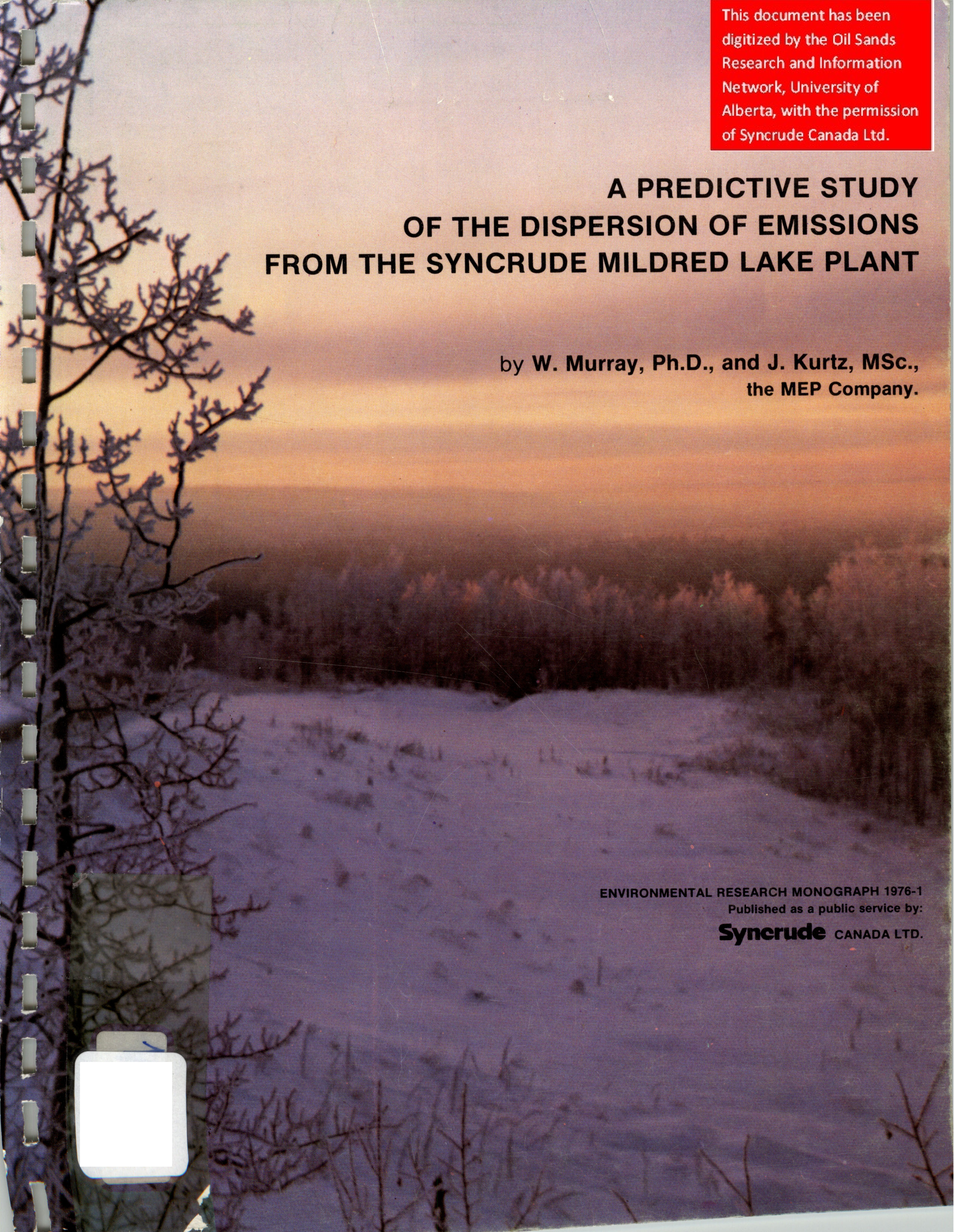

A PREDICTIVE STUDY OF THE DISPERSION OF EMISSIONS FROM THE SYNCRUDE MILDRED LAKE PLANT

by **W. Murray, Ph.D., and J. Kurtz, MSc.,**
the MEP Company.

ENVIRONMENTAL RESEARCH MONOGRAPH 1976-1
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FOREWORD

Syncrude Canada Ltd. commissioned the MEP Company to undertake research designed to verify predictions of the effect of Syncrude's planned SO_2 emissions on ground level air quality in the Athabasca Tar Sands. This monograph consists of MEP's final report to Syncrude describing research undertaken in 1974 and 1975.

It is Syncrude's policy to publish its consultants' final reports as they are received, withholding only proprietary technical information or that of a financial nature. Because we do not necessarily base our decisions on just one consultants' opinion, recommendations found in the text should not be construed as commitments to action by Syncrude.

Syncrude Canada Ltd. welcomes public and scientific interest in its environmental activities. Please address any questions or comments to Syncrude Environmental Affairs, Box 5790, EDMONTON, Alberta, T6C 4G3.

SUMMARY

This predictive study is based on the results of the first year of data collection respecting the meteorological factors that may influence the dispersion of atmospheric emissions in and through the air over the Athabasca Tar Sands region executed by MEP under contract to Shell Canada Ltd., Syncrude Canada Ltd., Home Oil Company Ltd., and Petrofina Canada Ltd. The initial objectives of that study were:

1. To obtain a representative sample of wind and temperature data for the Tar Sands region for a period of one year.
2. To determine the frequency of occurrence of various atmospheric dispersion phenomena insofar as these can be inferred from temperature and wind data.
3. To predict the air quality which would have been associated with the observed dispersion conditions if particular sources of emission of effluents into the atmosphere had been present in the area.

Routine daily soundings of the atmosphere began late September, 1974 at the Shell Canada lease (Lease C-13), and in February, 1975 at the Syncrude Canada lease (Lease C-17). Intensive field studies in February and August 1975 provided additional information regarding detailed regional variations of the meteorological variables which control dispersion.

The data were analyzed with particular emphasis on nocturnal inversion depths, mixing heights, wind and vertical temperature gradients in the plume layer.

The nocturnal inversion, which occurred on most mornings of the study year, extended to higher levels and lasted longer in fall and winter than in spring and summer. The median value of the afternoon mixing height was 200 metres in winter and in excess of 1000 metres in summer. There were far more cases of turbulent mixing under a stable lid in summer than in winter. When this condition (limited mixing) did occur, it generally covered the entire region.

On most mornings, the plume layer was stable, and stability was greater in winter than during the summer. In the afternoons, the plume layer had a neutral lapse rate on most days of the year; the remaining days had largely unstable lapse rates in summer and stable lapse rates in winter.

The mean wind speed in the estimated plume layer was near 6 metres per second; it was found to be invariable from morning to afternoon and from summer to winter. Very low and very high wind speeds were infrequent. In the plume layer, the wind blew predominantly from the southwest, during summer and fall. In winter, the wind directions were equally distributed over every octant except easterly. In spring, winds tended to be either northerly or southerly, the latter direction being reinforced by the drainage effect.

Regional variations in the profiles of wind and temperature were most pronounced in the lowest levels of the atmosphere. Differential heating and cooling and topographic influences produced local flow patterns; these were observed during the field study periods.

During the spring and summer months mean daily maximum surface temperatures were higher within the valley than on the higher terrain. At night, the highest temperatures were also measured in the valley, near Tar Island.

Perusal of surface data collected at Mildred Lake (Lease C-17) during the past five years indicates that the winter months of the year on which this study reports were atypically warm. It is probable that more surface-based inversions would occur during a colder winter.

The theoretical predictions of air quality were obtained through the use of a mathematical dispersion model. Essentially a Gaussian model, it also incorporates state of the art features such as limited mixing, curved plume trajectories, spatial variation of wind, independent choice of plume width and thickness, topographic effects, and inversion break-up. For each day covered by the study, the observed temperature and wind profiles were used to select the appropriate input parameters to the model.

For all hypothetical cases and conditions relating to a neutral or stable state of the lower atmosphere analyzed in this study, the sulphur dioxide ground concentrations were predicted to fall well below the design objective set for Syncrude in 1973 by the Government of Alberta. This design objective of not exceeding a calculated one-half hour average ground level concentration of 0.06 ppm of sulphur dioxide under neutral conditions appears fully met in that the concentrations are now predicted not to exceed 0.02 ppm under the stated conditions.

Dispersion predictions for some cases of a stratified lower atmosphere revealed however, that limited mixing and inversion break-up conditions could be so extreme as to lead to the prediction of somewhat less than 100% compliance with the Clean Air Regulations (Alberta) which were proclaimed on August 6, 1975.

This theoretical study, which yet requires verification under actual plant operating conditions concludes that the groundlevel concentrations of SO_2 attending the operation of the Syncrude 600 ft. stack will be lower than 0.2 ppm 99.3% of the time for a predicted actual emission rate of 2018 grams per second. For the permitted emission rate of 3363 grams per second, compliance is predicted to be 98.6%.

The small number of cases for which the concentration was predicted to exceed 0.2 ppm were mostly associated with inversion breakups. These fumigations are predicted to be much more frequent in summer and spring than in winter. Although inversions in the plume layer are more intense and more frequent in winter, daytime turbulence seldom reaches to the level of the plume. These fumigations were estimated to last about one half hour on the average and to affect only a small area.

Limited mixing fumigations would affect a larger area and persist for a longer period (typically three hours) but they are predicted to be very infrequent - only on three days for the emission rate specified on the Permit to Construct issued to Syncrude in 1973.

Definite verification of the above predictions will only be accomplished with actual air quality measurements under normal plant operating conditions. Although the reliability of the predictions is constantly improving as atmospheric sounding work continues, the data base for this study covers only one year and the predictions contained in this report, while resulting from conservative interpretations, are not considered definite.

The MEP staff members who took part in the Prediction Study were:

Mory S. Hirt B.Sc. President

Mr. Hirt has extensive experience in meteorology both in government and in the private sector. He is a contributor to many publications dealing with air pollution and is an active member of the Meteorological Committee of the Air Pollution Control Association. During the period 1967-1972, while in the employ of the Government of Canada, he developed research procedures and measuring techniques to establish a better understanding of the relationship between meteorological controls and air quality. Many of these techniques and procedures are still being used as a basis for research by the Air Quality Research Branch of the Federal Department of the Environment.

Joel Kurtz, M.Sc.

Prior to joining the MEP Company, Mr. Kurtz was employed as a Meteorologist for the Government of Canada, and more recently with the Air Research Division for the Province of Ontario. He has had experience in diffusion modelling, operational forecasting for Supplemental control systems, and field programs in air pollution meteorology. Mr. Kurtz Supervised the Tar Sands Prediction Air Quality study during 1974 and 1975.

William Murray, Ph. D.

Dr. Murray who was responsible for preparation of this report is the new manager for the Tar Sands Study. Dr. Murray has experience as an operational weather forecaster with the Government of Canada, and as a researcher in Cloud Physics. More recently he has been involved in environmental impact reports on the effects of plume dispersion on air quality for industrial sources at many locations in Canada and abroad.

Boris Weisman, Ph. D.

Dr. Weisman created the dispersion model which is the basis of this predictive study. His background in Theoretical Physics has been invaluable in his principal activity with MEP, the development of practical physical models of atmospheric dispersion.

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available upon request from Syncrude Canada Ltd.,
Environmental Affairs Department, P.O. Box 5790,
Edmonton, Alberta, T6C 4G3

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I INTRODUCTION

An atmospheric sounding program was initiated in the Athabasca Tar Sands by the MEP Company in September, 1974. The program was designed to produce a dispersion climatology of the area. It would be used to determine air quality effects of the atmospheric emissions on which the environmental design of the Syncrude Plant was based, and would be applied to the environmental evaluation of stack design parameters for extraction plants proposed to be constructed at that time by Shell, Home, and Petrofina, also lease-holders in the Tar Sands. This four-company dispersion climatology study was coordinated by Mr. Ralph Gorby, Staff Engineer, Shell Canada Limited.

Two minisonde release stations were established to carry out atmospheric soundings. The C-13 (Shell) station began operating in late September, 1974, while the C-17 (Syncrude) station commenced releases in February, 1975. Vertical profiles of temperature and wind were obtained for the early morning and mid-afternoon at each station, and used to generate seasonal statistics for meteorological factors that influence dispersion.

During the winter, and the summer, intensive field studies were carried out by a MEP crew and staff of the four Tar Sands lease-holders that jointly fund this study. These periods of intensive study were required to explore the regional variations in the meteorological factors and to calibrate balloon ascent rates at the C-13 and C-17 stations.

This report presents the dispersion statistics derived from the twelve month period of observation encompassed by the study.

It is possible to formulate a qualitative assessment of potential air quality resulting from the dispersion climatology. In winter, the early morning plumes are likely to be contained within a stable layer. As the day progresses, a turbulent layer normally grows from the ground to a height sufficient to entrain emissions from low level sources, but too low to entrain high level emissions. However, in those few cases when the turbulent layer does reach the plume, it probably remains near the critical level - the critical mixing height. In spring and summer, the early morning plumes are less likely to be contained within a stable layer. If they are trapped, however, they have a high probability of fumigating to the ground upon inversion breakup. Also, limited mixing will be common though the lid is usually high and the ventilation substantial. The channeling effect of the Athabasca Valley implies that if dispersion factors induce a reduction of air quality, a north-south corridor centered on the source will experience this more frequently than areas to the east and to the west of the source.

A qualitative analysis is useful in providing a generalized description of the dispersive character of the region independent of any particular sources of emission. The analysis is universal in that it can apply to

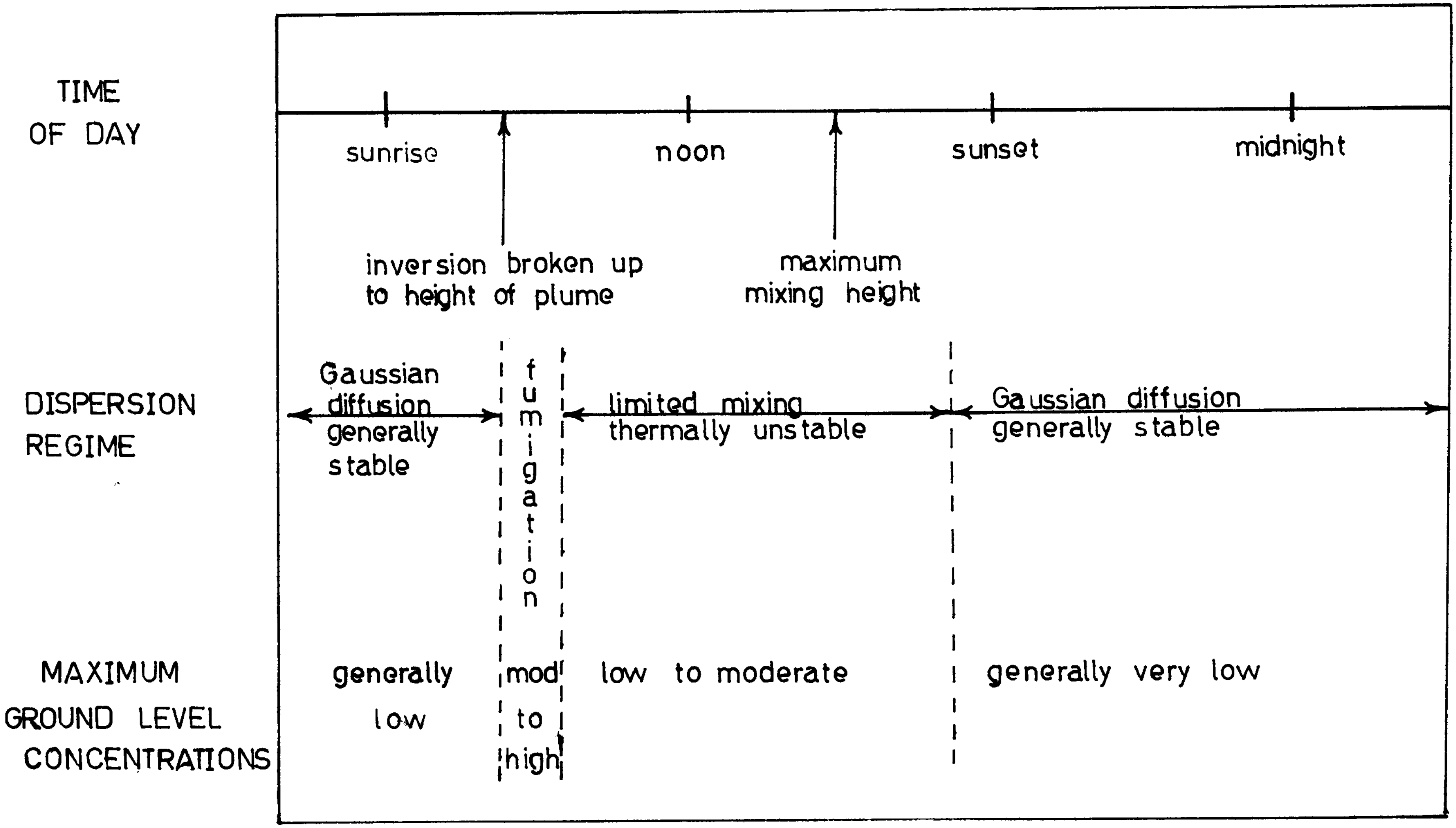


Figure 1 Generalized diurnal cycle of dispersion regime and related ground level air quality (no topographic obstacles)

any type of Tar Sands operation. In Chapter IX the air quality assessment is quantified and applied to the specific emission source to lay the basis for the identification of plant operation strategies that might enhance the compliance with air quality standards for atmospheric conditions not foreseen when approval of the environmental design of the Syncrude Mildred Lake Plant was given in 1973.

Meteorological data, obtained from atmospheric soundings during the study year, were input to a regional model which estimates ground level concentrations that might have resulted had emissions occurred during the study year. The regional model assumes the generalized diurnal cycle of dispersion regime which is summarized schematically in Figure 1. The Figure is idealized; the precise sequence of events depends on the meteorology. A day with overcast skies and strong winds, for example, may exhibit Gaussian diffusion under neutral atmospheric stability for the entire 24 hour period.

Fumigation and limited mixing cases were investigated in detail; these may produce significant ground level concentrations. Gaussian diffusion under stable atmospheric conditions is predicted not to produce ground level concentrations in excess of the air quality standards of Alberta.

The primary meteorological controls on air quality are lapse rate, wind speed and mixing height. The combination of a stable lapse rate in the plume layer, a low wind speed, and the existence of a turbulent layer between the ground and the plume commonly produces measurable ground concentrations of emissions. The theoretical frequency of this type of occurrence (based on the one-year study period) is reported in the statistics. If an inversion breakup should occur, the higher ground concentrations are associated with lower wind velocities. The theoretical frequency of this type of occurrence is also reported.

The reader should bear in mind that air quality predictions reported here are based on simulations produced by a mathematical model. Though some measure of practical verification has been obtained from the G.C.O.S. operation, the topography and emission parameters associated with the Syncrude project are sufficiently different from G.C.O.S. to require a separate validation. This must be done under actual operating conditions before the current dispersion model can be accepted as valid in the scientific sense.

G.C.O.S. did not participate in the four-company dispersion climatology on which the ex-post-facto evaluation of the Syncrude plant design is based.

The topographic location of the G.C.O.S. plant is so different from the Syncrude locale that modelling of the dispersion of G.C.O.S. emissions would have required the operation of a minisonde release station in the valley proper of the Athabasca River during the year of meteorological observations on which this report is based.

Neither the C-17 nor the C-13 atmospheric soundings provide sufficient information respecting the state of the lower atmosphere over the Athabasca Valley proper through which the G.C.O.S. emissions often appear to be dispersed. An analysis of the dispersion of G.C.O.S. emissions using the methodology applied to the Syncrude plant could not be undertaken without leaving substantial doubts respecting the reliability of the results. The present study reports the predicted incremental effect of the addition of the Syncrude plant over the air quality baseline state as conditioned by the operation of the G.C.O.S. plant.

An evaluation of the combined effect of the two plants on the regional quality of the air will have to await the completion of studies currently underway in the structure of the Alberta Oil Sands Environmental Study Program.

II TOPOGRAPHY

Figure 2 shows the topography of the study area. The locations of three proposed plant sites, the present G.C.O.S. plant, the Syncrude plant currently under construction, and the nearby forestry and climatological stations are indicated on the map.

The study region centres on Fort MacKay, circa 55 km north of Fort McMurray. The Shell, Home and Petrofina sites lie east of the Athabasca River, while Syncrude is to its west. The G.C.O.S. plant is situated within the actual river valley (Figure 3) and at a lower elevation than the other projects.

The Athabasca flows from south to north at an elevation of circa 230 metres above mean sea level. Its valley has a bowl shape with slopes steeper in the south than in the north. At the latitude of the Shell site, the land rises gently to the east to a height of 380 metres at a distance of 30 km while to the west it rises more rapidly to a height of 460 metres at a distance of 30 km. At the latitude of the Syncrude and G.C.O.S. plants, the land rises much more rapidly to the east to an elevation of 520 metres at 25 km distance. To the west the rise is similar to that found further north (Figure 3).

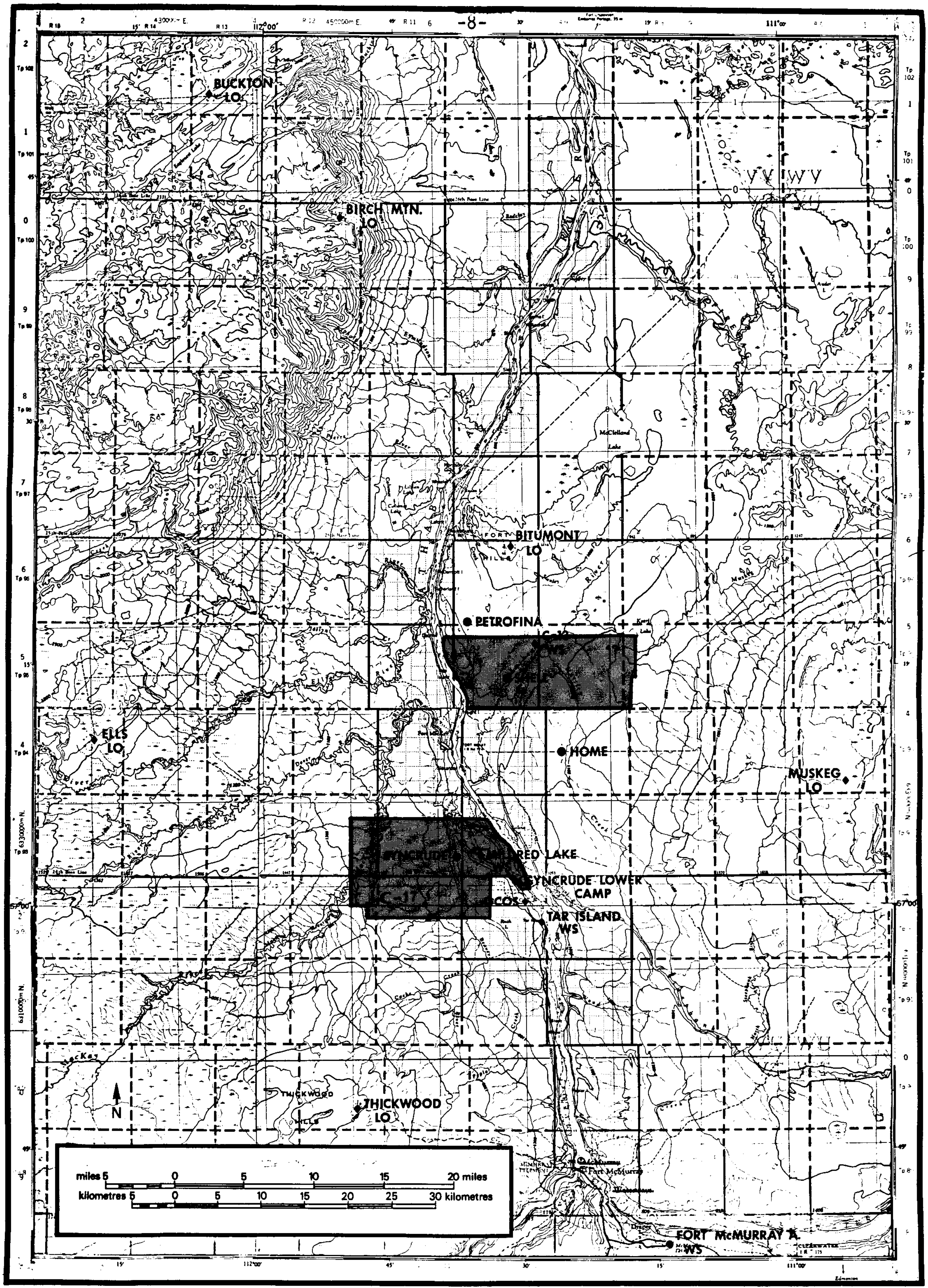


Figure 2 Topographic map of the study area showing the location of 4 proposed plant sites (●) and the climate, forestry lookout, synoptic and supplementary stations supplying meteorological data (◆). Weather stations - WS; forestry lookout towers - LO.

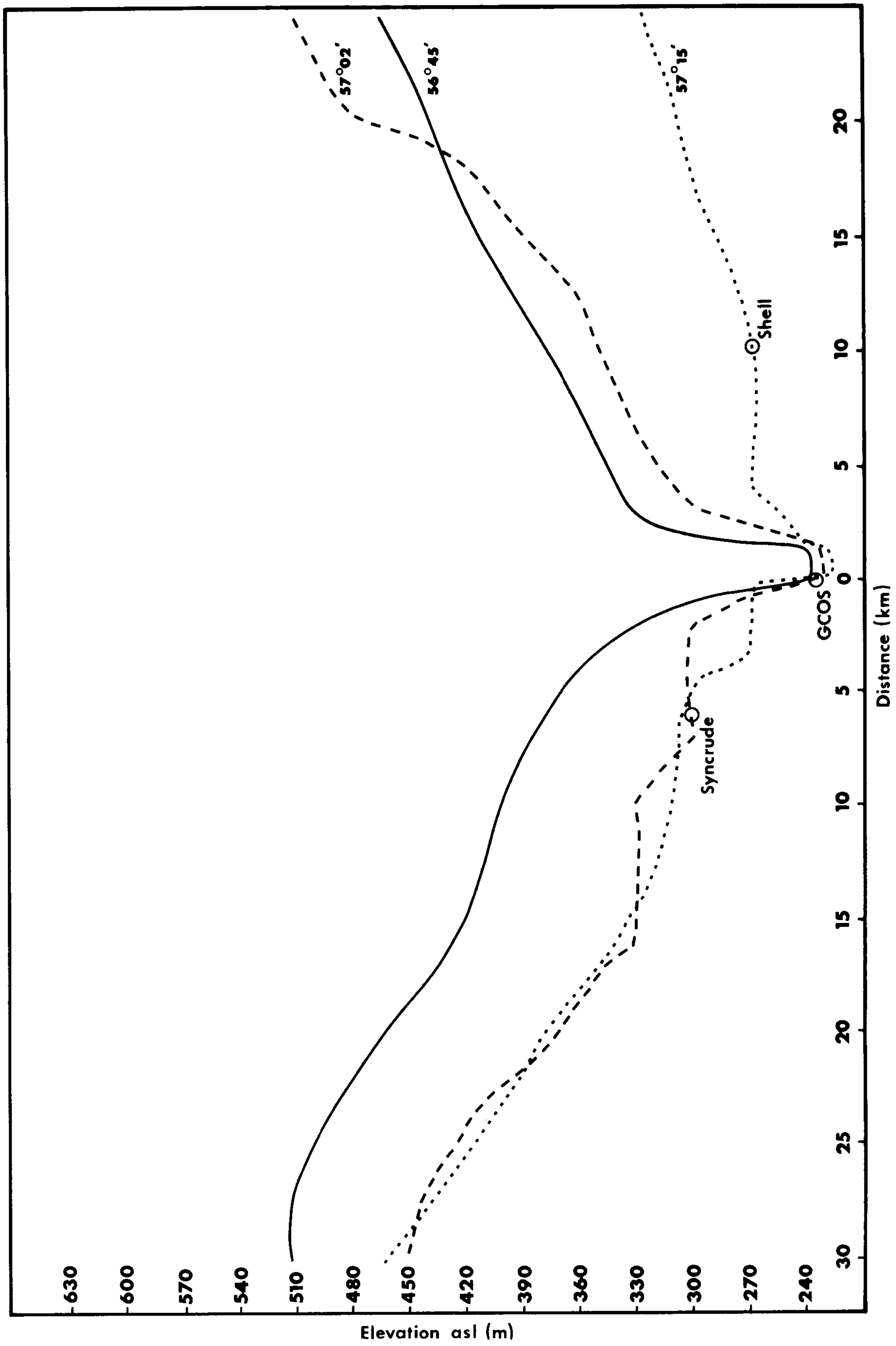


Figure 3 Three east-west topographic cross-sections centered on the Athabasca River demonstrate the change in valley configuration with changing latitude. The solid, dashed and dotted sections are progressively further north respectively at the indicated latitudes.

A number of smaller river valleys are also cut into the landscape. The deepest (circa 60 m) is that of the MacKay River, which joins the Athabasca at Fort MacKay.

McLelland (circa 40 km^2) and Kearl (circa 15 km^2) Lakes are the major bodies of standing water in the study area (Figure 2). All drainage of the study area is tributary to the Athabasca River. On the average, this river freezes over on November 2nd and break-up occurs on April 21st.

The mesoclimatic phenomena and the associated dispersion characteristics, which are the subject of this report, are largely controlled by the local topography.

III CLIMATOLOGY

1. Introduction

The macroscale climate is controlled by the solar heat input (i.e. latitude and season) and by the uneven distribution of continents and oceans. These factors, along with the further influence of mountain barriers and ocean currents, create low and high pressure cells that control the flow of air and result in the formation of air masses. Air masses are large bodies of air which have common temperature and humidity characteristics throughout and range in areal extent from that of a province to that of half a continent. The movement of the air masses and their collisions result in large scale weather patterns which are described in terms of temperature, pressure, humidity, precipitation, wind speed and direction, etc. Statistics gathered over a period of 20 years can describe the macroclimate of a region. These statistics are based on weather observations made at widely spaced stations; they apply to areas as large as an average province.

Local variability of the climate is not described by the macroclimate. The influence of a range of hills, a river valley or geographic concentration of industrial activity can only be determined from observations made on a more closely spaced grid of measurement stations. Mesoclimatic statistics describe such situations.

2. Macroscale Climatology

Only a summary of the macroclimate of northern Alberta is included in this report. Several references provide additional detail [1,2].

Air Masses

The Athabasca River Valley is influenced by three separate air masses; the continental Arctic, the maritime Pacific and infrequently the maritime Tropical. The continental Arctic air mass originates over the giant land mass to the north and is dry, stable and cold. Maritime Pacific air originates from over the waters of the Pacific and is moist and unstable giving rise to rain and thunderstorms. Less frequently, the maritime Tropical air mass penetrates into the Athabasca Valley from the direction of the Gulf of Mexico producing hot, humid and moderately unstable weather.

Winter

During the winter, northern Alberta is dominated by cold continental Arctic air. Occasionally, the weather is modified by the intrusion of somewhat milder maritime Pacific air. The Arctic air produces clear skies, very low temperatures, and light winds. Once this air mass has moved into a region it is very difficult to dislodge.

The dispersion characteristics of Arctic air are largely determined by the strong and deep nocturnal inversions, which result from radiative cooling of the ground. During the winter, these inversions can persist for several days at a time.

In general, the winter Arctic air mass is conducive to air quality at ground level if emission sources are elevated. Plumes emitted from high stacks into an inversion undergo very little vertical dispersion and travel long distances without reaching the ground. Exceptions would occur over terrain which rises sufficiently above the stack tops to meet the plumes at some downwind distance.

The inversion can be broken up by heating of the surface, which is a slow, ineffective process during the winter. In this case, a shallow ground-based, turbulent layer of air is formed in which rapid vertical movements produce a thorough mixing. Pollutants emitted into this layer are mixed through it, resulting in an increase in ground level concentrations. During this season, only the pollutants from low-level sources such as automobiles, residential chimneys of apartment buildings and short industrial stacks commonly contribute to the reduction of air quality under circumstances of shallow limited mixing.

Summer

Maritime Pacific air dominates the area during the summer months. Its characteristics imply a potential for higher ground level concentrations of pollutants from elevated sources. As this air mass subsides over the eastern slopes of the Rockies, it warms, giving rise to a subsidence inversion which will lower as the air mass persists over the region. With light winds and a relatively low limit to vertical mixing as controlled by the subsidence inversion, the dispersive capability is limited; the probability of occurrence of elevated ground level concentrations is thus enhanced.

Unlike the winter inversion, the nocturnal inversions of summer are commonly broken up by surface heating. The inversion break-up brings effluents, previously emitted into the inversion layer, to the ground, causing a fumigation episode[9].

3. Mesoscale Climatology

When skies are cloudy, there is little differential heating and local temperature gradients are weak. The mesoscale flow patterns, controlled by temperature differences, are weak as well.

When skies are clear, as when a high pressure system dominates the area, differential heating across the region creates horizontal temperature gradients. For example, in a valley where one slope is heated more strongly than the other, circulations as shown in Figure 4 can be established. The warm air on the heated slope rises by day as an upslope valley wind. At night, the slope is rapidly cooled, and a downslope mountain wind can result. Around mid-day, when solar heating is intense, the valley floor is hotter, by virtue of its lower elevation, than the higher ground. This produces local differences in dispersion characteristics. The higher temperatures induce higher mixing heights over the valley (see Figure 7). Thus, greater dilution of emissions and lower ground concentrations result.

At night under clear skies, the ground radiates heat into space.

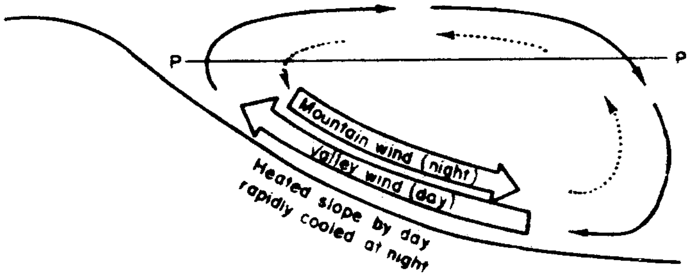


Figure 4 Circulation patterns arising from differential heating in a valley

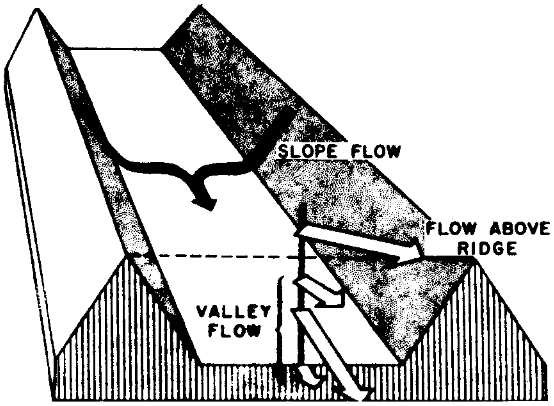


Figure 5 Idealized representation of the circulation that might be expected in a typical valley on a clear night

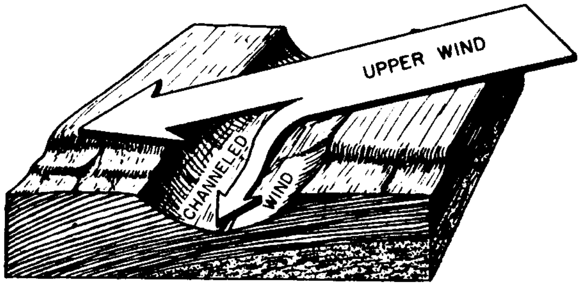


Figure 6 Channeling of the wind by a valley

The air near the ground becomes cooler, thus heavier, and flows downslope and downvalley (Figure 5). Nocturnal radiative cooling could lead to the establishment of a temperature inversion; the accumulation of cold air commonly makes the inversion deeper and more intense over the valley floor than at higher elevations (Figure 8). Emissions originating from sources at lower elevations in the valley are more likely to be contained within the inversion and may contribute to a rise in ground concentrations of pollutants, should the inversion be broken up. However, sufficiently buoyant emissions from a high stack at a higher elevation may rise above the inversion and escape entrapment; no fumigation would then occur upon breakup of the inversion.

Quite independent of valley effects associated with differential heating, there often occurs a topographic channeling of the synoptic wind along the line of the valley. The channeling effect is most pronounced in the lowest levels of the atmosphere where winds may vary markedly from the upper wind (Figure 6). For this study, surface winds have been obtained from 12 metre towers and the upper winds have been determined by balloon techniques.

Finally, the water temperature of the Athabasca River may affect the local circulation patterns, particularly when the upper winds are light. During the day, cool air from over the water may move inland to replace the rising warmer air over the land. The circulation may then be completed by a return flow of warm air at high levels.

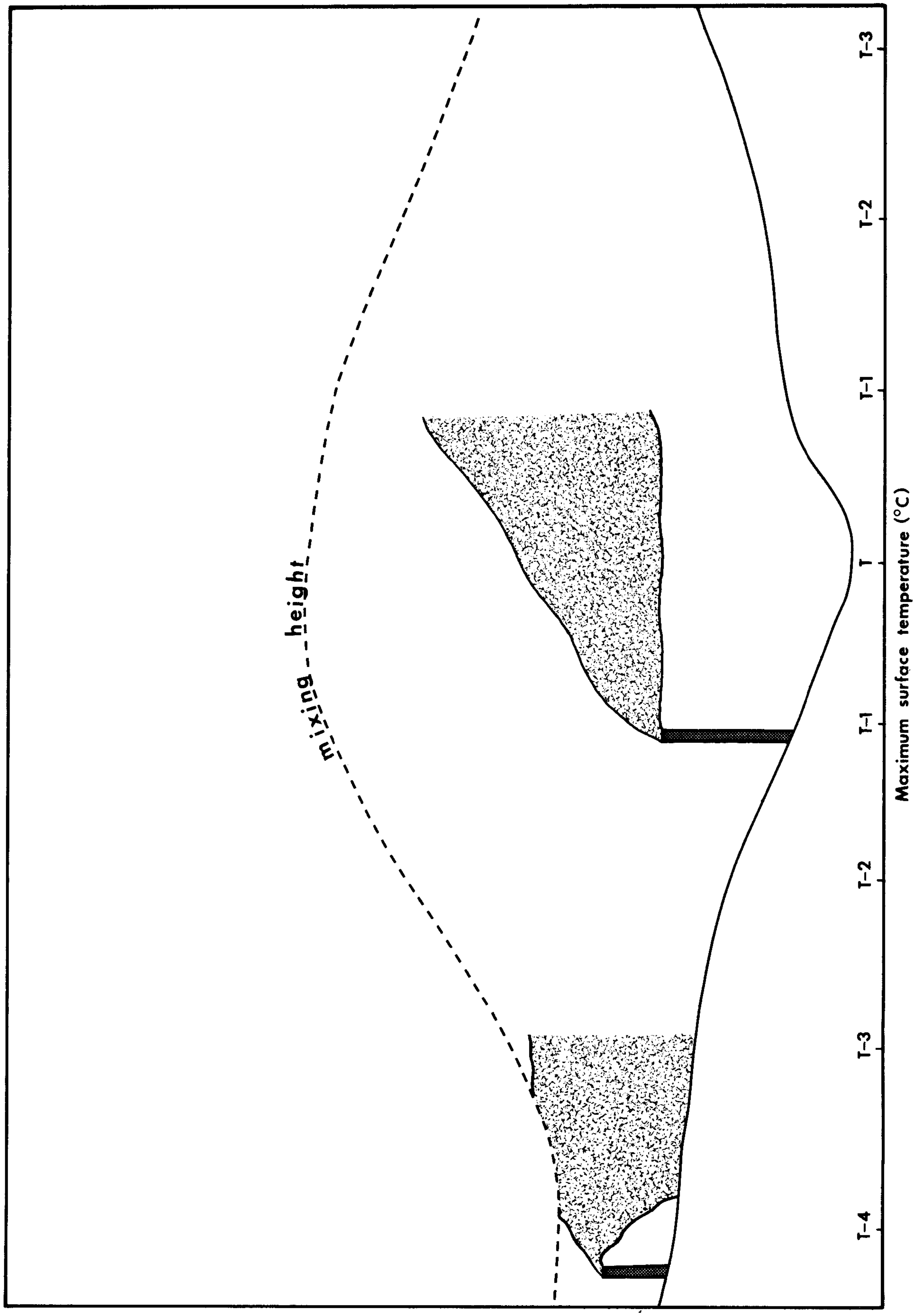


Figure 7 The variation of mixing height across a typical broad, smooth valley. Dashed line indicates mixing height. Greater vertical mixing occurs near the valley bottom because of greater mixing height.

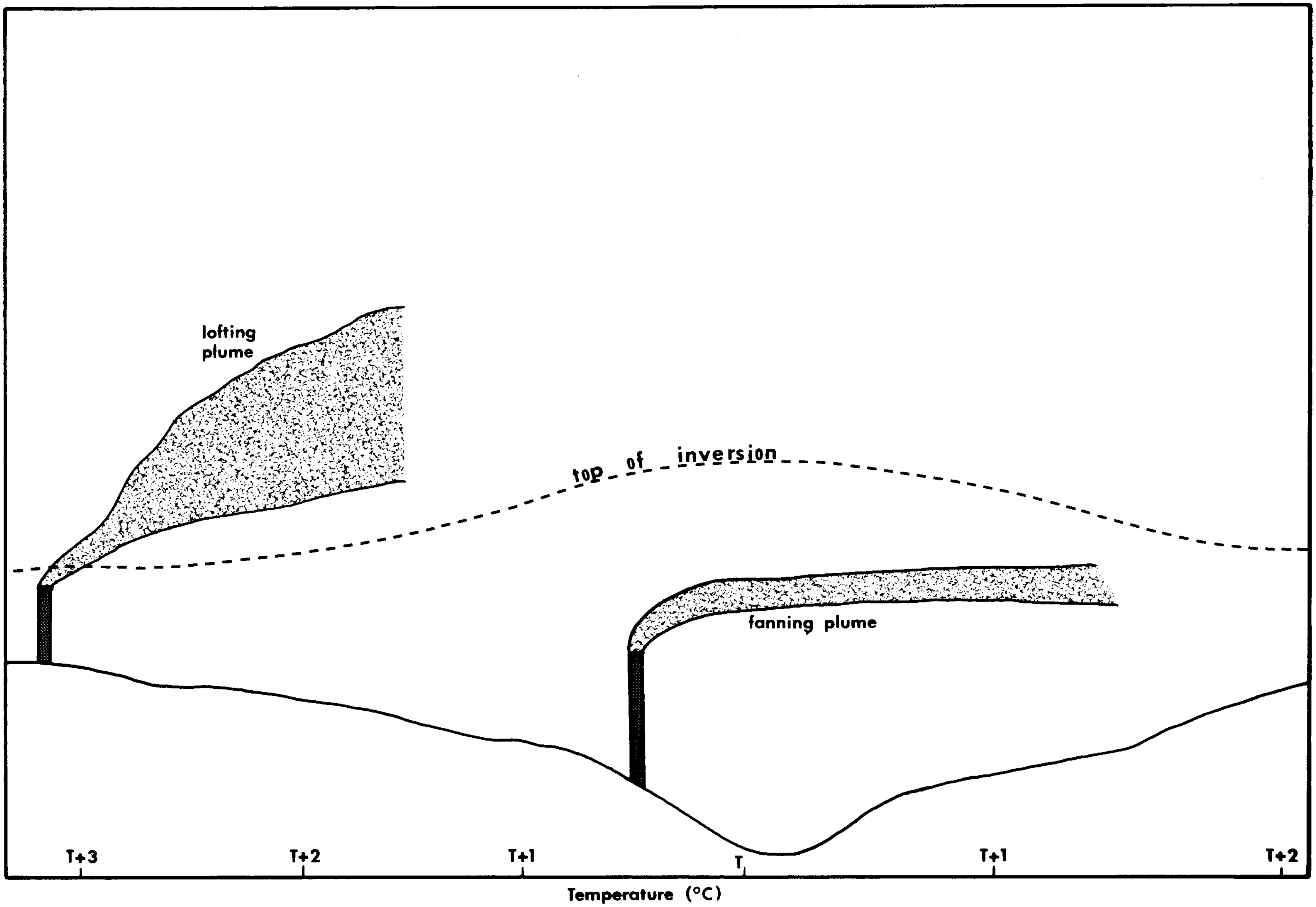


Figure 8 Schematic diagram of the variation of the height of the nocturnal inversion over a wide valley with gentle sideslope

At night, when the land is cooler than the water, the process is reversed with the establishment of a land to water flow at low levels. Although such circulations are normally associated with large bodies of water, broad rivers can generate similar circulations, though they are more localized and weaker. As an example, Klassen[3] found that slope winds in the valley at Edmonton drained down to the river edge, then began to rise in a two-cell fashion.

4. Sources of Climatic Data

The stations from which meteorological and climatic data were obtained for this study are depicted in Figure 2. They include the climatological stations (temperature and precipitation) at Mildred Lake (operated by Syncrude Canada Limited) and Tar Island (operated by G.C.O.S.), the synoptic station (hourly meteorological observations) at Fort McMurray, the Forest Lookout stations (temperature and precipitation in the summer months only), and the supplemental stations at C-13 (Shell) and C-17 (Syncrude). Both supplemental stations have 12 metre instrumented towers for wind measurements, and instrumentation for temperature, humidity, precipitation, pressure and sunshine measurements.

IV REVIEW OF METEOROLOGICAL PARAMETERS AFFECTING THE DISPERSION CHARACTERISTICS OF THE ATMOSPHERE

The dispersion potential of the lower atmosphere is controlled by the vertical distribution of air temperature and air movements, i.e. by the temperature and the wind profile. The temperature at a particular level above the surface is not significant by itself; the change of temperature versus height, or the temperature lapse rate, determines whether the atmosphere is stable, neutral, or unstable. These three terms distinguish between three basic states of the atmosphere. In a stable atmosphere, a parcel of air, if moved upward by whatever cause, has a tendency to return to its former level. In a neutral atmosphere such a parcel has a tendency to stay at the level to which it was raised. In an unstable atmosphere, however, the parcel once set into motion will continue moving in the direction of the displacement.

Any vertical motion of air parcels in the atmosphere will trigger compensating motions in the opposite direction. In an unstable atmosphere, a downward movement of air parcels occurs in response to rising thermals (or thermal air currents). The result is vertical mixing.

The capacity of the lower atmosphere to disperse pollutants is related to the lapse rate (or the decrease in temperature per unit of height, in C^{o} per 100 m). A temperature inversion exists when the lapse rate is negative, i.e. when the air temperature increases with height. A rapid decrease of temperature with height characterizes an unstable atmosphere.

As air rises, it cools and expands. Air that is not saturated with water vapour cools at a known constant rate of 0.98° C per 100 m of atmospheric rise. This lapse rate is commonly referred to as the neutral or dry adiabatic lapse rate.

If a parcel of air were lifted from the ground to any height in an atmosphere in which a dry adiabatic lapse rate exists, its temperature would be identical to that of the surrounding air at that elevation. That is, the parcel would be neither warmer nor colder than the surrounding air, and consequently it would neither rise nor fall due to a difference in density; it would behave neutrally.

Potential temperature [5] is a useful measure of stability. It is defined here as that temperature which an air parcel at any height would have if it were lowered to the ground in dry adiabatic fashion. In other words, an air parcel at height H with temperature T would have a potential temperature of $T+0.0098H$ since 0.0098 is the dry adiabatic lapse rate in units of C° per metre.

The potential temperature remains constant with height in a layer of neutral stability. When the potential temperature increases with height (potential temperature inversion), the atmospheric layer is stable. A decrease of potential temperature with height characterizes an unstable layer.

When the layer of atmosphere between the ground and a plume falls into the unstable category, emissions will be mixed down to the ground. When it falls into the stable category, vertical mixing is suppressed and emissions will not reach the ground in any significant concentration.

Figures 9 and 10 explain the relationship between lapse rate and stability in graphical fashion. The dry adiabatic lapse rate is shown on a plot of temperature versus height (Figure 9) and potential temperature versus height (Figure 10). As Figure 10 shows, any potential temperature lapse rate is unstable if it has a negative slope, and stable if it has a positive slope. A temperature at any height in the atmosphere can be converted to its equivalent potential temperature by following a neutral lapse rate line drawn through that graph point to the ground.*

Two typical temperature soundings of the lower atmosphere are shown in Figures 11 and 12. They are the morning and afternoon sounding results of February 8, 1975 obtained at C-13. The morning sounding shows a very stable lapse rate based at the ground. Emissions from the chimney depicted in Figure 11 would result in low ground level concentrations, if any. By late afternoon, however, an unstable lapse rate developed in the lowest layers due to surface heating (Figure 12). In this case mixing would occur from the ground to 280 metres (the elevation of the top of the turbulent layer) and result in measurable increases in ground level concentrations.

*The strict definition of potential temperature requires that the line extend to the 1000 millibar pressure surface rather than to the ground. For comparison purposes within a specific region however, it is more convenient to reference to ground level.

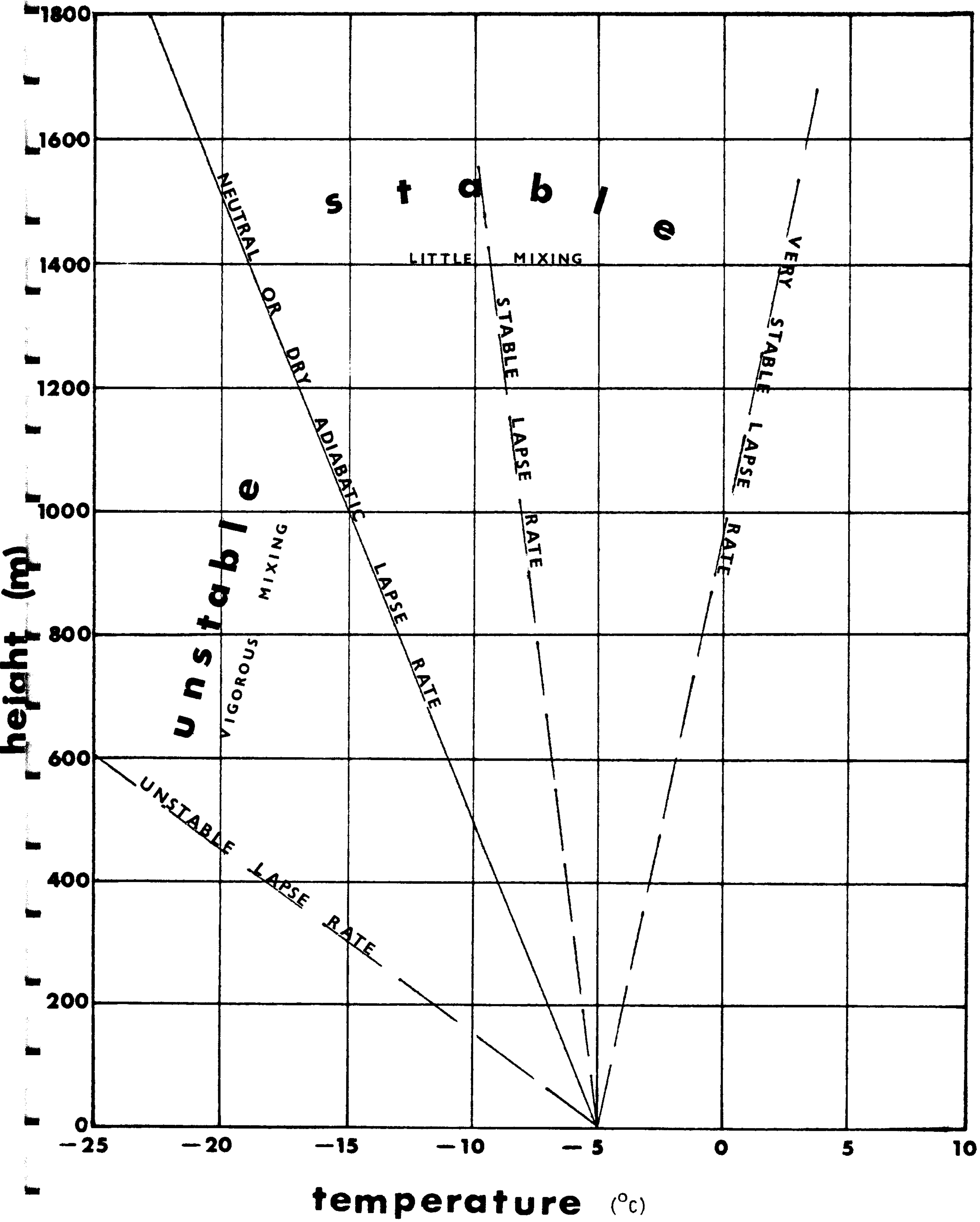


Figure 9. Atmospheric lapse rates and mixing on a plot of temperature vs height

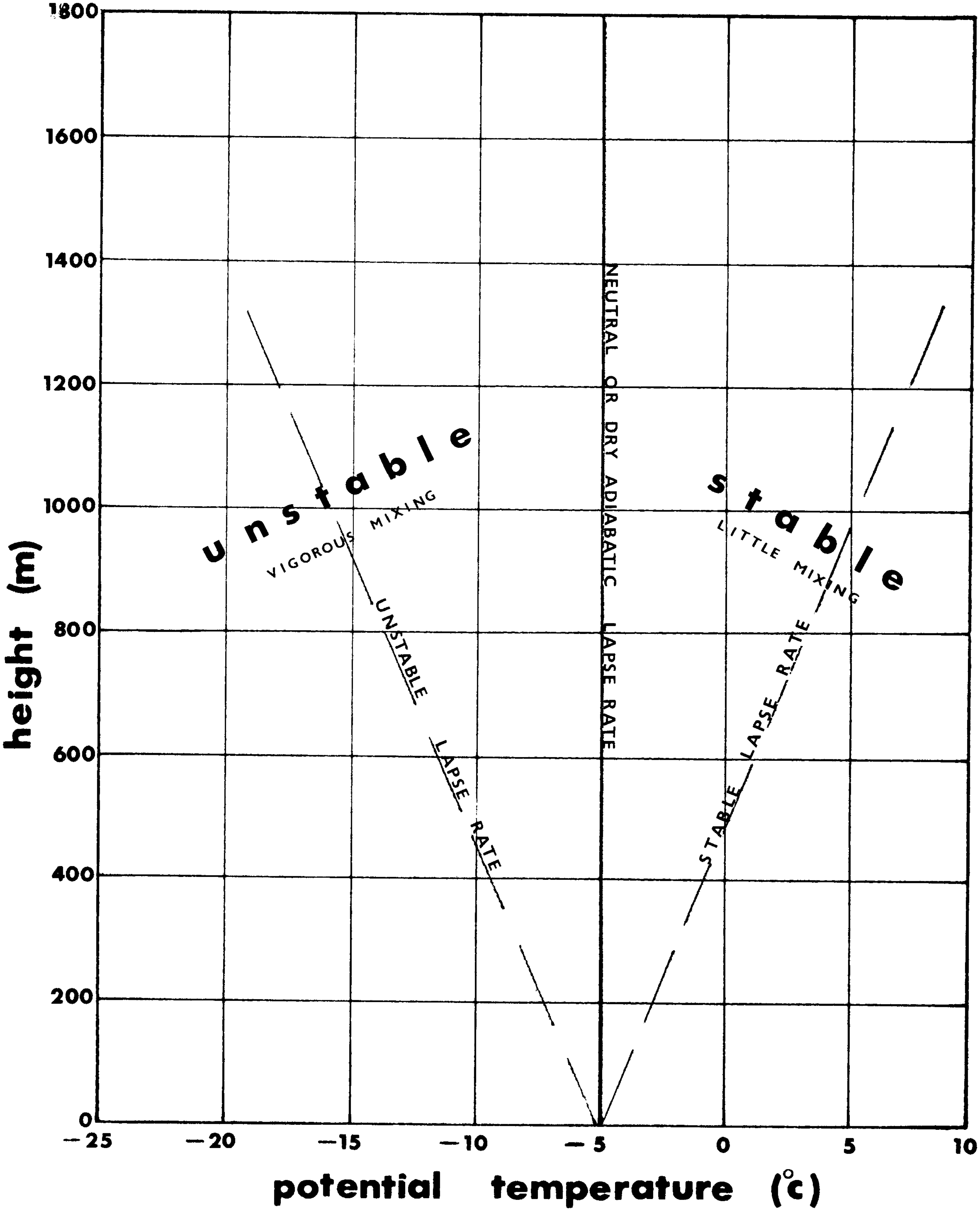


Figure 10 Atmospheric lapse rates and mixing on a plot of potential temperature vs height

Wind profiles are also shown in these Figures. The wind is portrayed as blowing in the direction along the wind arrow away from the barb; the bottom of the page would be south, the top north, etc. A northerly** wind blows in a downward direction and a westerly wind blows towards the right. Wind speeds are indicated by the barb on the wind arrow. A wind barb is 3-7 m/s and a large barb is 8-12 m/s. For example, the wind at 1300 metres in Figure 12 is from 300° at 13 m/s. The wind profiles demonstrate how winds in the Northern Hemisphere generally veer (swing in a clockwise sense) and increase in magnitude as height increases.

**The standard meteorological convention of labeling wind direction by the compass point from which the wind blows is followed.

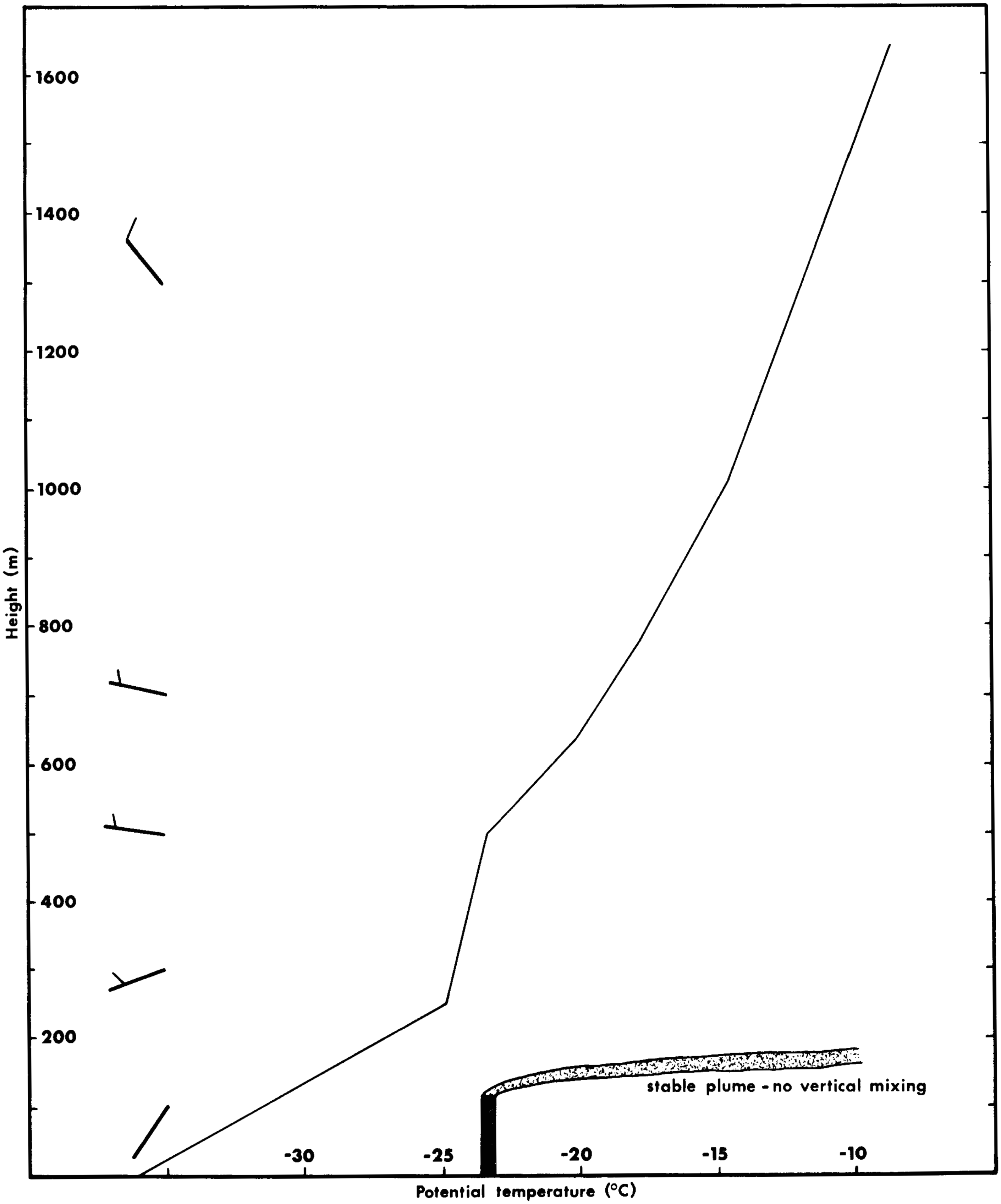


Figure 11 Variation of potential temperature with height: morning (0930) sounding at C-13 on February 8, 1975.

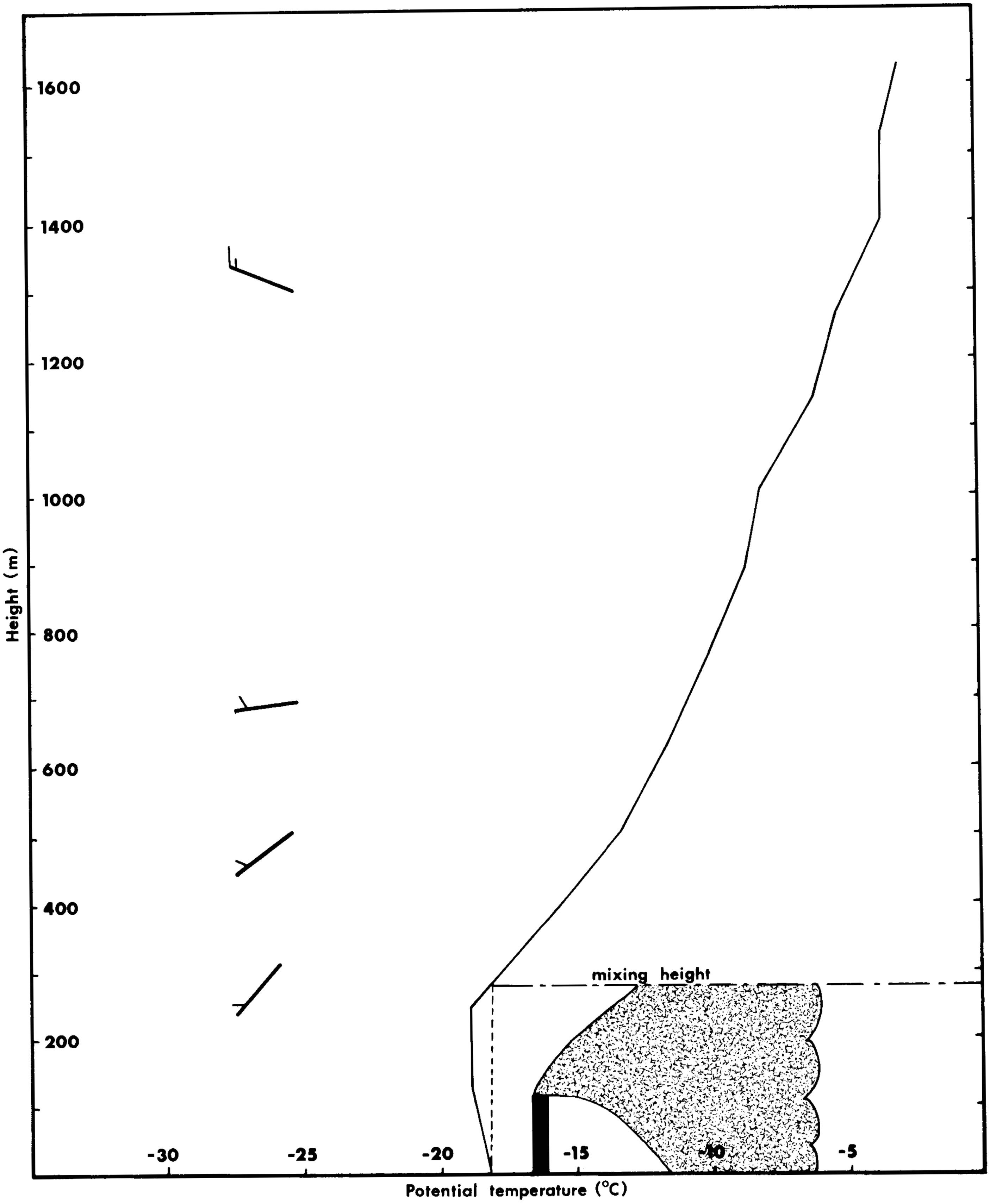


Figure 12 Variation of potential temperature with height: afternoon (1545) sounding at C-13 on February 8, 1975.

V DATA ACQUISITION

This section describes the sources of the data used in this report, namely:

(1) the daily minisonde release program;

and (2) the winter and summer field studies.

1) Daily Minisonde Release Program

The minisonde is a device consisting of a miniature radio transmitter with an instrument to measure temperature attached to it. It is sent aloft into the atmosphere in a small balloon so that recordings of observed temperature can be transmitted to the ground by means of radio signals. In the standard procedure for minisonde releases, a single balloon is inflated with helium to the appropriate lifting force and, with minisonde transmitter attached, the balloon is released and tracked by one man with a theodolite, a surveying instrument used to measure vertical and horizontal sighting angles while a second person operates the receiver/recorder. The data obtained by theodolite tracking of the balloon yield information on wind direction and speed at various altitudes. Whenever only one operator is available, two balloons are released separately. The first, a balloon without payload, is tracked by theodolite. The second balloon carries the minisonde transmitter aloft, and its transmissions are recorded by the same operator. In order to obtain the same rate of ascent for both balloons, more helium is used for the second release. Alternatively, different rates of ascent could be used in the temperature and wind computations. The theoretical relationship between the balloon lift and its ascent rate [6] is used to determine altitudes. For a more detailed discussion of the data collection procedures, see Appendix 1.

Once the release is completed, theodolite readings are transcribed from the cassette tape recorder, and voltages for computing temperature are read at appropriate intervals on the output voltage trace. These field data were sent to the MEP office in Calgary for checking, computer coding, key-punching and processing. The computer output comprises temperatures and winds at levels up to 2000 metres and derived quantities, such as mixing heights and lapse rates.

The Syncrude site, where meteorological data are collected, is shown in Figures 13,and 14.

2) Field Studies

The field studies had two objectives. They were designed to provide detailed information regarding the regional variations of the meteorological factors. And, equally important, a check on the calculated constant balloon ascent rates for the c-13 and c-17 (single theodolite) soundings had to be obtained to verify the accuracy of the data obtained from the daily soundings.

A. Winter Field Study

The winter field study comprise two periods. The first lasted from February 5-10, 1975 during which a three-man crew employed double theodolite tracking techniques. The second lasted from February 18-21, 1975, during which a two-man crew utilized single theodolite techniques.

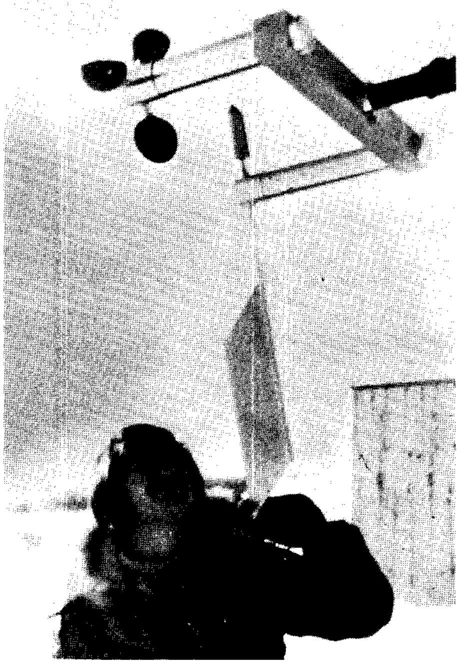


Figure 13 Technician reading meteorological instruments at Syncrude Camp.

Figure 14 Syncrude Meteorological station, fluid coker in background.

For double theodolite tracking of the balloon, two theodolites are set up along a baseline of known length. (Although a long baseline is preferable, it is not always practical, since there must be a clear line of sight from one theodolite to the other). From the two sets of simultaneous theodolite readings, wind speed and direction and the exact height of the balloon above the terrain at any point in time can be determined using vector analysis. Since the double theodolite tracking method allows one to dispense with the use of a calculated constant ascent rate, it permits a calibration of ascent rate assumptions used for single theodolite soundings.

Double theodolite work was performed at the proposed Petrofina stack location, the Shell (C-13) Camp and the Home Camp (Figure 2). Extremely cold weather during the first part of the field study incapacitated one of the theodolites for some time; several of the releases were thus carried out with one theodolite. The maximum baseline length which would (1) provide a clear line of sight between theodolites, and (2) not approach too close to the trees or other obstructions that could interfere with optical tracking of the balloon, was used in all cases.

During the second part of the winter field study, temperature and wind profiles were obtained at the Syncrude Lower Camp on the shore of the Athabasca River to probe the effect of the valley on the dispersion climatology of the area. A daily intensive release sequence was completed at the Home Camp during this part of the study.

In addition to the routine two minisonde releases per day carried out at C-13 and C-17, two extra releases were made during each day of the winter field study. At a third site (alternatively Petrofina, Home, or Syncrude Lower Camp) four daily releases were made during the study. These soundings were taken at sunrise, late morning, early afternoon and late afternoon.

3) Summer Field Study

The summer field study lasted from July 28 to August 8, 1975, and involved a three-man crew using double theodolite tracking techniques at three sites. Once again, the maximum possible baseline length was used.

Ideally, the summer sites would have been identical to those of the winter study. Due to access difficulties, other sites had to be selected on the Home and Petrofina Leases, however. The new sites were the Home Airstrip and the Fina Camp. Program results were not affected by this change, as no significant topographic differences exist between the summer and winter sites.

A photograph showing the sounding site at Syncrude lower camp during the summer field study is shown in Figure 15.

Figure 15 Technician releasing minisonde balloon.

IV RESULTS OF INTENSIVE FIELD STUDIES

1. Regional Variations

The mixing height parameter states the height above the ground of the upper boundary of the zone of vigorous turbulent mixing. For a plume that is trapped within a turbulent layer, lower mixing heights result in higher ground level concentrations of pollutants from an emission source operating at a constant rate.

The valley effect on mixing heights was determined to have been minimal during the winter field study period, presumably because near-surface temperature gradients are small when the ground is snow-covered. Mixing heights did not vary regionally, although some local effects could be demonstrated.

The region was found to have been homogeneous in daytime dispersive character during the summer field study period, some short-term variations excepted. On summer nights, however, local industrial activity is thought to have influenced temperatures demonstrably. This was particularly suggested by the C-17 and the Syncrude Lower Camp data, which show higher minimum temperatures than at the sites east of the Athabasca River.

At elevations greater than 200 metres above ground, the wind direction was the same at each site. Local low-level variations, however, are interpreted as reflecting the valley circulation patterns described in Section IV. In winter, the predominant valley circulation pattern was the downslope mountain wind which results from rapid cooling of the slopes. This often was associated with a drainage wind down the length of the valley. During summer, the daytime upslope flow predominated. Valley channeling was evident during summer and winter as demonstrated by stronger low-level winds measured at C-17 than at C-13. The valley is broader near the latter location (Figure 3).

2. Calibration of Single Theodolite Ascent Rates

Results obtained by single and double theodolite techniques are compared in Figure 16. In this Figure, a wind profile obtained by analysis of two sets of simultaneous theodolite readings (i.e. double theodolite method) is shown alongside a profile based on analysis of data from only one theodolite (i.e. single theodolite method). In the profiles, wind directions at a particular level in the first kilometre vary by at most 10° and the wind speeds differ by a maximum of 0.6 m/s.

The validity of the assumption of a constant ascent rate, which is required in the single theodolite determination, is examined in Figures 17, 18, and 19 where height of balloon is plotted against time from release for each of the double theodolite soundings of the summer field program. These curves have a generally constant slope which averages 170 metres per minute (see also Appendix 1).

The double theodolite technique is generally preferred for obtaining precise balloon positions. However, the additional precision was not warranted in this study in light of the increase in cost and the manner in which the data are employed (i.e. for establishing a climatology of the region). (For a detailed discussion of single theodolite precision, see Appendix 1).

The single theodolite technique should be augmented by an ascent rate calibration. The technique is based on the principle that the temperature profiles within a homogeneous airmass will agree at high elevations.

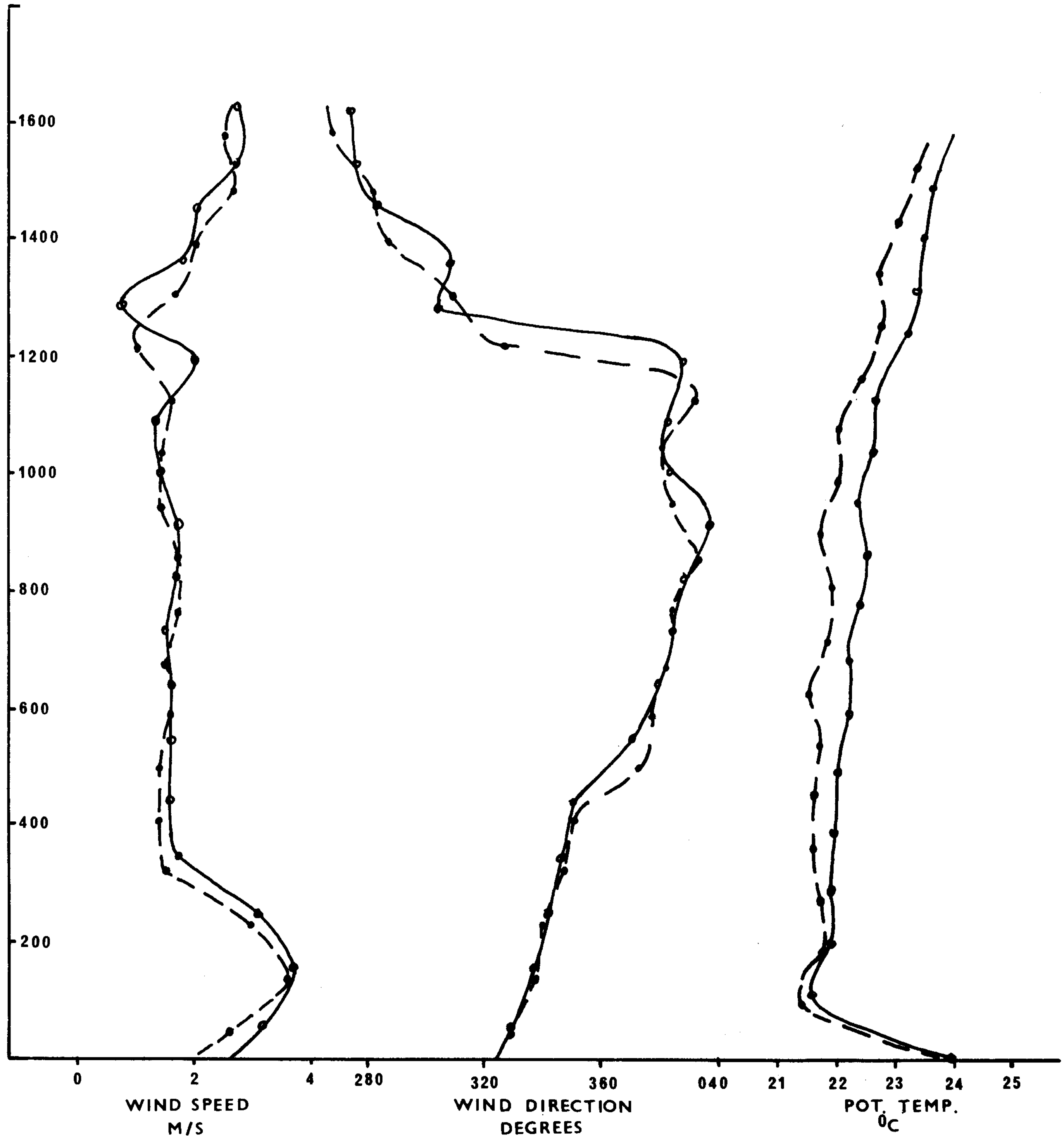


Figure 16 Single and Double Theodolite determinations for wind and temperature profiles.

——————— double theodolite
- - - - - - - single theodolite

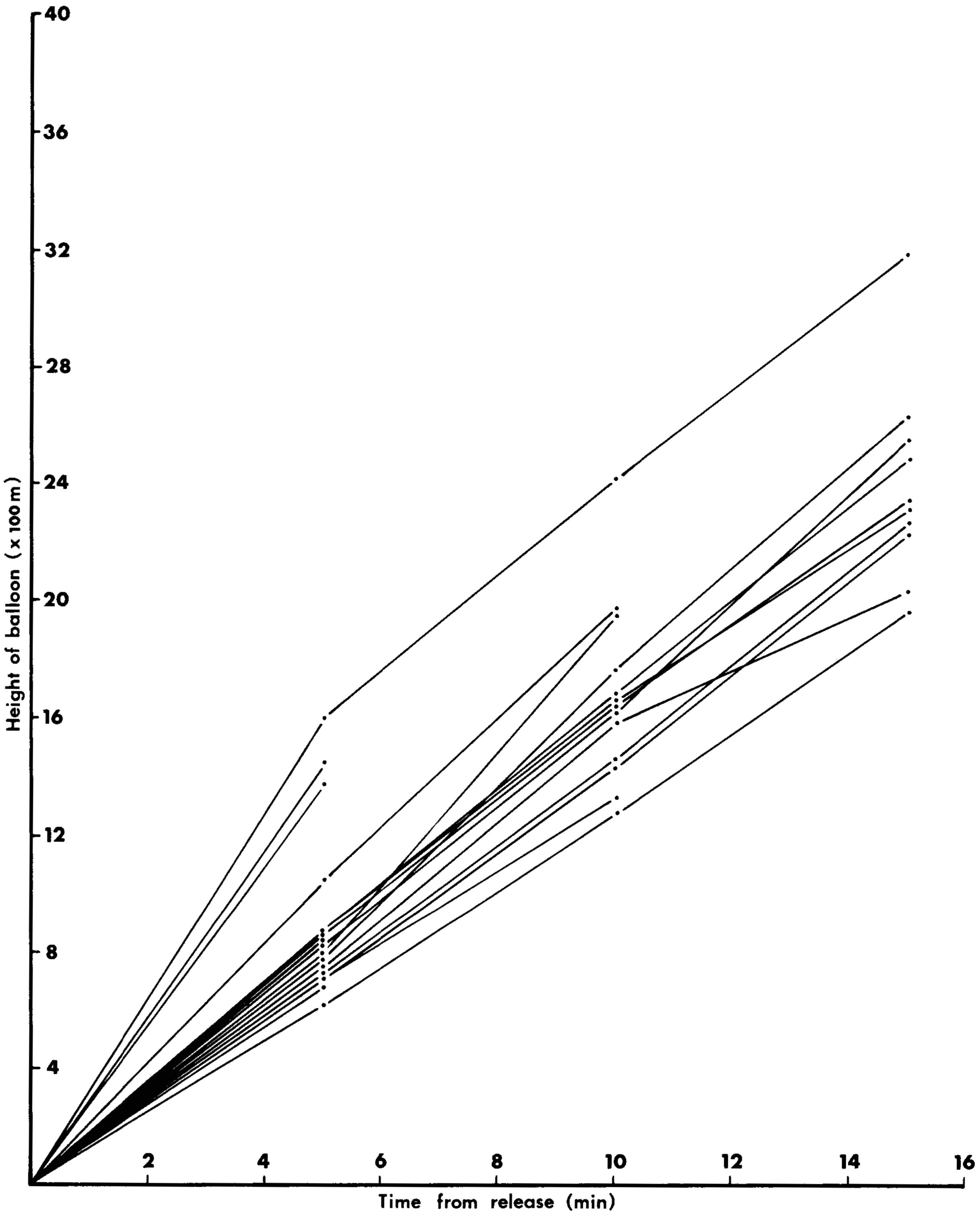


Figure 17 Height of balloon as a function of time from release (determined by double theodolite tracking) during the summer field program for the Home Airstrip

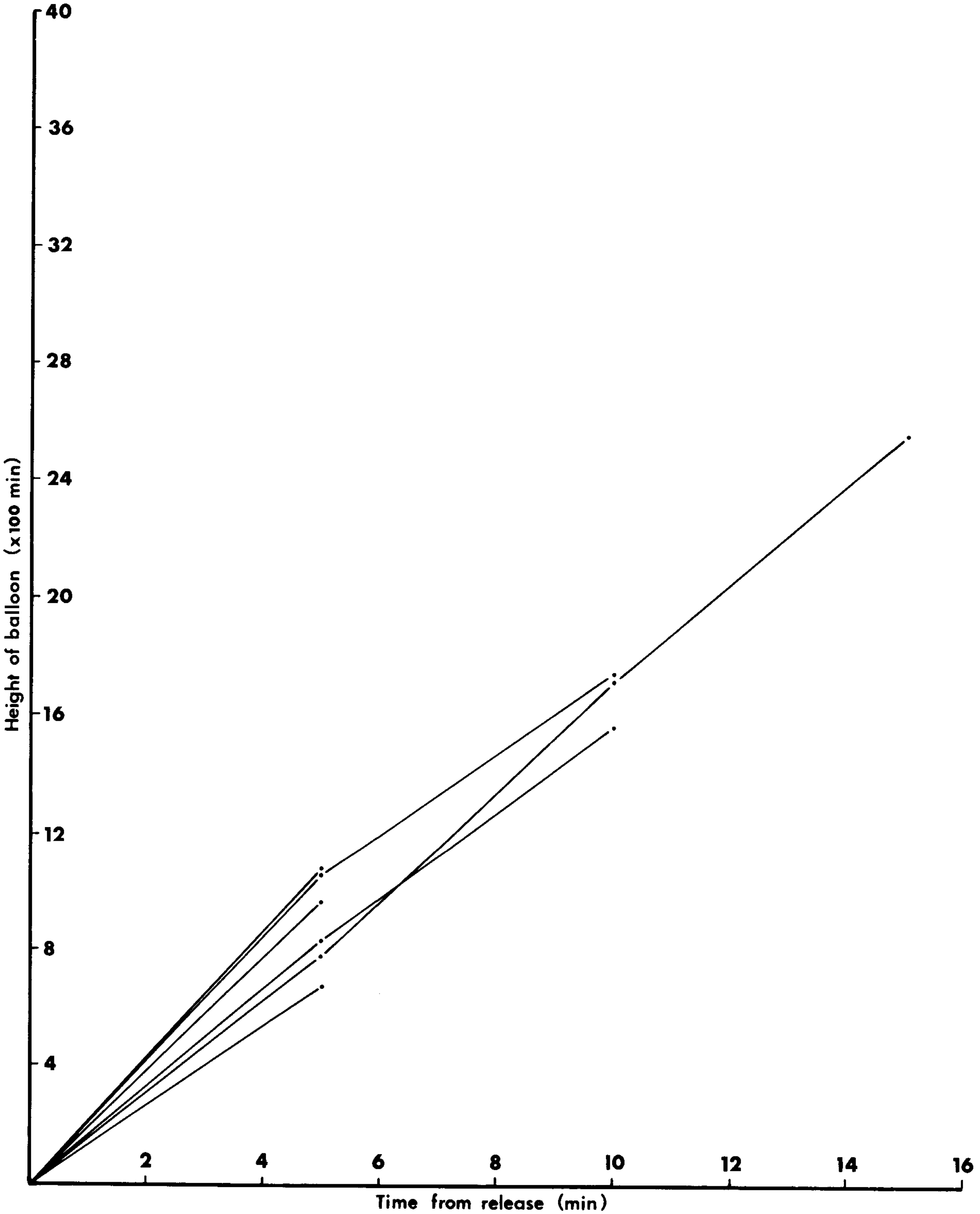


Figure 18 Height of balloon as a function of time from release (determined by double theodolite tracking) during the summer field program for the Fina Camp

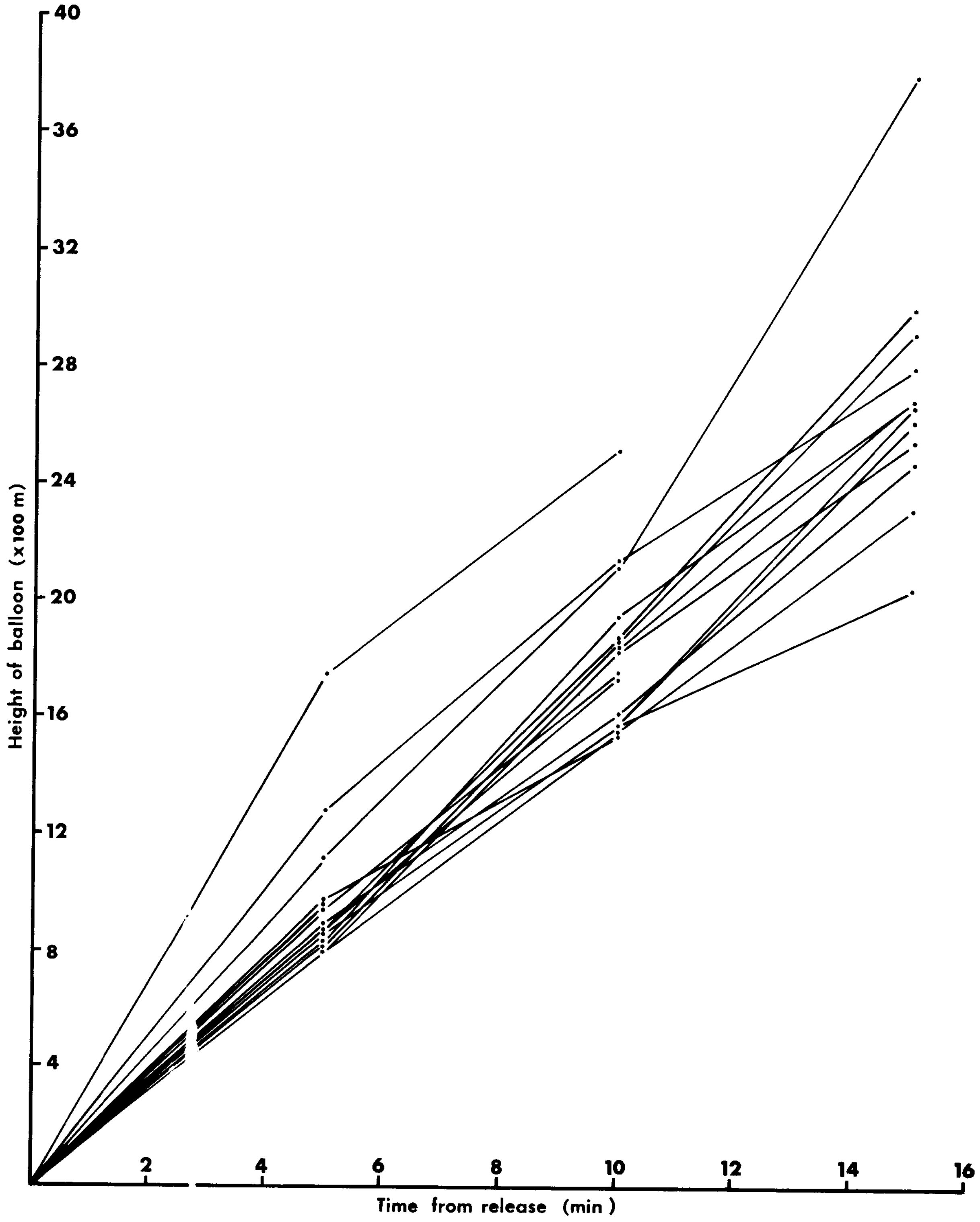


Figure 19 Height of balloon as a function of time from release (determined by double theodolite tracking) during the summer field program for the Syncrude Lower Camp

In Figure 20, the solid curve represents a double theodolite profile obtained at the Home Airstrip. The long-dashed curve represents the concurrent C-13 profile, obtained simultaneously, based on an assumed ascent rate of 140 metres per minute, while the short-dashed curve represents the same C-13 profile, obtained simultaneously, based on an assumed ascent rate of 140 metres per minute, while the short-dashed curve represents the same C-13 profile for a 170 metre per minute rate of ascent. Since the latter curve agreed with the more precise double theodolite profile at high elevations, the correct rate of ascent for this particular sounding was judged to be 170 metres per minute. The two curves did not overlap in the lowest layer due to local variations. All the C-13 and C-17 single theodolite soundings made during the summer field program were calibrated in this way in order to verify the rates of ascent used in the analysis. The technique can only be used if the airmass is homogeneous over the area which was indeed the case during the entire summer field program.

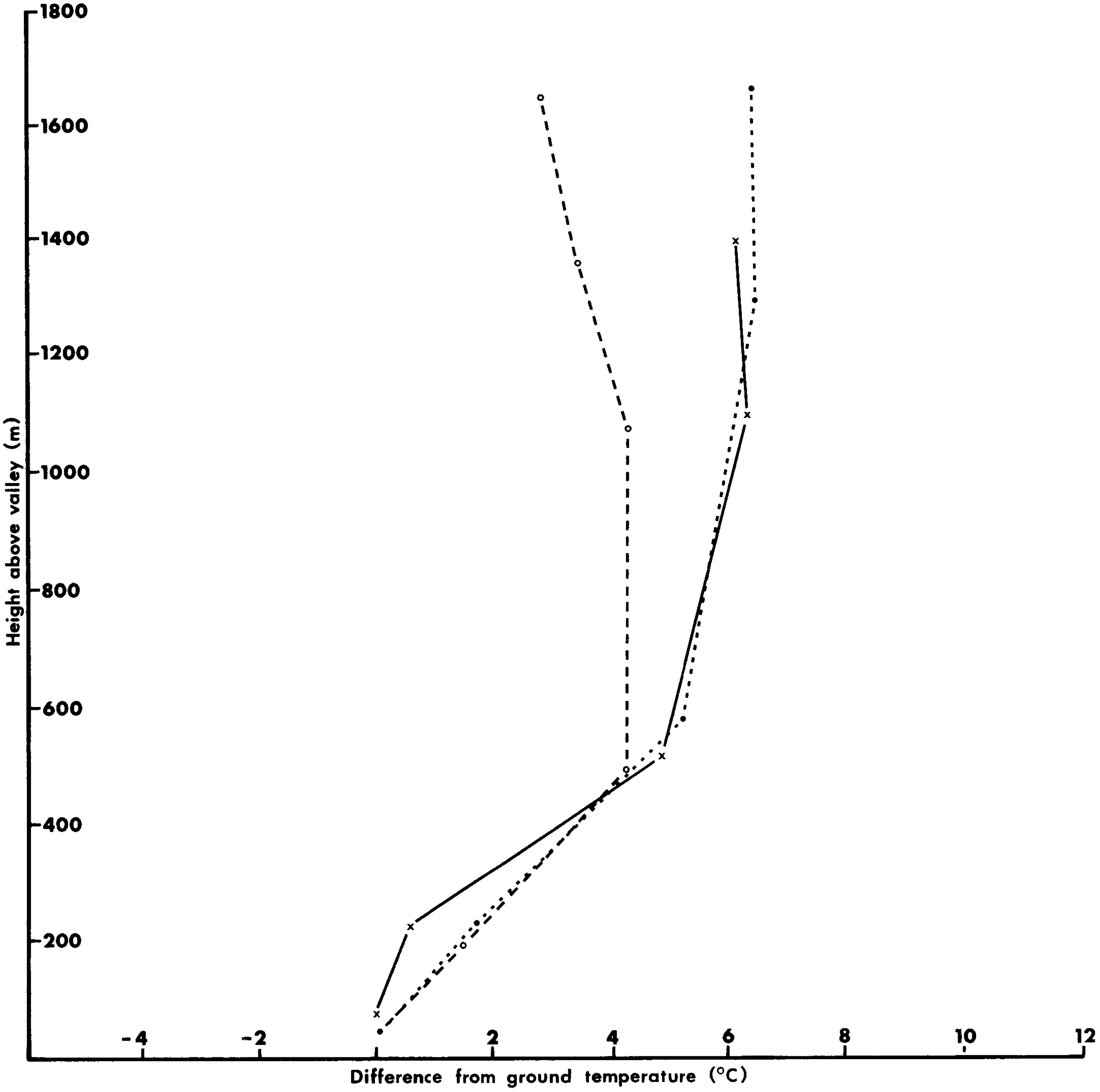


Figure 20 Ascent rate determination for 0830 sounding, July 30, 1975. ○- - - - - - - -○, single theodolite sounding from C-13 - ascent rate 140 metres per minute; •············•, single theodolite sounding from C-13 - ascent rate 170 metres per minute; ×————×, double theodolite sounding - Home airstrip.

VII DISPERSION CLIMATOLOGY

This section of the report is based on an analysis of the frequency of occurrence of specific values of the dispersion parameters for the entire study period (September 1974 to September 1975). The parameters considered included inversions, lapse rates, mixing heights, wind at plume level and surface temperature; the statistics are presented for four seasons.

1. Inversions

An inversion is a stable atmospheric layer in which the temperature increases with height (Figure 9). Effluents emitted into an inversion do not usually reach ground level in any significant concentration[7]. The nocturnal inversion is a ground based phenomenon which normally occurs on clear nights with light winds when the rate of heat loss from the surface is maximal. During the study period, and particularly on cloudy winter nights, this phenomenon often occurred as an elevated (not based at the ground) inversion. These elevated inversions may in some cases be due to local heat sources, but for the most part they are associated with fronts or moving weather systems. Consequently each 200 metre layer up to 1000 metres was investigated as to its potential temperature lapse rate.

In Table 1, the frequency of occurrence of a temperature inversion in each 200 metre layer up to 1000 metres is expressed as a fraction of the total number of morning atmospheric soundings. No attempt has been made to separate nocturnal from frontal or other types of inversions in this analysis. Approximately two thirds of the morning inversions are nocturnal. In the layer next to the ground (0-200 m.) an inversion was present on most mornings throughout the year. The relatively low fraction of ground-based inversions for the winter season (0.51) is considered to be misleading. Equipment failures

TABLE 1

Fraction of Mornings on which Various Layers of the Lower Atmosphere Were Isothermal* or More Stable (as measured by the morning soundings)

	Layer					
	0-200m	200-400m	400-600m	600-800m	800-1000m	Total No. Soundings
C-13						
Fall	.67	.55	.32	.27	.30	60
Winter	.51	.65	.63	.51	.44	43
Spring	.79	.68	.30	.19	.18	80
Summer	.91	.59	.24	.08	.03	74
C-17						
Spring	.69	.55	.29	.31	.22	58
Summer	.95	.73	.16	.02	.00	44

* In a isothermal layer, the potential temperature gradient is equal to +1.0.°C/100m

due to extreme cold weather are most likely to occur on very cold, clear mornings; it is probable that fewer inversions were recorded than actually occurred. The winter inversions were very deep, however, and as many as 44 % of the soundings measured inversions in the 800-1000 metre layer. This percentage fell to about 20 in spring and less than 3 in summer. The mean height of the top of the nocturnal inversion ranged from 800 metres in winter to 400 metres in summer. In spring and fall, the mean height of the top of the nocturnal inversion was near 500 metres.

C-13 and C-17 statistics of inversion depth are similar; the effects of any regional differences between the sites did not show up in spring and summer (the seasons when the stations were operated contemporaneously).

2. Potential Temperature Gradient (200 to 400 metres)

Potential Temperature Gradient is a factor controlling plume rise; a plume will rise higher in a neutral or unstable layer (i.e. a layer in which potential temperature remains constant or falls with height) than in a stable layer (where potential temperature increases with height). A reduction in plume rise (other factors remaining constant) induces a rise in ground concentrations of emissions. In addition, dispersion is faster when the potential temperature gradient is less positive. For an elevated plume more rapid dispersion makes it more likely that effluents will be mixed to ground level.

The potential temperature lapse rate distribution, for mornings and afternoons, is tabulated in Tables 2 and 3 for the layer between 200 and 400 metres. Table 2 underscores the finding that on most mornings throughout the year, the 200-400 metre (plume) layer was stable; it was frequently extremely stable.

Neutral and unstable lapse rates were infrequent, particularly in winter. Table 3 shows that in each season, the afternoon lapse rate was most often in the neutral range (potential temperature lapse rate near zero). Stable afternoon lapse rates were frequent in winter; unstable lapse rates were common in the summer season.

3. Mixing Height

The mixing height parameter measures the vertical limit to vigorous mixing (Figure 12). When a plume is trapped within a turbulent layer, lower mixing heights would result in higher ground concentrations of emissions[8]. Of special importance is the critical mixing height. The critical mixing height is the one which is sufficiently high to trap a plume yet low enough to severely inhibit vertical dispersion. Its value depends on wind speed, lapse rate, and plume characteristics. Winter and summer mixing heights had median values of 200 metres and over 1000 metres[*] respectively. Although the mixing heights were lower in winter, limited mixing beneath a stable lid is less frequent in that season (i.e. Syncrude's effective stack height will often be above the lid). In winter, the mixing heights show the influence of the extreme stability of the atmosphere, with a median value of around 200 metres. As a result, a Syncrude plume from the 183 metre chimney would have been above the mixed layer most of the time during winter with the meteorological scenario measured during the first year of this study.

4. Wind Speeds

A second factor (besides potential temperature gradient) controlling plume rise is the wind speed in the plume layer. Higher wind speeds tend to reduce

[*] Neither the mean nor median value of mixing height could be accurately determined for the warm months since several values exceeded the range of the sounding.

TABLE 2

Percentage Distribution by Season of Morning Potential Temperature Lapse Rates in the Layer 200-400 Metres (as measured by the morning soundings)

	Potential Temperature Gradient (°C/100m)				
	Less than -0.5	-0.5 - +0.5	+0.5 - +1.5	>1.5	Total No. Soundings
C-13					
Fall	0	28	30	42	57
Winter	0	7	36	57	44
Spring	0	15	49	36	78
Summer	0	13	45	42	67
C-17					
Spring	0	34	40	26	58
Summer	0	16	51	33	49

TABLE 3

Percentage Distribution by Season of Morning Potential Temperature Lapse Rates in the the Layer 200-400 Metres (as measured by the afternoon soundings)

	Potential Temperature Gradient ($^{o}C/100m$)				
	Less than -0.5	-0.5 - +0.5	+0.5 - +1.5	>1.5	Total No. Soundings
C-13					
Fall	5	48	32	15	61
Winter	4	47	22	27	45
Spring	18	71	8	3	80
Summer	27	69	4	0	70
C-17					
Spring	25	67	6	2	51
Summer	19	68	13	0	54

TABLE 4

Percentage Distribution by Season of Afternoon Mixing Heights (as measured by afternoon soundings)

	Stable at Sfc.	0-200m	200-400m	400-600m	600-800m	800m	Total No. Soundings
C-13							
Fall	11	12	31	12	8	26	66
Winter	35	12	35	8	4	6	51
Spring	17	5	17	15	6	40	82
Summer	12	3	8	5	7	65	76
C-17							
Spring	7	8	17	15	3	50	60
Summer	11	2	20	4	7	56	56

plume rise, but on the other hand tend to enhance dilution[10]. Mean morning wind speeds during the study period, for each of the eight compass points of wind direction, are given in Table 5. At C-13, the mean wind in the plume layer did not vary seasonally from a value of about 6 metres per second. Wind speed was slightly higher at C-17 during the spring and summer.

The mean afternoon wind speeds in the plume layer, recorded in Table 6, were again close to 6 metres per second. Figure 21 shows that for both morning and afternoon soundings, wind speeds in the plume layer were rarely less than 1 or greater than 13 metres per second.

5. Wind Directions

A knowledge of wind direction in the plume layer is essential for a determination of the potentially affected areas in the vicinity of proposed operations. The fall wind roses from the morning soundings (Figure 22) and from the afternoon soundings (Figure 23) show that winds between westerly and southwesterly dominated in that season. In winter (Figures 24 and 25), the winds were from every compass point except east. During the spring season, the flow was largely up or down the length of the valley, i.e. south or north (Figures 26 and 27), while in summer, the winds returned to the southwesterly quadrant (Figures 28 and 29). (See also Tables 5 and 6).

6. Surface Temperatures

Spatial variations in surface temperature are of interest because of their implicit relationship to mixing heights, inversion intensities and mesoscale

TABLE 5

Mean Morning Wind Speeds (m/s) in the Plume Layer * for Eight Compass Points of Wind Direction

	N	NE	E	SE	S	SW	W	NW	Mean
C-13									
Fall	6.9	6.3	-	3.0	7.1	5.2	8.6	6.2	6.2
Winter	5.6	4.8	-	3.5	4.3	5.7	9.0	5.8	5.5
Spring	7.1	5.6	4.7	5.7	7.2	7.3	7.3	4.5	6.2
Summer	6.2	4.8	5.3	5.7	6.2	6.1	5.6	6.4	5.8
C-17									
Spring	6.9	2.8	5.3	8.8	8.7	8.6	5.4	5.5	6.5
Summer	5.9	5.0	6.3	6.3	9.2	6.2	6.9	7.5	6.7

* The plume layer is taken to be between 200 and 400 metres above ground. This is the layer in which the plume will normally be located in the morning.

TABLE 6

Mean Afternoon Wind Speeds (m/s) in the Plume Layer * for Eight Compass Points of Wind Direction

	N	NE	E	SE	S	SW	W	NW	Mean
C-13									
Fall	6.0	4.7	-	-	5.3	6.4	5.8	6.8	5.8
Winter	6.0	4.3	-	5.0	4.5	4.4	9.0	7.5	5.8
Spring	5.7	4.3	6.0	5.9	5.9	7.0	6.0	4.6	5.7
Summer	6.0	4.7	7.3	5.0	5.3	6.1	4.9	6.7	5.8
C-17									
Spring	6.5	5.0	5.8	6.6	4.9	2.5	5.4	5.2	5.2
Summer	5.6	4.0	7.5	7.3	4.6	6.4	7.7	4.0	5.9

*The plume layer is taken to be between 200 and 400 metres above ground. This is the layer in which the plume will generally be located. An exception would occur under unstable conditions with very low wind speed which would contribute to a high plume rise.

TABLE 6

Mean Afternoon Wind Speeds (m/s) in the Plume Layer * for Eight Compass Points of Wind Direction

	N	NE	E	SE	S	SW	W	NW	Mean
C-13									
Fall	6.0	4.7	-	-	5.3	6.4	5.8	6.8	5.8
Winter	6.0	4.3	-	5.0	4.5	4.4	9.0	7.5	5.8
Spring	5.7	4.3	6.0	5.9	5.9	7.0	6.0	4.6	5.7
Summer	6.0	4.7	7.3	5.0	5.3	6.1	4.9	6.7	5.8
C-17									
Spring	6.5	5.0	5.8	6.6	4.9	2.5	5.4	5.2	5.2
Summer	5.6	4.0	7.5	7.3	4.6	6.4	7.7	4.0	5.9

*The plume layer is taken to be between 200 and 400 metres above ground. This is the layer in which the plume will generally be located. An exception would occur under unstable conditions with very low wind speed which would contribute to a high plume rise.

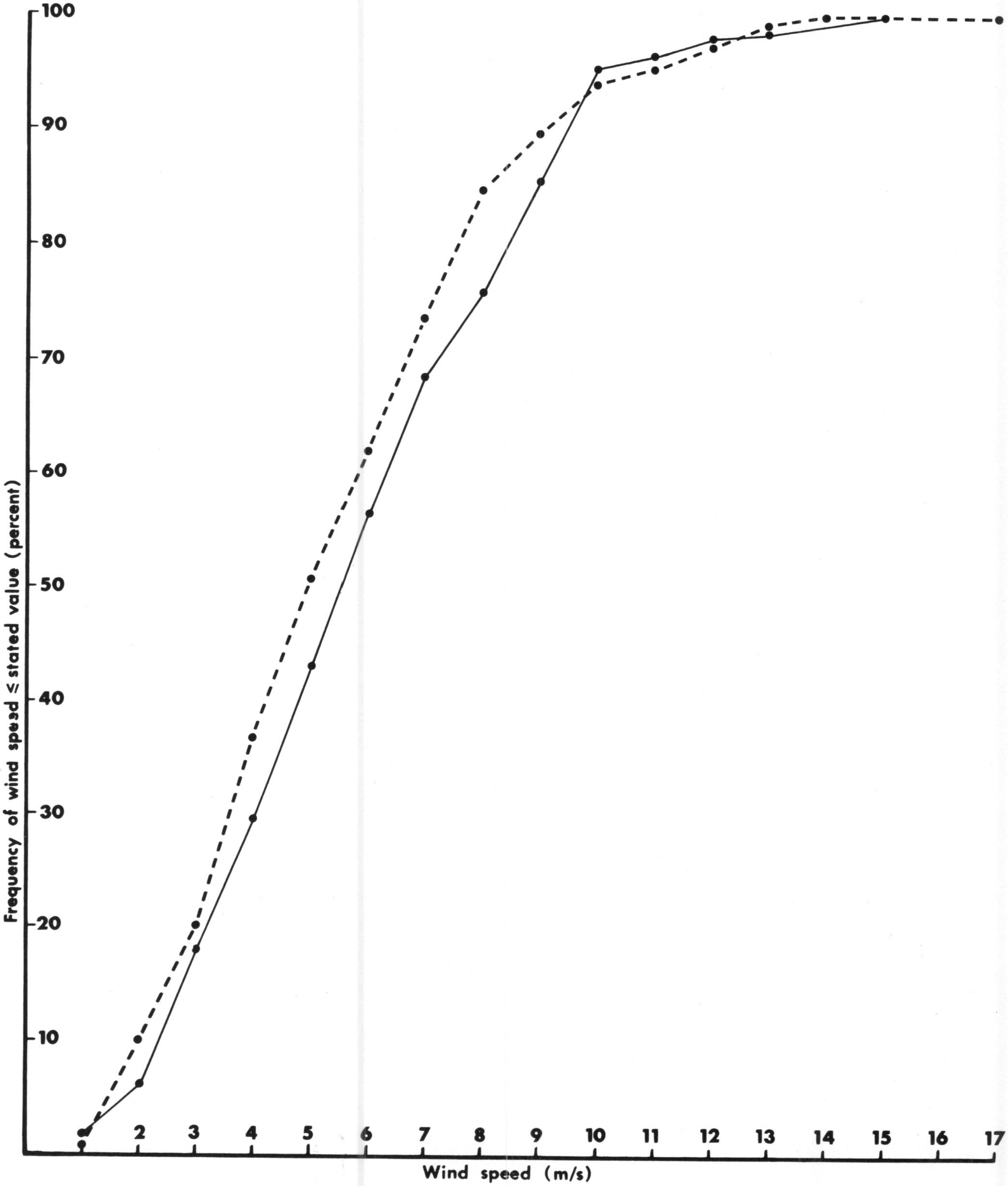


Figure 21 Cumulative frequency of wind speed in plume layer at C-13, for the period Sept/74 to Sept/75. - - - - - - afternoon soundings; ——— morning soundings.

flow patterns (see Section III - 3). Detailed regional temperature variations, however, could be determined only for the late spring and summer seasons - the period when the Forest Lookout Stations were operational.

Figures 30 through 32 indicate significantly higher afternoon temperatures at low elevations in the valley than in the higher terrain. These temperature patterns are typical of a valley area in summer (see Section III - 3). The "hot spot" in the vicinity of Tar Island may be associated with local activity in the area.

The highest maximum temperatures were recorded in July. This result is consistent with the highest mixing heights in that month. In August, the whole region, and the higher terrain in particular, began to cool rapidly.

It had been expected (Section III-3), that the coolest night-time temperatures would occur at the lowest elevations in the valley. In a classic valley location, cool (dense) night-time air normally pools at the lowest elevation. This was not the case for the Tar Sands Athabasca valley during the study period, where warm night-time temperatures centered around Tar Island. (See Figures 34 through 37). It is thought that this phenomenon may relate to the G.C.O.S. activity.

7. Data Interpretation

The reliability of the statistics depends both on the amount of data utilized and on the extent to which the data available can be termed

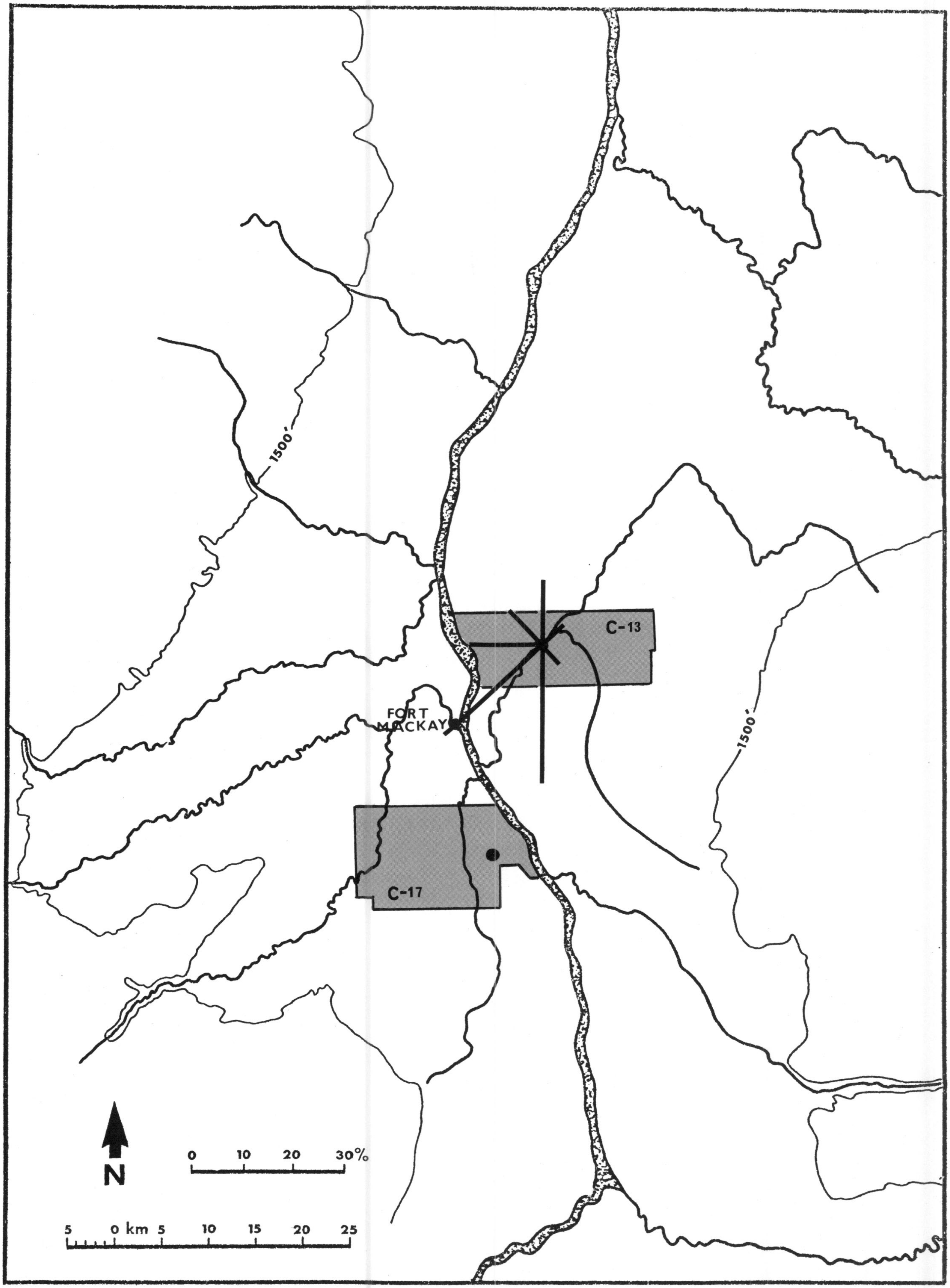


Figure 22 - Wind rose for fall mornings; C-13. Observations in the layer 200 - 400 metres above the release site.

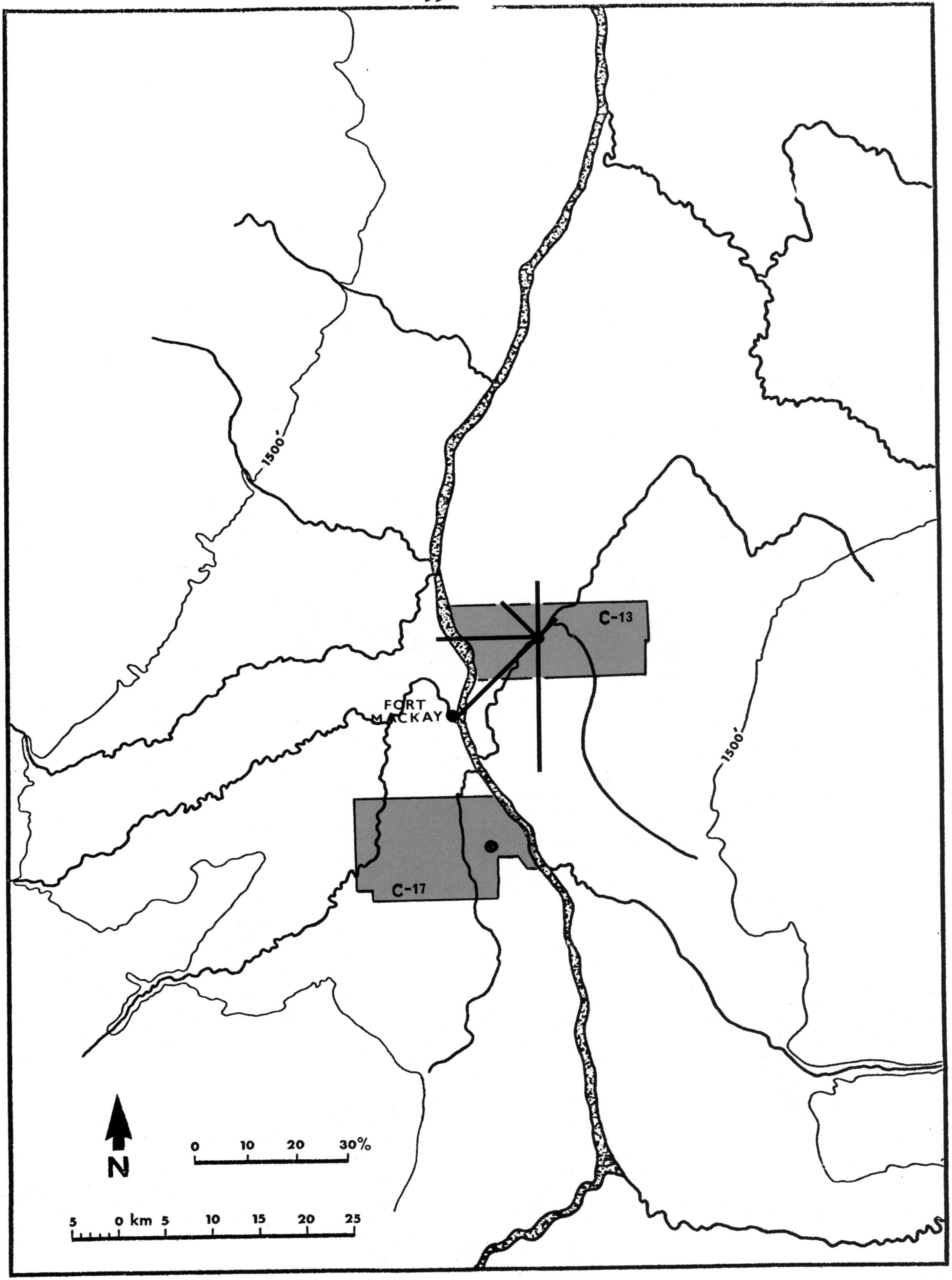


Figure 23 - Wind rose for fall afternoons; C-13. For layer 200 - 400 m.

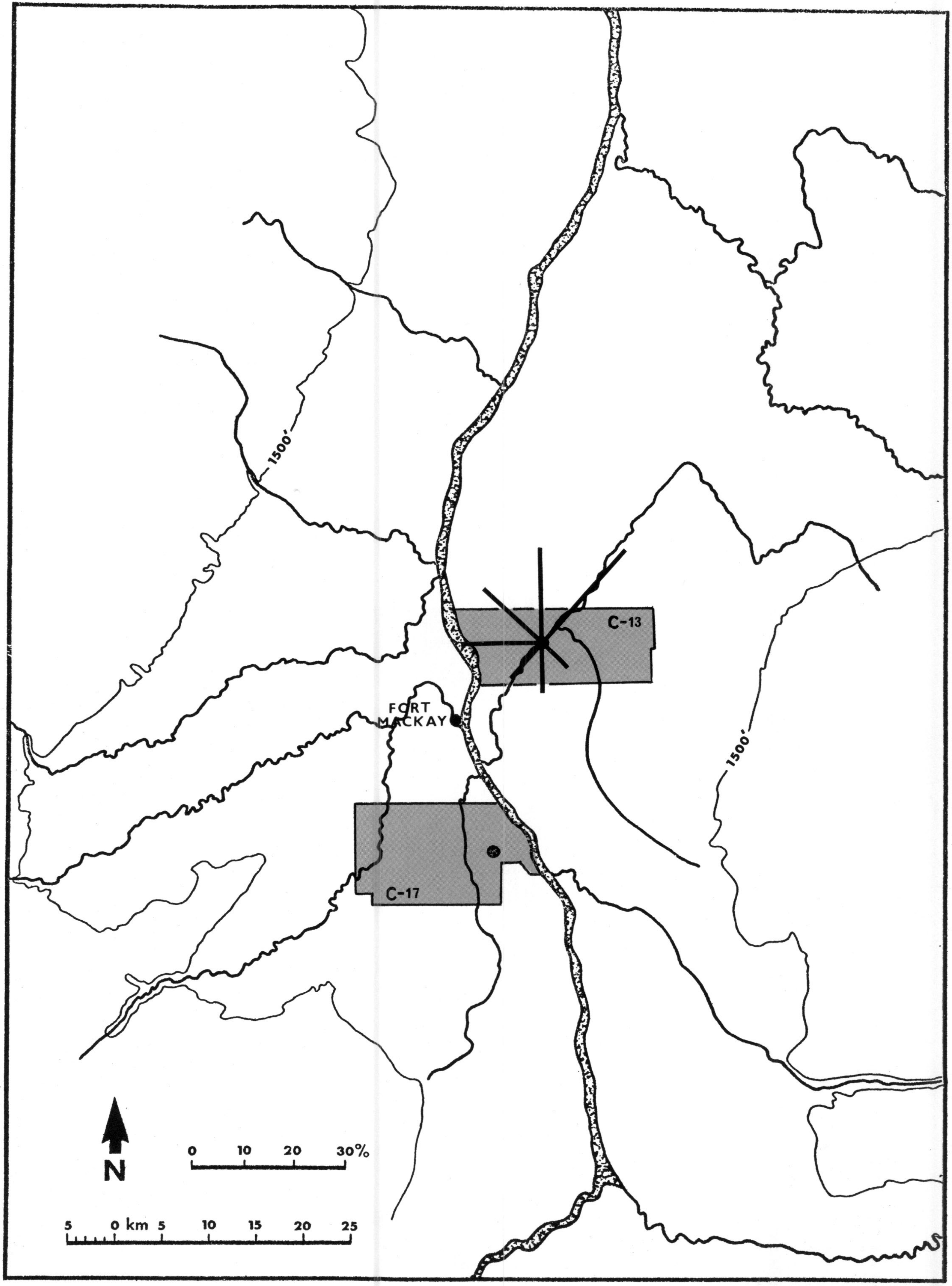


Figure 24 - Wind rose for winter mornings; C-13. For layer 200 - 400 m.

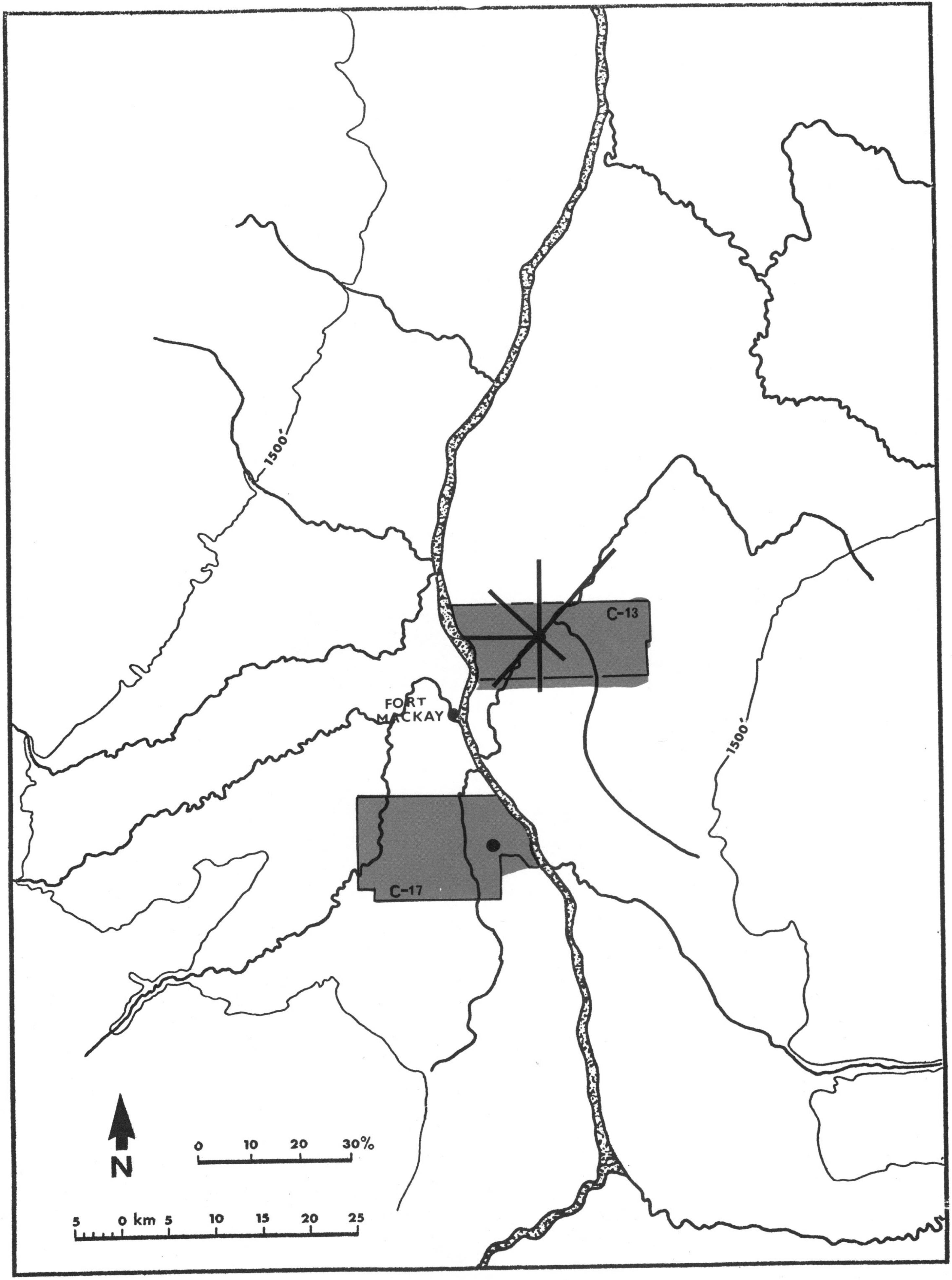


Figure 25 - Wind rose for winter afternoons; C-13. For layer 200 - 400 m.

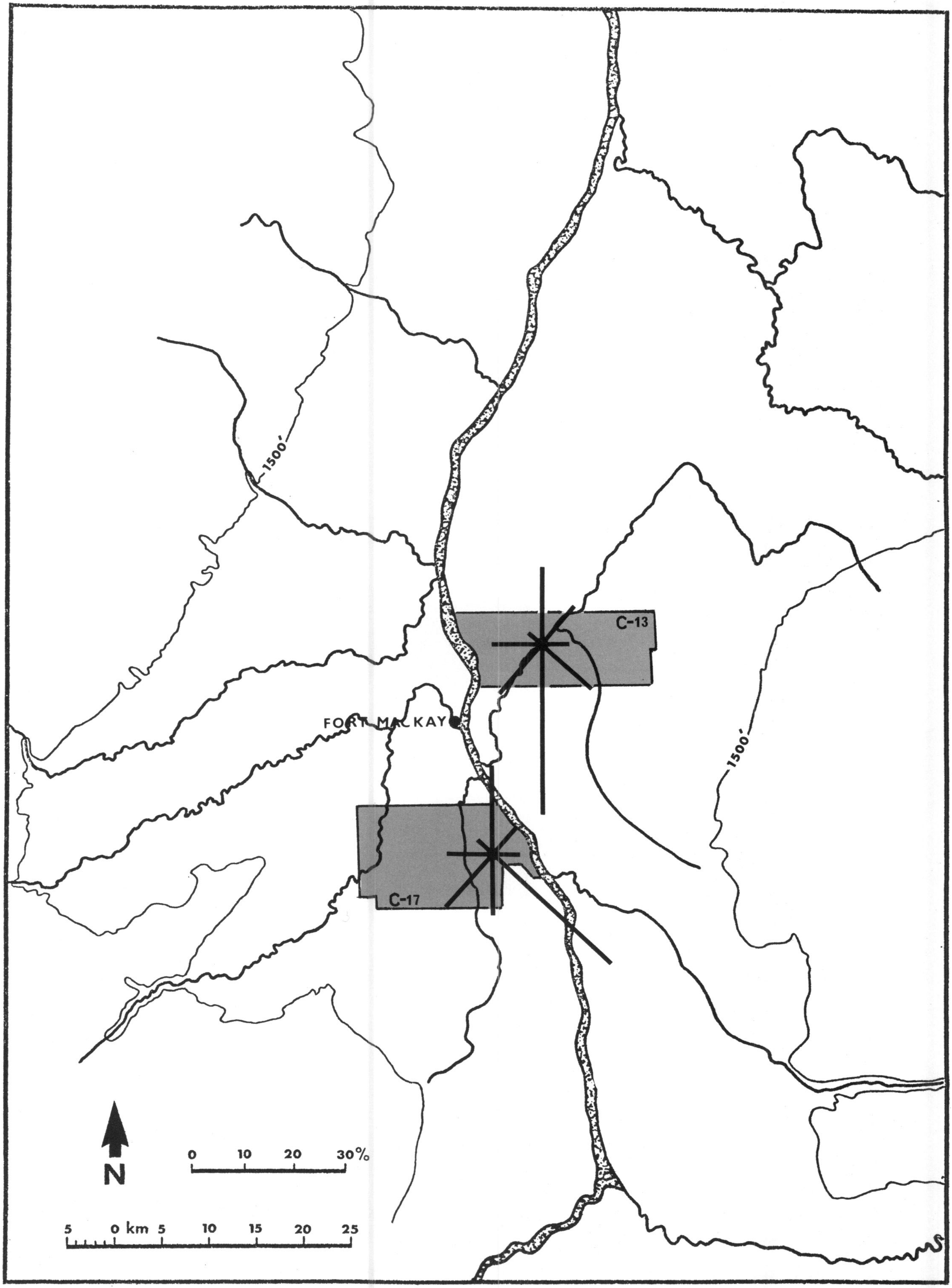


Figure 26 - Wind roses for spring mornings; C-13 and Mildred Lake. For the layer 200 - 400 m.

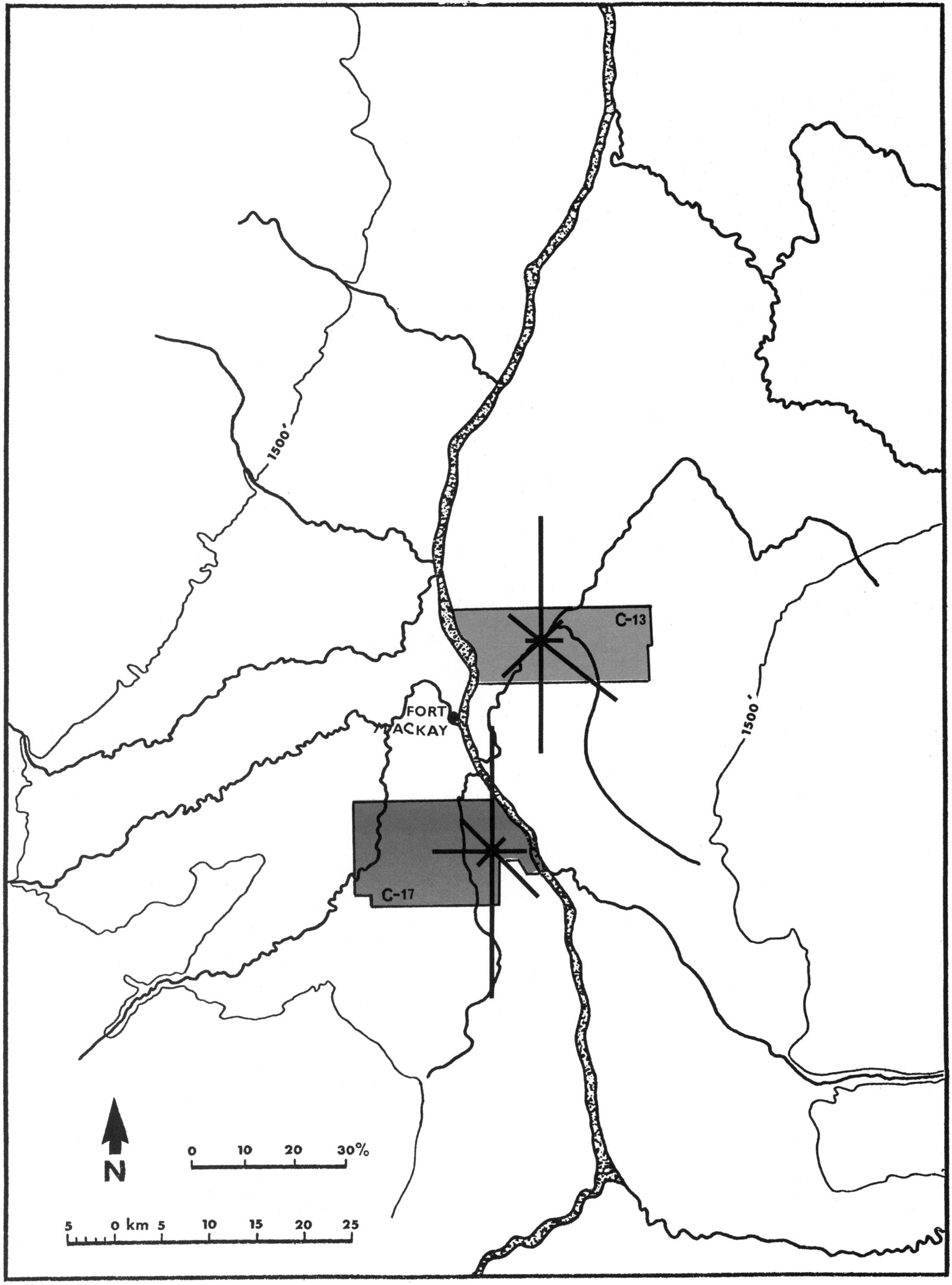


Figure 27 - Wind roses for spring afternoons; C-13 and Mildred Lake. For the layer 200- 400 m.

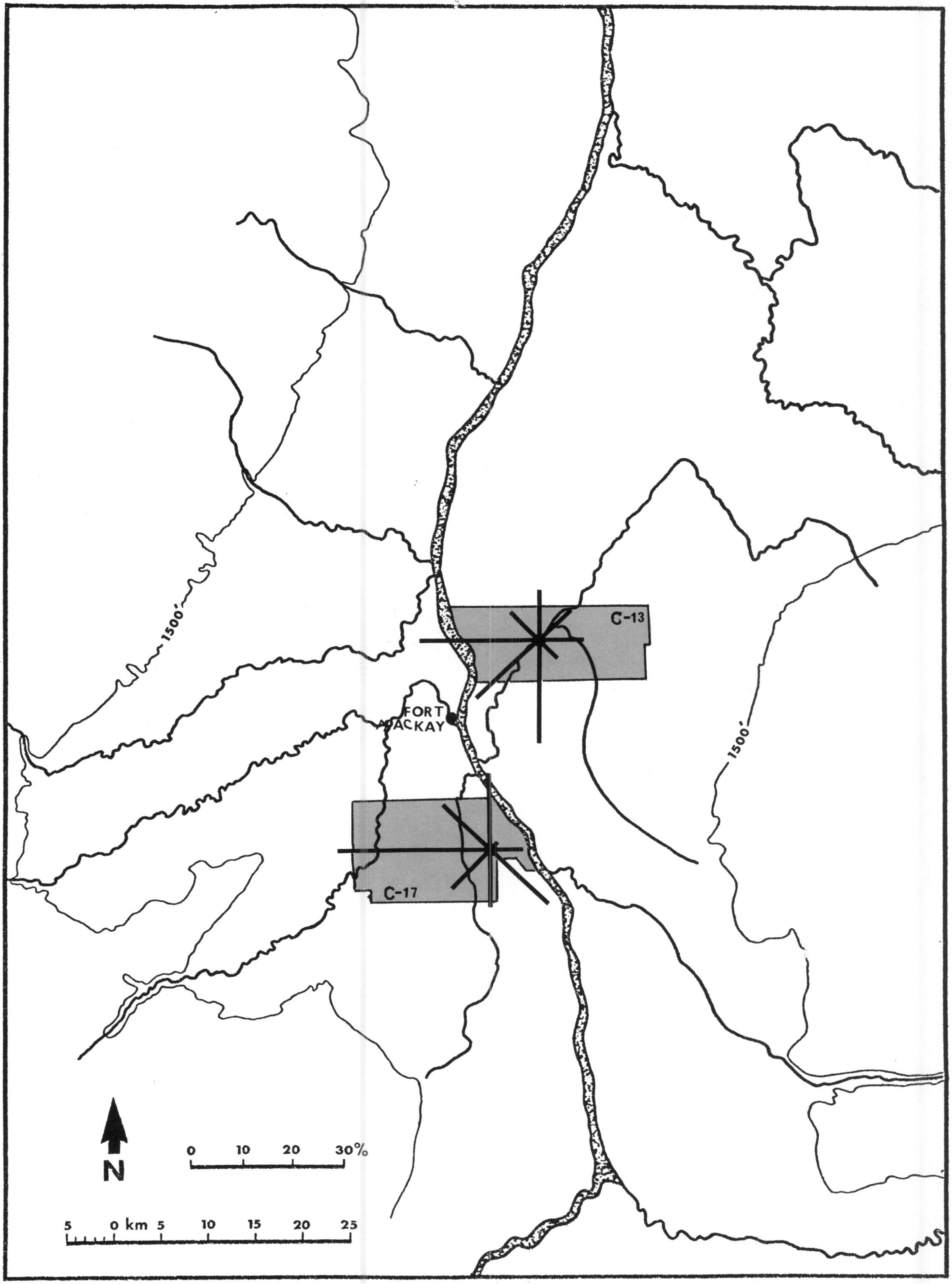


Figure 28 - Wind roses for summer mornings; C-13 and Mildred Lake.
For the layer 200 - 400 m.

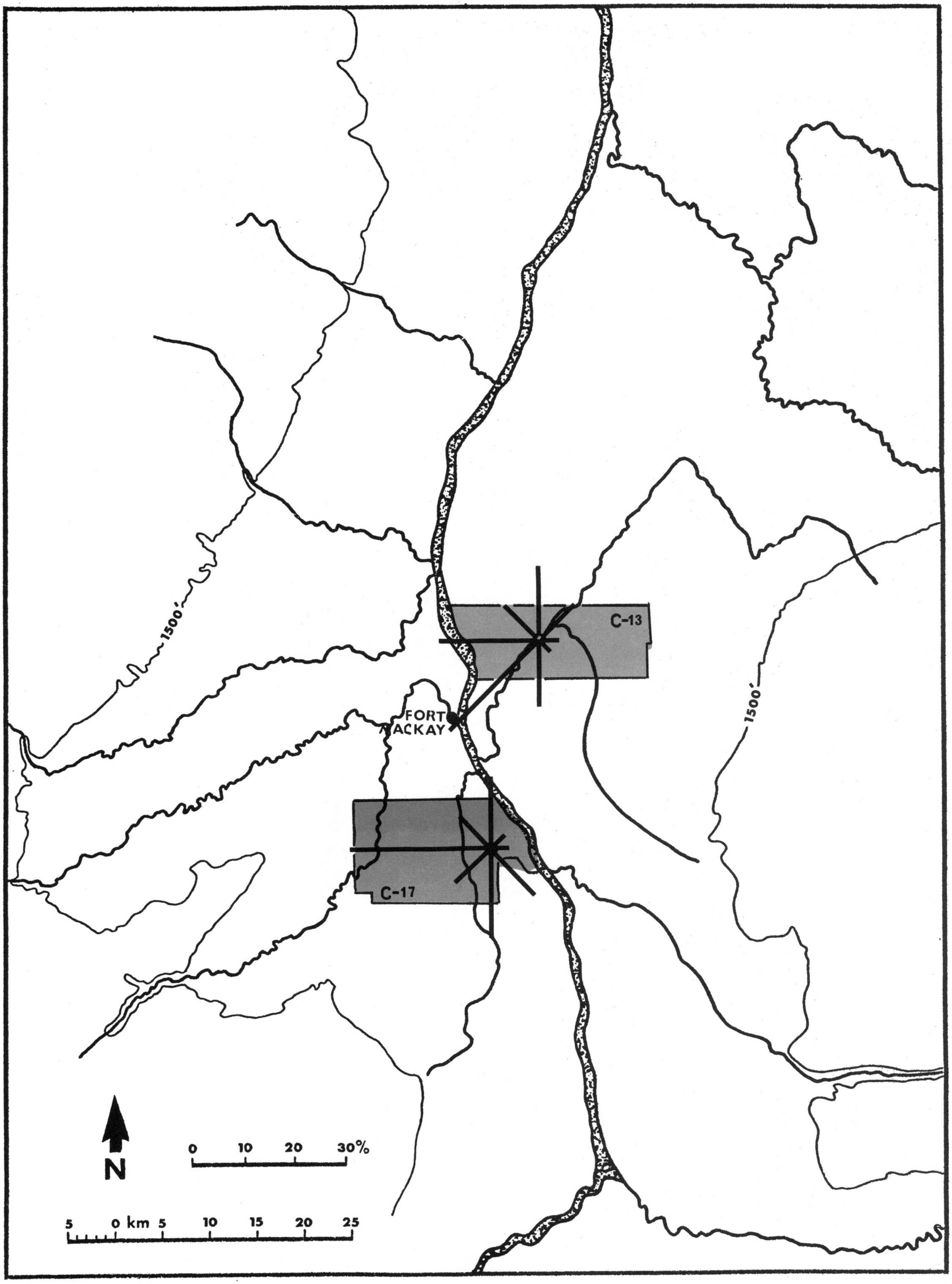


Figure 29 - Wind roses for summer afternoons; C-13 and Mildred Lake. For the layer 200 - 400 m.

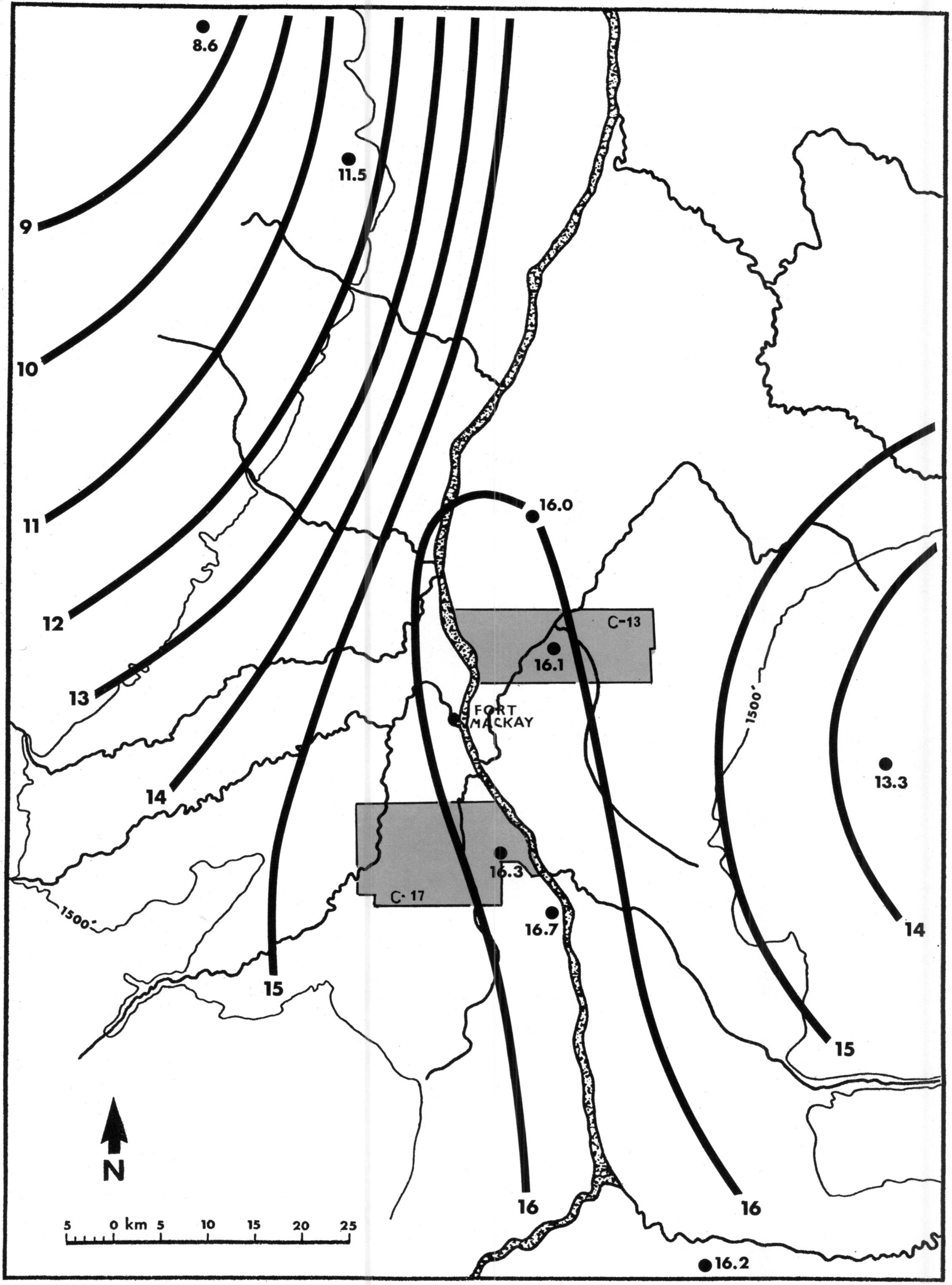


Figure 30 - May maximum temperatures (°C)

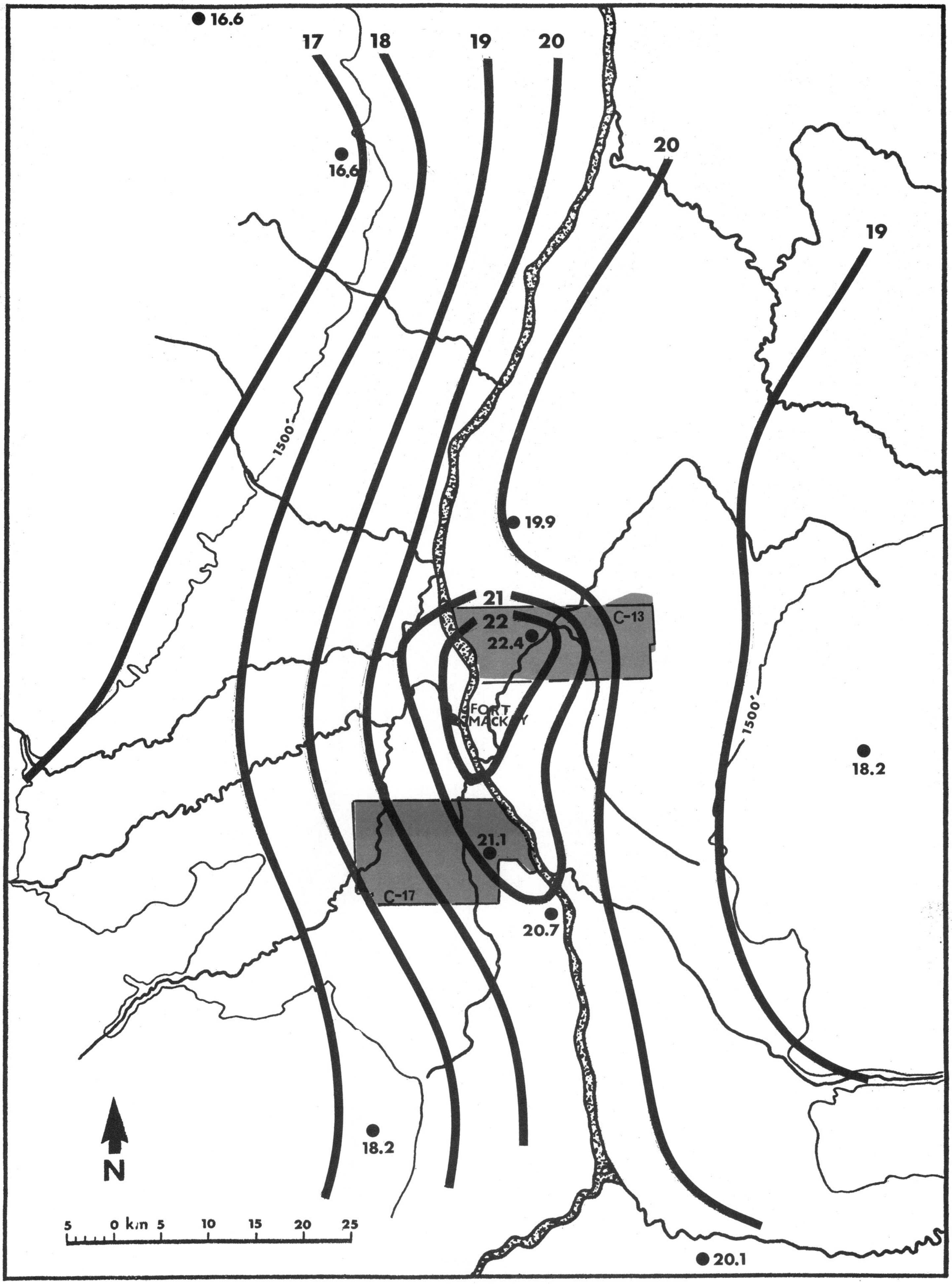


Figure 31 - June maximum temperatures (°C)

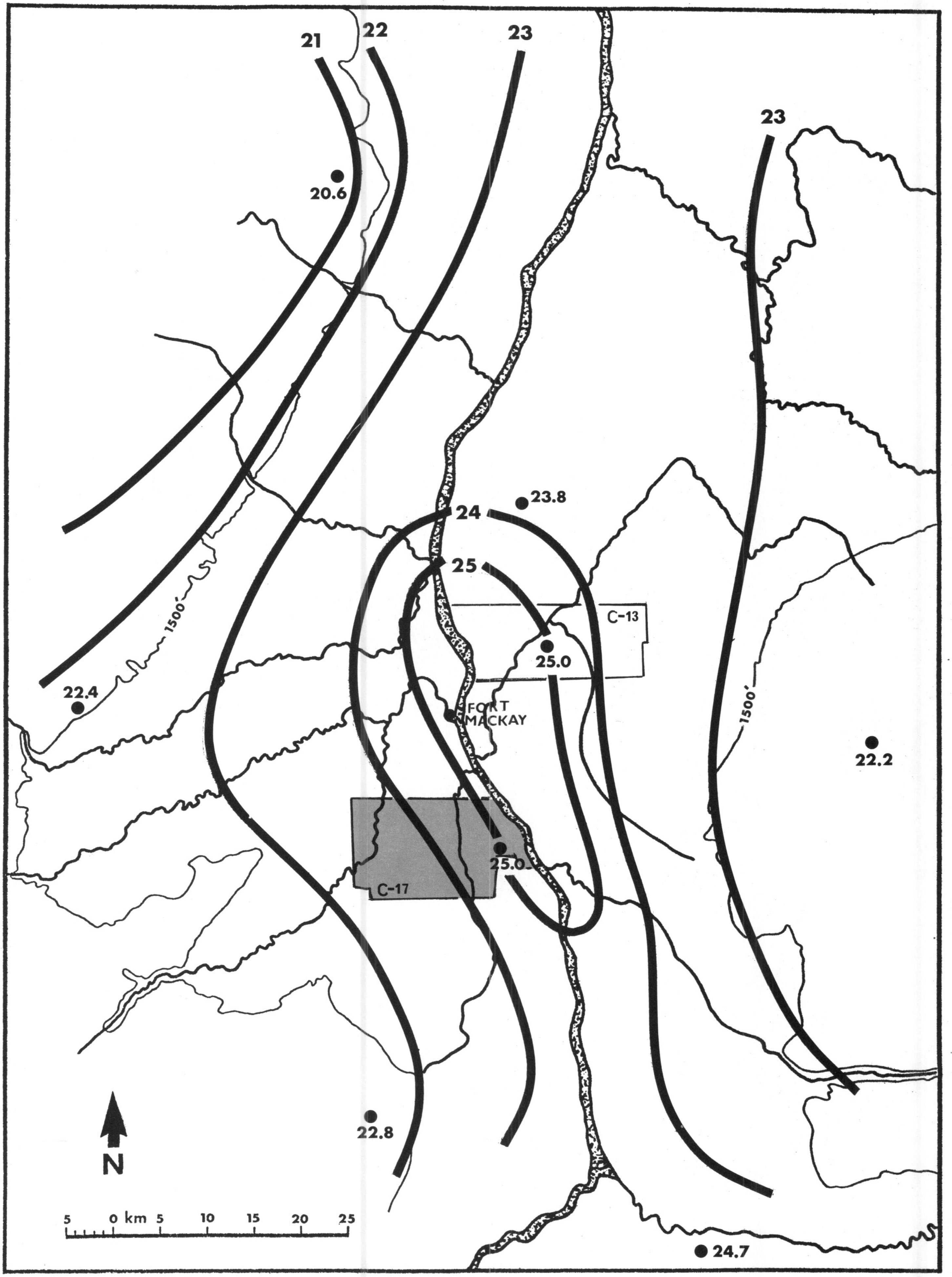


Figure 32 - July maximum temperatures (^{O}C)

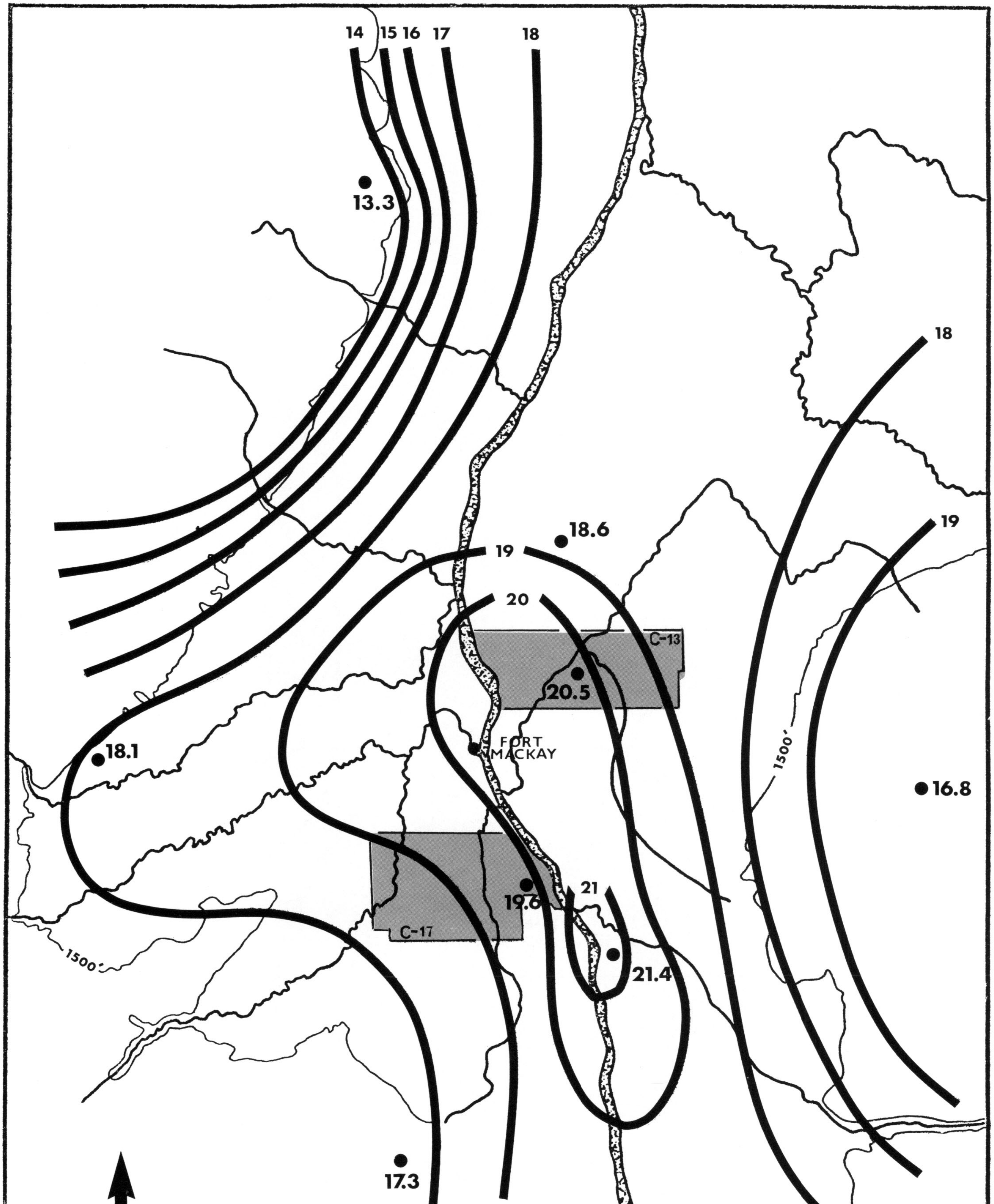


Figure 33 - August maximum temperatures (°C)

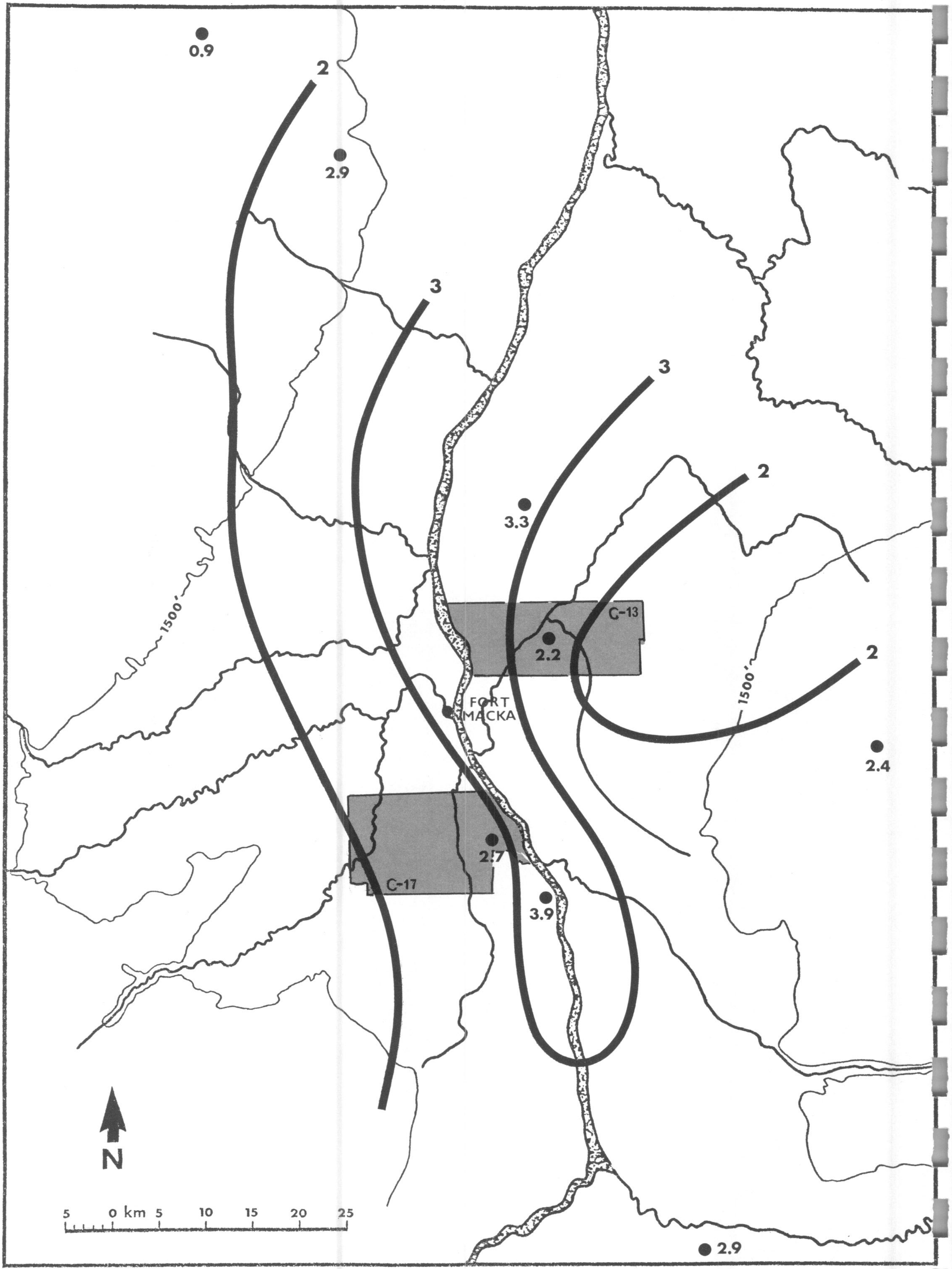


Figure 34 - May minimum temperatures (^{O}C)

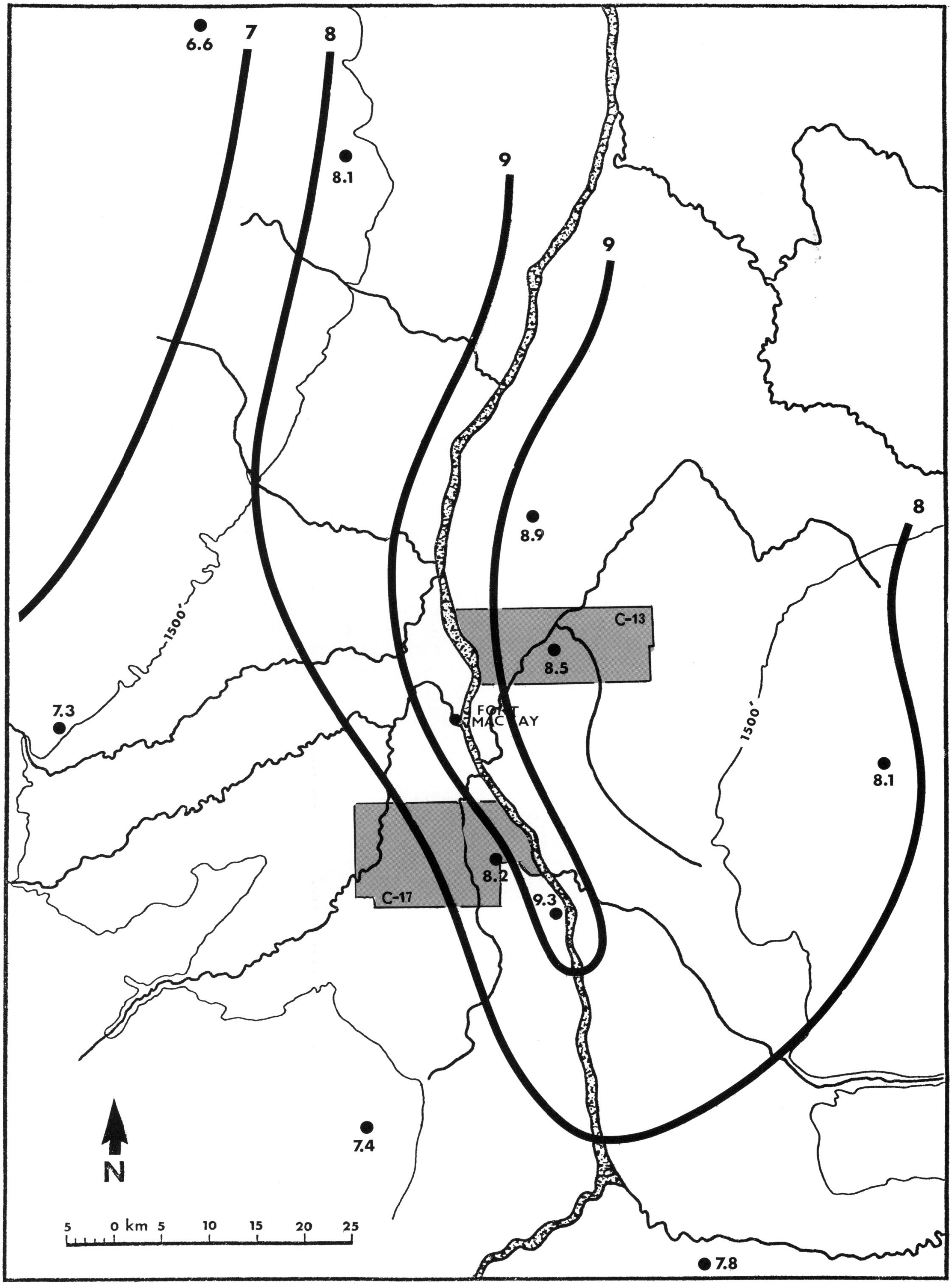


Figure 35 - June minimum temperatures (^{0}C)

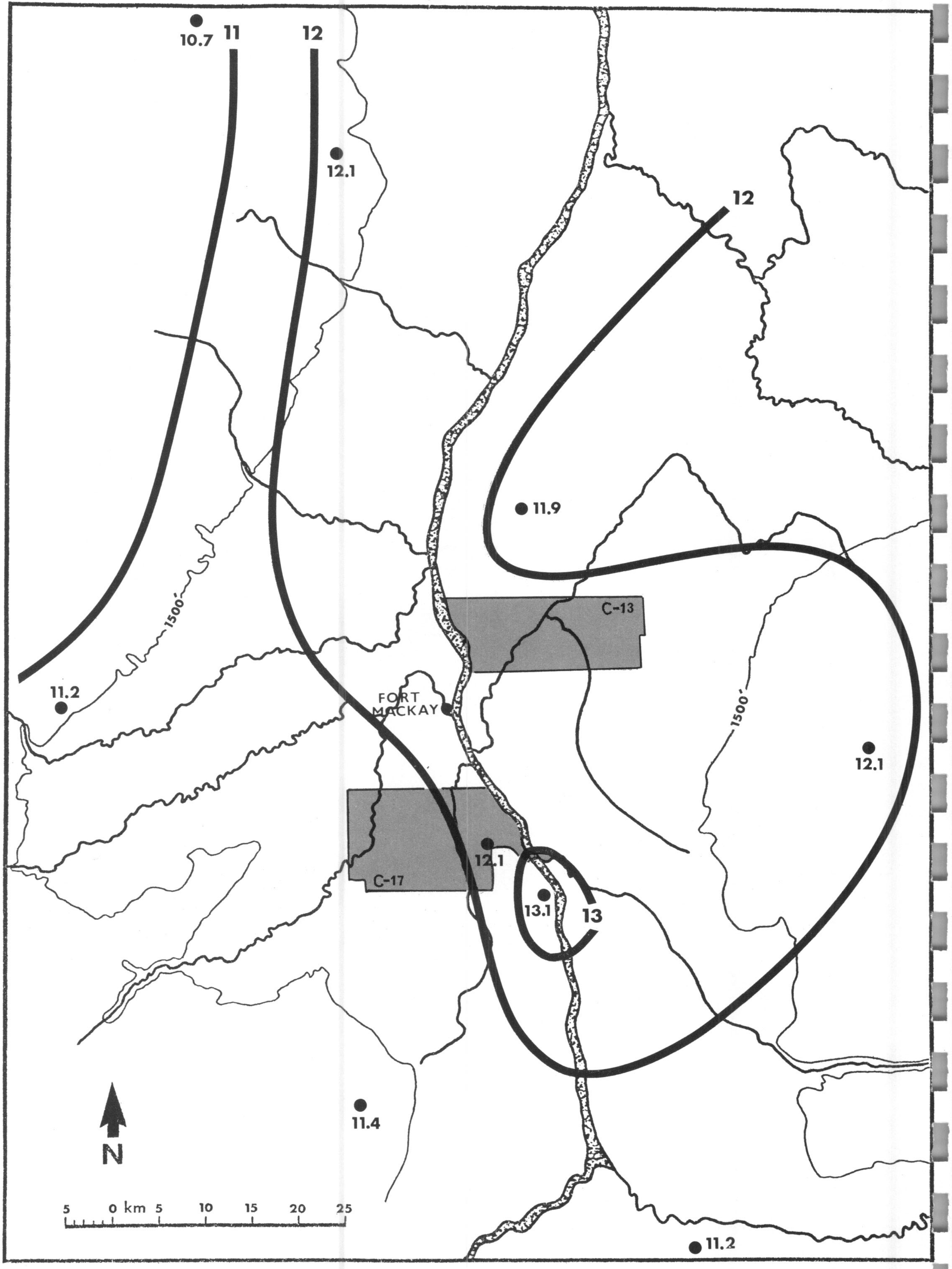


Figure 36- July minimum temperatures (^{O}C)

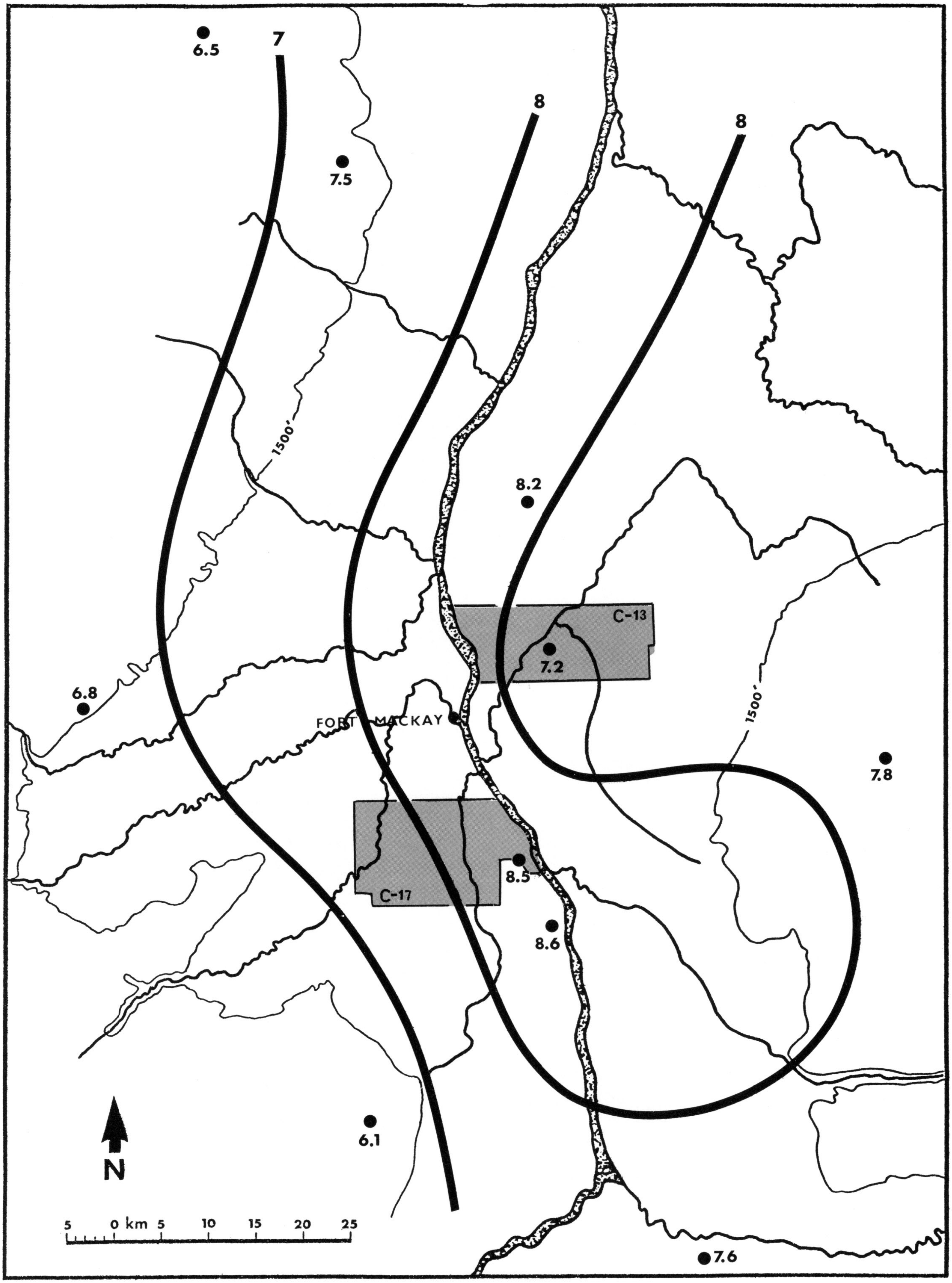


Figure 37 - August minimum temperatures (^{O}C)

"representative". Relative to the first factor, it is noted that this study had made use of atmospheric sounding data covering about 75% of the days from September 1974 through September 1975, while the minimum period required for a meaningful climatology is normally considered to be three years. The study is continuing through 1976, however, and the reliability of the statistics will constantly improve.

At lease C-17 a minisounding was not performed on 72 days because the program operated on a five day work week. Soundings were missed on 22 occasions because of equipment or electrical power problems. Severe weather prevented a sounding 17 times. On 9 occasions technical personnel were unavailable to perform the sounding.

The representative nature of the data available is difficult to assess. One method, which utilizes historical data from Mildred Lake Climatological Station, is as follows.

The value of a parameter may be considered typical if its deviation from the normal is less than the standard deviation from the normal[11]. Whether the surface temperature was typical during the period was determined in Table 7 with the conclusion that the months of November and December were atypically warm. With respect to total rainfall (Table 8), July and September were atypically wet.

From this rather simplistic approach, one might conclude that typically, the winter is colder and the summer is drier than it was during the study year. The colder winter would likely have more frequent surface-based inversions and thus a lower probability of the plume reaching the ground. The effect of a drier summer is less predictable.

TABLE 7

Mean Monthly Temperatures at Mildred Lake (^{O}F) (see text)

	Mean Temperature	Five-Year Mean	Standard Deviation	Deviation From Five-year Mean
September, 1974	46	47	5	1
October, 1974	39	37	3	2
November, 1974	25	16	8	9
December, 1974	15	-1	10	16
Janurary, 1975	-6	-9	7	3
February, 1975	1	4	7	3
March, 1975	12	15	8	3
April, 1975	34	36	3	2
May, 1975	51	52	4	1
June, 1975	59	59	3	0
July, 1975	66	63	3	3
August, 1975	59	60	3	1

TABLE 8

Total Monthly Precipitation Amounts at Mildred Lake (inches)
(see text)

	Mean Precipitation	Five-Year Mean	Standard Deviation	Deviation From Five-year Mean
September, 1974	0.4	1.3	0.7	0.9
October, 1974	0.4	1.1	0.7	0.7
November, 1974	0.4	0.8	0.9	0.4
December, 1974	0.9	0.9	0.3	0.0
January, 1975	0.8	1.0	0.2	0.2
February, 1975	0.1	0.4	0.3	0.3
March, 1975	0.6	0.4	0.4	0.2
April, 1975	0.9	0.7	0.6	0.2
May, 1975	1.1	1.1	0.7	0.0
June, 1975	3.4	3.5	1.0	0.1
July, 1975	4.8	3.3	1.2	1.5
August, 1975	2.9	.7	0.8	0.2

VIII DESCRIPTION OF MEP AIR QUALITY MODEL

The theoretical prediction of air quality in the Tar Sands region as expected to be affected by the operations of Syncrude's Mildred Lake Plant required mathematical modeling of the dispersion of airborne emissions for a single source and allows for the influence of local controls such as topography, valley flows, and thermal stratification.

The art of dispersion modeling is in an early state of development. Since existing numerical models were considered lacking in reliability, an alternative program was adopted by M.E.P. that would allow for the simulation of many of the local characteristics in a simple and direct manner that would yield simply interpretable and universally acceptable results.

The basis of the M.E.P. model is the Gaussian Plume Model. To incorporate the multiple sources and the topographic controls, calculations are performed for a fixed grid network of arbitrary spacing, where the elevation and gradient direction is specified at each point of a rectangular grid. For the Tar Sands Regional Model, the grid covers the area between 111° 0'' and 112° 7' 30'' west longitude and between 56° 39' 30'' and 57° 33' 48'' north latitude; a one kilometre grid spacing is used.

Each source is assumed to produce a plume whose centreline describes a trajectory in space which is determined by the variation of wind direction along the plume both in the horizontal and vertical and by the influence of topography in elevating or depressing plume height[16]. The material is then assumed to be distributed in a Gaussian dependence in the horizontal. In the vertical, the spread is assumed Gaussian for singly-stratified turbulent layers, but also allowing for reflection at ground and at an overlying stable layer.

In the plume calculation, plume rise is governed by buoyancy and atmospheric stratification as described in the theoretical development of Briggs[17], where up to 5 layers of stratification can be specified.

The following computational characteristics allow for the simulation of realistic dispersion regimes:

1) The variation of wind speed with height can be specified either by specifying a wind speed at each level, or by use of the power law behaviour[18].

2) The Pasquill dispersion coefficients are adjustable as dictated by local observations.

3) Gaussian Diffusion, Limited Mixing, and Inversion Breakup may be simulated.

4) Concentrations can be evaluated at a desired monitor elevation, allowing for a mapping of the three-dimensional plume.

5) The height of the limit to mixing (mixing height) can be made variable in the horizontal direction.

6) Depletion of pollutant by fallout and scavenging can be incorporated in the computation.

7) The sampling time is variable by applying the power law on the dispersion coefficients.

The model was applied to map the plume structure of a three stack source as described in a full-scale study of the plume and accompanying meteorological conditions of a recent study[19]. The results indicate the overall structure as well as the specific averaged plume-centreline and ground level concentrations are well reproduced by the model.

IX MAXIMUM GROUND LEVEL CONCENTRATIONS OF SO_2*

This chapter describes the results of air quality computations which estimate maximum ground level concentrations which would have been associated with observed dispersion conditions during the study period, if the Syncrude plant would have been operating during that time. For each day covered by the study, the observed temperature and wind profiles were used to select the appropriate meteorological input parameters to the model. All of the meteorological input was measured onsite except for the period September, 1974 - January, 1975 prior to the initiation of the C-17 sounding program. The Shell/Lease C-13 profiles were used along with the maximum temperature data from Mildred Lake.

The emission parameters used are stated in Table 9. Computations were done for three different stack heights and two emission rates. Meteorological techniques were used to speculate on dispersion conditions for those days for which no data were available. Examination of available data indicated that mixing height remains below plume level on days with a trace or more of precipitation. Hence, it was assumed that, if data were missing and rain reported by the Mildred Lake climatological station, no fumigation would have occurred. Days with missing data, but no rain reported were assumed to have the same frequency distribution of ground level concentrations as similar days when minisoundings were available. Thus, the statistics were normalized over the period and could be expressed in terms of

*Note that all maximum ground level concentrations of SO_2 are expressed in terms of a half hour average, for which the Alberta air quality standard is 0.2 ppm.

seasonal and annual statistics. The computations are described below.

1. Limited Mixing Computations

When a turbulent layer exists beneath a stably stratified layer, effluents emitted into the turbulent layer will be prevented from diffusing upwards. In effect, the pollutant is trapped under the capping lid and the resulting limited volume of air for dilution then leads to increased ground level concentrations. Under these conditions, concentrations are estimated by a method derived by Bierly and Hewson[20]. When the capping lid is very much higher than the stack top, the limited mixing model reduces to Gaussian Diffusion under unstable atmospheric conditions.

Syncrude requested that, in addition to the actual height of 600 ft. of the recently completed stack, maximum ground level concentrations would also be computed for theoretical stack heights of 400 and 800 ft. The objective is to establish how efficient an increase in stack height would be in terms of attaining 100% compliance with the current ambient air quality standards of the Province of Alberta.

The distribution of maximum ground level concentrations as obtained from the computations for the limited mixing conditions is shown in Figure 38 for the emission rate of 3363 grams per second. Figure 39 shows the result for an emission rate of 2018 grams per second. (Note that each of the distribution curves must pass through an ordinate value of 365 corresponding to an abscissa value of zero. In other words, the number of afternoons with zero concentration or greater during the course of the year must be 365. The curves are smoothed to indicate how distribution curves, based on a longer period, might appear.)

TABLE 9

Parameters Used in Air Quality Computations

Stack Height (ft)	600
SO_2 Emission Rate (g/s)	2018/3363
Total Gas Flow Rate (m^3/s)	1082
Gas Temperature (^{o}k)	502

As both Figures demonstrate, the number of incidents of ground concentration greater than 0.2 ppm (half hour average) predicted to be associated with a 400 foot stack is considerably larger than expected to result from taller stacks. The Figures also indicate that no significant gains, in terms of a reduction of the predicted number of occurrences of events in excess of 0.2 ppm, due to limited mixing, can be derived from extending these stacks beyond 600 feet.

The 600 foot stack (Figure 39) with the lower emission rate would have contributed to 4 events in excess of 0.2 ppm while the higher emission rate (Figure 38) was associated with 19 such occurrences. These figures also indicate that no significant reduction in the number of events with concentrations larger than 0.2 ppm can be obtained by a reduction of emissions below circa 2000 g/s of SO_2 (in the case of limited mixing).

The predicted occurrence of ground concentrations in excess of 0.2 ppm, associated with limited mixing, would have been equally divided among the seasons.

Measurable ground concentrations resulting from limited mixing would typically cover a large area and persist for two or three hours. Assuming an average three hour duration, the Syncrude 600 ft. stack would have been associated with compliance percentages in terms of the half-hour average air quality standard of 99.8% and 99.4% of the time for the lower and higher emission rates respectively, should non-compliance have resulted from limited mixing conditions only. (Note that these percentages are derived by multiplying the appropriate number of occurrences by 3 hours (average duration) and dividing by 8760 - the number of hours in a year).

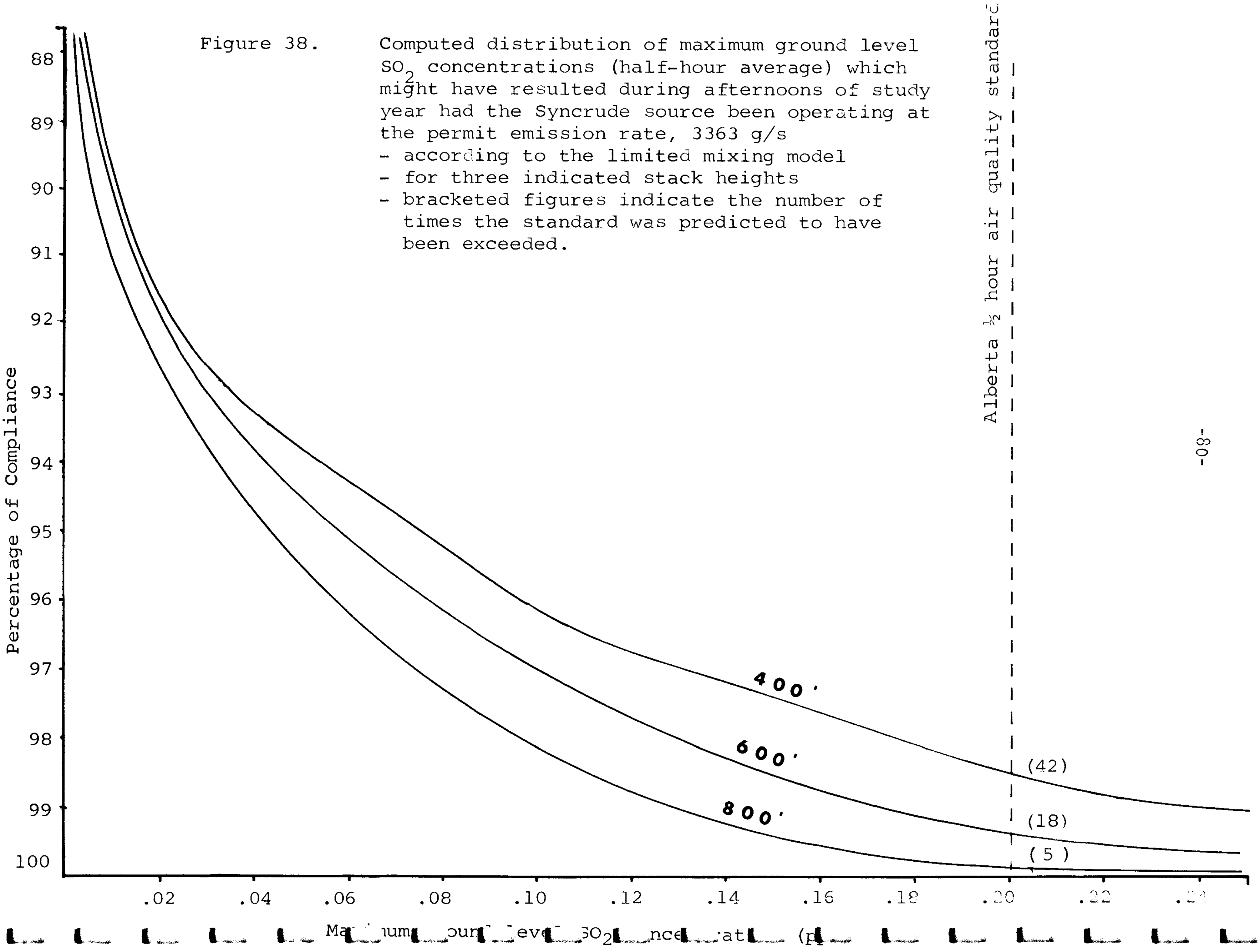


Figure 38. Computed distribution of maximum ground level SO_2 concentrations (half-hour average) which might have resulted during afternoons of study year had the Syncrude source been operating at the permit emission rate, 3363 g/s
- according to the limited mixing model
- for three indicated stack heights
- bracketed figures indicate the number of times the standard was predicted to have been exceeded.

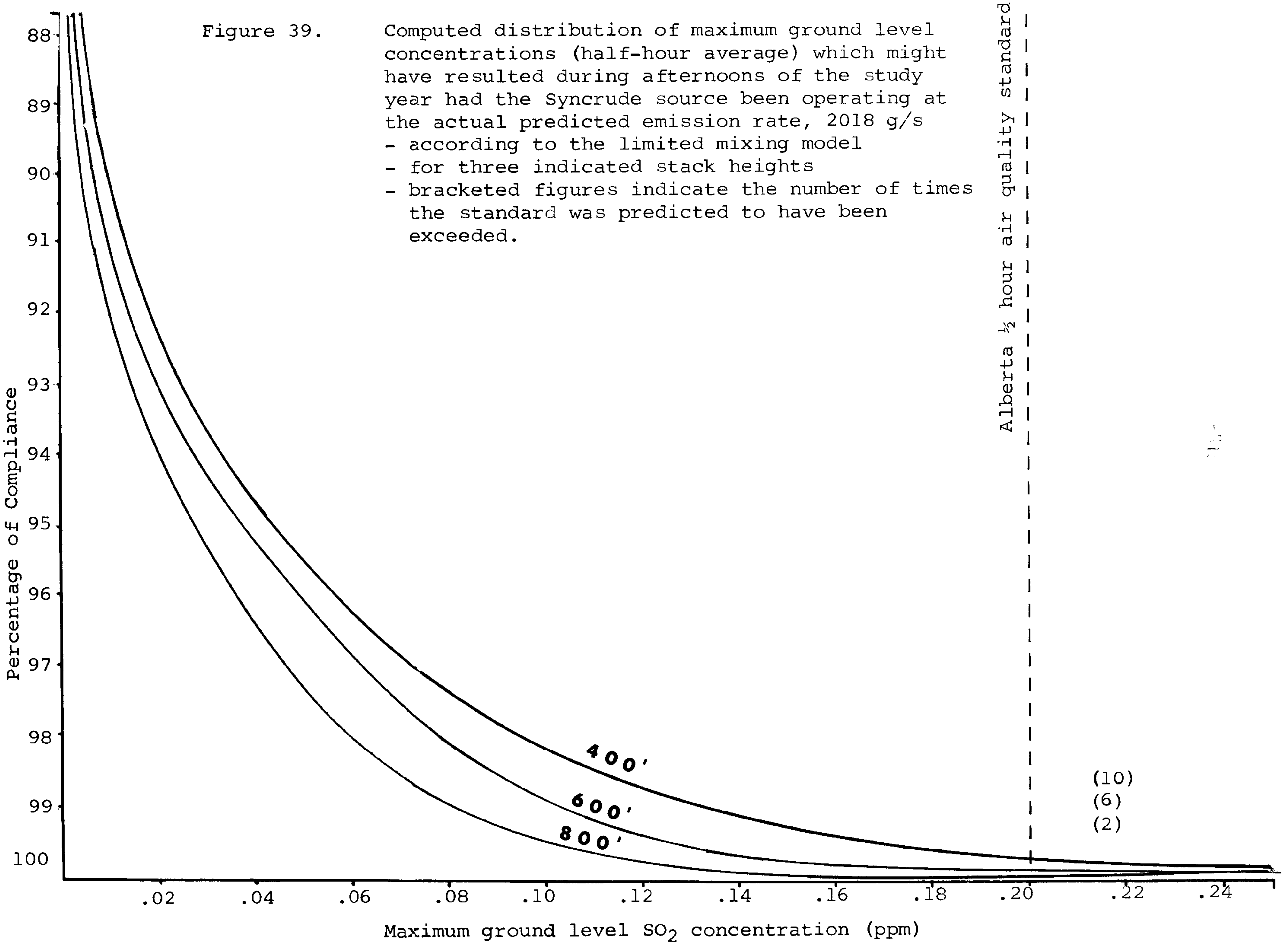


Figure 39. Computed distribution of maximum ground level concentrations (half-hour average) which might have resulted during afternoons of the study year had the Syncrude source been operating at the actual predicted emission rate, 2018 g/s
- according to the limited mixing model
- for three indicated stack heights
- bracketed figures indicate the number of times the standard was predicted to have been exceeded.

2. Inversion Breakup Fumigation Computations

The inversion breakup fumigation is a result of a change in stability at plume level. The fumigation develops in the following manner.

Before sunrise, effluents emitted into a stable layer will form a narrow well-defined plume. After sunrise, the heating of the ground by the sun creates a turbulent layer of air which can grow sufficiently in depth to eventually entrain the plume. The resultant mixing of the plume leads to high ground level concentrations which are generally short-lived (20-30 minutes). Under these conditions, concentrations are estimated by equations given in Pooler[21].

The results of maximum ground level concentration computations are displayed in Figures 40 and 41 for the 3363 and 2018 gram/sec. emission rates. (For the same reasons given in Section III-1, these curves must pass through 365 at an abscissa value of zero.) Figure 41 indicates that even with an 800 foot stack, 55 occurrences (0.3% of the year, assuming a 30-minute duration[22]) in excess of 0.2 ppm might be expected for the lower emission rate.

The predicted occurrences of concentrations of 0.2 ppm or greater as a function of stack height are shown in Figures 42 (emission rate of 3363 grams/sec.) and 43 (emission rate of 2018 grams/sec.). For the permitted emission level of 3363 grams/sec., it can be concluded that an increase of the stack height by 200 ft. above the design height would have reduced ground level fumigation events as much as a reduction of the actual stack height by 200 ft. would have increased the number.

For events of a magnitude well below and well above the half-hour average air quality standard of Alberta, no significant improvement can be gained from extending the stack beyond 600 ft.

In the case of the currently predicted emission level of 2018 grams/sec, the most substantial benefit of increasing the actual stack height by 200 ft. would be gained in terms of a reduction of the number of predicted events of a magnitude of circa 0.2 ppm and smaller. The number of more serious events would not be reduced significantly.

The distribution of the predicted occurrence of ground level concentrations in excess of 0.2 ppm (half hour average) with inversion break-ups is shown in Figure 44, broken down by month. More ground level concentration events in excess of 0.2 ppm would have occurred during the warm season (March to September) than during the colder months. The highest number of inversion break-up events, that would have been associated with significant ground level concentrations, occurred during the months of March and August.

Inversion break-up frequencies may peak in early spring and fall since in winter, the number of break-ups is limited due to insufficient solar heating, while in summer nocturnal inversion frequencies are low.

The distribution of inversion break-up fumigation maxima relative to the 600 foot Syncrude stack and based on soundings taken at the Mildred Lake Weather Station is shown in Figure 45. The distribution shows no marked preference for any direction although there are more maxima in the northern sector than in the southern. Over 95% of the maxima fall within 15 kilometres of the source.

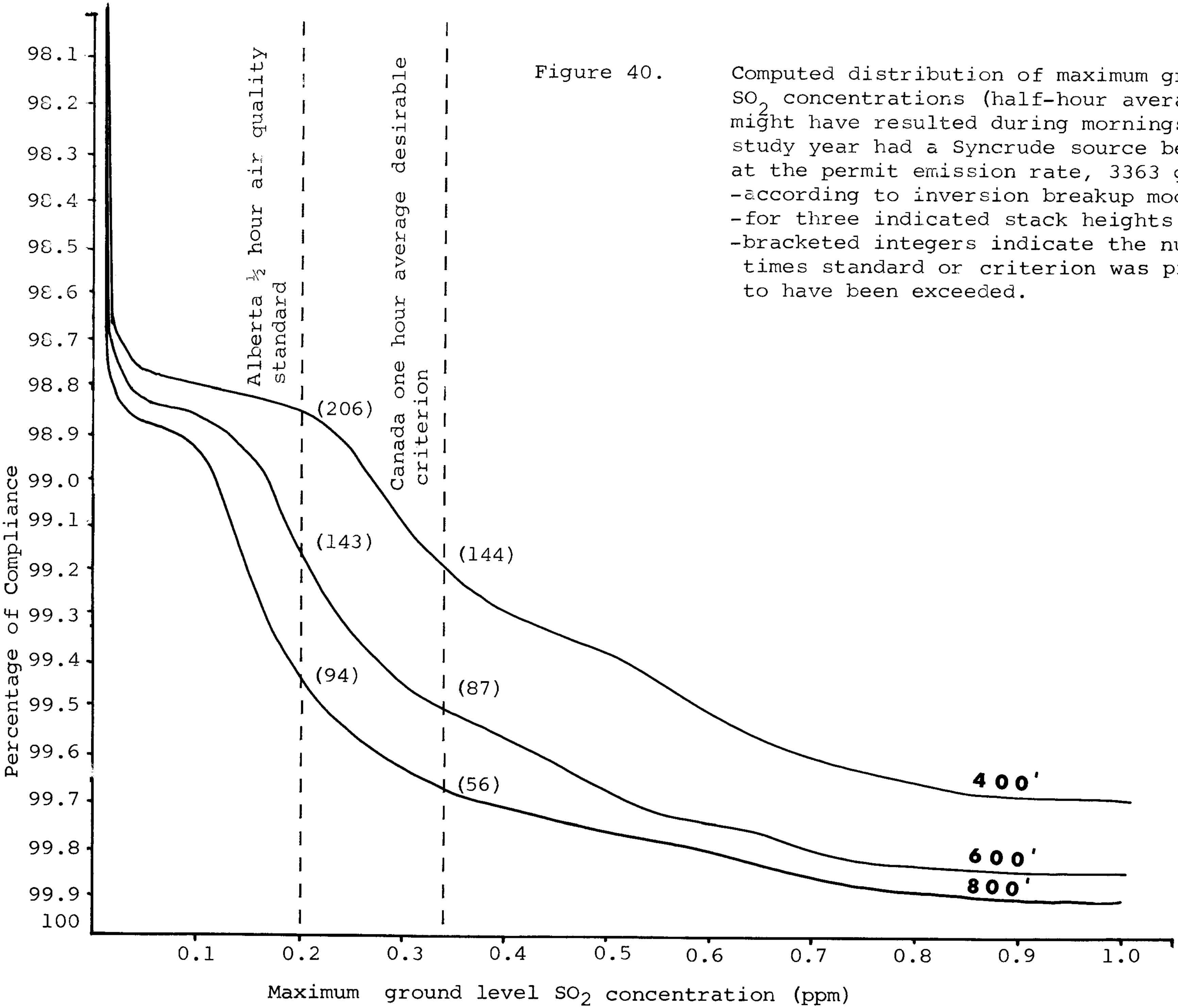


Figure 40. Computed distribution of maximum ground level SO_2 concentrations (half-hour average) which might have resulted during mornings of the study year had a Syncrude source been operating at the permit emission rate, 3363 g/s
-according to inversion breakup model
-for three indicated stack heights
-bracketed integers indicate the number of times standard or criterion was predicted to have been exceeded.

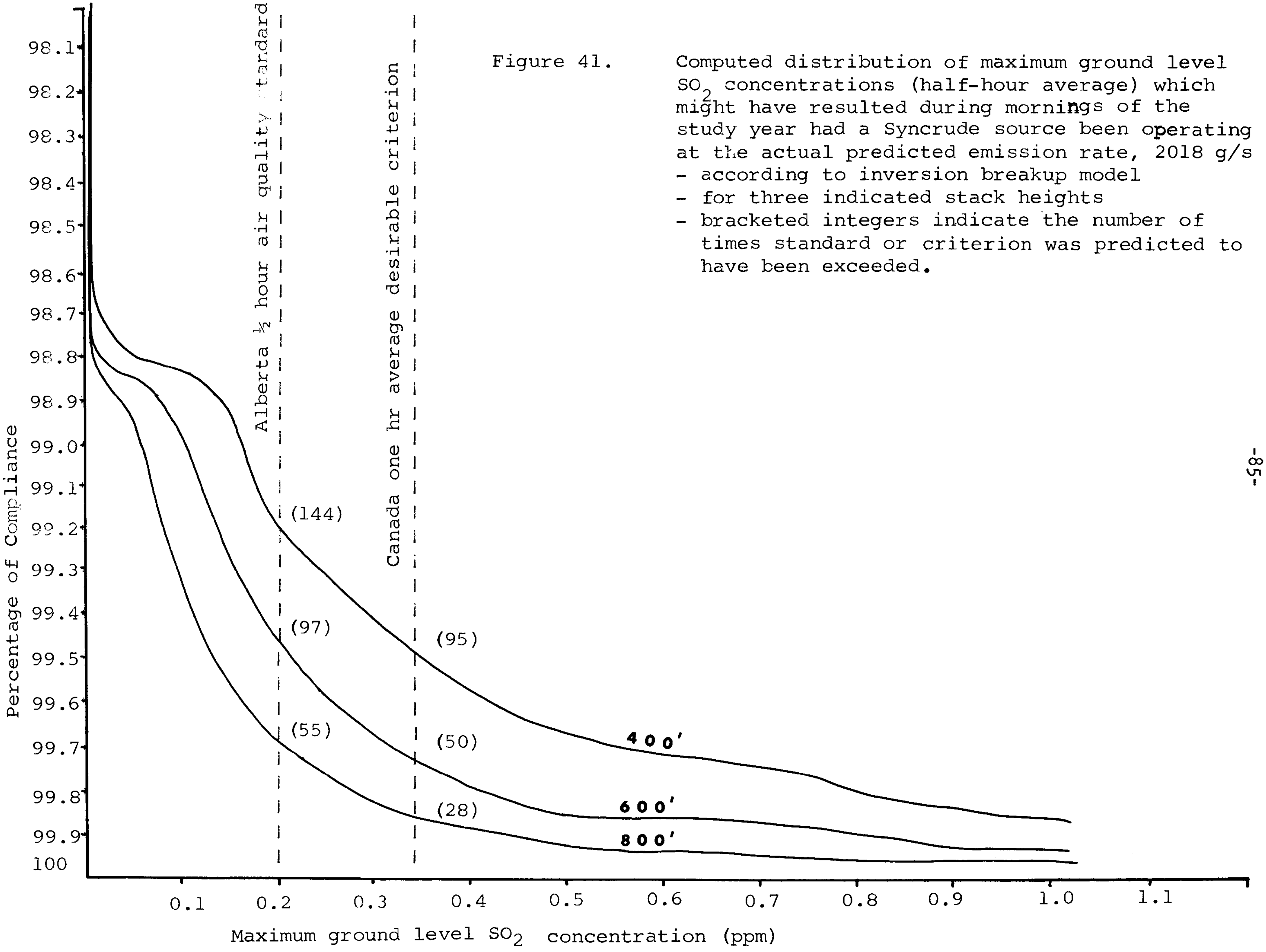


Figure 41. Computed distribution of maximum ground level SO_2 concentrations (half-hour average) which might have resulted during mornings of the study year had a Syncrude source been operating at the actual predicted emission rate, 2018 g/s
- according to inversion breakup model
- for three indicated stack heights
- bracketed integers indicate the number of times standard or criterion was predicted to have been exceeded.

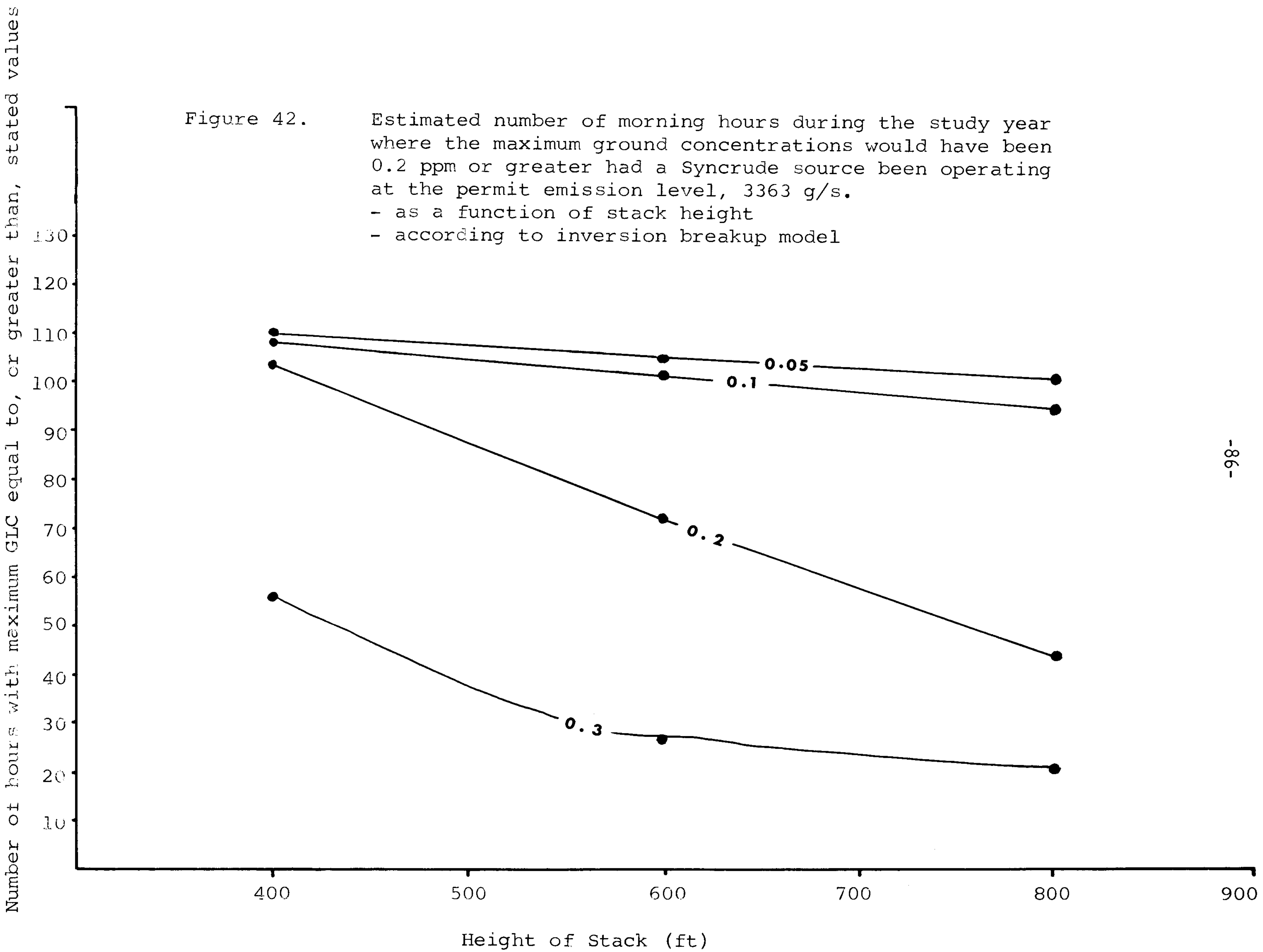


Figure 42. Estimated number of morning hours during the study year where the maximum ground concentrations would have been 0.2 ppm or greater had a Syncrude source been operating at the permit emission level, 3363 g/s.
- as a function of stack height
- according to inversion breakup model

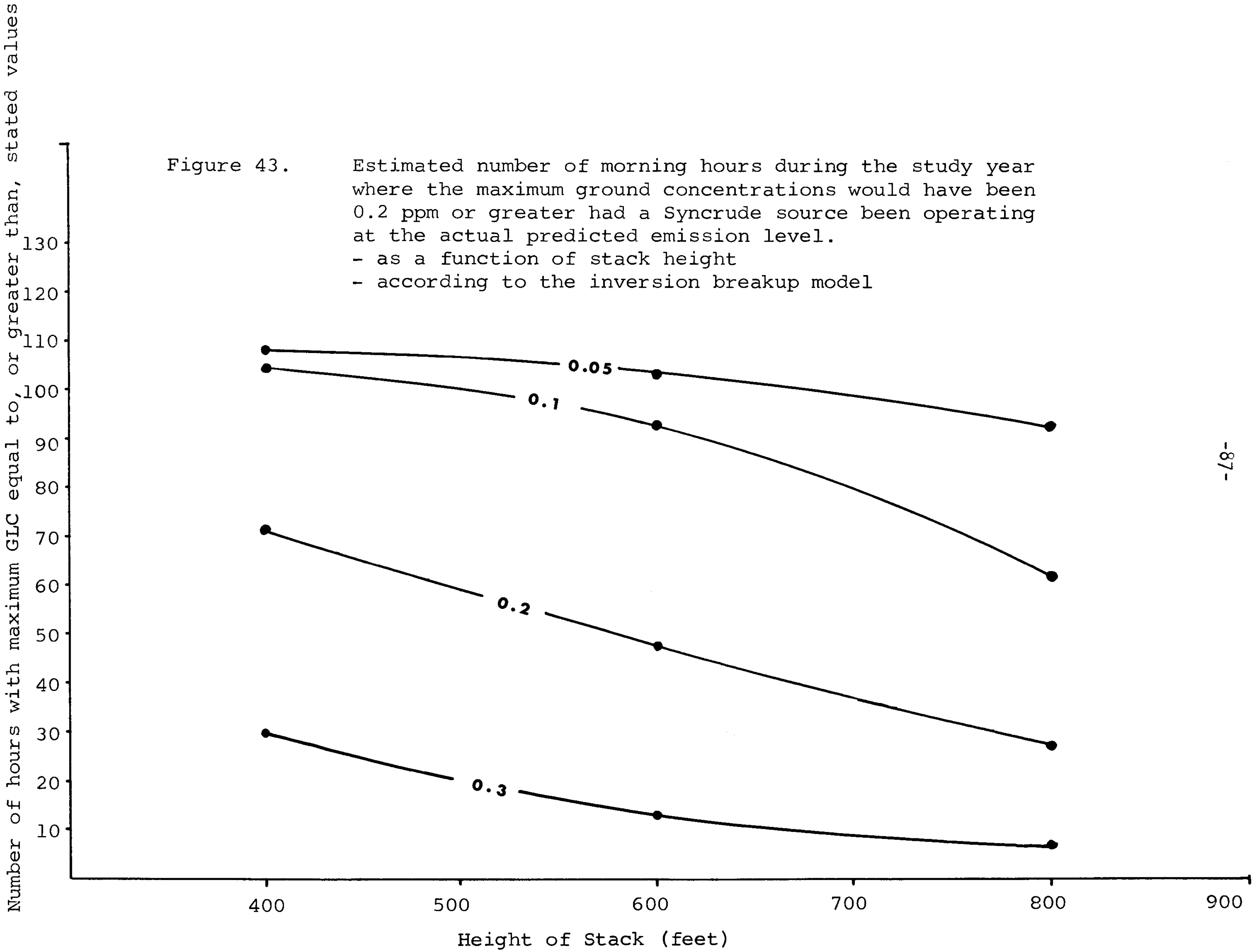
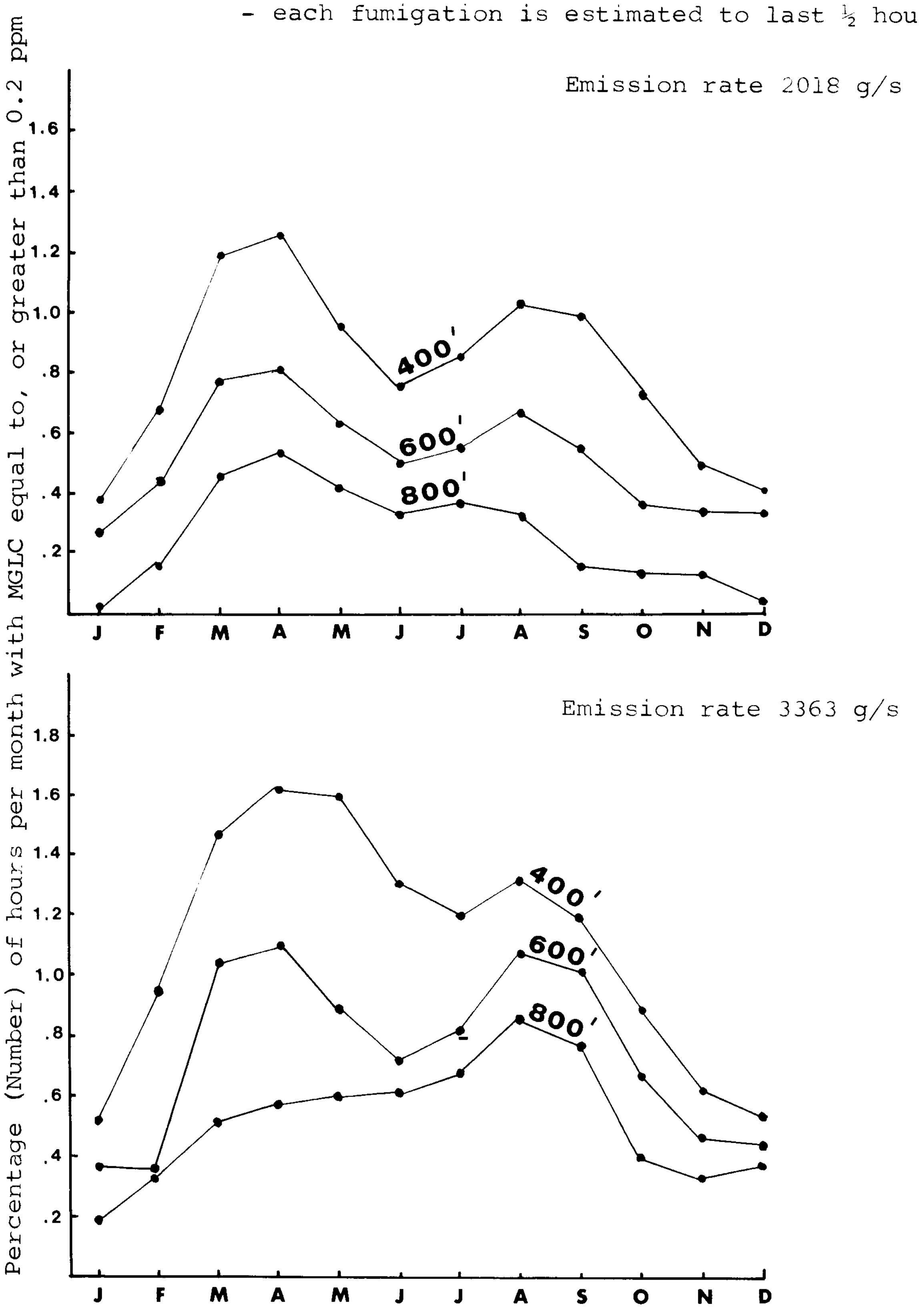


Figure 43. Estimated number of morning hours during the study year where the maximum ground concentrations would have been 0.2 ppm or greater had a Syncrude source been operating at the actual predicted emission level.
- as a function of stack height
- according to the inversion breakup model

Figure 44 . Percentage (number) of hours per month with predicted maximum ground level concentration greater than, or equal to, 0.2 ppm.
- according to inversion breakup model
- for 2 indicated emission rates and 3 stack heights
- each fumigation is estimated to last ½ hour (see text)



3. Gaussian Diffusion in a Stable Atmosphere

Ground impingement has been observed in the case of the G.C.O.S. plume[4].

Whether ground impingement could occur under stable night-time conditions, in the case of the elevated Syncrude stack was investigated. It was found (see Section X) that under stable Gaussian diffusion, concentrations would not approach 0.06 ppm and were, in fact, generally much lower.

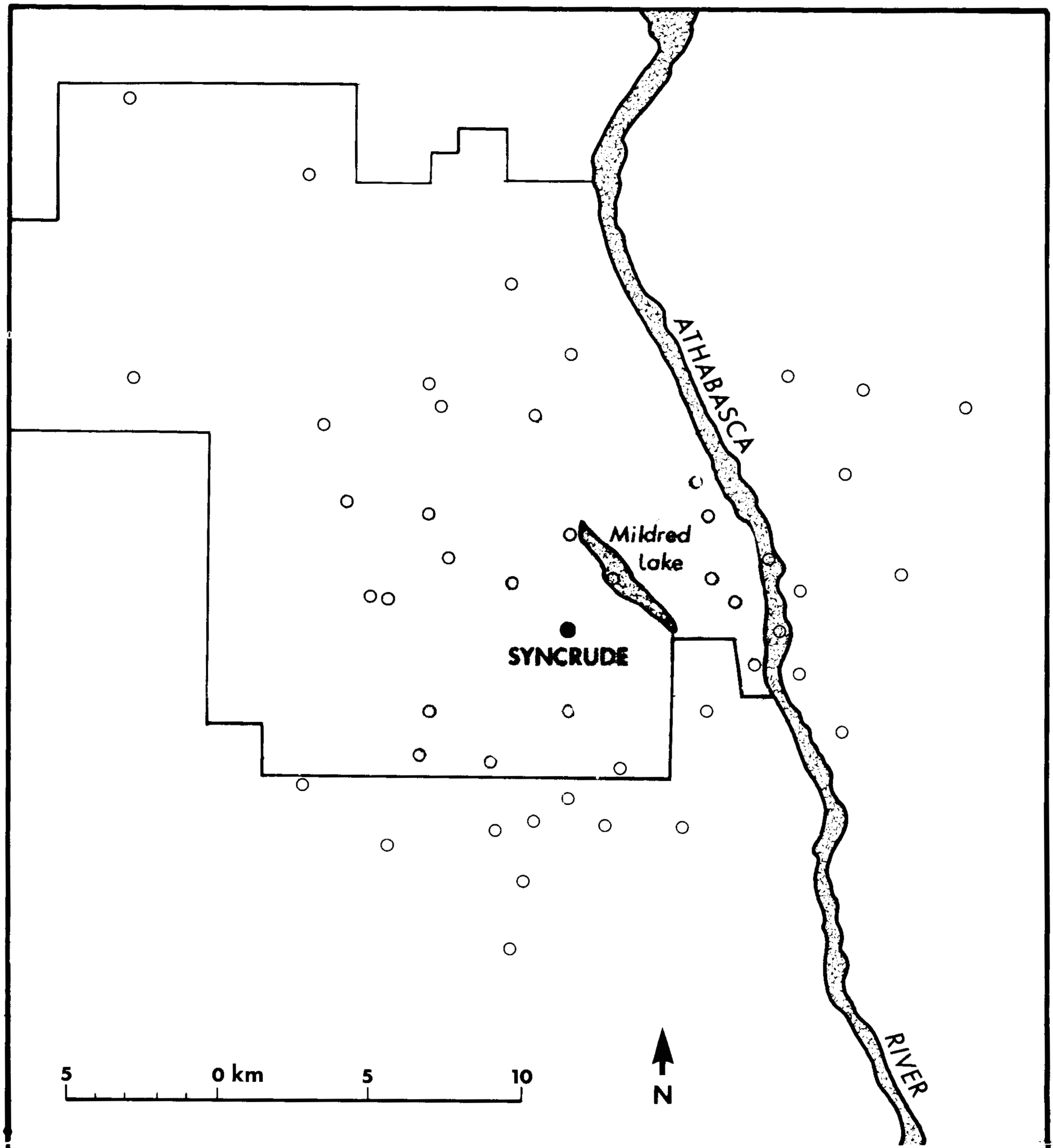


Figure 45. Locations of computed maximum ground level concentration of SO_2 associated with inversion breakup, equal to 0.2 ppm or greater that might have resulted during the study year had a Syncrude stack been operating according to the parameters of Table 9 with an emission rate of 3363 g/s.

- based on the analysis of 190 morning soundings at leases 13 and 17
- boundaries of Syncrude combined leases 17 and 22 are shown.

X MODEL COMPUTATIONS*

The regional model was used to compute ground concentrations, at each one kilometre grid point, corresponding to each day during the study period on which sounding data were available. This was done in order to investigate the size and shape of potentially affected areas. All computations were made for the permitted emission rate of 3363 grams/sec.

1. Concentration Patterns

Several cases of the computed ground level concentration patterns are discussed. The predicted ground level concentrations associated with the most severe case of limited mixing observed during the study year is shown in Figure 46. On this day, a lid height which is near the critical value combined with a low wind speed to yield a predicted potential maximum in excess of 0.5 ppm north of the Syncrude stack. The total area with concentrations in excess of .17 ppm would have been 39 square kilometres with the bulk of that area just north of the Syncrude stack. Note that the 0.02 ppm isopleth follows the river valley to the north. The abrupt termination of this isopleth at about 57° 33' marks the northern boundary of the grid. The .02 ppm isopleth might otherwise be seen to extend a further 15 or 20 km north.

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*Note that all model computations of SO_2 are expressed in terms of a one hour average, for which the Alberta air quality standard is 0.17 ppm.

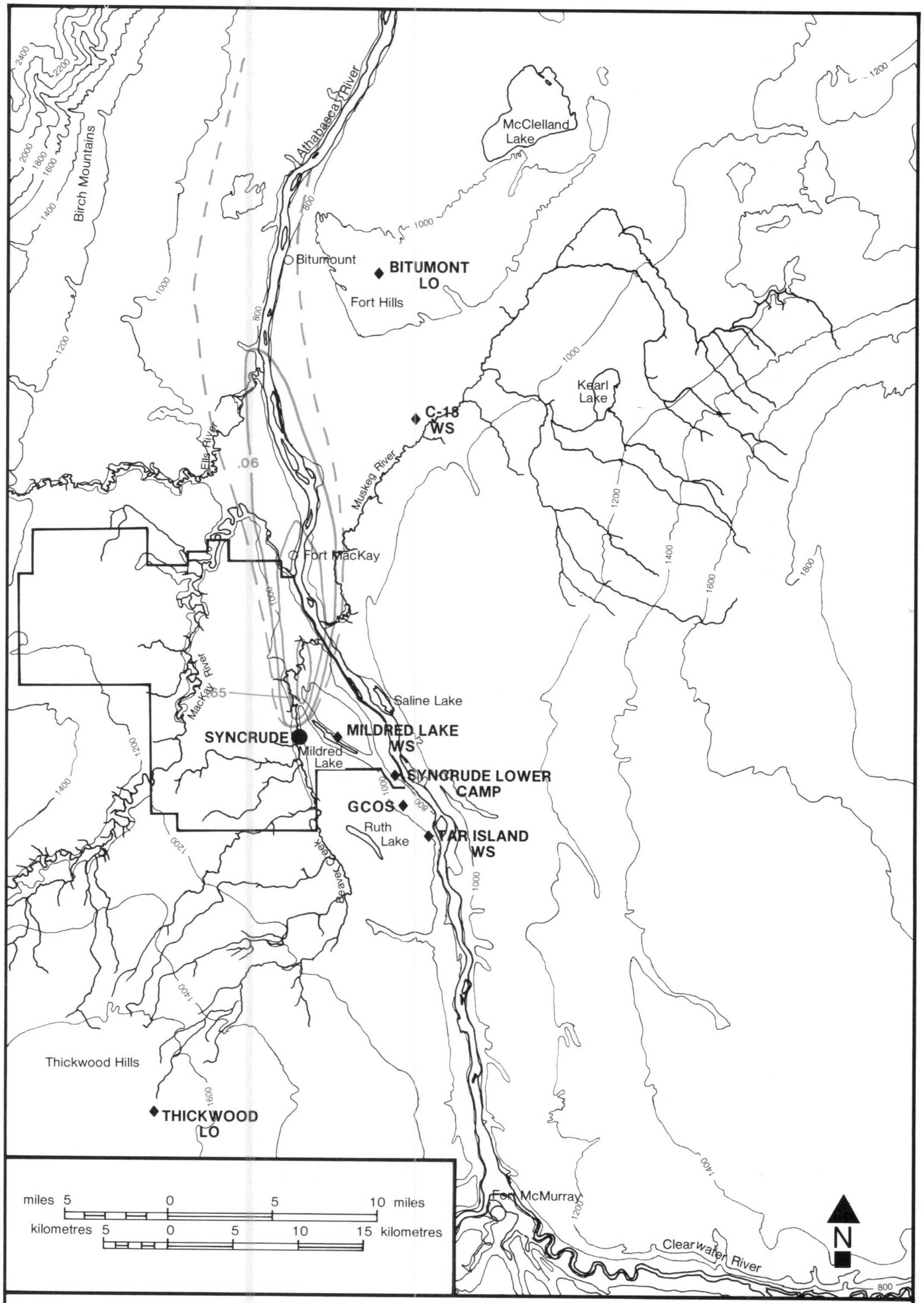

FIGURE 46

A limited mixing situation with near critical mixing height and a low wind speed. Mixing height= 440 m; wind speed = 0.9 m/s; plume layer stable. A situation of such limited ventilation was observed on only one afternoon of the study period.

The limited mixing condition of Figure 47 demonstrates the effect of a near critical mixing height combined with moderate wind speed. The critical mixing height is the one which is high enough to entrain the plume but low enough to severely reduce ventilation. Ground concentrations due to limited mixing which exceed 0.17 ppm might have occurred on 10 afternoons of the study year out of a total of the 273 for which sufficient data are available to perform the computation. The majority of limited mixing cases with near critical mixing height occurred in the fall and winter of the study year. The spring and summer mixing heights were generally high.

Figure 48 demonstrates a case of limited mixing under a very high lid; this is essentially Gaussian diffusion since the effects of plume reflection would not appear at the ground for a very great distance downwind. The accompanying low wind speed contributes to predicted ground concentrations up to 0.19 ppm. A high limit to mixing with low wind speed leading to ground concentrations in excess of 0.17 ppm would have occurred on 14 afternoons during the study period out of a possible 273. The occurence of this type of event was equally divided among the seasons.

Gaussian diffusion under stable conditions would not have been associated with ground concentrations in excess of 0.17 ppm during the study period. Figure 49 is an example of this typical night-time situation.

Figure 50 demonstrates a situation where an inversion breakup fumigation is predicted to result in ground concentrations as high as 1.1 ppm. The light wind speed was a major factor in producing these theoretical

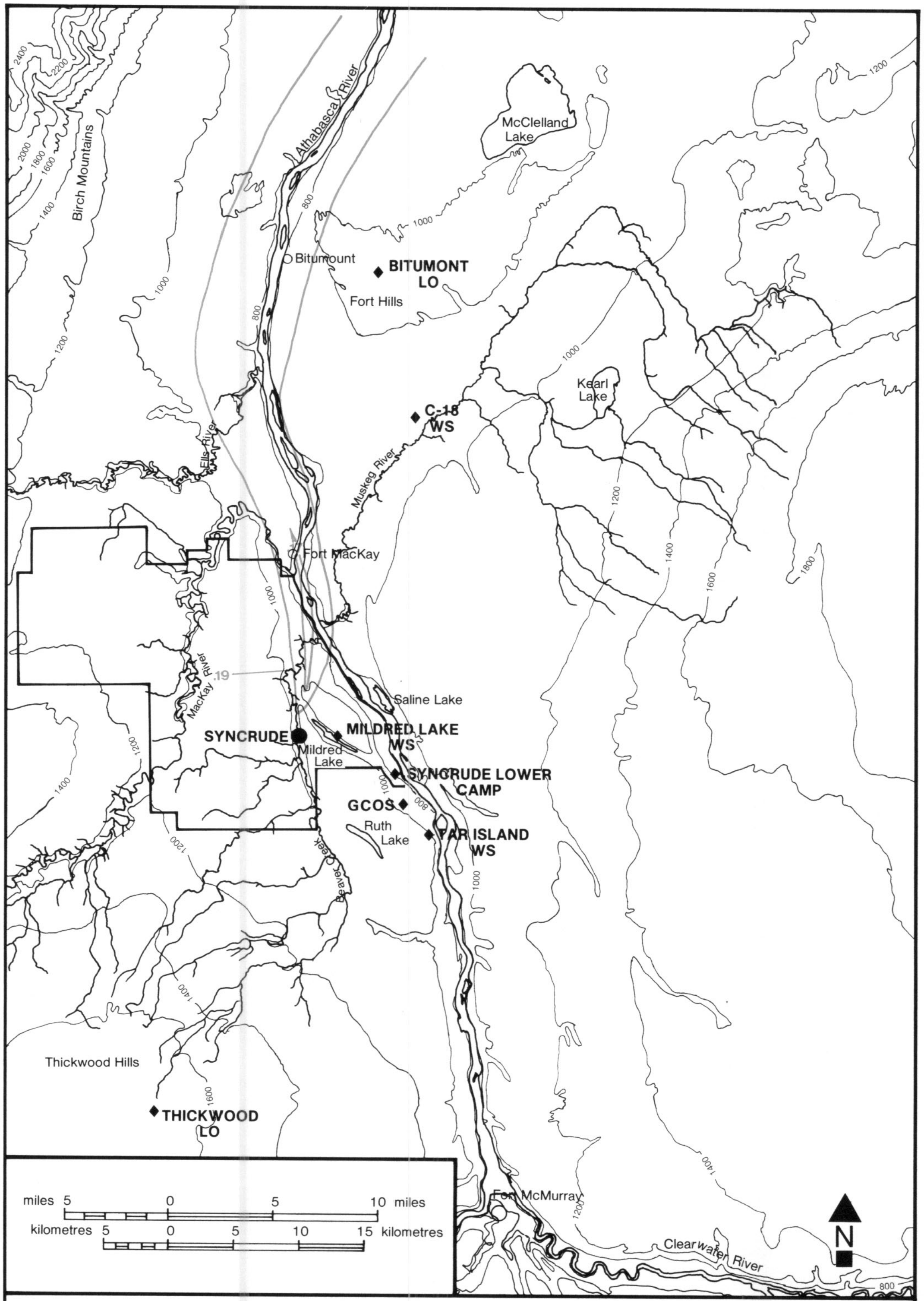

FIGURE 47

A limited mixing situation with near critical mixing height and a moderate wind speed. Mixing height = 512 m; wind speed= 4.5 m/s; plume layer slightly stable. Near critical mixing heights leading to a ground concentration in excess of 0.17 ppm would have occurred on 10 afternoons (of a possible 275) during the study period and predominately during the cold season.

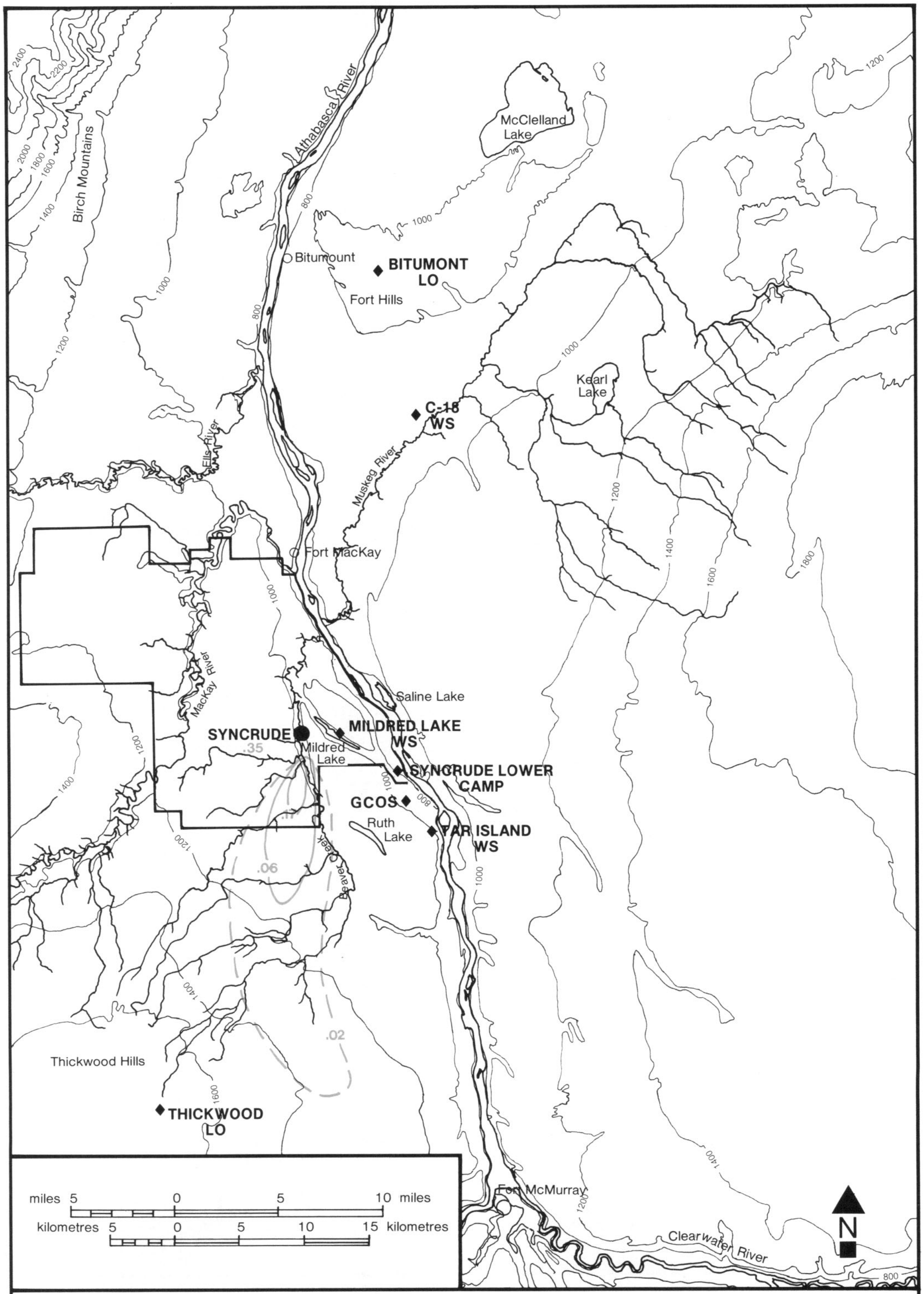

FIGURE 48

A limited mixing situation with a very high lid (essentially Gaussian Diffusion) and low wind speed. Wind speed = 1.3 m/s; mixing height 1312 m; plume layer slightly stable. A high limit to mixing with low wind speed leading to ground concentrations in excess of 0.17 ppm would have occurred on 14 (of a possible 273) afternoons during the study period. The incidents were divided evenly among the seasons.

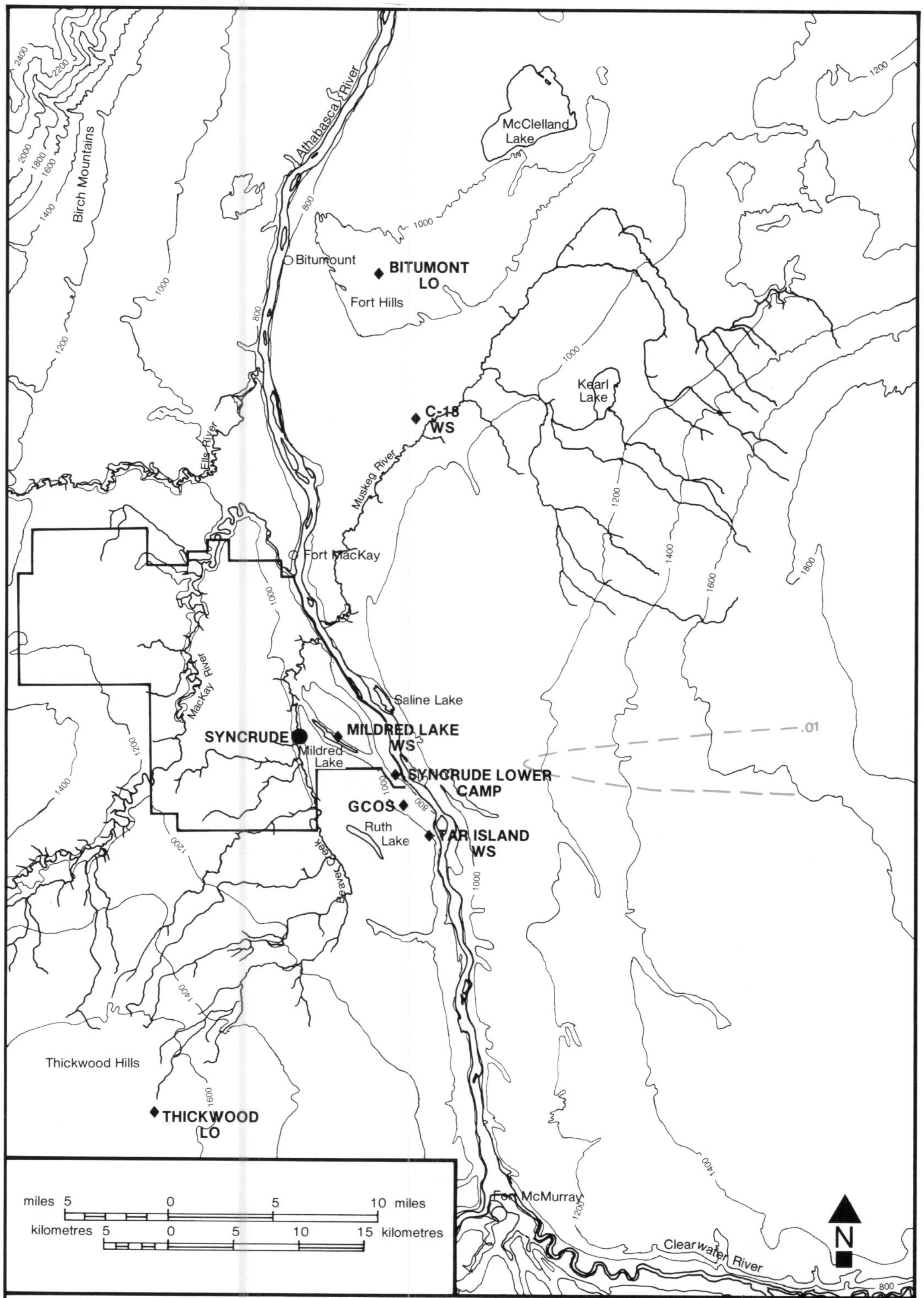

FIGURE 49

Gaussian diffusion under stable conditions and moderate wind speed. Class 5 stability; wind speed = 3 m/s; plume layer stable. This typical night-time situation would have been associated with ground concentrations well below 0.17 ppm during the study period.

concentrations. Fumigations predicted to result in such high ground concentrations (i.e. 1.0 ppm or greater) would have occurred on 17 out of a possible 251 mornings during the study period. These episodes generally last for 30 minutes or less, however.

In Figure 51, a more common type of inversion breakup fumigation is depicted - that associated with a moderate wind speed. Inversion breakups which may have resulted in ground concentrations greater than 0.17 ppm occurred on 97 mornings out of a possible 251 during the study period. They would have been most frequent during the spring and summer seasons.

2. Regional distribution of the number of predicted events

In order to assess cumulative effects, the number of occurrences of computed concentrations which equalled or exceeded 0.17 ppm at each point in the Tar Sands grid (spacing = 1 km.) were summed over 3 month periods. All computations were done assuming the emission parameters of Table 9 and an emission rate of 3363 grams per second. The results are displayed in maps (Figures 52 through 55) which show isopleths of the predicted number of occurrences of ground concentrations of 0.17 ppm or greater. The area outside the outer solid line would have experienced no events. The area inside this line could have experienced one or more occurrences. Nine occurrences of a ground concentration in excess of 0.17 ppm was the maximum found for any grid point during any season.

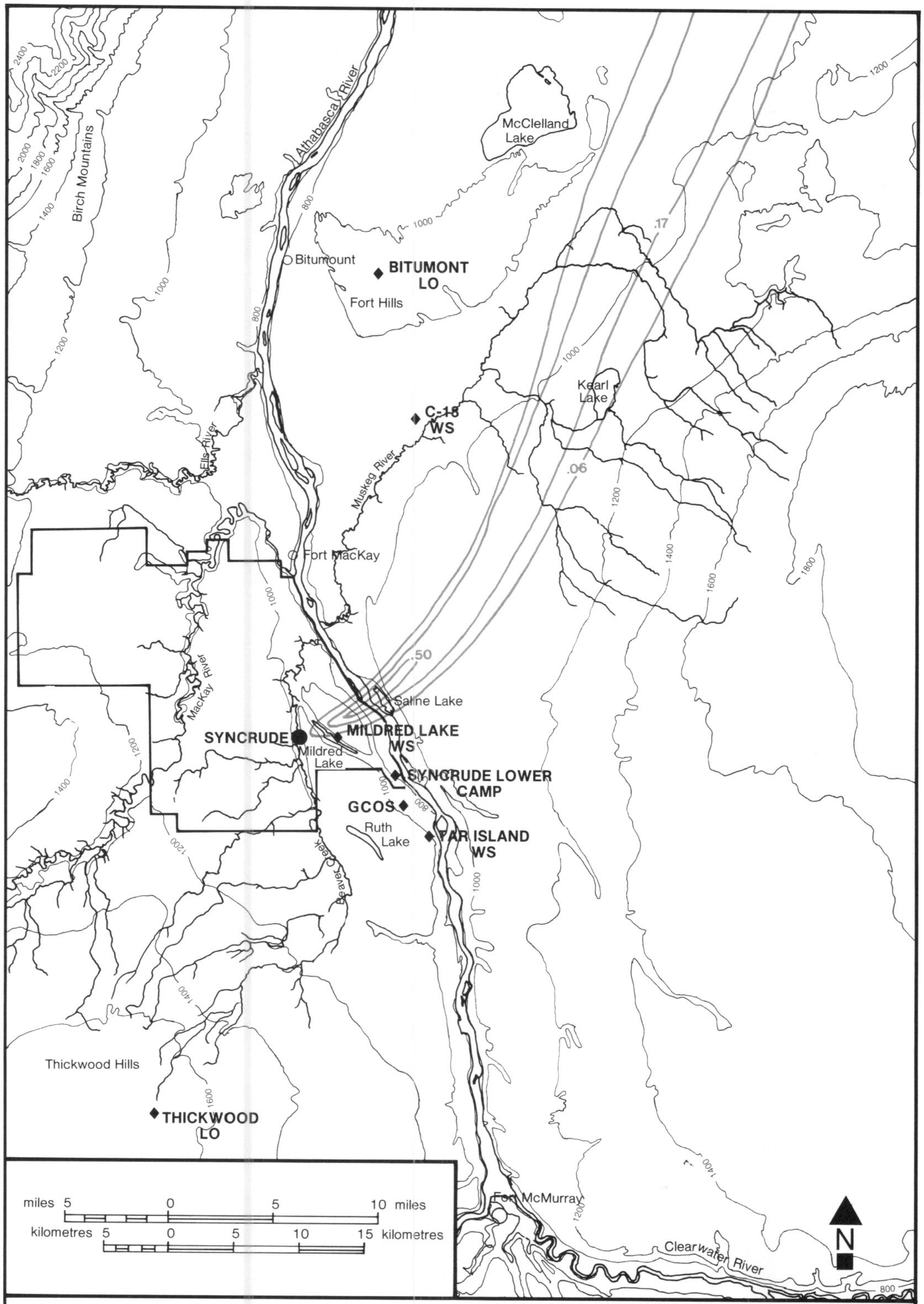

FIGURE 50

An inversion breakup fumigation (mean duration about 30 minutes) with light wind speed. Class 3 stability upon breakup; wind speed =1.8 m/s. Inversion breakup fumigations resulting in such severe ground concentration would have occurred on 17 mornings (of a possible 251) during the study period.

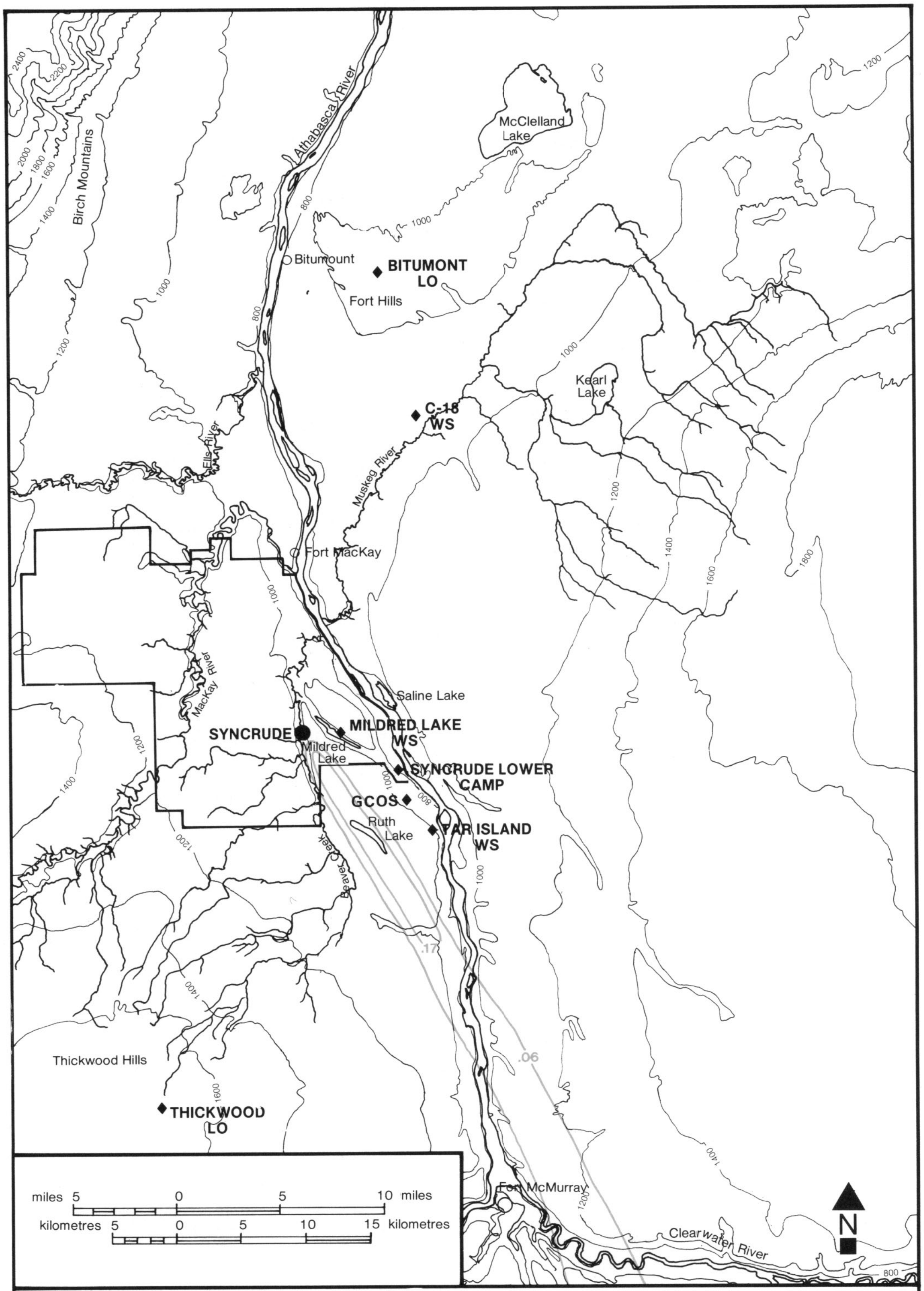

FIGURE 51

An inversion breakup fumigation (mean duration about 30 minutes) with moderate wind speed. Class 2 stability; upon breakup; wind speed = 4.2 m/s. Inversion breakup fumigations resulting in ground concentrations in excess of 0.17 ppm could have occurred on 97 mornings (of a possible 251) during the study period and would have been most frequent during the Spring and Summer seasons.

Isopleths of the predicted number of occurrences of 0.17 ppm or greater for the entire twelve month study are shown in Figure 56. Fourteen occurrences was the maximum found at any grid point.

For the autumn season (Figure 52) based on 54 mornings and 61 afternoon soundings (i.e. 64% of the data), the area that would have experienced one or more incidents of greater than 0.17 ppm would have covered 50 square kilometres north and east of the Syncrude stack. The area affected to the greatest extent was a 3 square kilometre region north of the Syncrude chimney.

The winter season (Figure 53) was based on 41 morning and 48 afternoon soundings (49% of the data). More than a single incident of greater than 0.17 ppm would have been experienced over a relatively small area (about 14 square kilometres) lying east of the Syncrude source. The analysis of the spring season distribution (Figure 54) was based on 86 morning and 86 afternoon sounding (96% of data). The coverage is far more extensive than either of the previous seasons, and the pattern is quite complex. In all, an area of about 1200 square kilometres could have experienced ground concentrations in excess of 0.17 ppm on more than one occasion. Approximately 200 square kilometres could have been affected by more than three occurrences, and 13 square kilometres by seven, eight, or nine occurrences. This latter area lies north of the stack.

The summer distribution analysis (Figure 55) was based on 70 morning and 78 afternoon soundings (82% of data). The area coverage is similar to the spring season prediction consisting of 1200 square kilometres with ground

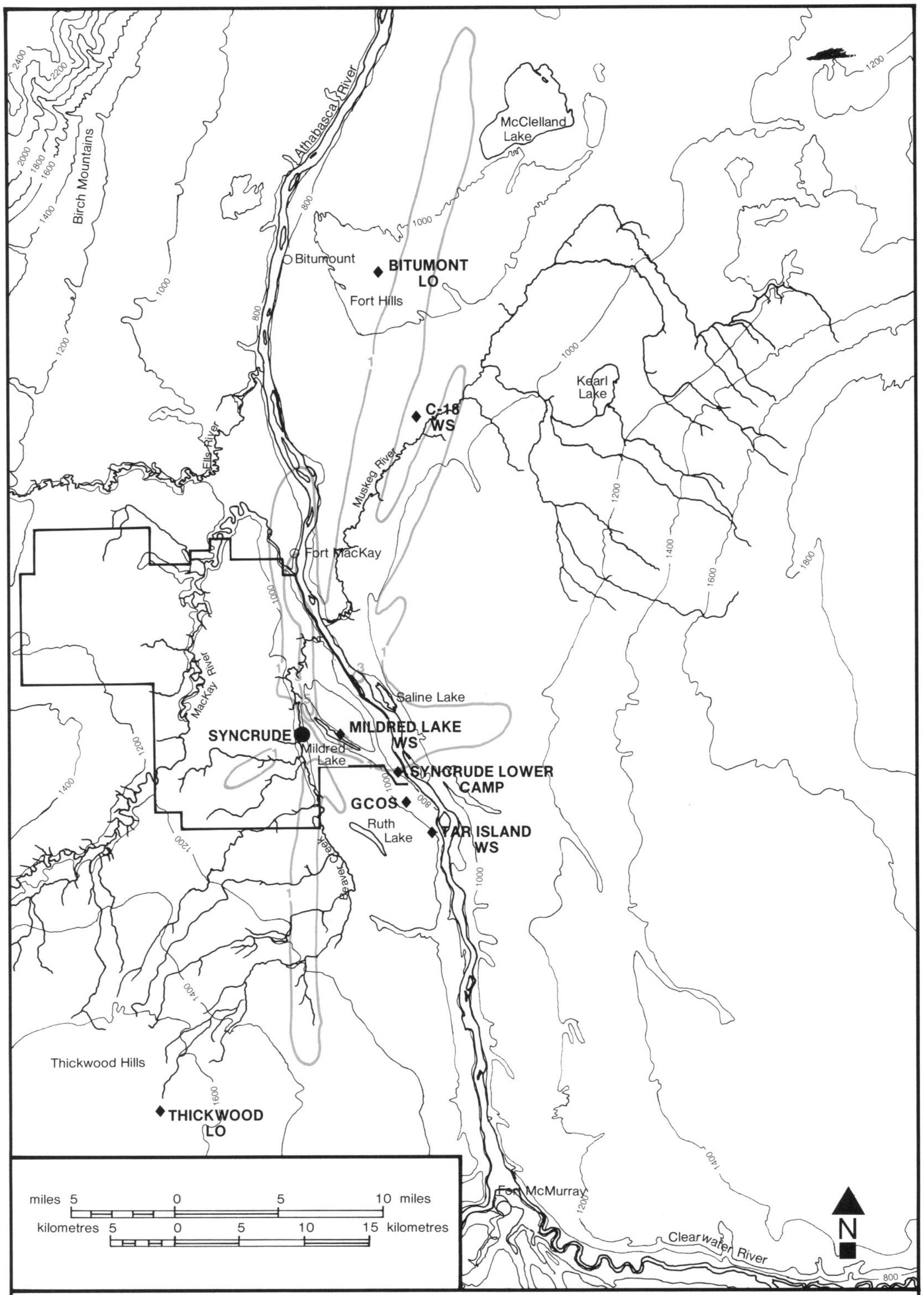

FIGURE 52

Estimate of area that would have experienced ground concentrations of 0.17 ppm SO_2 (one hour average) or greater during fall 1974 due to Syncrude emissions alone, based on temperature and wind data covering 54 mornings and 61 afternoons. Measured meteorological data were input to the MEP air quality model to estimate the frequency of such occurrences at each grid intersection of a 1 kilometre grid covering the study area. The analysis assumed the emission parameters of table 9 with an emission rate of 3363 g/s. G.C.O.S. emissions are not included.

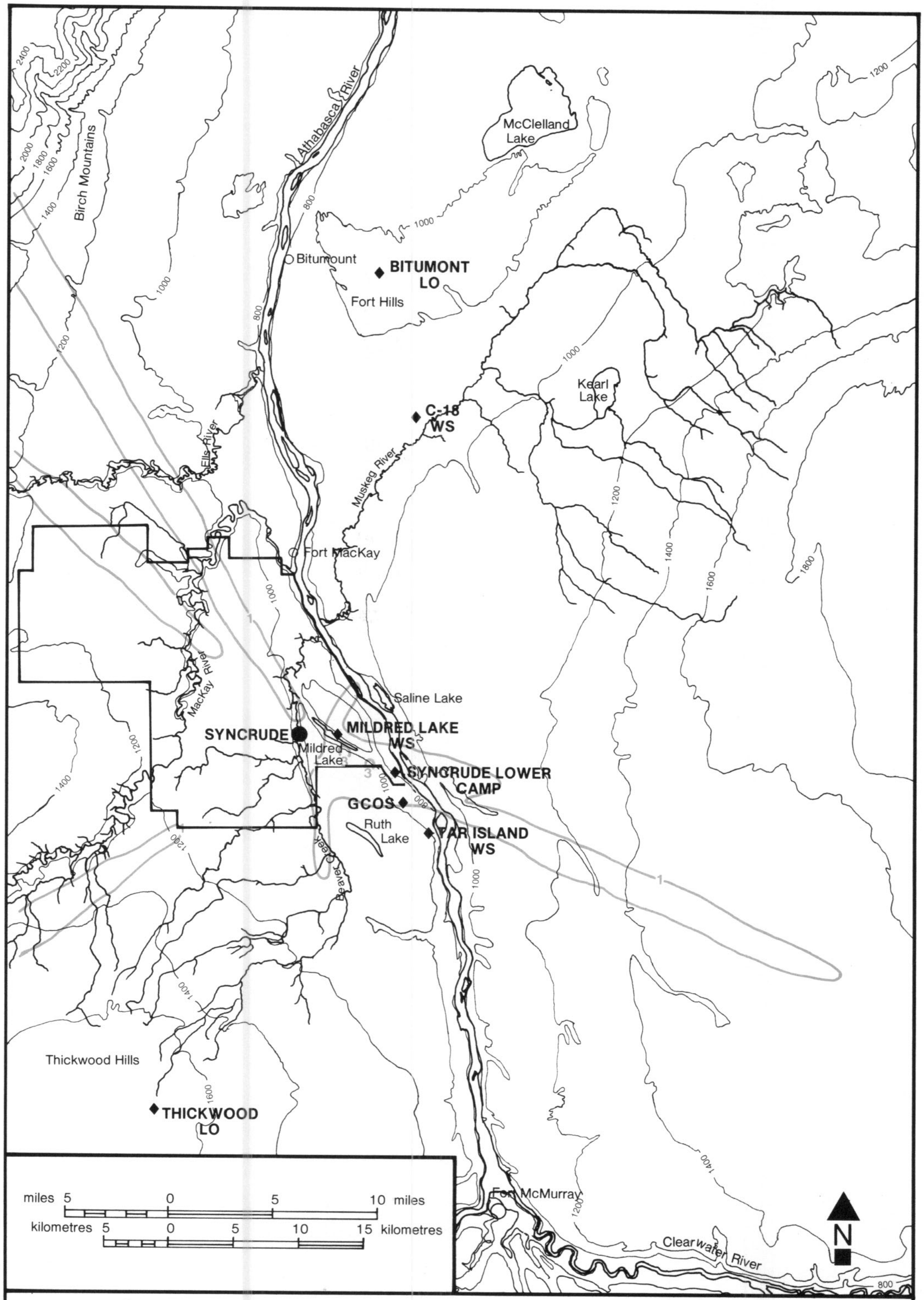

FIGURE 53

Estimate of area that would have experienced ground concentrations of 0.17 ppm SO_2 (one hour average) or greater during winter 1974-5 due to Syncrude emissions alone, based on temperature and wind data covering 41 mornings and 48 afternoons. Measured meteorological data were input to the MEP air quality model to estimate the frequency of such occurrences at each grid intersection on a 1 kilometre grid covering the study area. The analysis assumed the emission parameters of table 9 with an emission rate of 3363 g/s. G.C.O.S. emissions are not included.

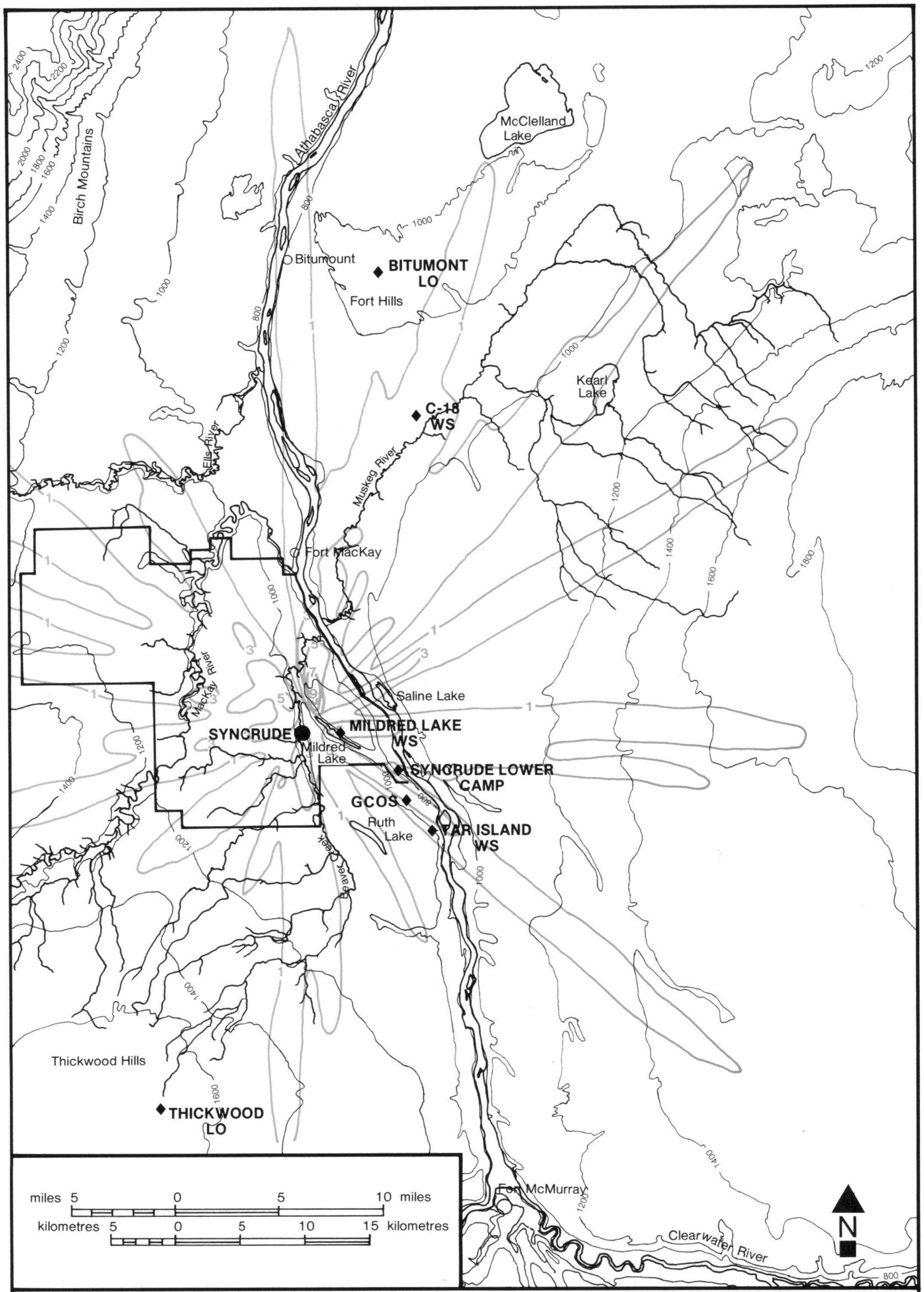

FIGURE 54

Estimate of area that would have experienced ground concentrations of 0.17 ppm SO_2 (one hour average) or greater during spring 1975 due to Syncrude emissions alone, based on temperature and wind data covering 86 mornings and 86 afternoons. Measured meteorological data were input to the MEP air quality model to estimate the frequency of such occurrences at each grid intersection on a 1 kilometre grid covering the study area. The analysis assumed the emission parameters of table 9 with an emission rate of 3363 g/s. G.C.O.S. emissions are not included.

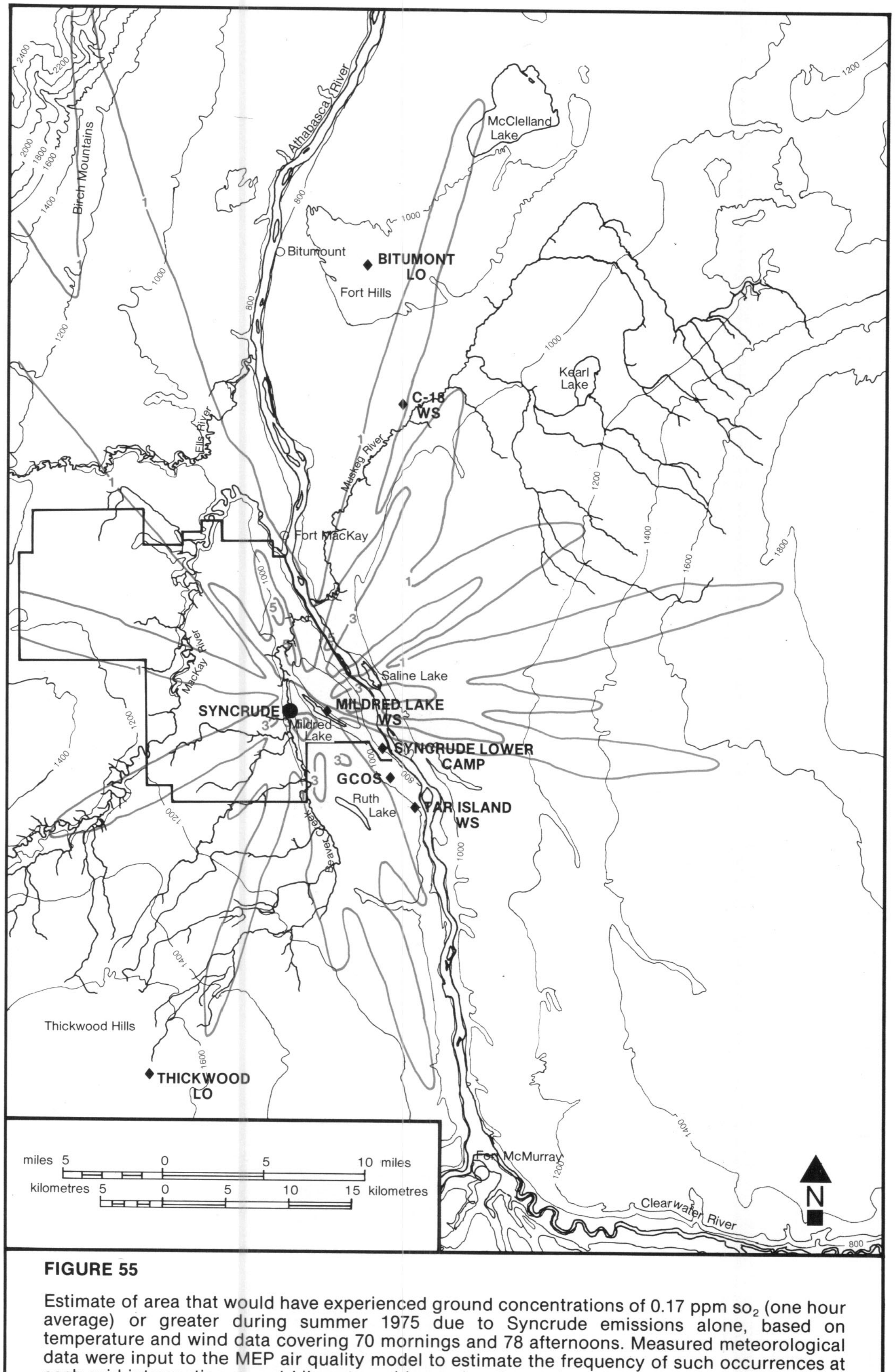

FIGURE 55

Estimate of area that would have experienced ground concentrations of 0.17 ppm SO_2 (one hour average) or greater during summer 1975 due to Syncrude emissions alone, based on temperature and wind data covering 70 mornings and 78 afternoons. Measured meteorological data were input to the MEP air quality model to estimate the frequency of such occurrences at each grid intersection on a 1 kilometre grid covering the study area. The analysis assumed the emission parameters of table 9 with an emission rate of 3363 g/s. G.C.O.S. emissions are not included.

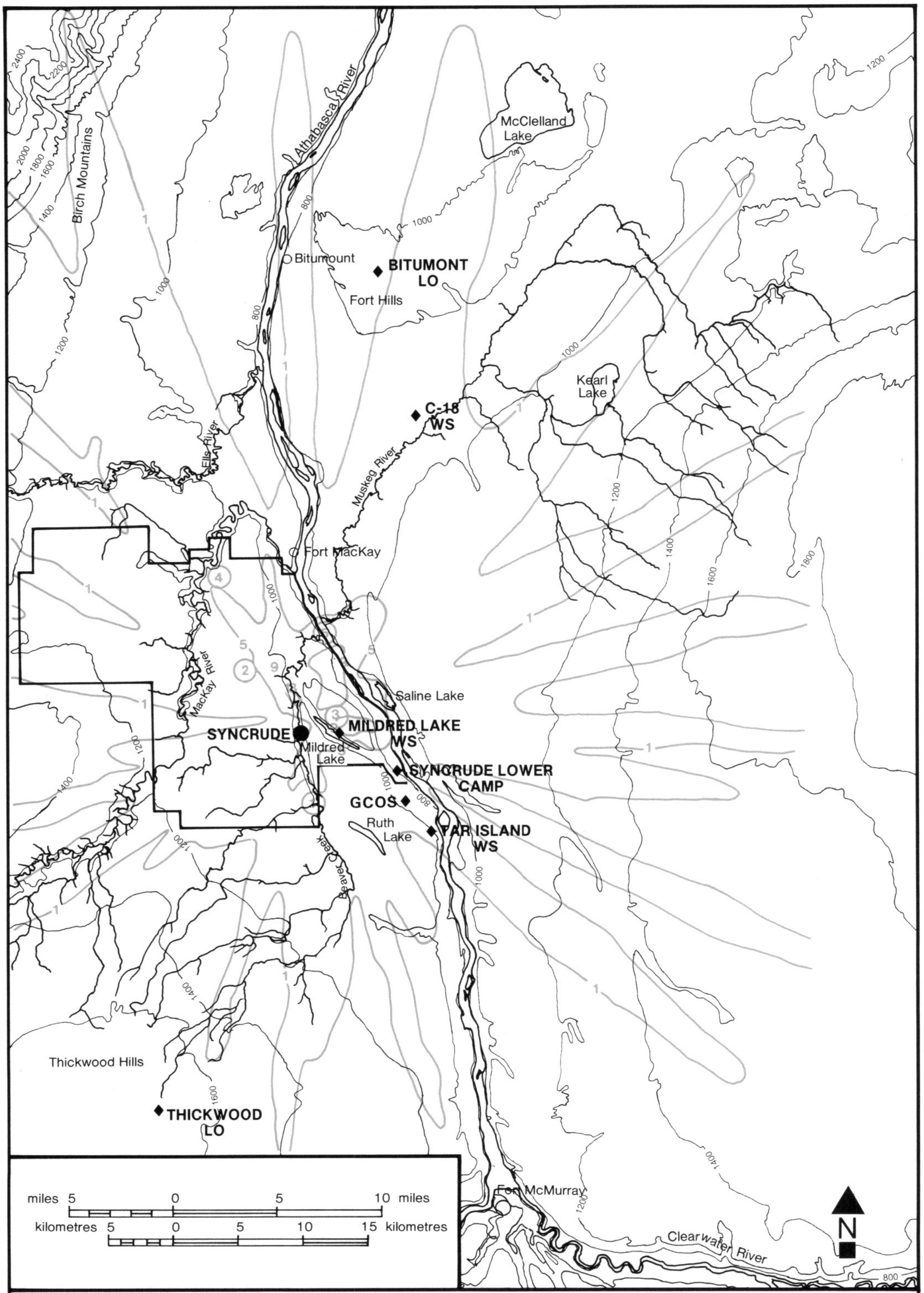

FIGURE 56

Estimate of area that would have experienced ground concentrations of 0.17 ppm so$_2$ (one hour average) or greater during the entire study period due to Syncrude emissions alone, based on temperature and wind data covering 251 mornings and 273 afternoons. Measured meteorological data were input to the MEP air quality model to estimate the frequency of such occurrences at each grid intersection on a 1 kilometre grid covering the study area. The analysis assumed the emission parameters of table 9 with an emission rate of 3363 g/s. G.C.O.S. emissions are not included, MONITOR LOCATION 2 concentrations greater than 0.17 ppm on more than one occasion, and 200 square kilometres on which concentrations could have exceeded 0.17 ppm on over seven occasions. The areas that were predicted to be affected to the greatest extent are located within five kilometres of the stack.

The event statistics are presented in an alternative form, that is, in terms of compliance percentages in figures 57 through 61. These percentages were calculated by assuming that the duration of inversion breakup and limited mixing events were one half hour and three hours respectively. Predicted ground concentrations were less than 0.17 ppm more than 99% of the time at all grid points.

The results should be interpreted as estimates of what might have ensued during the one year atmospheric sounding program. As stated earlier, they apply only to those days during the study year for which atmospheric sounding data were available; the number of mornings and afternoons included is indicated on each map.

They assume potential operations consistent with the parameters of Table 9 with the stack height at 600 feet and emission rate of 3363 grams per second.

While a study of this nature can assist the designers of new plants in the selection of strategies for the control and dispersion of emissions to meet regulatory requirements and standards, the Syncrude plant was subjected

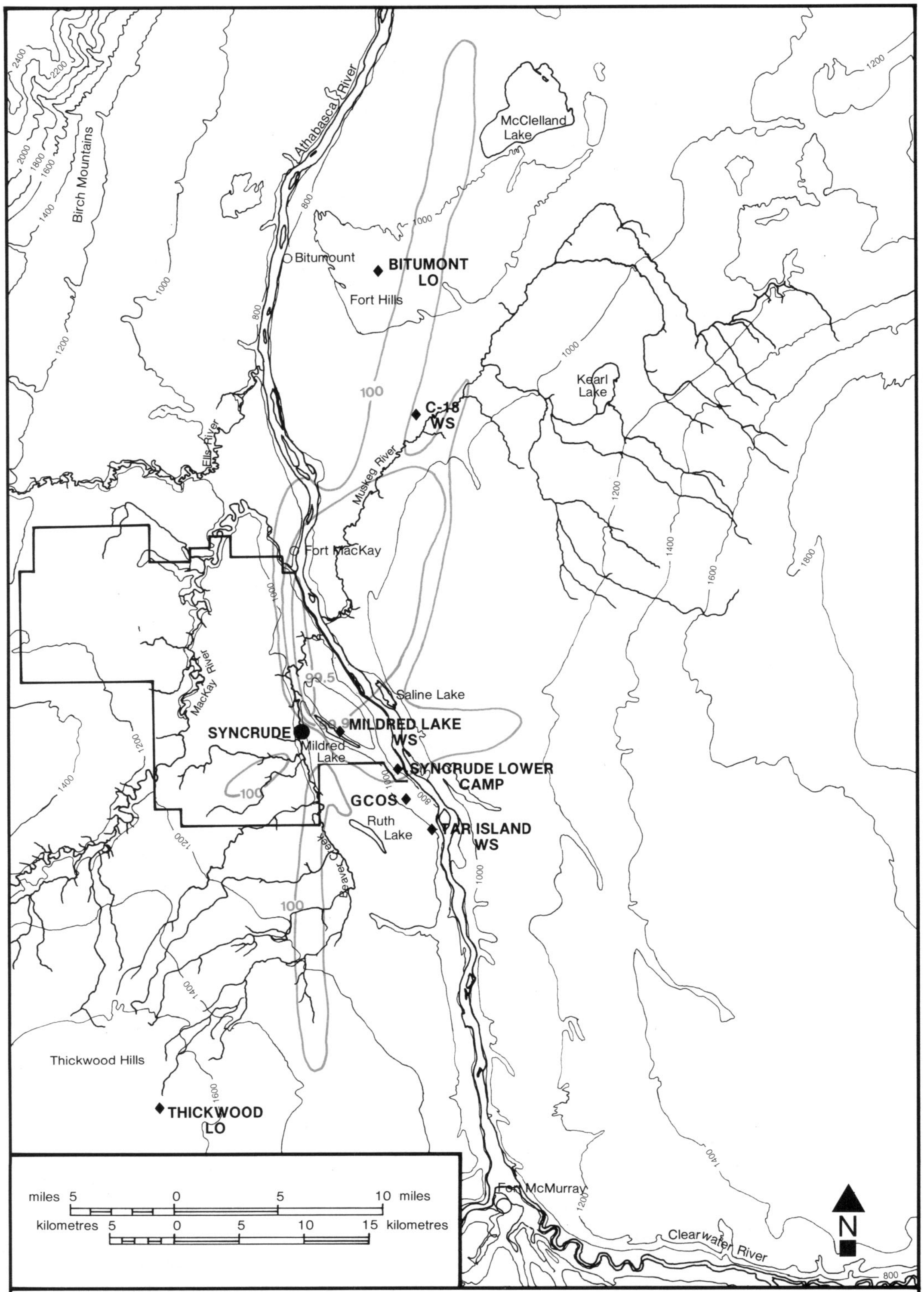

FIGURE 57

Estimated percentage of the time with ground concentrations less than 0.17 ppm so$_2$ (one hour average) during fall 1974 due to Syncrude emissions alone, based on temperature and wind data covering 54 mornings and 61 afternoons. Measured meteorological data were input to the MEP air quality model to estimate the frequency of such occurrences at each grid intersection on a 1 kilometre grid covering the study area. Inversion breakup and limited mixing events were assumed to have an average duration of 0.5 and 3 hours respectively. The analysis assumed the emission parameters of table 9 with an emission rate of 3363 g/s. G.C.O.S. emissions are not included.

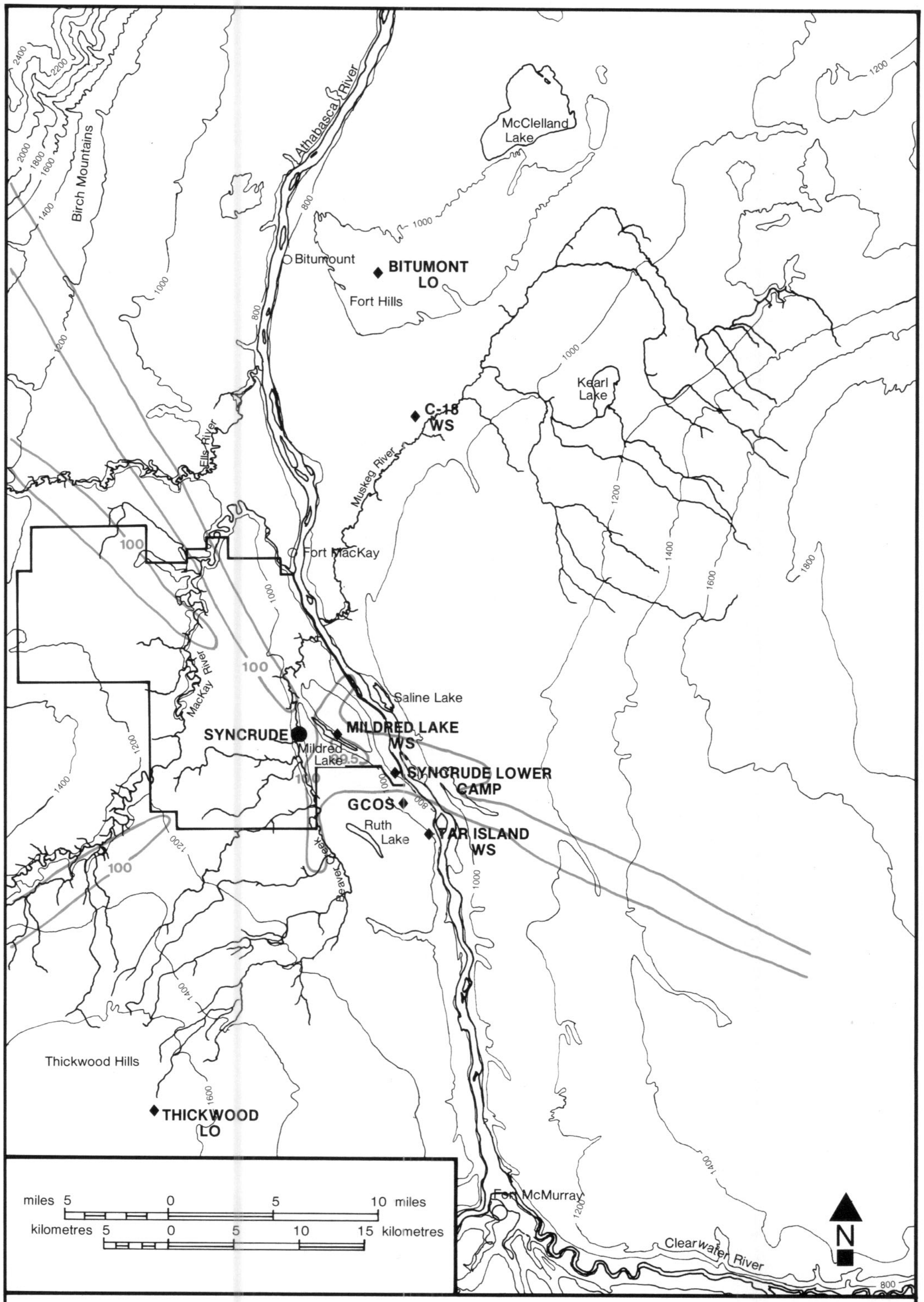

FIGURE 58

Estimated percentage of the time with ground concentrations less than 0.17 ppm SO_2 (one hour average) during winter 1974-5 due to Syncrude emissions alone, based on temperature and wind data covering 41 mornings and 48 afternoons. Measured meteorological data were input to the MEP air quality model to estimate the frequency of such occurrences at each grid intersection on a 1 kilometre grid covering the study area, inversion breakup and limited mixing events were assumed to have an average duration of 0.5 and 3 hours respectively. The analysis assumed the emission parameters of table 9 with an emission rate of 3363 g/s. G.C.O.S. emissions are not included.

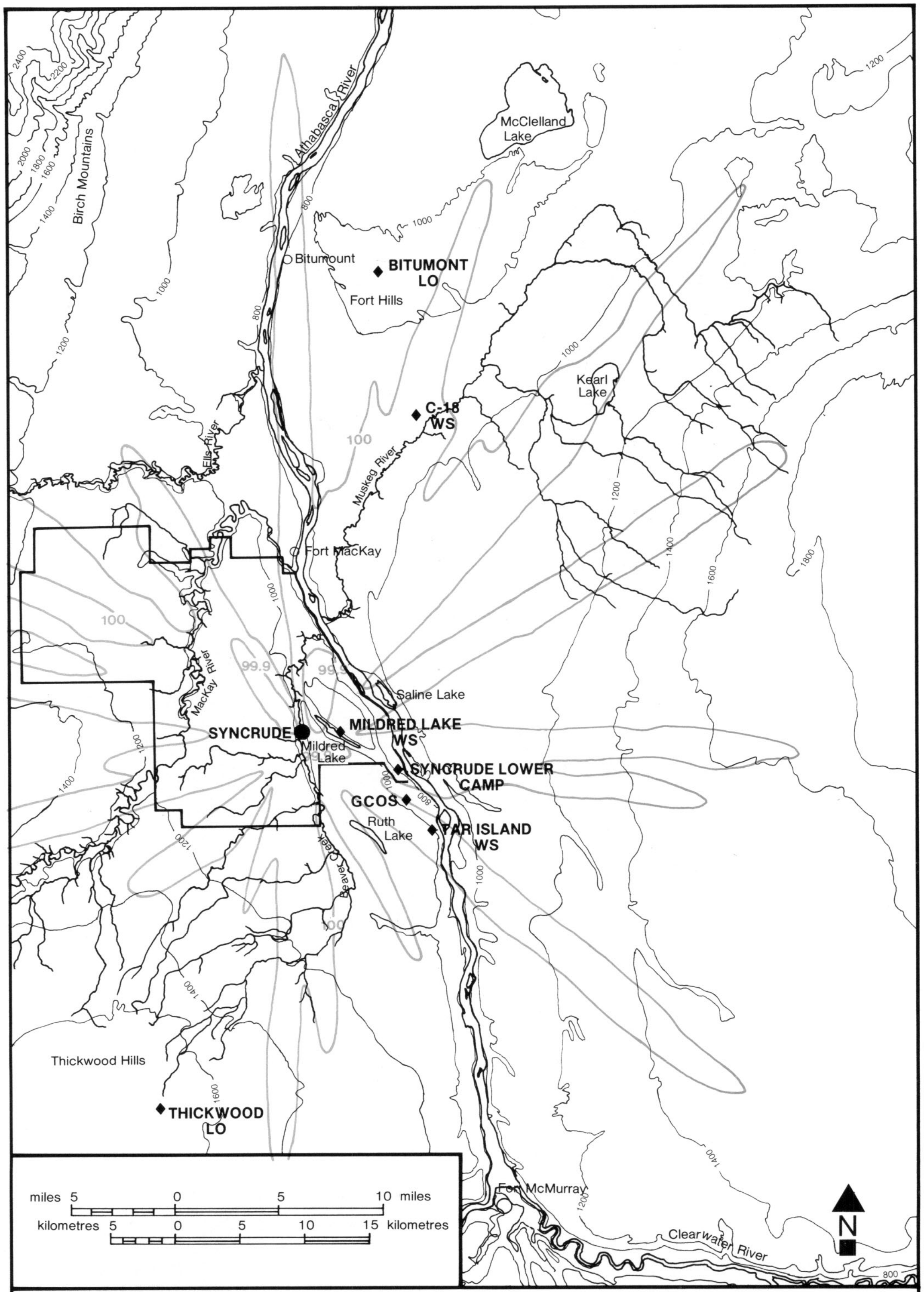

FIGURE 59

Estimated percentage of the time with ground concentrations less than 0.17 ppm so$_2$ (one hour average) during spring 1975 due to Syncrude emissions alone, based on temperature and wind data covering 86 mornings and 86 afternoons. Measured meteorological data were input to the MEP air quality model to estimate the frequency of such occurrences at each grid intersection of a 1 kilometre grid covering the study area. Inversion breakup and limited mixing events were assumed to have an average duration of 0.5 and 3 hours respectively. The analysis assumed the emission parameters of table 9 with an emission rate of 3363 g/s. G.C.O.S. emissions are not included.

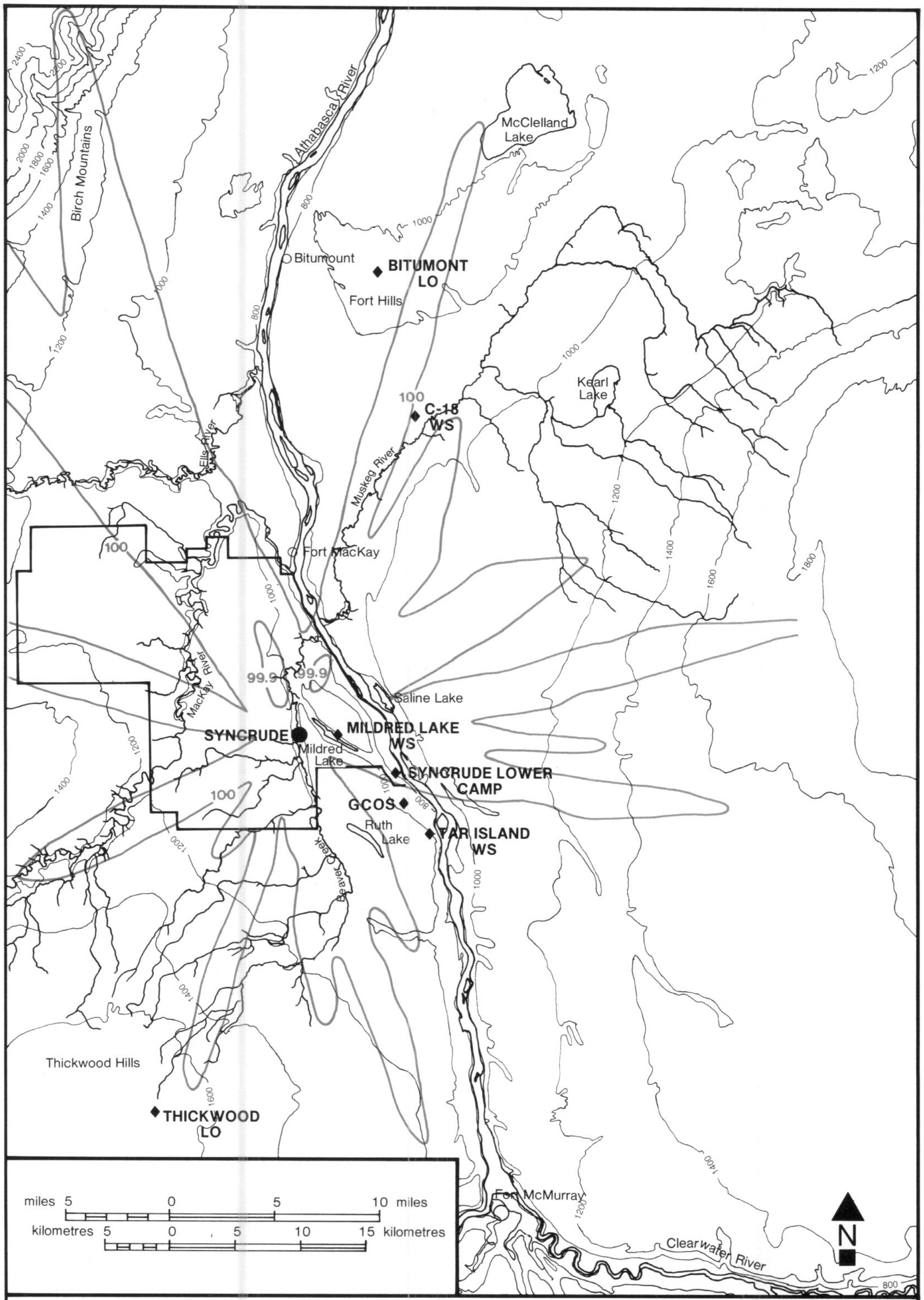

FIGURE 60

Estimated percentage of the time with ground concentrations less than 0.17 ppm so_2 (one hour average) during summer 1975 due to Syncrude emissions alone, based on temperature and wind data covering 70 mornings and 78 afternoons. Measured meteorological data were input to the MEP air quality model to estimate the frequency of such occurrences at each grid intersection on a 1 kilometre grid covering the study area. Inversion breakup and limited mixing events were assumed to have an average duration of 0.5 and 3 hours respectively. The analysis assumed the emission parameters of table 9 with an emission rate of 3363 g/s. G.C.O.S. emissions are not included.

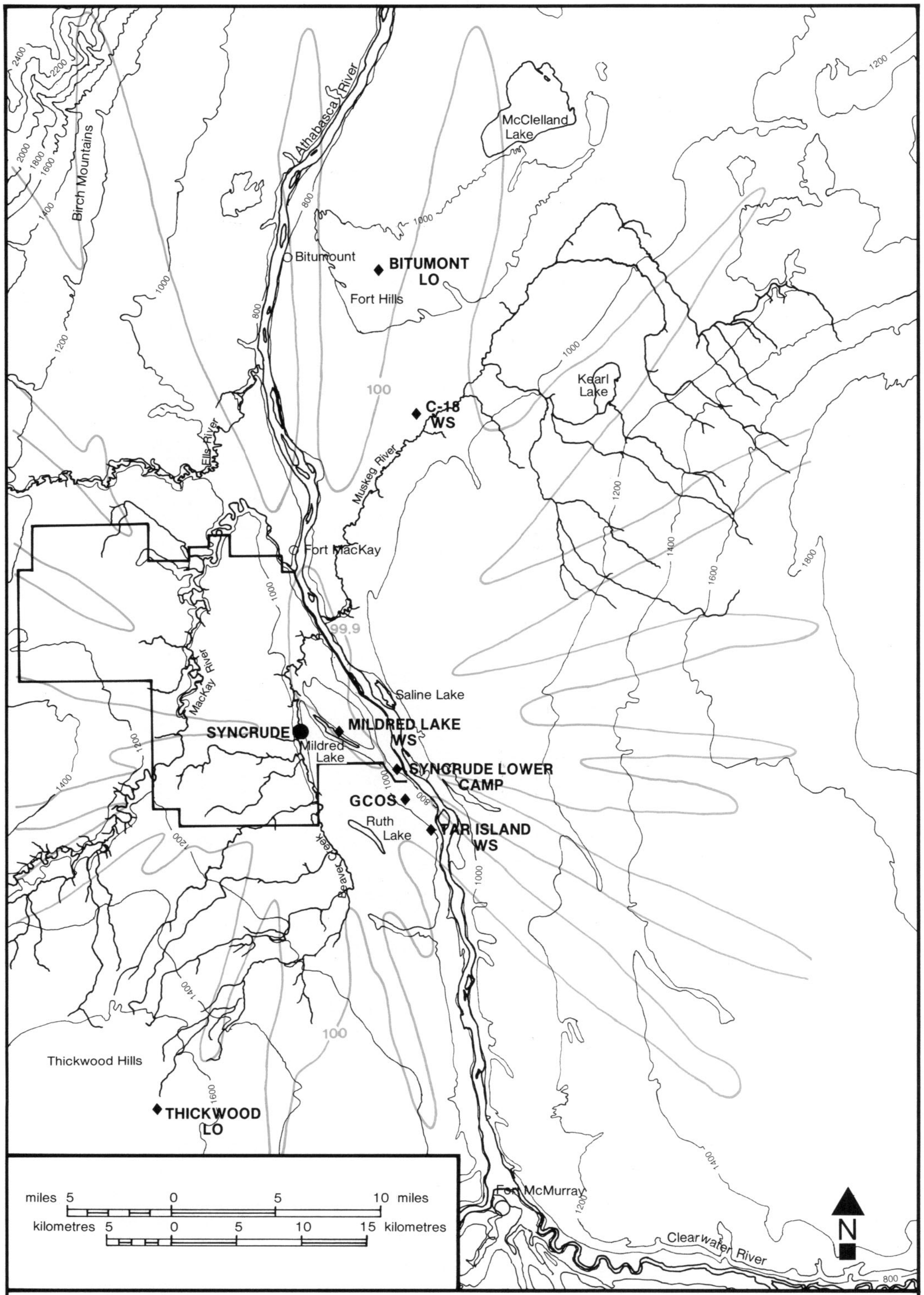

FIGURE 61
Estimated percentage of the time with ground concentrations less than 0.17 ppm so_2 (one hour average) during the entire study period due to Syncrude emissions alone, based on temperature and wind data covering 251 mornings and 273 afternoons. Measured meteorological data were input to the MEP air quality model to estimate the frequency of such occurrences at each grid intersection on a 1 kilometre grid covering the study area. Inversion breakup and limited mixing events were assumed to have an average duration of 0.5 and 3 hours respectively. The analysis assumed the emission parameters of table 9 with an emission rate of 3363 g/s. G.C.O.S. emissions are not included.

to an ex post facto analysis. The analytical techniques used for atmospheric environmental predictions during the preparation of the Syncrude Applications have since been overtaken by new developments in predictive dispersion climatology. This section of the report investigates the actual effects on regional air quality that can now be predicted by the use of advanced atmospheric technology. Moreover, it addresses the question regarding the measure in which ambient air quality monitoring stations reflect the actual effects of an industrial operation such as the Mildred Lake Plant on regional air quality.

This section reports on the contribution of one project only, to the regional emission load on the atmospheric systems. The baseline situation, in existence since the Great Canadian Oil Sands plant became operational is not well known. This baseline had to be excluded from the scope of this study since neither the actual, and variable emission parameters, nor an adequate number of soundings for the physical location of the plant were available for study and processing through the Tar Sands Air Quality model.

The predictive model attempts to describe by means of mathematical equations the physical process of pollutant spreading in the atmosphere. Many simplifying assumptions are made. To facilitate solution of these equations, empirical constants are introduced. Because these constants were evaluated in diffusion experiments in other areas of the world they may or may not be appropriate to the Tar Sands. Consequently, the prediction of compliance percentages by the model is imperfect, but the best which can be made given the current state of technical knowledge. Compliance percentages can be measured directly by a network of monitors over a period of years, but of course this is not prediction and can not aid the preoperational design of industrial process emissions.

Inversion breakup fumigation affects a relatively small area so the chances that it will be observed at a fixed monitor location are small unless there are a large number of monitors. It is estimated that several hundred fixed monitors would be required to measure all maximum fumigation concentrations to within 5% accuracy. In fact less than ten fixed stations will monitor ground concentrations, so that compliance as measured by the monitors will be much higher than the model predictions.

The actual time for which instantaneous concentrations exceed a standard value may be quite different from the duration as expressed in terms of moving averages. According to the results of this study most events are associated with inversion breakup fumigations which characteristically show sharp brief peaks of ground concentrations at a monitor. Although the actual duration of the event may be a matter of a few minutes, its effects would show up in the moving average for some time after the event ended.

As a result of the fluctuating nature of the ground concentrations, the measured concentrations will depend upon for how long a time period sampling is carried out. In general the average concentration decreases with increasing sampling duration. In the MEP dispersion model concentrations are assumed to vary with the one fifth power of the sampling period. This assumption is conservative for unstable conditions where discrete puffs of effluent may arrive at the monitor so that there are extreme fluctuations of concentration with time. The short-term concentrations can be 5 to 10 times the longer term averages whereas the factor in the MEP model relating 15 minute to one hour concentrations is only 1.3.

3. Predicted monthly average concentration distributions

Monthly average concentrations were predicted at each grid point for September 1974 and January, March and July 1975 by adding together the predictions corresponding to individual soundings. Again limited mixing events were assumed to persist for three hours and inversion breakups for one half hour.

Alberta does not specify an average maximum permissible monthly concentration. However, to put the calculated values into proper perspective, interpolation between the 24 hour and annual standards gives a monthly average of 0.025 ppm.

In September 1974 (Figure 62), concentrations in excess of 0.02 ppm were predicted to occur in a small area 5 km. northeast of the Syncrude source. Secondary maxima of greater than 0.005 and 0.01 ppm were predicted to occur at 20 km. to the north-northwest and 3 km. south respectively.

In January 1975 (Figure 63) an area from 13 km. southwest to the edge of the model grid was predicted to be influenced by concentrations in excess of 0.01 ppm.

Small areas 2-5 km. north, south and northwest of the source were predicted to have concentrations in excess of 0.01 ppm during March 1975 (Figure 64).

A region 2-5 km. northeast of the Syncrude stack was expected to have monthly average concentrations in excess of 0.01 ppm during July 1975 (Figure 65).

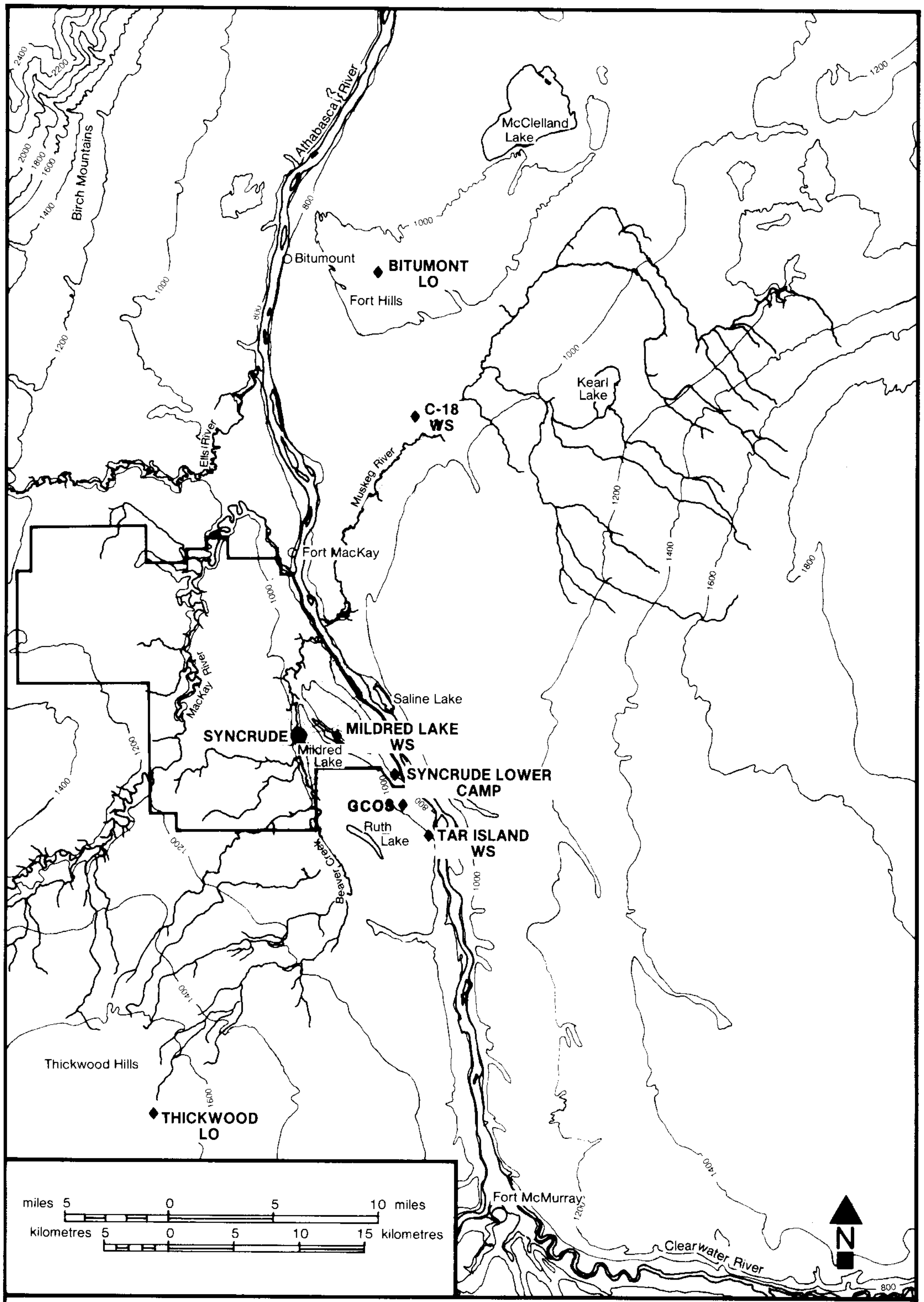

FIGURE 62

Estimated monthly average ground concentrations of SO_2 for September 1974.

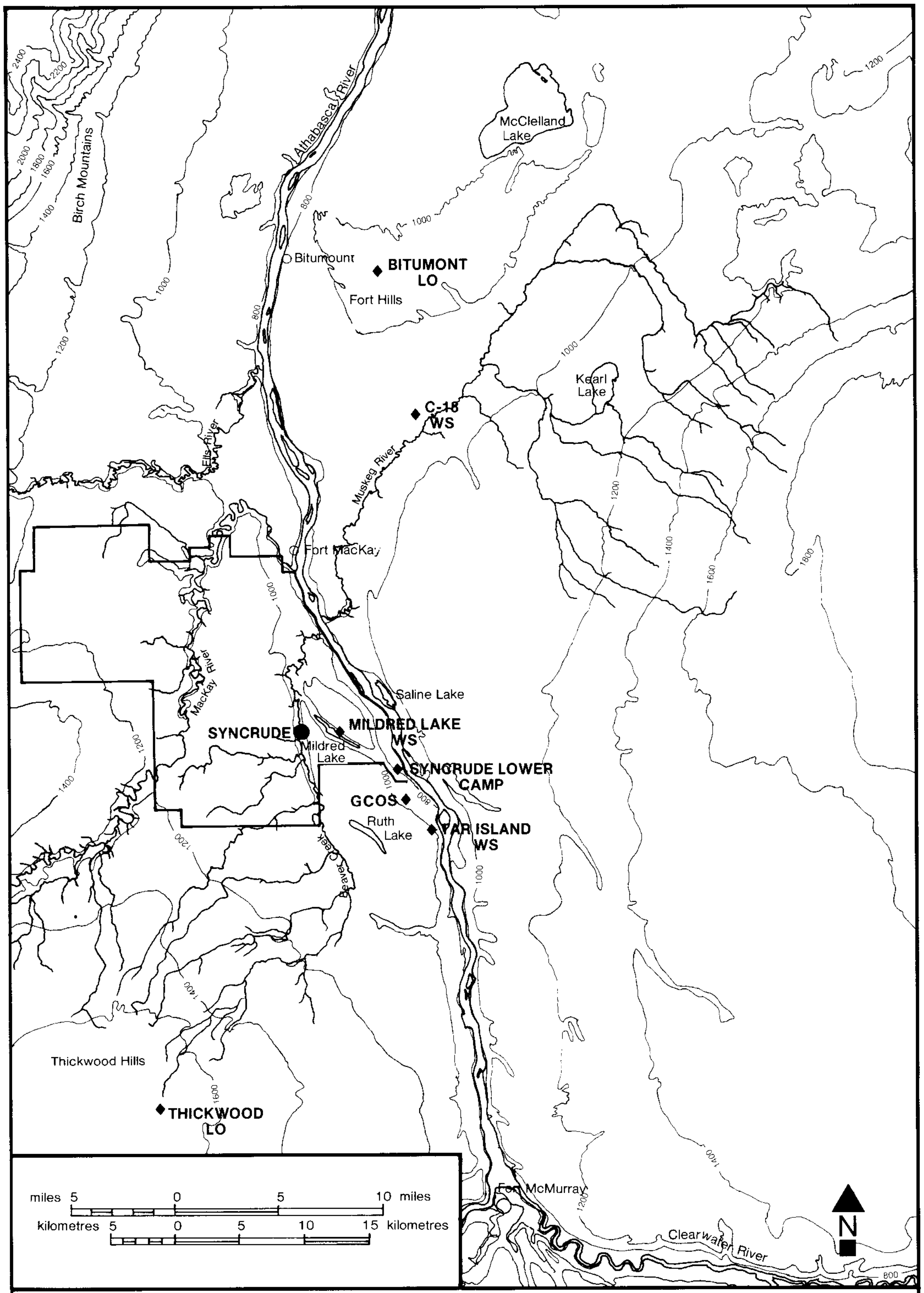

FIGURE 63

Estimated monthly average ground concentrations of SO_2 for January 1975.

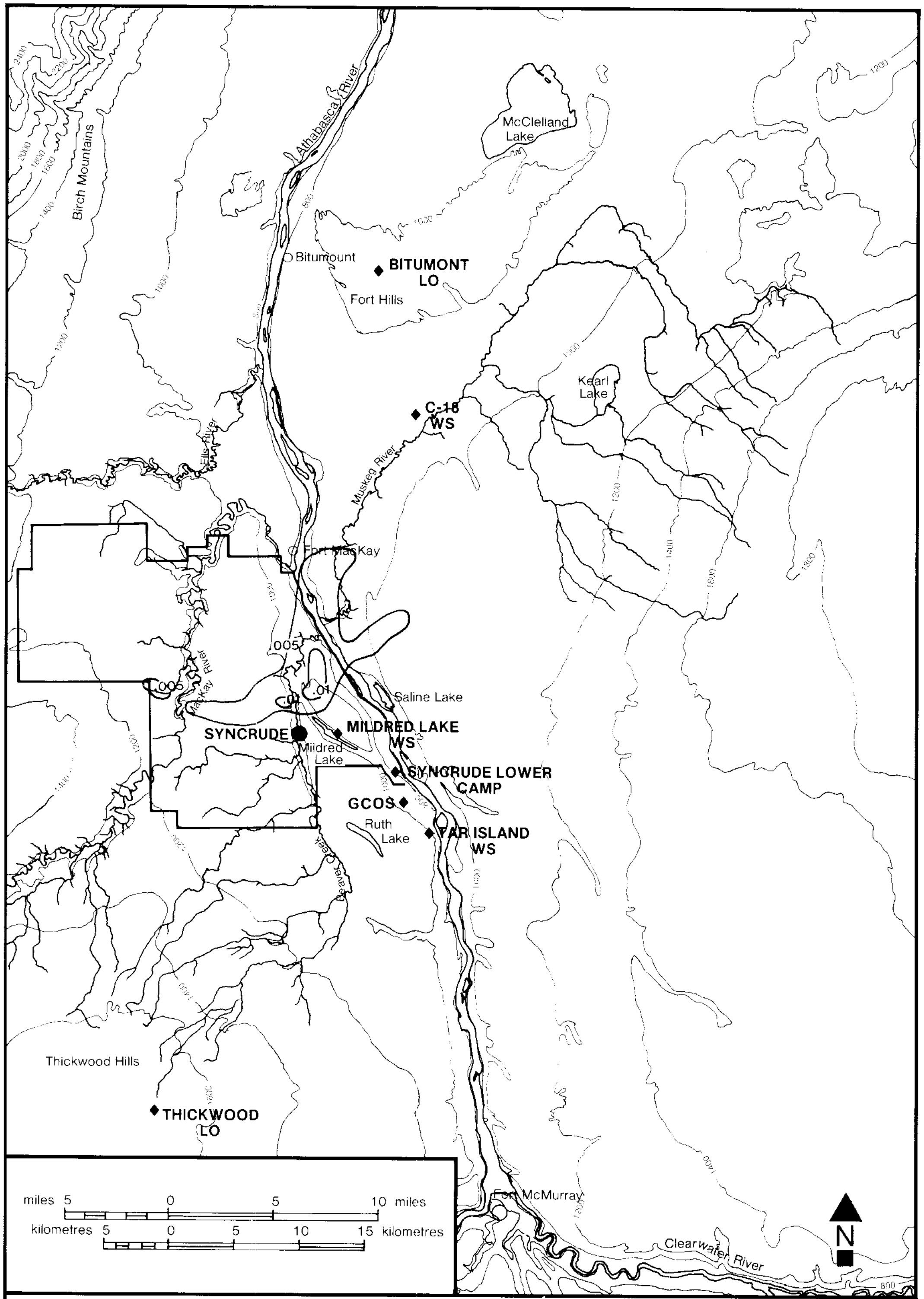

FIGURE 64

Estimated monthly average ground concentrations of SO_2 for March 1975.

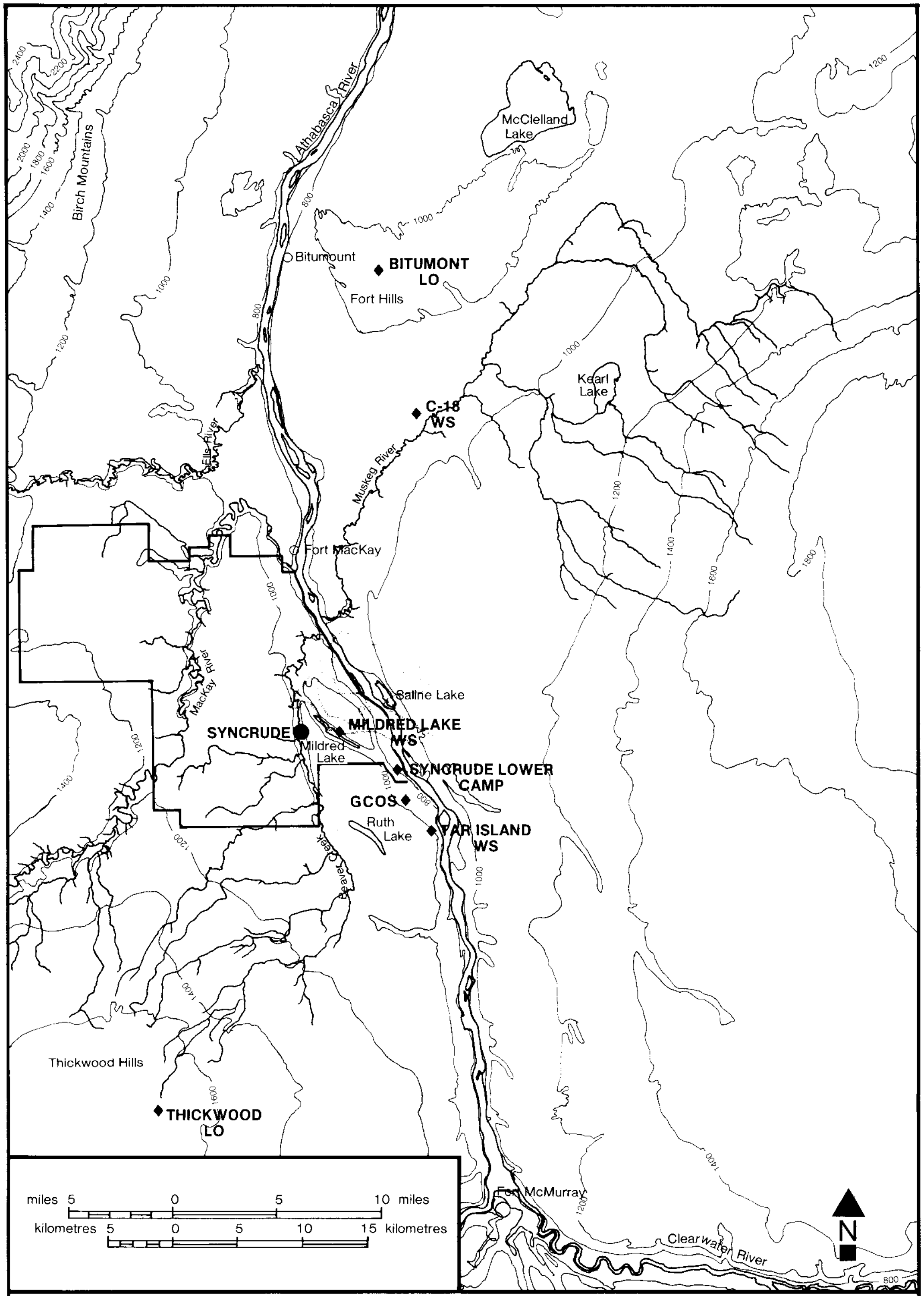

FIGURE 65

Estimated monthly average ground concentrations of SO_2 for July 1975.

4. Ambient air quality monitoring site selection

Five continuous air monitors were sited in locations where a high probability of plume impingement existed during the period September 1974 through August 1975. The locations were determined on the basis of the air quality model which was described in section VIII together with wind and temperature profiles from soundings taken over a 12 month period at the Shell Weather Station on Lease 13 and the Mildred Lake Weather Station at Lease 17. The recommended monitoring sites were located as follows relative to the Syncrude stack:

Site No.	Azimuth ($^\circ$)	Distance (km)
1	180	6.5
2	315	6.5
3	075	2.0
4	330	14.5
5	010	7.8

The proposed monitor locations are shown in figure 56 which also maps the number of events which were predicted to occur annually. The Monitor sites are near places where events were predicted to occur most frequently, but have been displaced outward to avoid the tailings pond and mined out area.

Recommendations were made for the design of a static exposure cylinder (or plate) network. The network should cover a large part of the area in which ground concentration of SO_2, due to the Syncrude source, are expected to exceed 0.1 ppm as a half hour average. Based on the study period, an area roughly enclosed by the triangle described below meets this requirement.

Location of Vertices Relative to Syncrude Stack

Azimuth ($^{\circ}$)	Distance (km)
315	28
045	23
160	20

The determination of precise exposure sites will require further logistical considerations.

The use of sulphation plates was recommended with two plates at each of the 40 exposure sites and an additional three plates near the intake of each continuous monitor.

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APPENDIX 1

1. Theoretical Considerations on the Ascent Rate of Pilot Balloons

A balloon filled with a buoyant gas to a free lift F will experience upward acceleration. As it ascends into a less dense region, it will expand in diameter, thus giving rise to greater drag on the balloon. Under the influence of the opposing forces, the balloon will very quickly attain a nearly constant ascent rate V which can be written as[12]

$$V^2 = Fg/pd^2k$$

where g is the acceleration of gravity, p is air density, d is the balloon diameter, and k is the coefficient of aerodynamic resistance.

It can be shown that within the first kilometre, the ascent rate will, according to the above formula, increase by at most 5% under any atmospheric stratification[13].

It should be pointed out that these considerations presuppose an atmosphere that is free of vertical motions that would carry the balloon with them. Under such conditions (such as lake induced fronts, and pronounced valley circulations) an independent way of establishing balloon height must be used, for example the double theodolite method.

2. Experimental Verification and Validation

The constancy of the ascent rate of pilot balloons and the value of the ascent rate has been investigated by several researchers. A recent investigation by Boatman [14] shows that under the conditions assumed in the derivation of the above formula, a nearly constant ascent rate was achieved which agreed well with the theoretically derived value for the ascent rate.

An investigation by Ontario Hydro [15] also shows that the constant ascent rate applies quite well in the first kilometre of ascent. Both studies show that care must be exercised in the filling procedure to ensure that the same free lift will apply for all flights, and allow use of the theoretical value for the ascent rate.

In order to examine the effect of the constant ascent rate assumption on the wind and temperature profiles, a comparison is made of the double theodolite evaluation with a single theodolite analysis based on one of the theodolite's data and assuming constant ascent rate. The results are shown in Figure 16. The actual ascent rate as determined by double theodolite varied between 132 m/min and 246 m/min with an average rate of 186 m/min. The single theodolite calculation assumed an ascent rate of 180 m/min. It can be seen that there is very good agreement both for winds and temperatures, and this agreement would be improved at the higher elevations if an ascent rate of 186 m/min were used. Thus the fluctuation in ascent rate of as much as 30% and deviation from average rate of ascent by 5% do not significantly affect the profiles of the first kilometre. Similar conclusions were reached by Ontario Hydro Research Division[15].

3. Operational Considerations

In using the single theodolite technique, care must be exercised in the filling procedure to ensure uniformity of results. In order to evaluate the procedure used, it is advisable to calibrate data obtained by single theodolite against double theodolite observations, and use this information to determine the appropriate constant ascent rate value to be used.

If wind and temperature soundings are done separately, the total elapsed time between the soundings should be kept to a minimum. This consideration is important if the wind and temperature information is to be used jointly to determine some characteristics of the atmospheric motion such as the lake-breeze regimes. Under these conditions a double theodolite procedure must be employed. For general purposes and in climatological work this consideration is not critical, as the data so obtained can be considered as representative of the time of day at which it was taken.

APPENDIX II

GLOSSARY OF TERMS

Dispersion Climatology	-	statistics of those parameters which control the spreading of gases or small particles in the atmosphere
Double Theodolite Method	-	a technique for determining upper level winds as well as the rise rate by tracking a single balloon simultaneously with two theodolites separated by a known distance or baseline
Dry Adiabatic Lapse Rate	-	the cooling rate of a parcel of unsaturated air as it is lifted without addition of external heat (.98°C/100m)
Effective Stack Height	-	the plume rise added to the physical stack height
Fanning	-	behaviour of plume rising through a stable layer (It loses buoyancy and levels off - see Figure 11)
Fumigation	-	a high ground level concentration of effluents
Inversion	-	an atmospheric layer in which air temperature increases with height
Inversion Breakup	-	destruction of the inversion layer by thermal or mechanical turbulence
Isothermal	-	invariant in temperature
Lapse Rate	-	the rate of decrease of air temperature with height
Limited Mixing Condition	-	mixing of effluents in a turbulent atmospheric layer "capped" by a stable stratified layer
Lofting	-	behaviour of plume which penetrates a ground-based inversion and diffuses upward but is prevented by the stability below from diffusing downward (see Figure17)
Macroclimatology	-	large scale (measured in thousands of square kilometres) statistics of climate
Mesoclimatology	-	medium scale (measured in hundreds of square kilometres) statistics of climate

Mixing Height	- the height of the surface-based layer in which vertical mixing can occur
Neutral Layer	- an atmospheric layer in which the lapse rate is equal to the dry adiabatic lapse rate
Plume Layer	- the atmospheric layer bounded by the physical stack height and the effective stack height
Pollution Potential	- capability of the atmosphere to dilute and disperse effluents
Potential Temperature	- the temperature that a parcel of air would have if it were brought dry adiabatically from any elevation to 1000 millibars
Potential Temperature Lapse Rate	- the rate of decrease of potential temperature with height
Single Theodolite Method	- the determination of upper level winds with one theodolite, where a constant rise rate for the balloon must be assumed
Synoptic Wind	- the large scale surface wind as can be read off continental weather maps

Murray, W. and J. Kurtz, 1976. A predictive study of the dispersion of emissions from the Syncrude Mildred Lake plant. Syncrude Canada Ltd., Edmonton, Alberta. Environmental Research Monograph 1976-1. 128 pp.