 P9	20	0.6	134.	315.	6.8	129.	321.	192.	8.4	225.	-7.2	42.	168.	282.	113.	255.	UUUU	UUUU	UUUU	UUUUU
	50	0.7	138.	321.	5.4	131.	328.	197.	6.8	230.	-5.4	47.	183.	276.	93.	113.	UUUU	UUUU	UUUU	UUUUU
	100	1.0	143.	325.	3.4	124.	344.	220.	4.3	234.	-2.2	52.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	0.5	121.	304.	2.8	111.	314.	204.	3.2	213.	-2.2	30.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
BIRCHTREE	25	3.3	112.	294.	17.5	100.	306.	207.	19.2	203.	-12.6	21.	118.	288.	170.	1543.	160.	246.	86.	236.
	5	3.1	117.	299.	15.6	104.	312.	208.	17.3	208.	-11.1	25.	124.	291.	167.	1321.	174.	241.	67.	163.
	10	2.5	123.	305.	12.5	110.	318.	207.	14.2	214.	-9.2	31.	135.	293.	157.	931.	UUUU	UUUU	UUUU	UUUUU
63 P10	20	1.6	130.	313.	9.0	120.	323.	203.	10.7	222.	-7.4	39.	153.	291.	138.	512.	UUUU	UUUU	UUUU	UUUUU
	50	1.3	137.	320.	6.7	126.	330.	204.	8.4	228.	-5.8	46.	169.	287.	118.	261.	UUUU	UUUU	UUUU	UUUUU
	100	1.7	150.	332.	4.6	127.	356.	229.	6.2	241.	-2.7	59.	198.	284.	86.	67.	UUUU	UUUU	UUUU	UUUUU
	150	1.6	145.	323.	3.9	116.	357.	241.	4.9	237.	-1.7	54.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
BIRCHTREE	25	0.3	123.	305.	8.5	121.	307.	187.	9.9	214.	-9.2	32.	153.	276.	123.	392.	UUUU	UUUU	UUUU	UUUUU
	5	0.5	122.	305.	8.1	119.	308.	189.	9.3	213.	-8.3	31.	154.	273.	120.	334.	UUUU	UUUU	UUUU	UUUUU
	10	0.8	127.	309.	7.6	121.	315.	194.	6.9	218.	-7.3	36.	159.	278.	119.	302.	UUUU	UUUU	UUUU	UUUUU
63 P11	20	0.7	129.	312.	6.3	123.	318.	194.	7.5	221.	-6.1	38.	169.	272.	103.	172.	UUUU	UUUU	UUUU	UUUUU
	50	0.6	134.	317.	4.4	126.	325.	198.	5.3	226.	-4.1	43.	203.	248.	45.	13.	UUUU	UUUU	UUUU	UUUUU
	100	0.4	130.	313.	3.0	122.	321.	199.	3.6	221.	-2.7	39.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	0.6	121.	304.	2.4	104.	321.	216.	2.7	213.	-1.5	30.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
BIRCHTREE	25	4.0	119.	301.	13.4	97.	323.	227.	14.8	210.	-6.7	28.	124.	296.	172.	1074.	UUUU	UUUU	UUUU	UUUUU
	5	3.3	123.	305.	11.9	104.	325.	221.	13.3	215.	-6.8	32.	133.	296.	162.	868.	UUUU	UUUU	UUUU	UUUUU
	10	2.5	130.	313.	8.9	112.	332.	220.	10.3	222.	-5.3	39.	150.	294.	144.	495.	UUUU	UUUU	UUUU	UUUUU
63 P12	20	2.1	143.	325.	6.9	124.	344.	220.	8.7	234.	-4.5	52.	169.	299.	130.	311.	UUUU	UUUU	UUUU	UUUUU
	50	1.4	154.	336.	4.1	134.	356.	222.	5.8	245.	-2.9	62.	209.	281.	72.	39.	UUUU	UUUU	UUUU	UUUUU
	100	1.2	151.	333.	2.6	120.	364.	244.	3.4	242.	-1.1	60.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	1.2	148.	331.	2.2	103.	11.	273.	2.8	240.	-0.5	57.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
ORR LAKE	25	1.6	122.	304.	10.7	113.	313.	201.	12.2	213.	-8.9	30.	141.	285.	145.	672.	UUUU	UUUU	UUUU	UUUUU
	5	1.6	123.	305.	10.4	114.	314.	201.	11.8	214.	-8.6	31.	142.	285.	143.	635.	UUUU	UUUU	UUUU	UUUUU
	10	1.6	126.	309.	9.5	116.	319.	202.	11.0	218.	-7.8	35.	148.	287.	139.	539.	UUUU	UUUU	UUUU	UUUUU
64 A1	20	2.9	124.	306.	11.9	107.	323.	215.	13.4	215.	-7.6	33.	135.	295.	159.	866.	UUUU	UUUU	UUUU	UUUUU
	50	2.3	136.	313.	7.5	115.	339.	225.	8.9	227.	-4.3	45.	160.	294.	134.	345.	UUUU	UUUU	UUUU	UUUUU
	100	1.7	151.	334.	3.9	121.	364.	243.	5.2	243.	-1.7	60.	222.	263.	41.	6.	UUUU	UUUU	UUUU	UUUUU
	150	0.4	211.	393.	0.2	188.	51.	229.	1.5	302.	-0.7	120.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
ORR LAKE(2)	25	3.2	108.	291.	14.4	93.	306.	212.	15.7	200.	-9.3	17.	117.	282.	165.	1133.	161.	219.	38.	16.
	5	2.6	116.	293.	12.3	102.	312.	210.	13.5	207.	-8.4	24.	129.	285.	156.	861.	UUUU	UUUU	UUUU	UUUUU
	10	2.0	128.	311.	10.0	116.	323.	207.	11.6	220.	-7.6	37.	147.	292.	146.	625.	UUUU	UUUU	UUUU	UUUUU
64 A2	20	2.0	134.	315.	8.9	120.	330.	210.	10.7	225.	-6.6	43.	154.	295.	141.	523.	UUUU	UUUU	UUUU	UUUUU
	50	1.8	142.	324.	6.1	124.	343.	219.	7.7	233.	-4.0	51.	175.	291.	116.	203.	UUUU	UUUU	UUUU	UUUUU
	100	1.7	154.	336.	3.5	121.	4.	247.	4.8	245.	-1.5	63.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU
	150	1.4	171.	353.	2.2	121.	38.	281.	3.3	262.	-0.5	30.	UUUU	UUUU	UUUU	UUUUU	UUUU	UUUU	UUUU	UUUUU

Appendix E

DESCRIPTION OF REIMER'S ESTIMATION PROCEDURES

Reimer (1978) used linear regression to establish a relationship between the deviation of the surface soil temperature from the monthly mean and atmospheric conditions for each month. The meteorological variables which were most closely associated with surface soil temperatures included daily maximum and minimum air temperatures, and daily hours of bright sunshine. Reimer's regression equations applied to the Pinawa research site and were calculated for the months of June, July, August, and January. Therefore a separate set of regression equations were derived for this study utilizing data recorded near Brandon (62 G 5) airport. Brandon (62 G 5) was chosen as a sample site to test Reimer's model because of the convenient and complete data base. Equations F1 - F12 illustrate how meteorological variables were combined to form the regression equations for each month.

$$\text{Jan} = 0.0044 - 0.0008(\text{TMAX}) + 0.0025(\text{TMIN}) + 0.0120(\text{SUN}) \qquad \text{F1}$$
$$\text{Feb} = 0.9777 - 0.0033(\text{TMAX}) + 0.0542(\text{TMIN}) + 0.0298(\text{SUN}) \qquad \text{F2}$$
$$\text{Mar} = 0.8744 - 0.0000(\text{TMAX}) + 0.0809(\text{TMIN}) + 0.0365(\text{SUN}) \qquad \text{F3}$$
$$\text{Apr} = 0.4009 + 0.0073(\text{TMAX}) + 0.2852(\text{TMIN}) + 0.0394(\text{SUN}) \qquad \text{F4}$$
$$\text{May} = -1.5548 + 0.0117(\text{TMAX}) + 0.2252(\text{TMIN}) + 0.0247(\text{SUN}) \qquad \text{F5}$$
$$\text{Jun} = -0.4929 - 0.0012(\text{TMAX}) + 0.0566(\text{TMIN}) - 0.0033(\text{SUN}) \qquad \text{F6}$$
$$\text{Jul} = -0.0304 - 0.0020(\text{TMAX}) + 0.0076(\text{TMIN}) + 0.0015(\text{SUN}) \qquad \text{F7}$$
$$\text{Aug} = -0.8429 - 0.0056(\text{TMAX}) + 0.0595(\text{TMIN}) + 0.0523(\text{SUN}) \qquad \text{F8}$$
$$\text{Sep} = -2.1343 + 0.0923(\text{TMAX}) + 0.1630(\text{TMIN}) - 0.0369(\text{SUN}) \qquad \text{F9}$$
$$\text{Oct} = -0.3484 + 0.0246(\text{TMAX}) + 0.1768(\text{TMIN}) + 0.0635(\text{SUN}) \qquad \text{F10}$$
$$\text{Nov} = 1.2140 + 0.0213(\text{MAXT}) + 0.1585(\text{TMIN}) + 0.0977(\text{SUN}) \qquad \text{F11}$$
$$\text{Dec} = -0.1199 + 0.0214(\text{TMAX}) - 0.0137(\text{TMIN}) + 0.0099(\text{SUN}) \qquad \text{F12}$$

Where Jan,Feb, etc.=the deviation of a daily mean temperature from the long term soil surface monthly mean
TMAX = daily max. air temperature
TMIN = daily min. air temperature

SUN = daily hours of bright sunshine.

In the regression analysis independent variables included maximum and minimum air temperatures and hours of bright sunshine, while the dependent variable was the deviation of soil surface temperatures from the monthly mean.

The resulting equations, based on real data, were used to determine the extent to which estimated soil temperatures on a given day deviated from a long term monthly mean. A Fourier series equation (F13) was the basis for all further calculations involving monthly and daily means as well as subsurface annual and diurnal temperature fluctuations.

$$T = A + B(EXP - z/d)SIN(2\ t/p - z/d) \qquad (F13)$$

where A = long term mean
B = amplitude
t = time of year or day
p = period
p = 365 for annual waves; and P = 24 for diurnal waves
z = soil depth
d = damping depth
T = estimated annual or diurnal temperature means at depth Z.

Once the annual Fourier series curve had been obtained it was utilized in the estimation of daily mean soil surface temperatures. Each month of the year was represented by a portion of the annual Fourier series curve. The regression equations for each month were then used to determine the daily deviation of temperatures from the appropriate one month section of the curve. Owing to the passage of frontal systems and the variations in cloud conditions, daily meteorological measurements contained random fluctuations. The utilization of unsmoothed data for the prediction of daily means resulted in widely fluctuating values which greatly exceeded observed temperatures. Therefore, a moving three day smoothing function was adopted to eliminate random fluctuations. Using a weighting scheme, the temperatures for a given day were combined with the temperatures from one day previous and one day later than the day in question. For example, the final product was obtained when the first, second, and third day temperatures were added together after being multiplied by .25, .50 and .25, respectively. This procedure was executed for consecutive days for the entire data base.

Having calculated a daily mean, daily subsoil temperatures were calculated from equation (F13) using soil thermal properties derived from DeJong's (1978) thermal diffusion formula (as described below), and the appropriate amplitude and phase shift values. Annual subsoil temperatures were predicted in the same manner with the exception that the appropriate coefficients were assigned annual rather than diurnal values.

E.1 SOLUTION OF EQUATION F13

For annual soil temperature waves the mean, A, was obtained from the sine wave for Brandon (based on ten years of data) where "A" represented the long term mean of the sine wave. For diurnal application the mean was calculated from regression equations and the annual Fourier series wave (as described below).

The amplitudes of annual and diurnal curves were obtained empirically by examining soil temperature waves derived by Reimer and Shaykewich (1980). Annual soil temperature waves varied between sites depending on elevation, latitude and soil characteristics. Diurnal amplitudes were assumed to be less site specific and more dependent on atmospheric conditions. From Reimer's data, amplitudes were assigned to diurnal waves depending on the time of year and atmospheric conditions. During May, June, July and August, the amplitude for clear conditions was 10C, while for overcast conditions it was 1.5C and during cloudy weather, it was equal to the mean (less than a few tenths of a degree Celcius). During April, September and October, 5C of amplitude were observed for clear conditions and amplitudes for cloudy and overcast weather were equal to the mean. A blanket of snow from November to March reduced amplitudes to 1/10 of a degree.

The value of "t" (Equation F13) denoted a particular day number or hour of the day depending on whether the equation represented an annual or diurnal curve. Unlike regular numbering sequences, the value of "t" did not equal one on January 1 (or one at 1 A.M. for diurnal applications). The zero point of this particular time scale was chosen such that when $t = 0$, the surface temperature equaled the mean.

Appendix D lists the dates on which the surface temperature of each MSS site reached the mean for its location. For the southern Manitoba region, the annual temperature waves intersected the yearly mean on April 13. Therefore April 13 was denoted as day one and May 1 represented day number 18.

The value of d, the damping depth, was calculated from the following formula (Reimer, 1978):

$$d = (2K/w)$$

where w = angular frequency
K = thermal diffusivity.

The value of w was obtained by dividing 2π by the number of seconds in the period. Therefore, for the diurnal variation $W = 2\pi / 86400 = 7.27 \times 10^{-5}\ \mathrm{SEC}^{-1}$ and for annual curves $W = 2\pi / 3.15 \times 10^{-7} = 1.99 \times 10^{-7}$. Thermal diffusivity values were not available for MSS sites and direct calculations of these values was impractical. Therefore, a method outlined by DeJong (1978) was employed to determine thermal diffusivity from the long term amplitude and phase relationships of sine waves from two different soil depths (Equation F6).

$$K = 1/2w\ (z2 - z1)/t \qquad (F6)$$

where w = radial frequency
z = soil depth
t = time lag in seconds.

The t, time lag value was derived by calculating the time lag in seconds between the points of maximum temperature occurrence at two different soil depths. To minimize the effects of frequent moisture fluctuations on soil surface thermal properties, the 20 and 100 cm depths were used in the calculation of t. The assumptions made (DeJong, 1978) were a homogeneous soil with constant diffusivity and a sinusoidal temperature wave at the soil surface.

The terms (Exp $-z/d$) and $-z/d$ in Equation F13 determined the change in amplitude and phase angle with depth, respectively. In the characterization of surface soil temperatures these values equaled zero since there is no change in phase or amplitude.

By taking the sine of $2\pi t/P$, values of t were converted into angles. Leap years posed problems since, P was equal to 365 days and leap years contained 366 days. This was rectified by omitting data recorded on January 1 of a leap year. The loss of this data is insignificant since on a leap year the calendar date is almost an entire day behind the solar date. This is the result of a solar year being 365.25 days in length while a calendar year is only 365 days in length. Therefore, on a leap year the calendar date of January 1 is actually 3/4 of a day behind the solar date. By the completion of a leap year (December 31) the calendar day is a full day behind the solar day as determined by earth-sun relationships. Therefore, measurements taken on January 1 of a leap year represent the first day of the calendar year, but not the first day of the solar year. January 2 was thus considered to be day 1 and leap years contained 365 rather than 366 days.

de Vries (1963) outlined five assumptions which must be made concerning the prediction of surface soil temperature from Fourier series:

1. At all depths temperature varies as a pure harmonic function of time.
2. Mean temperatures are assumed to be the same for all depths.
3. The zero point of the time scale will be chosen such that at $t = 0$, the surface is at the average temperature.
4. At an infinite depth ($Z = \infty$), the temperature is assumed to be a periodic function for all times, no separate initial condition is required.
5. At depth Z, the amplitude is smaller by a factor of $\exp(-Z/D)$.

E.2 SUMMARY OF THE ESTIMATION PROCEDURE

1. Before using Reimer's model, one requires surface soil temperatures (1 cm depth), sky conditions, and snow cover at the time that soil temperatures were recorded, maximum and minimum air temperatures, and daily hours of bright sunshine.
2. A diffusivity value must be obtained for the soil either by direct measurement or by calculating the time lag between similar points on temperature waves from two different soil depths.

3. Annual amplitude and a long term mean must also be calculated for soil surface temperature data.
4. Using the long term mean and amplitude from step 3, calculate an annual Fourier series curve for the soil surface (using Equation F13). Estimated values from this curve represent daily mean soil surface temperatures. Day one on the curve is the date on which a wave representing real soil surface temperature data, intersects the long term mean in the spring.
5. Separate the Fourier curve into monthly sections and calculate a mean temperature for each month.
6. Determine the deviation of estimated daily soil surface temperatures (step 4) from the appropriate monthly means.
7. Using regression analysis, correlate meteorological data (independent variables) with the deviations of soil temperatures from monthly means (dependent variable). The resulting regression equations represent the deviation of daily soil surface means from monthly means.
8. Smooth meteorological data using the weighted 3 day smoothing function.
9. Submit the smoothed meteorological data to the regression equations to obtain daily departures of soil temperature from the monthly mean. Add these daily departure values to the monthly means to obtain estimated daily means.
10. Utilizing daily means (step 9) as long term averages for Equation F13, calculate daily subsurface temperature curves by adjusting the phase lag and depth variables. The amplitudes for these curves depend on sky conditions, snow cover and time of year.

11. Annual curves can also be calculated by substituting daily means and amplitudes with annual values.

Appendix F

COMPUTER PROGRAM FOR THE EXECUTION OF REIMER'S ESTIMATION PROCEDURES

```
//GEOGRAPH JOB '0075,SIN,98,T=40,L=10,I=50,F=23','J KRPAN',MSGLEVEL=1
/*TSO SOIL
//  EXEC WATFIV,SIZE=512K
//GO.SYSIN DD *
$JOB WATFIV KRPAN,NOEXT
C
C            PROGRAM TO CALCULATE AND DISPLAY COEFFICIENTS
C            OF EQUATIONS USED TO ANALYSE SOIL TEMPERATURE
C                           DATA
C
C
C                   DEFINITION OF VARIABLES
C
C     BCOS  = SLOPE "F" IN EQUATION: T = CONST + F * COS(6.28*DAY/365)
C     BSIN  = SLOPE "E" IN EQUATION: T = CONST + E * SIN(6.28*DAY/365)
C     COUNT = COUNTER TO COUNT # OF OBSERVATIONS
C     DAY   = DAY OF THE YEAR, E.G. FEB 1 = DAY NO 32
C     DAYMAX= DATE ON WHICH THE MAXIMUM TEMP OCCURS
C     DAYMIN= DATE ON WHICH THE MINIMUM TEMP OCCURS
C     NDAY  = INTEGER VALUE OF DAY
C     NT    = INTEGER VALUE OF T - TEMPERATURE
C     NTHAT = INTEGER VALUE OF TEMP ESTIMATED BY REGRESSION EQUATION
C     RSQ   = THE SQUARE OF THE CORRELATION COEFFICENT FOR THE
C             EQUATION: TEMP = A + B * SIN(DAY ANGLE + ALPHA).
C             IT IS THE PROPORTION OF THE VARIATION IN TEMP THAT
C             CAN BE EXPLAINED BY THE RELATIONSHIP TO TIME OF YEAR.
C     SDAY  = SUM OF DAY NUMBER EXPRESSED AS AN ANGLE, I.E.
C             SUM(SIN(6.28 * DAY/365 + ALPHA))
C     SQCOS = SUM OF SQUARES OF DAY NUMBER EXPRESSED AS THE COSINE OF
C             THE EQUIVALENT ANGLE, I.E. SUM(COS(6.28 * DAY/365) ** 2)
C     SQSIN = SUM OF SQUARES OF DAY NUMBER EXPRESSED AS THE SINE OF
C             THE EQUIVALENT ANGLE, I.E. SUM(SIN(6.28 * DAY/365) ** 2)
C     SQT   = SUM OF SQUARES OF TEMPERATURES
C     SQTEMP= SUM OF SQUARES OF TEMPERATURES
C     SQDAY = SUM OF SQUARES OF THE SINE OF DAY + ALPHA EXPRESSED AS A
C             ANGLE, I.E. SUM((SIN(6.28 *DAY/365 + ALPHA)) ** 2)
C     SQDIF = SUM OF SQUARES OF THE DIFFERENCES BETWEEN OBSERVED AND
C             PREDICTED TEMPERATURES ACCORDING TO THE RELATIONSHIP:
C             TEMP = A + B * SIN(DAY ANGLE + ALPHA).
C     STDAY = SUM OF CROSS PRODUCTS OF: SIN(6.28*DAY/365) * TEMP
C     STEMP = SUM OF ACTUAL TEMP OBSERVATIONS
C     SUMCOS= SUM OF DAY NUMBERS EXPRESSED AS THE COSINE OF THE
C     CONSTA= MEAN ANNUAL TEMPERATURE
C     DAYMXA= DATE ON WHICH MAX. TEMP. OCCURS
C     DAYMNA= DATE ON WHICH MIN. TEMP. OCCURS
C     FROSTA= FROST FREE DAYS
C     FIVE1A= DATE OF OCCURENCE OF 5 DEG. C (SPRING)
C     FIVE2A= DATE OF OCCURENCE OF 5 DEG. C (FALL)
C     DAY5A = DAYS ABOVE 5 C
C     DEG5A = DEGREE DAYS ABOVE A 5 C BASE
C     DAY15A= DAYS ABOVE 15 DEG. C
C     IDEPTH= SOIL DEPTH
C     AVSUMA= AVERAGE SUMMER SOIL TEMP.
C     DAY1A = DATE OF OCCURENCE OF 0 DEG. C (SPRING)
```

```
       IF (LOCATE(J).EQ.BLANK)GO TO 14
       NUMBER=NUMBER +1
       J=J+1
       GO TO 1
 14    DO 200 B=1,7
        SUMT=SQT=SUMCOS=SQCOS=SUMSIN=SQSIN=COUNT=SUMCT=SUMST=
     /  SSQT=CHEVY=0.0
      BSIN=BCOS=AVT=AVSIN=AVCOS=CONSIN=CONCOS=ALPHA1=ALPHA2=
     /ALPHA3=ALPHA4=STEMP=SQTEMP=SDAY=SQDAY=STDAY=BETA=AVDAY=
     /CONST= SUMDIF=ZERO1=ZERO2=FIVE1=FIVE2=FIF1=FIF2=J=I=ALPHA=0.0
C
C          THIS SECTION OF THE PROGRAM CHECKS FOR MISSING DATA
C     AND IT ASSIGNS T(SOIL TEMP.) THE VALUES FOR THE APPROPRIATE
C     SOIL DEPTH ACCORDING TO THE VALUE OF B. FOR EXAMPLE, IF
C     B=3, T IS ASSIGNED THE VALUES FOR THE 20 CM. DEPTH.
C
C
        WHILE (NUMBER.GT.COUNT) DO
 2     I=I+1
       COUNT=COUNT + 1
         IF(B.EQ.1) THEN DO
          DO 301 JDB=1,NUMBER
           T(JDB)=SOIL1(JDB)
301       CONTINUE
           IF(TEMP1(I).EQ.BLANK) THEN DO
           IF (I .EQ. NUMBER) GO TO 3
            CHEVY=CHEVY+1
            GO TO 2
          ELSE DO
          END IF
        END IF
        IF (B.EQ.2) THEN DO
         DO 302 JDB=1,NUMBER
          T(JDB)=SOIL2(JDB)
302      CONTINUE
          IF (TEMP2(I).EQ.BLANK) THEN DO
          IF(I.EQ.NUMBER)GO TO 3
           CHEVY=CHEVY+1
           GO TO 2
          ELSE DO
          END IF
        END IF
        IF (B.EQ.3) THEN DO
         DO 303 JDB=1,NUMBER
          T(JDB)=SOIL3(JDB)
303      CONTINUE
          IF(TEMP3(I).EQ.BLANK) THEN DO
          IF (I.EQ. NUMBER) GO TO 3
           CHEVY=CHEVY+1
           GO TO 2
         ELSE DO
         END IF
       END IF
       IF (B.EQ.4)THEN DO
```

```
C     DAY2A = DATE OF OCCURENCE OF 0 DEG. C (FALL)
C     FIF1A = DATE OF OCCURENCE OF 15 C (SPRING)
C     FIF2A = DATE OF OCCURENCE OF 15 C (FALL)
C     TMINA = MINIMUM TEMPERATURES
C     TMAXA = MAXIMUM TEMPS
C     LOCATE= LEGAL DISCRIPTION OF RECORDING STATIONS
C     T     = SOIL TEMPERATURE
C     CHEVY
C     JOHN
C     JDB
C     KATH      COUNTER VARIABLES
C     IGOR
C     NUMBER
C     COUNT
C     Y      = COUNTER VARIABLE FOR STATIONS. WHEN Y=1, DATA
C              FOR RECORDING STATION ONE IS ANALIZED.
C     B      = COUNTER VARIABLE FOR SOIL DEPTH. WHEN: B=1,
C              SOIL DEPTH = 5 CM.;IF B=2, SOIL DEPTH = 10 CM.;
C              IF B=3, SOIL DEPTH = 20 CM.;IF B=4, SOIL DEPTH=
C              50 CM.;IF B=5, SOIL DEPTH = 100 CM.;AND IF B=6
C              SOIL DEPTH = 150 CM..
C
C
      REAL BLANK/'    '/
      DIMENSION  N(20), DAY(150), T(150), COSDAY(150), SINDAY(150),
     1THAT(150), NTHAT(150), NT(150), Z(150), NN(20), NDAY(150),
     1CONSTA(109,7), DAYA2A(109,7), FROSTA(109,7), TMINA(109,7),
     /TMAXA(109,7), DAYMNA(109,7), DAYMXA(109,7), FIVE1A(109,7),
     /FIVE2A(109,7), DAY5A(109,7), DEG5A(109,7), FIF1A(109,7),
     /FIF2A(109,7), DAY15A(109,7),IDEPTH(7),DAYA1A(109,7),AVSUMA(109,7)
      DIMENSION DEG15A(109,7),STORE(7),DATE(4271),SOIL7(150),
     /          SOIL1(150),SOIL2(150),SOIL3(150),TEMP6(150),
     /          SOIL4(150),SOIL5(150),SOIL6(150),LOCATI(109),
     /        NUM(109),DAY1A(109,7),DAY2A(109,7),DISC(150),
     /          TITLE1(109),TITLE2(109),TITLE3(109),TEMP7(150)
     / ,TEMP1(150),TEMP2(150),TEMP3(150),TEMP4(150),TEMP5(150)
      REAL LOCATE(150)
      INTEGER Y,B,I,JD,JDBK,JK,NUMBER, COUNT,SAVE,CHEVY
      BSIN=BCOS=AVT=AVSIN=AVCOS=CONSIN=CONCOS=ALPHA1=ALPHA2=
     /ALPHA3=ALPHA4=STEMP=SQTEMP=SDAY=SQDAY=STDAY=BETA=AVDAY=
     /CONST=SUMDIF=ZERO1=ZERO2=FIVE1=FIVE2=FIF1=FIF2=J=0.0
C
C     READ IN DATA
C
C
      DO 100 Y=1,104
       I=0
       NUMBER=0
       J=1
       READ 55,NUM(Y),LOCATI(Y),TITLE1(Y),TITLE2(Y),TITLE3(Y)
 1     READ 25,LOCATE(J),DATE(J),DAY(J),SOIL1(J),TEMP1(J),
     /         SOIL2(J),TEMP2(J),SOIL3(J),TEMP3(J),SOIL4(J),
     /         TEMP4(J),SOIL5(J),TEMP5(J),SOIL6(J),TEMP6(J)
     /         ,SOIL7(J),TEMP7(J)
```

```
           DO 304 JDB=1,NUMBER
            T(JDB)=SOIL4(JDB)
 304       CONTINUE
            IF(TEMP4(I).EQ.BLANK) THEN DO
            IF (I .EQ. NUMBER) GO TO 3
             CHEVY=CHEVY+1
             GO TO 2
            ELSE DO
            END IF
          END IF
          IF (B.EQ.5) THEN DO
           DO 305 JDB=1,NUMBER
            T(JDB)=SOIL5(JDB)
 305       CONTINUE
            IF(TEMP5(I).EQ.BLANK) THEN DO
            IF (I .EQ. NUMBER) GO TO 3
             CHEVY=CHEVY+1
             GO TO 2
            ELSE DO
            END IF
          END IF
          IF(B.EQ. 6) THEN DO
           DO 306 JDB=1,NUMBER
            T(JDB)=SOIL6(JDB)
 306      CONTINUE
            IF(TEMP6(I).EQ.BLANK) THEN DO
            IF (I .EQ. NUMBER) GO TO 3
             CHEVY=CHEVY+1
             GO TO 2
            ELSE DO
             END IF
          END IF
          IF (B.EQ.7) THEN DO
           DO 307 JDB=1,NUMBER
            T(JDB)=SOIL7(JDB)
 307      CONTINUE
            IF (TEMP7(I) .EQ. BLANK) THEN DO
            IF (I .EQ. NUMBER) GO TO 3
             CHEVY=CHEVY + 1
             GO TO 2
            ELSE DO
            END IF
          END IF
      GO TO 5
 3     CHEVY=CHEVY+1
 5     CONTINUE
C
 25   FORMAT(T1,A9,T10,A6,T16,F3.0,T28,F4.1,T28,A4,
     /      T32,F4.1,T32,A4,T36,F4.1,
     /       T36,A4,T40,F4.1,T40,A4,T44,F4.1,T44,A4,T48,F4.1,
     /       T48,A4,T52,F4.1,T52,A4)
 55   FORMAT(T1,A5,7X,A9,5X,A4,A4,A4)
C
C        THIS PART OF THE PROGRAM CONVERTS  THE DAY OF THE
```

```
C        YEAR TO AN ANGLE
C
      IF(CHEVY.EQ.NUMBER) GO TO 4
         COSDAY(I) = (COS(6.28*DAY(I)/365.))
         SINDAY(I) = SIN(6.28*DAY(I)/365.)
         SUMT =SUMT+T(I)
         SSQT=SSQT+ABS(T(I)*T(I))
         SUMCOS= SUMCOS+COSDAY(I)
         SUMSIN= SUMSIN+SINDAY(I)
         SQCOS=SQCOS+ABS(COSDAY(I)*COSDAY(I))
         SQSIN=SQSIN+ABS(SINDAY(I)*SINDAY(I))
         SUMCT=SUMCT+T(I)*COSDAY(I)
         SUMST=SUMST+T(I)*SINDAY(I)
  4      CONTINUE
        END WHILE
C
        COUNT=COUNT-CHEVY
        IF (COUNT.EQ.0)GO TO 199
C
C     PRINT,'B=',B,'Y=',Y,'N=',NUMBER,'C=',COUNT,'SUMST=',SUMST
        BSIN=(SUMST-SUMT*SUMSIN/COUNT)/(SQSIN-SUMSIN*SUMSIN
     /  /COUNT)
        BCOS=(SUMCT-SUMT*SUMCOS/COUNT)/(SQCOS-SUMCOS*SUMCOS
     1  /COUNT)
        AVT=SUMT/COUNT
        AVSIN = SUMSIN/COUNT
        AVCOS=SUMCOS/COUNT
        CONSIN=AVT-BSIN*AVSIN
        CONCOS= AVT-BCOS *AVCOS
C
C
C     THERE ARE FOUR POSSIBLE VALUES OF ALPHA.   TWO OF THESE
C     VALUES MUST BE IDENTICAL AND ALPHA IS DEFINED AS  THAT
C     VALUE WHICH OCCURS TWICE.
C
        IF (BCOS.EQ.0.OR.BSIN.EQ.0)THEN DO
        ALPHA = 0
      ELSE DO
        ALPHA1=ARSIN(BCOS/SQRT(BSIN*BSIN+BCOS*BCOS))
        ALPHA2=ARSIN(-BCOS/SQRT(BSIN*BSIN+BCOS*BCOS))
        ALPHA3=ARCOS(BSIN/SQRT(BSIN*BSIN+BCOS*BCOS))
        ALPHA4=ARCOS(-BSIN/SQRT(BSIN*BSIN+BCOS*BCOS))
      END IF
C
C
        IF ((ALPHA1-ALPHA3).EQ.0) THEN DO
         ALPHA=ALPHA1
        ELSE DO
         IF ((ALPHA1-ALPHA4).EQ.0) THEN DO
          ALPHA=ALPHA1
         ELSE DO
          ALPHA=ALPHA2
         END IF
        END IF
```

```
 C
         STEMP=SQTEMP=SDAY=SQDAY=STDAY=SUMDIF=SQDIF=0
 C
 C
 C
 C
          DO 300 I=1,COUNT
           STEMP=STEMP+T(I)
           SQTEMP=SQTEMP+ABS(T(I)*T(I))
           SDAY=SDAY+SIN(6.28*DAY(I)/365.+ALPHA)
           SQDAY=SQDAY+ABS(SIN(6.28*DAY(I)/365.+ALPHA)* SIN
      /    (6.28*DAY(I)/365.+ALPHA))
           STDAY=STDAY+SIN(6.28*DAY(I)/365.+ALPHA)*T(I)
  300       CONTINUE
 C
          BETA=(STDAY - STEMP * SDAY/COUNT)/(SQDAY-SDAY*SDAY/
      /   COUNT)
          AVDAY=SDAY/COUNT
          CONST=AVT-BETA*AVDAY
          SUMDIF=SQDIF=0
 C
 C
 C        THE FOLLOWING SECTION DETERMINES MEAN ANNUAL TEMP.
 C        MEAN SUMMER TEMP,MAX AND MIN TEMP. ETC.
 C
 C
          DAYA1A(Y,B)=365.-ALPHA * 365./ 6.28
          DAYA2A(Y,B)= 182.5 - ALPHA * 365./6.28
          CONSTA(Y,B)= CONST
          AVSUMA(Y,B)= (COS(6.28 * 151./365.+ ALPHA)- COS
      /                (6.28*243/365. + ALPHA)) * BETA *
      /                 (365./6.28)/92. + CONST
          DAYMNA(Y,B)= (1.5708 - ALPHA) * 365/6.28
          DAYMXA(Y,B)=(4.7124 - ALPHA) * 365/6.28
          TMINA(Y,B)= CONST + BETA * SIN(6.28*DAYMNA(Y,B)/
      /               365 + ALPHA)
         TMAXA(Y,B) = CONST + BETA * SIN(6.28 * DAYMXA(Y,B)/
      /                365 + ALPHA)
 C
 C        CALCULATION  OF THE DATES ON WHICH THE SOIL TEMP.
 C        IS ZERO
 C
 C
 C     PRINT, 'COUNT = ',COUNT,'Y = ',Y
 C     PRINT, 'BETA=',BETA,'-CON=',-CONST
 C     PRINT, STDAY,STEMP,SDAY,SQDAY
         IF ((TMAXA(Y,B)-1).LT.0) GO TO 175
         IF ((-CONST/BETA).GT.1) THEN DO
          ZERO1 = ARSIN(1.)
          ZERO2 = ARSIN(-1.)
        ELSE DO
          ZERO1 = ARSIN(-CONST/BETA)
          ZERO2 = ARSIN(CONST/BETA)
         END IF
```

```
C
         DAY2A(Y,B)= ( ZERO1-ALPHA) * 365/6.28 + 365.
         DAY1A(Y,B)= (ZERO2 - ALPHA) * 365/6.28 + 182.5
         FROSTA(Y,B)= DAY2A(Y,B) - DAY1A(Y,B)
C
         IF(DAY2A(Y,B).LT. 365) THEN DO
         ELSE DO
          DAY2A(Y,B) = DAY2A(Y,B) - 365
         END IF
C
       IF (TMAXA(Y,B).LT. 5 ) GO TO 175
C
C      CALCULATION OF THE DATES OF OCCURENCE OF 5 C AND THE
C      DAYS ABOVE 5 DEG. C.
C
         FIVE2 = ARSIN(-(CONST-5.)/BETA)
         FIVE1 = ARSIN((CONST-5.)/BETA)
         FIVE2A(Y,B)= (FIVE2 - ALPHA) * 365/6.28 + 365
         FIVE1A(Y,B)= (FIVE1 - ALPHA) * 365 /6.28 +182.5
         DEG5A(Y,B)= (COS(6.28*FIVE1A(Y,B)/365 + ALPHA) - COS
     /               (6.28* FIVE2A(Y,B)/365 + ALPHA)) * BETA
     /               * 365/6.28 - (FIVE2A(Y,B) - FIVE1A(Y,B)
     /               ) * (5. - CONST)
        DAY5A(Y,B) = FIVE2A(Y,B) - FIVE1A(Y,B)
C
         IF ( TMAXA(Y,B) .LE. 15) GO TO 175
C
C        CALCULATION OF THE DAYS ABOVE 15 DEG. C AND THE DATES
C        OF OCCURENCE (SPRING AND FALL) OF 15 DEG. C. ABOVE A
C        15 C BASE ARE ALSO CALCULATED.
C
         FIF2 = ARSIN(-(CONST -15.)/BETA)
         FIF1 = ARSIN((CONST - 15.)/BETA)
         FIF2A(Y,B) = (FIF2 - ALPHA) * 365. /6.28 + 365.
         FIF1A(Y,B) =(FIF1 - ALPHA) * 365./ 6.28  + 182.5
         DAY15A(Y,B) = FIF2A(Y,B) - FIF1A(Y,B)
         DEG15A(Y,B) = (COS(6.28 * FIF1A(Y,B)/365. + ALPHA)
     /                 - COS ( 6.28 * FIF2A(Y,B)/365. + ALPHA))
     /                 * BETA * 365. / 6.28 - DAY15A(Y,B) *
     /                 (15. - CONST)
 175  DO 76 JOHN = 1,COUNT
C
C
C      THIS SECTION OF THE PROGRAM CALCULATES AN R SQUARED
C      VALUE FOR PREDICTED AND OBSERVED VALUES.
C
       TPRED = CONST+BETA*SIN(6.28*DAY(JOHN)/365.+ALPHA)
       DIFF = T(JOHN) - TPRED
       SUMDIF = SUMDIF + DIFF
       SQDIF = SQDIF + ABS(DIFF * DIFF)
 76   CONTINUE
      RSQ=1.-SQDIF/(SQTEMP-STEMP*STEMP/COUNT)
      PRINT 77, RSQ
 77   FORMAT (' ','R SQUARED = ',F6.2)
```

```
      DO 78  KATH=1,92
       NDAY(KATH)=KATH*4
       THAT(KATH)=CONST+BETA*SIN(NDAY(KATH)*6.28/365.+ALPHA)
       NTHAT(KATH)=THAT(KATH)+1.5
 78   CONTINUE
C
      NCOUNT=COUNT
      DO 79 IGOR=1,NCOUNT
        NT(IGOR)=T(IGOR)+1.5
 79   CONTINUE
C
      TPRED=DIFF=RSQ=NCOUNT=0
C
      DO 150 JD=1,NUMBER
       T(JD)=0
       COSDAY(JD)=0
       SINDAY(JD)=0
 150  CONTINUE
C
 199  CONTINUE
 200     CONTINUE
      DO 700 IN=1,NUMBER
       DAY(IN)=0
       SOIL1(IN)=0
       SOIL2(IN)=0
       SOIL3(IN)=0
       SOIL4(IN)=0
       SOIL5(IN)=0
       SOIL6(IN)=0
       SOIL7(IN)=0
 700  CONTINUE
 100     CONTINUE
C
C
       IDEPTH(1) = 2.5
       IDEPTH(2) = 5
       IDEPTH(3) = 10
       IDEPTH(4) = 20
       IDEPTH(5) = 50
       IDEPTH(6) = 100
       IDEPTH(7) = 150
C
       PRINT 10
       PRINT 20
       PRINT 30
       PRINT 40
       PRINT 50
       PRINT 60
       PRINT 70
       PRINT 80
       PRINT 90
        DO 400 Y=1,107
          SAVE= Y
          DO 500 B=1,7
```

```
        IF( MOD(SAVE,7).EQ. 0 ) THEN DO
         PRINT 10
         PRINT 20
         PRINT 30
         PRINT 40
         PRINT 50
         PRINT 60
         PRINT 70
         PRINT 80
         PRINT 90
        ELSE DO
        END IF
        SAVE=2
C
C
C      THE FOLLOWING PRINT STATEMENTS PRINT COEFFICIENTS SUCH
C      AS DEGREE DAYS, MAX. AND MIN. TEMPS., MEAM ANNUAL,
C      MEAN SUMMER ETC.
C
        PRINT 101,TITLE1(Y),TITLE2(Y),TITLE3(Y),IDEPTH(B),
     /           CONSTA(Y,B),DAYA2A(Y,B),DAYA1A(Y,B),
     /           AVSUMA(Y,B),DAY1A(Y,B),DAY2A(Y,B),FROSTA(Y,B),
     /           TMAXA(Y,B),DAYMXA(Y,B),TMINA(Y,B),DAYMNA(Y,B),
     /           FIVE1A(Y,B),FIVE2A(Y,B),DAY5A(Y,B),DEG5A(Y,B),
     /           FIF1A(Y,B),FIF2A(Y,B),DAY15A(Y,B),DEG15A(Y,B)
       IF (B.EQ.7) PRINT 102
C
C
 500     CONTINUE
 400    CONTINUE
C
CC     FORMAT STATEMENTS
C
 10     FORMAT('1',T58,'TABLE OF DATA')
 20     FORMAT('0',T2, 123('*'))
 30     FORMAT('0',T8, 'SITE',T14,'DEPTH',T21,'SOIL TEMPERATURE',
     /       T43,'DATE 0C',T55,'DAYS',T82,'DATE 5C', T97,'DEGREE',T106,
     /       'DATE 15C',T115,'DAYS',T120,'DEG.')
 40     FORMAT(' ',T61,'T.',T72,'T.',T93,'DAYS')
 50     FORMAT(' ',T54,'ABOVE',T60,'MAX',T66,'DAY',T71,'MIN',
     /       T77,'DAY',T92,'ABOVE',T98,'DAYS',T115,'ABOVE',
     /       T121,'DAYS')
 60     FORMAT(' ',T15,'CM',T20,'MEAN',T25,'SPRING',T32,'FALL',
     /       T37,'MEAN',T42,'SPRING',T49,'FALL',T81,'SPRING',
     /       T88,'FALL',T103,'SPRING',T110,'FALL')
 70     FORMAT(' ',T20,'FOR',T36,'SUMMER',T50,'OR',T55,'0 C',T93,'5 C',
     /       T98,'5 C',T115,'15 C',T120,'15 C')
 80     FORMAT(' ',T20,'YEAR',T48,'WINTER')
 90     FORMAT(' ',T2,' ')
 101    FORMAT(' ',T2,A4,T6,A4,T10,A4,
     /       T15,I3,T20,F4.1,T26,F4.0,T32,F4.0,T37,
     /       F4.1,T43,F4.0,T49,F4.0,T54,F4.0,T60,F4.1,T66,
     /       F4.0,T70,F5.1,T77,F4.0,T82,F4.0,T88,F4.0,T93,
     /       F4.0,T98,F5.0,T105,F4.0, T110,F4.0,T115,F4.0,
```

```
     /        T120,F5.0)
 102  FORMAT('  ',T2,'           ')
      DO 450 B=1,6
       DO 550 Y=1,107
         PRINT 103,FIVE1A(Y,B),FIVE2A(Y,B),DAY5A(Y,B),
     /           DEG5A(Y,B),FIF1A(Y,B),FIF2A(Y,B),DAY15A(Y,B),
     /           DEG15A(Y,B)
      IF(Y.EQ.1) GO TO 41
      IF(MOD(107,Y).EQ. 0) PRINT 104
 41   CONTINUE
 550  CONTINUE
 450  CONTINUE
C
 103  FORMAT(' ',T3,F4.0,1X,F4.0,
     /      1X,F4.0,1X,F5.0,1X,F4.0,1X,F4.0,1X,F4.0,1X,F5.0)
 104  FORMAT(' ','   ')
C
      DO 888 B=1,6
       DO 999 Y=1,104
        PRINT 1111,AVSUMA(Y,B)
        IF (Y.EQ.1) GO TO  42
        IF(MOD(105,Y).EQ. 0)PRINT 104
 42    CONTINUE
 999  CONTINUE
 888  CONTINUE
 1111  FORMAT(' ',T12,F4.1)
      STOP
      END
$ENTRY
```

Appendix G

PREDICTED SOIL TEMPERATURES (2.5 CM) FOR JANUARY, JUNE, JULY, AND AUGUST FOR BRANDON 1974, CALCULATED BY REIMER'S ESTIMATION PROCEDURES.

In Appendix G, the values in each column represent the hours of the day, 1 through 24. However, the first value is not hour 1 (i.e. 1 am). It is the point on the Fourier curve where the curve representing daily temperatures intersects the line delineating the long term mean. For example, during the summer this occurs between 5 and 6 am.

TABLE OF DAILY TEMPERATURE CURVE DATA.

JANUARY

Hr. of Day

1	2	3	4	5	6	7	8		10	11	12	13	14
-9.646	-11.930	-8.741	-10.343	-10.132	-7.101	-9.808	-9.399	-8.695	-4.909	-6.939	-8.320	-12.029	-12.361
-9.626	-11.910	-8.721	-10.322	-10.112	-7.081	-9.789	-9.378	-8.675	-4.889	-6.919	-8.300	-12.009	-12.340
-9.607	-11.891	-8.702	-10.304	-10.093	-7.062	-9.770	-9.360	-8.656	-4.870	-6.900	-8.281	-11.990	-12.322
-9.591	-11.875	-8.686	-10.288	-10.077	-7.046	-9.754	-9.344	-8.640	-4.854	-6.884	-8.265	-11.974	-12.306
-9.579	-11.863	-8.674	-10.276	-10.065	-7.034	-9.741	-9.331	-8.629	-4.842	-6.872	-8.253	-11.962	-12.294
-9.571	-11.856	-8.667	-10.268	-10.058	-7.027	-9.734	-9.324	-8.621	-4.835	-6.864	-8.246	-11.954	-12.286
-9.569	-11.853	-8.664	-10.266	-10.055	-7.024	-9.731	-9.321	-8.618	-4.832	-6.862	-8.243	-11.952	-12.284
-9.572	-11.856	-8.667	-10.268	-10.058	-7.027	-9.734	-9.324	-8.621	-4.835	-6.865	-8.246	-11.955	-12.286
-9.580	-11.864	-8.675	-10.276	-10.066	-7.035	-9.742	-9.332	-8.629	-4.843	-6.873	-8.254	-11.963	-12.294
-9.592	-11.877	-8.688	-10.289	-10.079	-7.048	-9.755	-9.345	-8.642	-4.856	-6.885	-8.266	-11.975	-12.307
-9.609	-11.893	-8.704	-10.305	-10.095	-7.064	-9.771	-9.361	-8.658	-4.872	-6.902	-8.283	-11.991	-12.323
-9.627	-11.912	-8.723	-10.324	-10.114	-7.083	-9.790	-9.380	-8.677	-4.891	-6.920	-8.302	-12.010	-12.342
-9.648	-11.932	-8.743	-10.344	-10.134	-7.103	-9.810	-9.400	-8.697	-4.911	-6.941	-8.322	-12.030	-12.362
-9.668	-11.952	-8.763	-10.364	-10.154	-7.123	-9.830	-9.420	-8.717	-4.931	-6.961	-8.342	-12.050	-12.382
-9.686	-11.971	-8.782	-10.383	-10.173	-7.142	-9.849	-9.439	-8.736	-4.950	-6.979	-8.361	-12.069	-12.401
-9.702	-11.987	-8.798	-10.399	-10.189	-7.158	-9.865	-9.455	-8.752	-4.966	-6.995	-8.377	-12.085	-12.417
-9.715	-11.999	-8.810	-10.411	-10.201	-7.170	-9.877	-9.467	-8.764	-4.978	-7.008	-8.389	-12.097	-12.429
-9.722	-12.007	-8.817	-10.419	-10.209	-7.177	-9.885	-9.475	-8.772	-4.985	-7.015	-8.396	-12.105	-12.437
-9.725	-12.009	-8.820	-10.421	-10.211	-7.180	-9.887	-9.477	-8.774	-4.988	-7.018	-8.399	-12.107	-12.439
-9.722	-12.006	-8.817	-10.419	-10.208	-7.177	-9.884	-9.474	-8.771	-4.985	-7.015	-8.396	-12.105	-12.436
-9.714	-11.998	-8.809	-10.411	-10.200	-7.169	-9.876	-9.466	-8.763	-4.977	-7.007	-8.388	-12.097	-12.429
-9.701	-11.986	-8.797	-10.398	-10.188	-7.157	-9.864	-9.454	-8.751	-4.965	-6.994	-8.376	-12.084	-12.416
-9.685	-11.969	-8.780	-10.382	-10.171	-7.140	-9.848	-9.438	-8.735	-4.948	-6.978	-8.359	-12.068	-12.400
-9.666	-11.951	-8.762	-10.363	-10.153	-7.122	-9.829	-9.419	-8.716	-4.930	-6.959	-8.340	-12.049	-12.381
M= -9.65	M=-11.93	M= -8.74	M=-10.34	M=-10.13	M= -7.10	M= -9.81	M= -9.40	M= -8.70	M= -4.91	M= -6.94	M= -8.32	M=-12.03	M=-12.36

15	16	17	18	19	20	21	22	23	24	25	26	27	28
-12.164	-12.150	-6.410	-5.960	-5.588	-9.303	-11.625	-12.218	-9.810	-12.186	-11.418	-9.942	-12.278	-10.192
-12.144	-12.130	-6.390	-5.940	-5.568	-9.282	-11.605	-12.198	-9.789	-12.166	-11.398	-9.922	-12.258	-10.172
-12.125	-12.111	-6.371	-5.921	-5.549	-9.264	-11.586	-12.179	-9.771	-12.147	-11.379	-9.903	-12.239	-10.153
-12.109	-12.095	-6.355	-5.905	-5.533	-9.248	-11.570	-12.163	-9.755	-12.131	-11.363	-9.887	-12.223	-10.137
-12.097	-12.083	-6.343	-5.893	-5.521	-9.236	-11.558	-12.151	-9.743	-12.119	-11.351	-9.875	-12.211	-10.125
-12.090	-12.075	-6.336	-5.885	-5.513	-9.228	-11.550	-12.143	-9.735	-12.112	-11.343	-9.867	-12.204	-10.117
-12.087	-12.073	-6.333	-5.883	-5.511	-9.226	-11.548	-12.141	-9.733	-12.109	-11.341	-9.865	-12.201	-10.115
-12.090	-12.076	-6.336	-5.886	-5.514	-9.228	-11.551	-12.144	-9.735	-12.112	-11.344	-9.868	-12.204	-10.118
-12.098	-12.084	-6.344	-5.894	-5.522	-9.236	-11.559	-12.152	-9.743	-12.120	-11.352	-9.876	-12.212	-10.126
-12.111	-12.096	-6.357	-5.906	-5.534	-9.249	-11.571	-12.164	-9.756	-12.132	-11.364	-9.888	-12.225	-10.138
-12.127	-12.112	-6.373	-5.923	-5.550	-9.265	-11.587	-12.180	-9.772	-12.149	-11.381	-9.904	-12.241	-10.155
-12.146	-12.131	-6.392	-5.941	-5.569	-9.284	-11.606	-12.199	-9.791	-12.168	-11.399	-9.923	-12.260	-10.173
-12.166	-12.151	-6.412	-5.962	-5.589	-9.304	-11.626	-12.219	-9.811	-12.188	-11.420	-9.944	-12.280	-10.194
-12.186	-12.172	-6.432	-5.982	-5.610	-9.324	-11.645	-12.240	-9.831	-12.208	-11.440	-9.964	-12.300	-10.214
-12.205	-12.190	-6.451	-6.000	-5.628	-9.343	-11.665	-12.258	-9.850	-12.227	-11.458	-9.982	-12.319	-10.232
-12.221	-12.206	-6.467	-6.016	-5.644	-9.359	-11.681	-12.274	-9.866	-12.243	-11.474	-9.998	-12.335	-10.248
-12.233	-12.218	-6.479	-6.029	-5.656	-9.371	-11.693	-12.286	-9.878	-12.255	-11.487	-10.011	-12.347	-10.261
-12.240	-12.226	-6.486	-6.036	-5.664	-9.379	-11.701	-12.294	-9.886	-12.262	-11.494	-10.018	-12.355	-10.268
-12.243	-12.229	-6.489	-6.039	-5.667	-9.381	-11.703	-12.296	-9.888	-12.265	-11.497	-10.021	-12.357	-10.271
-12.240	-12.226	-6.486	-6.036	-5.664	-9.378	-11.701	-12.294	-9.886	-12.262	-11.494	-10.018	-12.354	-10.268
-12.232	-12.218	-6.478	-6.028	-5.656	-9.371	-11.693	-12.286	-9.878	-12.254	-11.486	-10.010	-12.346	-10.260
-12.220	-12.205	-6.466	-6.015	-5.643	-9.358	-11.680	-12.273	-9.865	-12.242	-11.473	-9.997	-12.334	-10.247
-12.203	-12.189	-6.449	-5.999	-5.627	-9.342	-11.664	-12.257	-9.849	-12.225	-11.457	-9.981	-12.317	-10.231
-12.185	-12.170	-6.431	-5.980	-5.608	-9.323	-11.645	-12.238	-9.830	-12.206	-11.439	-9.962	-12.299	-10.212
M=-12.16	M=-12.15	M= -6.41	M= -5.96	M= -5.59	M= -9.30	M=-11.63	M=-12.22	M= -9.81	M=-12.19	M=-11.42	M= -9.94	M=-12.28	M=-10.19

M = DAILY MEAN

TABLE OF DAILY TEMPERATURE CURVE DATA.

Hr. of Day

29	30	31	DAY 32	DAY 33	DAY 34	DAY 35	DAY 36	DAY 37	DAY 38	DAY 39	DAY 40	DAY 41	DAY 42
-10.913	-9.766	-6.767	-4.864	-4.893	-4.832	-4.951	-4.773	-4.961	-4.910	-4.925	-4.989	-4.865	-4.834
-10.893	-9.746	-6.747	-4.844	-4.873	-4.813	-4.931	-4.753	-4.941	-4.890	-4.905	-4.969	-4.845	-4.814
-10.874	-9.727	-6.728	-4.825	-4.854	-4.795	-4.913	-4.734	-4.922	-4.872	-4.886	-4.850	-4.826	-4.795
-10.858	-9.711	-6.712	-4.809	-4.838	-4.779	-4.897	-4.719	-4.906	-4.856	-4.870	-4.834	-4.810	-4.779
-10.846	-9.699	-6.700	-4.797	-4.826	-4.766	-4.884	-4.706	-4.894	-4.844	-4.859	-4.822	-4.798	-4.767
-10.839	-9.692	-6.693	-4.789	-4.819	-4.759	-4.877	-4.699	-4.887	-4.836	-4.851	-4.814	-4.790	-4.759
-10.836	-9.689	-6.690	-4.787	-4.816	-4.756	-4.874	-4.696	-4.884	-4.834	-4.849	-4.812	-4.788	-4.757
-10.839	-9.692	-6.693	-4.790	-4.819	-4.759	-4.877	-4.699	-4.887	-4.836	-4.851	-4.815	-4.791	-4.760
-10.847	-9.700	-6.701	-4.798	-4.827	-4.767	-4.885	-4.707	-4.895	-4.844	-4.859	-4.823	-4.799	-4.768
-10.860	-9.713	-6.713	-4.810	-4.840	-4.780	-4.898	-4.720	-4.908	-4.857	-4.872	-4.835	-4.811	-4.780
-10.876	-9.729	-6.730	-4.827	-4.856	-4.796	-4.914	-4.736	-4.924	-4.873	-4.889	-4.852	-4.828	-4.797
-10.895	-9.748	-6.749	-4.845	-4.875	-4.815	-4.933	-4.755	-4.943	-4.892	-4.907	-4.870	-4.846	-4.815
-10.915	-9.768	-6.769	-4.866	-4.895	-4.835	-4.953	-4.775	-4.963	-4.912	-4.927	-4.891	-4.867	-4.836
-10.935	-9.788	-6.789	-4.886	-4.915	-4.855	-4.973	-4.795	-4.983	-4.932	-4.947	-4.911	-4.887	-4.856
-10.954	-9.807	-6.808	-4.904	-4.934	-4.874	-4.992	-4.814	-5.002	-4.951	-4.966	-4.929	-4.905	-4.874
-10.970	-9.823	-6.824	-4.920	-4.950	-4.890	-5.008	-4.830	-5.018	-4.967	-4.982	-4.945	-4.921	-4.890
-10.982	-9.835	-6.836	-4.933	-4.962	-4.902	-5.020	-4.842	-5.030	-4.979	-4.994	-4.958	-4.934	-4.903
-10.990	-9.842	-6.843	-4.940	-4.970	-4.910	-5.028	-4.850	-5.038	-4.987	-5.002	-4.965	-4.941	-4.910
-10.992	-9.845	-6.846	-4.943	-4.972	-4.912	-5.030	-4.852	-5.040	-4.989	-5.004	-4.968	-4.944	-4.913
-10.989	-9.842	-6.843	-4.940	-4.969	-4.909	-5.027	-4.849	-5.037	-4.986	-5.001	-4.965	-4.941	-4.910
-10.981	-9.834	-6.835	-4.932	-4.961	-4.901	-5.019	-4.841	-5.029	-4.978	-4.993	-4.957	-4.933	-4.902
-10.969	-9.822	-6.823	-4.919	-4.949	-4.889	-5.007	-4.829	-5.017	-4.966	-4.981	-4.944	-4.920	-4.889
-10.953	-9.805	-6.806	-4.903	-4.932	-4.873	-4.991	-4.813	-5.001	-4.950	-4.964	-4.928	-4.904	-4.873
-10.934	-9.787	-6.787	-4.884	-4.914	-4.854	-4.972	-4.794	-4.982	-4.931	-4.946	-4.909	-4.885	-4.854
M=-10.91	M= -9.77	M= -6.77	M= -4.86	M= -4.89	M= -4.83	M= -4.95	M= -4.77	M= -4.96	M= -4.91	M= -4.93	M= -4.89	M= -4.87	M= -4.83

DAY 43	DAY 44	DAY 45	DAY 46	DAY 47	DAY 48	DAY 49	DAY 50	DAY 51	DAY 52	DAY 53	DAY 54	DAY 55	DAY 56
-4.978	-4.858	-4.729	-4.728	-4.719	-4.761	-4.750	-4.703	-4.763	-4.787	-4.885	-4.728	-4.728	-4.736
-4.958	-4.837	-4.709	-4.708	-4.699	-4.741	-4.730	-4.682	-4.743	-4.767	-4.865	-4.708	-4.708	-4.716
-4.939	-4.819	-4.691	-4.689	-4.681	-4.723	-4.711	-4.664	-4.724	-4.748	-4.846	-4.689	-4.689	-4.698
-4.923	-4.803	-4.675	-4.673	-4.665	-4.707	-4.695	-4.648	-4.708	-4.732	-4.830	-4.673	-4.673	-4.682
-4.911	-4.791	-4.663	-4.661	-4.652	-4.694	-4.683	-4.636	-4.696	-4.720	-4.818	-4.661	-4.661	-4.669
-4.903	-4.783	-4.655	-4.654	-4.645	-4.687	-4.675	-4.628	-4.688	-4.712	-4.810	-4.653	-4.654	-4.662
-4.901	-4.781	-4.653	-4.651	-4.642	-4.684	-4.673	-4.626	-4.686	-4.710	-4.808	-4.651	-4.651	-4.659
-4.904	-4.783	-4.655	-4.654	-4.645	-4.687	-4.676	-4.628	-4.689	-4.713	-4.811	-4.654	-4.654	-4.662
-4.912	-4.791	-4.663	-4.662	-4.653	-4.695	-4.684	-4.636	-4.697	-4.721	-4.819	-4.662	-4.662	-4.670
-4.924	-4.804	-4.676	-4.674	-4.666	-4.708	-4.696	-4.649	-4.709	-4.733	-4.831	-4.674	-4.675	-4.683
-4.940	-4.820	-4.692	-4.691	-4.682	-4.724	-4.713	-4.665	-4.725	-4.749	-4.847	-4.691	-4.691	-4.699
-4.959	-4.839	-4.711	-4.710	-4.701	-4.743	-4.732	-4.684	-4.744	-4.768	-4.866	-4.709	-4.710	-4.718
-4.979	-4.859	-4.731	-4.730	-4.721	-4.763	-4.752	-4.704	-4.764	-4.788	-4.886	-4.730	-4.730	-4.738
-4.999	-4.879	-4.751	-4.750	-4.741	-4.783	-4.772	-4.724	-4.785	-4.808	-4.906	-4.750	-4.750	-4.758
-5.018	-4.898	-4.770	-4.769	-4.760	-4.802	-4.791	-4.743	-4.803	-4.827	-4.925	-4.768	-4.769	-4.777
-5.034	-4.914	-4.786	-4.785	-4.776	-4.818	-4.807	-4.759	-4.819	-4.843	-4.941	-4.784	-4.785	-4.793
-5.046	-4.926	-4.798	-4.797	-4.788	-4.830	-4.819	-4.771	-4.831	-4.855	-4.953	-4.797	-4.797	-4.805
-5.054	-4.934	-4.806	-4.804	-4.796	-4.838	-4.825	-4.779	-4.839	-4.863	-4.961	-4.804	-4.805	-4.813
-5.056	-4.936	-4.808	-4.807	-4.798	-4.840	-4.829	-4.781	-4.841	-4.865	-4.963	-4.807	-4.807	-4.815
-5.054	-4.933	-4.805	-4.804	-4.795	-4.837	-4.826	-4.779	-4.839	-4.863	-4.961	-4.804	-4.804	-4.812
-5.046	-4.926	-4.797	-4.796	-4.787	-4.829	-4.813	-4.771	-4.831	-4.855	-4.953	-4.796	-4.796	-4.804
-5.033	-4.913	-4.785	-4.784	-4.775	-4.817	-4.805	-4.758	-4.818	-4.842	-4.940	-4.783	-4.784	-4.792
-5.017	-4.897	-4.769	-4.767	-4.759	-4.801	-4.783	-4.742	-4.802	-4.826	-4.924	-4.767	-4.767	-4.776
-4.998	-4.878	-4.750	-4.748	-4.740	-4.782	-4.770	-4.723	-4.783	-4.807	-4.905	-4.748	-4.749	-4.757
M= -4.98	M= -4.86	M= -4.73	M= -4.73	M= -4.72	M= -4.76	M= -4.75	M= -4.70	M= -4.76	M= -4.79	M= -4.89	M= -4.73	M= -4.73	M= -4.74

TABLE OF DAILY TEMPERATURE CURVE DATA.

Hr. of Day

				May								June	
DAY 141	DAY 142	DAY 143	DAY 144	DAY 145	DAY 146	DAY 147	DAY 148	DAY 149	DAY 150	DAY 151	1	2	3
17.700	17.605	17.758	17.763	17.847	17.809	17.869	17.635	17.841	17.676	17.822	29.690	30.946	31.088
18.092	21.391	21.544	21.549	19.858	18.110	19.880	17.937	19.852	19.687	19.834	31.692	31.248	33.099
18.282	24.908	25.061	25.066	21.727	18.390	21.748	18.217	21.721	21.556	21.702	33.560	31.528	34.967
18.522	27.915	28.068	28.074	23.325	18.630	23.346	18.456	23.319	23.154	23.300	35.158	31.768	36.565
18.705	30.210	30.363	30.368	24.544	18.813	24.565	18.639	24.538	24.373	24.519	36.377	31.951	37.784
18.818	31.634	31.787	31.792	25.300	18.926	25.322	18.753	25.295	25.130	25.276	37.134	32.064	38.541
18.855	32.092	32.245	32.250	25.544	18.963	25.565	18.789	25.538	25.373	25.519	37.377	32.101	38.784
18.812	31.552	31.705	31.710	25.257	18.920	25.278	18.746	25.251	25.086	25.232	37.090	32.058	38.497
19.692	30.050	30.203	30.209	24.459	18.800	24.481	18.627	24.453	24.288	24.434	36.292	31.938	37.700
18.504	27.690	27.843	27.849	23.205	18.612	23.227	18.439	23.199	23.034	23.180	35.038	31.750	36.446
18.260	24.632	24.785	24.790	21.580	18.368	21.602	18.195	21.574	21.409	21.555	33.413	31.506	34.821
17.978	21.083	21.236	21.242	19.695	18.086	19.717	17.912	19.689	19.524	19.670	31.528	31.223	32.936
17.675	17.286	17.439	17.445	17.678	17.783	17.699	17.609	17.672	17.507	17.653	29.511	30.921	30.918
17.373	13.500	13.653	13.658	15.666	17.481	15.687	17.308	15.660	15.495	15.641	27.499	30.619	28.906
17.093	9.981	10.134	10.139	13.796	17.201	13.819	17.027	13.790	13.625	13.771	25.629	30.339	27.037
16.853	6.969	7.122	7.127	12.196	16.961	12.218	16.787	12.190	12.025	12.171	24.029	30.099	25.437
16.670	4.670	4.823	4.828	10.975	16.778	10.995	16.604	10.969	10.804	10.950	22.808	29.915	24.215
16.556	3.240	3.393	3.398	10.215	16.664	10.236	16.490	10.209	10.044	10.190	22.048	29.801	23.456
16.519	2.776	2.929	2.934	9.968	16.627	9.991	16.453	9.962	9.797	9.944	21.802	29.764	23.209
16.561	3.310	3.463	3.469	10.252	16.669	10.274	16.496	10.246	10.081	10.227	22.086	29.807	23.493
16.680	4.806	4.959	4.964	11.047	16.788	11.069	16.615	11.041	10.876	11.022	22.880	29.926	24.288
16.868	7.161	7.314	7.320	12.298	16.976	12.320	16.802	12.292	12.127	12.274	24.132	30.114	25.539
17.111	10.216	10.369	10.374	13.921	17.220	13.943	17.046	13.915	13.750	13.896	25.755	30.357	27.162
17.394	13.762	13.915	13.921	15.805	17.502	15.827	17.329	15.799	15.634	15.781	27.639	30.640	29.046
M= 17.69	M= 17.43	M= 17.59	M= 17.59	M= 17.76	M= 17.79	M= 17.78	M= 17.62	M= 17.75	M= 17.59	M= 17.73	M= 29.59	M= 30.93	M= 31.00

4	5	6	7	8	9	10	11	12	13	14	15	16	17
31.047	30.877	31.116	30.465	31.010	30.359	31.060	31.119	30.917	30.975	31.004	31.001	29.972	30.600
31.348	32.888	33.127	30.767	31.312	32.370	36.077	33.130	32.928	31.276	33.016	33.012	31.984	32.611
31.629	34.756	34.995	31.047	31.592	34.239	40.737	34.999	34.796	31.557	34.884	34.881	33.852	34.480
31.868	36.354	36.593	31.286	31.832	35.837	44.723	36.597	36.394	31.796	36.482	36.479	35.450	36.078
32.051	37.573	37.812	31.469	32.015	37.056	47.764	37.815	37.613	31.979	37.701	37.697	36.669	37.297
32.165	38.330	38.569	31.583	32.128	37.812	49.651	38.572	38.370	32.093	38.458	38.454	37.426	38.053
32.201	38.573	38.812	31.619	32.165	38.056	50.258	38.815	38.613	32.129	38.701	38.697	37.669	38.297
32.158	38.286	38.525	31.576	32.122	37.769	49.542	38.528	38.326	32.086	38.414	38.410	37.382	38.010
32.038	37.489	37.728	31.457	32.002	36.971	47.552	37.731	37.529	31.966	37.617	37.613	36.584	37.212
31.850	36.235	36.474	31.269	31.814	35.717	44.425	36.477	36.275	31.778	36.363	36.359	35.330	35.958
31.607	34.610	34.849	31.025	31.570	34.092	40.272	34.852	34.650	31.535	34.738	34.734	33.705	34.333
31.324	32.725	32.964	30.742	31.287	32.207	35.670	32.967	32.765	31.252	32.852	32.849	31.820	32.448
31.021	30.707	30.946	30.439	30.985	30.190	30.638	30.949	30.747	30.949	30.835	30.831	29.803	30.431
30.719	28.695	28.934	30.138	30.683	28.178	25.620	28.938	28.735	30.647	28.823	28.820	27.791	28.419
30.439	26.826	27.065	29.857	30.403	26.308	20.957	27.068	26.666	30.367	26.954	26.950	25.921	26.509
30.199	25.226	25.465	29.617	30.163	24.708	16.966	25.468	25.266	30.127	25.354	25.350	24.321	24.949
30.016	24.004	24.243	29.434	29.979	23.487	13.919	24.246	24.044	29.944	24.132	24.128	23.100	23.728
29.902	23.245	23.483	29.320	29.865	22.727	12.024	23.487	23.284	29.830	23.372	23.369	22.340	22.968
29.865	22.998	23.237	29.283	29.829	22.480	11.419	23.240	23.038	29.793	23.126	23.122	22.098	22.721
29.907	23.282	23.521	29.326	29.871	22.764	12.117	23.524	23.322	29.835	23.410	23.406	22.377	23.005
30.027	24.077	24.315	29.445	29.990	23.559	14.099	24.319	24.117	29.955	24.204	24.201	23.172	23.800
30.214	25.328	25.567	29.632	30.178	24.810	17.221	25.570	25.368	30.142	25.456	25.452	24.423	25.051
30.458	26.951	27.190	29.876	30.421	26.433	21.269	27.193	26.991	30.386	27.079	27.075	26.046	26.674
30.740	28.835	29.074	30.159	30.704	28.317	25.968	29.077	28.875	30.668	28.963	28.959	27.930	28.558
M= 31.03	M= 30.79	M= 31.03	M= 30.45	M= 31.00	M= 30.27	M= 30.93	M= 31.03	M= 30.83	M= 30.96	M= 30.91	M= 30.91	M= 29.88	M= 30.51

M = Daily Mean.

TABLE OF DAILY TEMPERATURE CURVE DATA.

June

Hr of Day

18	19	20	21	22	23	24	25	26	27	28	29	30	1
31.443	31.385	31.158	30.477	31.185	31.468	30.316	29.611	30.947	30.678	29.950	30.086	30.555	29.058
31.745	33.397	31.460	30.779	33.197	33.480	32.327	31.622	32.958	32.689	30.252	32.097	32.567	31.069
32.025	35.265	31.740	31.059	35.065	35.348	34.196	33.490	34.827	34.557	30.532	33.965	34.435	32.938
32.265	36.863	31.980	31.298	36.663	36.946	35.794	35.088	36.425	36.155	30.772	35.563	36.033	34.536
32.449	38.082	32.163	31.481	37.882	38.165	37.013	36.307	37.643	37.374	30.955	36.782	37.252	35.754
32.561	38.839	32.276	31.595	38.639	38.922	37.770	37.064	38.400	38.131	31.068	37.539	38.009	36.511
32.598	39.082	32.313	31.631	38.882	39.165	38.013	37.307	38.643	38.374	31.105	37.782	38.252	36.754
32.555	38.795	32.270	31.598	38.595	38.878	37.725	37.020	38.357	38.087	31.062	37.495	37.965	36.467
32.435	37.997	32.150	31.469	37.797	38.081	36.928	36.223	37.559	37.290	30.942	36.698	37.167	35.670
32.247	36.743	31.962	31.281	36.543	36.827	35.674	34.969	36.305	36.036	30.754	35.444	35.913	34.416
32.003	35.118	31.718	31.037	34.918	35.202	34.049	33.344	34.680	34.411	30.510	33.819	34.288	32.791
31.720	33.233	31.436	30.754	33.033	33.316	32.164	31.459	32.795	32.526	30.227	31.934	32.403	30.906
31.418	31.216	31.133	30.451	31.016	31.299	30.147	29.441	30.777	30.508	29.925	29.916	30.386	28.888
31.116	29.204	30.831	30.150	29.004	29.287	29.135	27.429	28.766	28.496	29.623	27.904	28.374	26.877
30.836	27.334	30.551	29.869	27.134	27.418	26.265	25.560	26.896	26.627	29.343	26.035	26.504	25.007
30.596	25.734	30.311	29.629	25.534	25.818	24.665	23.960	25.296	25.027	29.103	24.435	24.904	23.407
30.412	24.513	30.129	29.446	24.311	24.596	23.444	22.738	24.074	23.805	28.919	23.213	23.683	22.185
30.298	23.753	30.014	29.332	23.553	23.836	22.684	21.979	23.315	23.045	28.805	22.453	22.923	21.426
30.261	23.507	29.977	29.295	23.307	23.590	22.438	21.732	23.068	22.799	28.768	22.207	22.677	21.179
30.304	23.791	30.019	29.338	23.590	23.874	22.721	22.016	23.352	23.083	28.811	22.491	22.961	21.463
30.423	24.585	30.138	29.457	24.385	24.668	23.516	22.811	24.147	23.877	28.930	23.285	23.755	22.258
30.611	25.837	30.326	29.645	25.636	25.920	24.767	24.062	25.398	25.129	29.118	24.537	25.007	23.509
30.854	27.460	30.570	29.888	27.259	27.543	26.390	25.685	27.021	26.752	29.361	26.160	26.630	25.132
31.137	29.344	30.852	30.171	29.143	29.427	28.274	27.569	28.905	28.636	29.644	28.044	28.514	27.016
M= 31.43	M= 31.29	M= 31.14	M= 30.46	M= 31.09	M= 31.38	M= 30.23	M= 29.52	M= 30.86	M= 30.59	M= 29.94	M= 30.00	M= 30.46	M= 28.97

July

2	3	4	5	6	7	8	9	10	11	12	13	14	15
28.795	28.375	28.566	27.956	29.091	28.750	28.716	29.376	29.034	29.003	27.356	27.222	29.092	29.281
29.097	28.677	28.868	28.257	31.103	34.210	29.019	31.388	31.046	29.304	29.367	29.233	31.104	29.583
29.377	28.957	29.148	28.537	32.971	39.475	29.298	33.256	32.914	29.585	31.236	31.102	32.972	29.863
29.617	29.197	29.388	28.777	34.569	43.892	29.533	34.854	34.512	29.824	32.834	32.700	34.570	30.103
29.900	29.380	29.571	28.960	35.788	47.262	29.721	36.073	35.731	30.007	34.053	33.918	35.789	30.285
29.913	29.493	29.684	29.074	36.545	49.354	29.834	36.830	36.488	30.121	34.810	34.675	36.546	30.399
29.950	29.530	29.721	29.110	36.788	50.026	29.871	37.073	36.731	30.157	35.053	34.918	36.789	30.435
29.907	29.487	29.678	29.067	36.501	49.233	29.823	36.786	36.444	30.114	34.766	34.631	36.502	30.392
29.787	29.367	29.558	28.947	35.703	47.028	29.708	35.988	35.646	29.994	33.968	33.834	35.704	30.273
29.599	29.179	29.370	28.759	34.449	43.561	29.520	34.734	34.392	29.806	32.714	32.580	34.451	30.085
29.355	28.935	29.126	28.516	32.824	39.070	29.276	33.109	32.767	29.563	31.089	30.955	32.826	29.841
29.073	28.653	28.843	28.233	30.939	33.858	28.993	31.224	30.882	29.280	29.204	29.070	30.940	29.558
29.770	28.350	28.541	27.930	28.922	28.282	28.691	29.207	28.865	28.977	27.187	27.052	28.923	29.255
28.468	28.048	28.239	27.628	26.910	22.720	28.389	27.195	26.853	28.675	25.175	25.041	26.911	28.950
28.188	27.768	27.958	27.348	25.040	17.552	28.109	25.325	24.983	28.395	23.305	23.171	25.042	28.673
27.948	27.528	27.719	27.108	23.440	13.129	27.869	23.725	23.383	28.155	21.705	21.571	23.442	28.433
27.765	27.345	27.535	26.925	22.219	9.753	27.685	22.504	22.162	27.972	20.484	20.349	22.220	28.250
27.651	27.231	27.421	26.811	21.459	7.652	27.571	21.744	21.402	27.858	19.724	19.590	21.460	28.136
27.614	27.194	27.384	26.774	21.213	6.971	27.535	21.499	21.156	27.821	19.477	19.343	21.214	28.099
27.656	27.236	27.427	26.816	21.496	7.756	27.577	21.782	21.439	27.863	19.761	19.627	21.498	28.142
27.775	27.355	27.546	26.936	22.291	9.952	27.696	22.576	22.234	27.983	20.556	20.422	22.292	28.261
27.963	27.543	27.734	27.123	23.542	13.411	27.884	23.828	23.486	28.170	21.907	21.673	23.544	28.449
28.207	27.787	27.977	27.367	25.165	17.498	28.127	25.451	25.109	28.414	23.470	23.296	25.167	28.692
28.489	28.069	28.260	27.649	27.049	23.106	28.410	27.335	26.993	28.696	25.314	25.180	27.051	28.975
M= 28.78	M= 28.36	M= 28.55	M= 27.94	M= 29.00	M= 28.50	M= 28.70	M= 29.29	M= 28.94	M= 28.99	M= 27.27	M= 27.13	M= 29.00	M= 29.27

M = Daily mean

TABLE OF DAILY TEMPERATURE CURVE DATA.

July

Hr of Day

16	17	18	19	20	21	22	23	24	25	26	27	28	29
29.339	29.148	28.654	27.699	27.928	28.450	28.766	28.552	28.999	28.812	28.837	28.837	28.833	29.064
29.641	31.160	30.665	29.710	29.939	30.462	30.777	30.564	31.011	29.113	30.849	30.849	30.845	31.076
29.921	33.028	32.533	31.579	31.808	32.330	32.645	32.432	32.879	29.394	32.717	32.717	32.713	32.944
30.161	34.626	34.131	33.177	33.406	33.928	34.243	34.030	34.477	29.633	34.315	34.315	34.311	34.542
30.344	35.845	35.350	34.396	34.625	35.147	35.462	35.249	35.696	29.816	35.534	35.534	35.530	35.761
30.457	36.602	36.107	35.152	35.381	35.904	36.219	36.006	36.453	29.930	36.291	36.291	36.287	36.518
30.494	36.845	36.350	35.396	35.625	36.147	36.462	36.249	36.696	29.966	36.534	36.534	36.530	36.761
30.451	36.558	36.063	35.109	35.338	35.860	36.175	35.962	36.409	29.923	36.247	36.247	36.243	36.474
30.331	35.760	35.266	34.311	34.540	35.062	35.378	35.164	35.611	29.803	35.449	35.449	35.445	35.676
30.143	34.506	34.012	33.057	33.286	33.808	34.124	33.911	34.357	29.615	34.195	34.195	34.191	34.422
29.899	32.882	32.387	31.432	31.661	32.183	32.409	32.286	32.732	29.372	32.570	32.570	32.567	32.797
29.616	30.996	30.501	29.547	29.776	30.299	30.614	30.400	30.847	29.089	30.685	30.685	30.681	30.912
29.314	28.979	28.484	27.530	27.759	28.281	28.596	28.383	28.830	28.786	28.668	28.668	28.664	28.895
29.012	26.967	26.472	25.518	25.747	26.269	26.584	26.371	26.818	28.484	26.656	26.656	26.652	26.883
28.732	25.097	24.603	23.648	23.877	24.399	24.715	24.502	24.948	28.204	24.786	24.786	24.782	25.013
28.492	23.497	23.003	22.048	22.277	22.799	23.115	22.902	23.348	27.964	23.186	23.186	23.182	23.413
28.308	22.276	21.781	20.827	21.056	21.578	21.893	21.680	22.127	27.781	21.965	21.965	21.961	22.192
28.194	21.516	21.021	20.067	20.296	20.818	21.134	20.920	21.367	27.667	21.205	21.205	21.201	21.432
28.157	21.270	20.775	19.820	20.049	20.572	20.887	20.674	21.121	27.630	20.959	20.959	20.955	21.186
28.200	21.554	21.059	20.104	20.333	20.855	21.171	20.958	21.404	27.672	21.242	21.243	21.239	21.469
28.319	22.348	21.853	20.899	21.128	21.650	21.966	21.752	22.199	27.792	22.037	22.037	22.033	22.264
28.507	23.600	23.105	22.150	22.379	22.901	23.217	23.004	23.450	27.979	23.288	23.289	23.285	23.515
28.750	25.223	24.729	23.773	24.002	24.524	24.840	24.627	25.073	28.223	24.911	24.912	24.908	25.138
29.033	27.107	26.612	25.657	25.886	26.408	26.724	26.511	26.958	28.505	26.795	26.796	26.792	27.022
M= 29.33	M= 29.06	M= 28.56	M= 27.61	M= 27.84	M= 28.36	M= 28.68	M= 28.46	M= 28.91	M= 28.80	M= 28.75	M= 28.75	M= 28.70	M= 28.97

August

30	31	1	2	3	4	5	6	7	8	9	10	11	12
28.778	28.812	25.512	24.766	25.312	25.891	25.938	26.395	26.179	25.910	25.792	25.361	25.501	25.808
30.789	29.114	30.282	26.778	27.323	27.902	27.950	28.406	28.191	27.822	27.803	25.662	25.803	26.150
32.658	29.394	34.711	28.646	29.191	29.770	29.818	30.274	30.059	29.690	29.672	25.943	26.083	26.430
34.256	29.634	38.500	30.244	30.789	31.368	31.415	31.872	31.657	31.288	31.270	26.182	26.323	26.670
35.475	29.817	41.390	31.463	32.008	32.587	32.635	33.091	32.876	32.507	32.488	26.365	26.506	-26.853
36.231	29.930	43.184	32.220	32.765	33.344	33.392	33.848	33.633	33.264	33.245	26.479	26.619	26.966
36.475	29.967	43.761	32.463	33.008	33.597	33.635	34.091	33.876	33.507	33.488	26.515	26.656	27.003
36.188	29.924	43.081	32.176	32.721	33.300	33.348	33.804	33.589	33.220	33.201	26.472	26.613	26.960
35.390	29.804	41.189	31.378	31.924	32.503	32.550	33.007	32.791	32.422	32.404	26.352	26.493	26.840
34.136	29.616	38.216	30.124	30.670	31.249	31.296	31.753	31.537	31.168	31.150	26.164	26.305	26.652
32.511	29.372	34.364	29.499	29.045	29.624	29.672	30.128	29.912	29.543	29.525	25.921	26.061	26.408
30.626	29.090	29.894	26.614	27.160	27.739	27.785	28.243	28.027	27.658	27.640	25.638	25.778	26.125
28.609	28.787	25.111	24.597	25.142	25.721	25.769	26.225	26.010	25.641	25.622	25.335	25.476	25.823
26.597	28.485	20.341	22.585	23.130	23.709	23.757	24.213	23.998	23.629	23.611	25.033	25.174	25.521
24.727	28.205	15.908	20.715	21.261	21.840	21.887	22.344	22.129	21.759	21.741	24.753	24.894	25.241
23.127	27.965	12.114	19.115	19.661	20.240	20.287	20.744	20.528	20.159	20.141	24.513	24.654	25.001
21.906	27.792	9.219	17.894	18.439	19.018	19.066	19.522	19.307	18.938	18.919	24.330	24.470	24.817
21.146	27.669	7.417	17.134	17.680	18.258	18.306	18.763	18.547	18.178	18.160	24.216	24.356	24.703
20.899	27.631	6.833	16.888	17.433	18.012	18.060	18.516	18.301	17.932	17.913	24.179	24.319	24.667
21.183	27.673	7.505	17.171	17.717	18.296	18.344	13.800	18.584	18.215	18.197	24.221	24.362	24.709
21.978	27.792	9.389	17.966	18.512	19.090	19.138	19.595	19.379	19.010	18.992	24.341	24.481	24.828
23.229	27.980	12.357	19.217	19.763	20.342	20.390	20.846	20.630	20.261	20.243	24.528	24.669	25.016
24.852	28.224	16.205	20.840	21.386	21.965	22.013	22.469	22.253	21.884	21.866	24.772	24.912	25.259
26.736	28.506	20.672	22.725	23.270	23.849	23.897	24.353	24.137	23.768	23.750	25.054	25.195	25.542
M= 28.69	M= 29.80	M= 25.30	M= 24.68	M= 25.22	M= 25.80	M= 25.85	M= 26.30	M= 26.09	M= 25.72	M= 25.70	M= 25.35	M= 25.49	M= 25.83

M = Daily Mean

TABLE OF DAILY TEMPERATURE CURVE DATA.

Hr of Day

August 13	14	15	16	17	18	19	20	21	22	23	24	25	26
26.312	25.123	25.071	25.918	26.356	25.884	25.843	24.357	24.344	24.539	24.800	24.808	24.785	24.152
31.081	29.892	29.840	26.215	28.367	27.895	27.854	29.126	29.113	26.550	25.102	26.819	25.087	24.453
35.511	34.321	34.270	26.496	30.235	29.764	29.723	33.556	33.542	28.418	25.382	28.688	25.367	24.734
39.300	38.110	38.059	26.735	31.833	31.362	31.321	37.345	37.331	30.016	25.622	30.286	25.607	24.973
42.189	41.000	40.949	26.918	33.052	32.581	32.539	40.235	40.221	31.235	25.805	31.504	25.790	25.156
43.984	42.795	42.743	27.032	33.809	33.338	33.296	42.029	42.016	31.992	25.918	32.261	25.903	25.270
44.560	43.371	43.320	27.068	34.052	33.581	33.539	42.606	42.592	32.235	25.955	32.504	25.940	25.306
43.880	42.691	42.639	27.025	33.765	33.294	33.252	41.926	41.912	31.948	25.912	32.217	25.897	25.263
41.989	40.800	40.748	26.905	32.968	32.496	32.455	40.034	40.021	31.150	25.792	31.420	25.777	25.143
39.016	37.827	37.775	26.717	31.714	31.242	31.201	37.061	37.048	29.896	25.604	30.166	25.589	24.955
35.163	33.974	33.922	26.474	30.089	29.617	29.576	33.209	33.195	28.271	25.360	28.541	25.345	24.712
30.693	29.504	29.452	26.191	28.204	27.732	27.691	28.739	28.725	26.386	25.077	26.656	25.063	24.429
25.910	24.721	24.670	25.888	26.186	25.715	25.673	23.956	23.942	24.369	24.775	24.638	24.760	24.126
21.140	19.951	19.899	25.596	24.174	23.703	23.662	19.186	19.172	22.357	24.473	22.627	24.458	23.824
16.707	15.518	15.467	25.306	22.305	21.833	21.792	14.753	14.739	20.487	24.193	20.757	24.178	23.544
12.914	11.725	11.673	25.066	20.705	20.233	20.192	10.959	10.946	18.887	23.953	19.157	23.938	23.304
10.018	8.828	8.777	24.883	19.483	19.012	18.970	8.063	8.049	17.666	23.769	17.935	23.755	23.121
8.216	7.027	6.975	24.769	18.723	18.252	18.211	6.262	6.248	16.906	23.655	17.176	23.641	23.007
7.632	6.443	6.391	24.732	18.477	18.005	17.964	5.678	5.664	16.660	23.618	16.929	23.604	22.970
8.305	7.116	7.064	24.774	18.761	18.289	18.248	6.350	6.337	16.943	23.661	17.213	23.646	23.012
10.189	9.000	8.948	24.894	19.555	19.084	19.043	8.234	8.221	17.738	23.780	18.008	23.765	23.132
13.156	11.967	11.915	25.081	20.807	20.335	20.294	11.201	11.188	18.990	23.968	19.259	23.953	23.319
17.004	15.815	15.763	25.325	22.430	21.958	21.917	15.050	15.036	20.613	24.211	20.882	24.197	23.563
21.471	20.282	20.230	25.607	24.314	23.842	23.801	19.517	19.503	22.497	24.494	22.766	24.479	23.845
M= 26.10	M= 24.91	M= 24.86	M= 25.90	M= 26.27	M= 25.79	M= 25.75	M= 24.10	M= 24.13	M= 24.45	M= 24.79	M= 24.72	M= 24.77	M= 24.14

27	28	29	30	31	(September) DAY 244	DAY 245	DAY 246	DAY 247	DAY 248	DAY 249	DAY 250	DAY 251	DAY 252
24.812	25.814	25.477	25.378	24.025	14.970	14.876	14.696	14.695	14.753	14.630	14.653	14.820	14.674
26.823	30.583	25.778	25.679	26.037	18.334	15.882	15.702	15.701	18.117	17.994	18.017	18.184	18.038
28.691	35.013	26.059	25.960	27.905	21.459	16.816	16.636	16.635	21.242	21.119	21.142	21.309	21.163
30.289	38.801	26.298	26.199	29.503	24.132	17.615	17.435	17.434	23.915	23.792	23.815	23.982	23.836
31.508	41.691	26.481	26.382	30.722	26.171	18.225	18.045	18.044	25.954	25.830	25.854	26.021	25.875
32.265	43.486	26.595	26.496	31.479	27.436	18.603	18.423	18.422	27.220	27.096	27.120	27.287	27.141
32.509	44.062	26.631	26.532	31.722	27.843	18.725	18.545	18.544	27.626	27.503	27.526	27.693	27.507
32.221	43.382	26.588	26.489	31.435	27.363	18.581	18.401	18.400	27.146	27.023	27.046	27.213	27.067
31.424	41.491	26.469	26.370	30.637	26.029	18.182	18.002	18.001	25.912	25.689	25.712	25.879	25.733
30.170	38.518	26.280	26.181	29.383	23.932	17.555	17.375	17.374	23.715	23.592	23.615	23.782	23.636
28.545	34.665	26.037	25.938	27.758	21.214	16.743	16.563	16.562	20.997	20.874	20.897	21.064	20.918
26.659	30.195	25.754	25.655	25.973	18.061	15.800	15.620	15.619	17.844	17.720	17.744	17.911	17.765
24.642	25.412	25.451	25.352	23.856	14.687	14.792	14.612	14.611	14.470	14.346	14.370	14.537	14.391
22.630	20.642	25.150	25.051	21.844	11.322	13.786	13.606	13.605	11.105	10.981	11.005	11.172	11.026
20.761	16.209	24.869	24.770	19.974	8.195	12.851	12.671	12.670	7.978	7.854	7.878	8.045	7.899
19.161	12.416	24.629	24.530	18.374	5.518	12.051	11.871	11.870	5.302	5.178	5.202	5.369	5.223
17.939	9.520	24.446	24.347	17.153	3.475	11.449	11.260	11.259	3.259	3.135	3.159	3.326	3.180
17.179	7.718	24.332	24.233	16.393	2.205	11.060	10.880	10.879	1.988	1.864	1.888	2.055	1.909
16.933	7.134	24.295	24.196	16.147	1.792	10.937	10.757	10.756	1.576	1.452	1.476	1.643	1.497
17.217	7.807	24.338	24.239	16.430	2.267	11.079	10.899	10.898	2.050	1.927	1.950	2.117	1.971
18.011	9.691	24.457	24.358	17.225	3.596	11.476	11.296	11.295	3.379	3.256	3.279	3.446	3.300
19.263	12.658	24.644	24.545	18.477	5.689	12.102	11.922	11.921	5.472	5.349	5.373	5.539	5.394
20.886	16.506	24.888	24.789	20.100	8.404	12.913	12.733	12.732	8.187	8.064	8.087	8.254	8.108
22.770	20.973	25.170	25.071	21.984	11.555	13.855	13.675	13.674	11.338	11.215	11.238	11.405	11.259
M= 24.72	M= 25.60	M= 25.46	M= 25.26	M= 23.93	M= 14.82	M= 14.83	M= 14.65	M= 14.65	M= 14.60	M= 14.48	M= 14.50	M= 14.67	M= 14.52

M = Daily mean