Meteorology Observations in the Athabasca Oil Sands Region

May, 1996

Prepared for:

Suncor Inc.

Prepared by:

Golder Associates

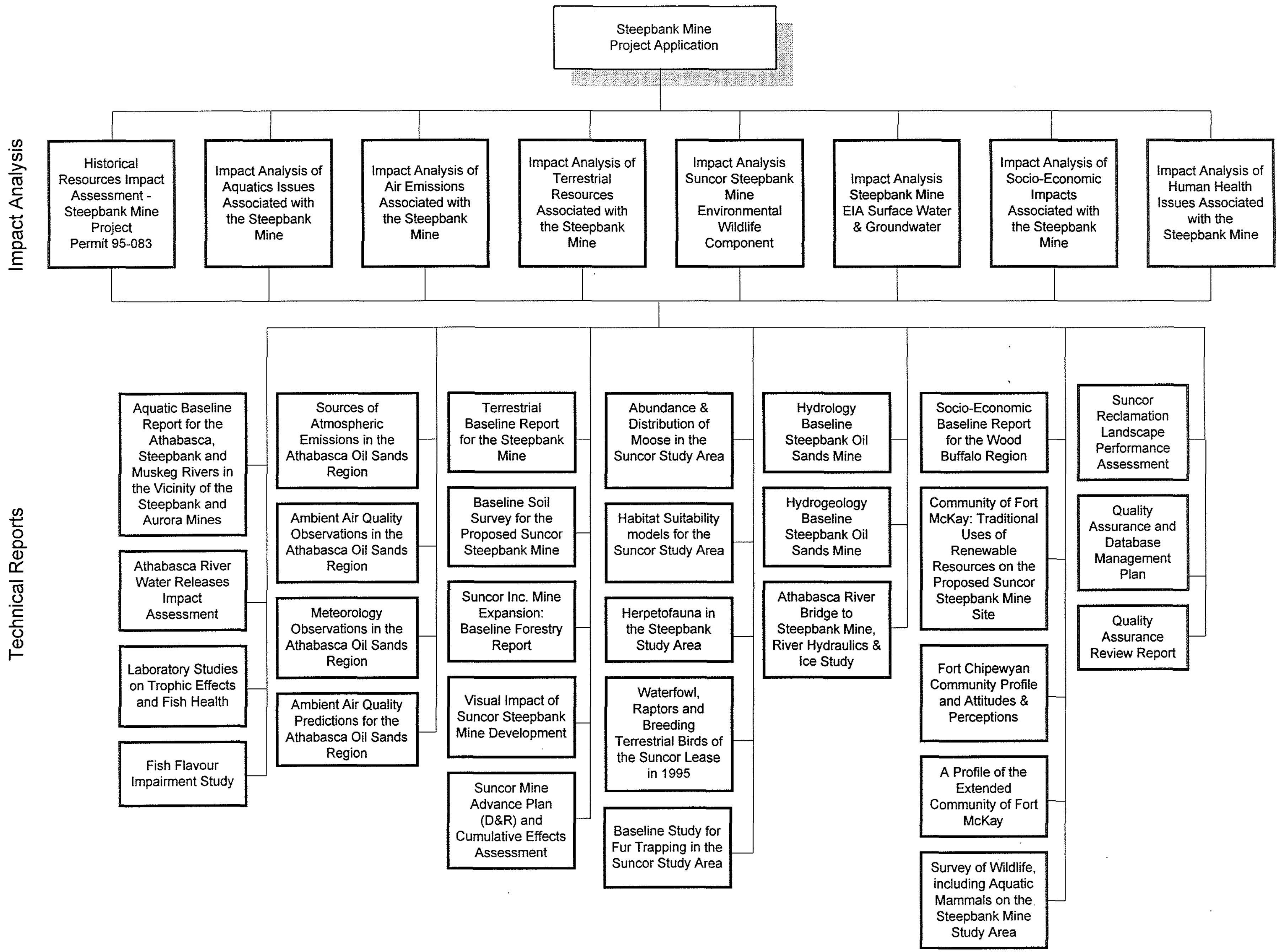
BOVAR Environmental

952-2307

This report is one of a series of reports prepared for Suncor Inc. Oil Sands Group for the Environmental Impact Assessment for the development and operation of the Steepbank Mine, north of Fort McMurray, Alberta. These reports provided information and analysis in support of Suncor's application to the Alberta Energy Utilities Board and Alberta Environmental Protection to develop and operate the Steepbank Mine, and associated reclamation of the current mine (Lease 86/17) with Consolidated Tailings technology.

For further information, please contact:

Manager, Regulatory Affairs
Suncor Oil Sands Group
P.O. Box 4001
Fort McMurray, AB
T9H 3E3



Reports Prepared for the Steepbank Mine Environmental Assessment

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METEOROLOGY OBSERVATIONS
IN THE
ATHABASCA OIL SANDS REGION

(Report 3)

Prepared for:

Suncor Inc., Oil Sands Group
and
Syncrude Canada Ltd.

Prepared by:

BOVAR Environmental

May 1996
(BE. 5316211-5530)

BOVAR Environmental

1600, 555 - 4th Avenue S.W.
Calgary, Alberta
Canada T2P 3E7
Phone: 403-264-2140
Fax: 403-237-7634

May 9, 1996

BE. 5316211-5530

Suncor Inc.
Oil Sands Group
P.O. Box 4001
Fort McMurray, Alberta
T9H 3E3

Attention: **Don Klym, Manager**
New Mine Approvals

BE. 5316232-5530

Syncrude Canada Ltd.
P.O. Bag 4009, MD X200
Fort McMurray, Alberta
T9H 3C1

Attention: **Peter Koning**
New Lease Environmental Coordinator

Subject: **Air Quality Technical Report**

We are pleased to submit our report entitled *Meteorological Observations in the Athabasca Oil Sands Region.* This report summarizes meteorological observations based on available information from Suncor, Syncrude, Fort McMurray Airport and various other previous monitoring programs in the area.

If you have any questions regarding this report, please contact Ann Jamieson at (403) 750-9328 or the undersigned at (403) 750-9335.

Yours sincerely,

BOVAR Environmental

Mervyn J.E. Davies
Manager, Air Quality Assessment

MJED/mp
Enclosure

c.c. Hal Hamilton, Golder Associates Ltd.
Judy Smith, BOVAR Environmental

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ACKNOWLEDGEMENTS

This report was prepared for Suncor Oil Sands Group and Syncrude Canada Ltd. by BOVAR Environmental. The data analyzed in this report were collected by Suncor Oil Sands Group. BOVAR Environmental would like to thank Mr. Gordon Kemp, Senior Environmental Engineer, with Suncor for providing the data for this assessment.

This background report was prepared for the Suncor Steepbank Mine Environmental Impact Assessment (EIA) and for the Syncrude Aurora Mine EIA. Coordinators for the Steepbank Mine EIA are Don Klym from Suncor and Hal Hamilton from Golder Associates Ltd. Coordinators for the Aurora Mine EIA are Peter Koning from Syncrude and Judy Smith from BOVAR Environmental.

Principal investigator for this study was Mervyn Davies, Manager of BOVAR Environmental's Air Quality Assessment Group in Calgary. Primary data analysis and report preparation were completed by Ann Jamieson with support from Ivan Dorin, Arthur Springer, Michael Brennand and Piotr Staniaszek. Report typing and formatting were completed by Maureen Parsons.

1.0 INTRODUCTION

1.1 Background

Alberta produces a significant portion of Canada's energy requirements through the production of fossil fuels which include natural gas, conventional crude oil, synthetic crude oil and coal. The oil sands sector produces almost 25% of Canada's energy needs through the production of synthetic crude oil from bitumen. In 1994, Syncrude Canada received approval to increase synthetic crude oil (SCO) production to 17.6 million m^3/a. Similarly, Suncor recently received approval for modifications to increase their bitumen throughput. Both Syncrude and Suncor plan to develop new oil sands leases and to further increase crude oil and bitumen production.

The development of new leases (e.g., SOLV-EX) and the continuing production at the existing extraction and upgrading facilities (e.g., Suncor and Syncrude) will have effects on the environment. In recognition of these effects, Suncor has proposed modifications to reduce SO_2 emissions to the atmosphere. As part of Syncrude's approval to increase production, they are required to develop additional ambient air quality, sulphur deposition and biomonitoring programs. The objective of these programs is to ensure environmental quality is not compromised due to atmospheric emissions associated with their operations.

1.1.1 *Provincial Initiatives*

In response to the interest in atmospheric emissions in Alberta, several initiatives have been undertaken to evaluate air quality management approaches in the province:

- The 1991 **Clean Air Strategy for Alberta** Report to the Ministers of the Environment and Energy presented a long-term framework for air quality management. This framework was developed through a multi-stakeholder consultation process. The report identified the vision and mission statements shown in Table 1.1 to provide the basis for future air quality management initiatives.

- In response to the 1991 Report, the **Clean Air Strategic Alliance (CASA)** was formed. CASA is a joint industry-government program which represents a partnership between government, industry, environmental and other key stakeholders. CASA is responsible for the strategic planning related to air quality issues in Alberta through a Comprehensive Air Quality Management System (CAQMS) for Alberta. The CAQMS allows regional stakeholders to design solutions specific to their regional air quality issues.

- In response to the CAQMS, the **West Central Regional Airshed Monitoring Committee (WCRAMC)** was established to design an environmental monitoring program for the West Central Zone of Alberta. The zone was developed in response to the zonal air quality management concept identified in the 1991 Report to the

Table 1.1 The Clean Air Strategy for Alberta vision and mission statements.

VISION STATEMENT
The air will be odourless, tasteless, look clear and have no measurable short- or long-term adverse effects on people, animals or the environment.
MISSION STATEMENT
Alberta's Clean Air Strategy is to provide guidelines for the management of emissions from human activity and encourage appropriate life-styles so as to protect human health and ecological integrity within a provincial, national and international context. *The strategy will be comprehensive but flexible and, through an ongoing consultative process, will employ a wide range of mechanisms available for implementing the strategy, including public education, market-based approaches, legislation, regulation, and research and development.*

Ministers and because of the relatively high interest of stakeholders in the area. The approach and concept for managing air quality in the West Central Zone was viewed as a prototype that could be used for other airshed zones in Alberta.

1.1.2 *Regional Initiatives*

Air quality issues have been addressed in the oil sands region through a number of processes that include the following:

- **Regulatory:** Terms and conditions specified by Licences-to-Operate that were issued under the former Clean Air Act. With the introduction of the Alberta Environmental Protection and Enhancement Act (EPEA), these licences are renewed as Environmental Approvals (under EPEA).

- **EIAs:** Various environmental impact assessments (EIAs) prepared for the development and expansion of existing and proposed oil sands developments have led to the collection of field data and associated air quality assessments.

- **Research:** The Alberta Oil Sands Environmental Research Program (AOSERP), a jointly funded federal and provincial program, conducted environmental and air quality research in the oil sands region from 1975 to 1981. The research program was continued by the Research Management Division of Alberta Environment from 1981 to 1986.

- **Multi-Stakeholder:** Various groups such as the Fort McMurray Regional Air Quality Task Force (AQTF) have been formed to address industry, government and stakeholder issues related to air emissions and their potential effects.

Multi-stakeholder air quality issues in the oil sands area are currently addressed by the Regional Air Quality Coordinating Committee (RAQCC) which is comprised of government, industry and community participation. RAQCC has been responsible for establishing a number of working groups to help identify, evaluate and resolve regional air quality issues.

1.1.3 *Background Reports*

Given that the oil sands will continue to play a significant role in Canada's energy requirements, and that air quality issues associated with oil sands mining, extraction and upgrading operations have a multi-stakeholder interest and furthermore, in consideration of the recent initiative associated with addressing air quality issues in Alberta, a series of background air quality reports have been prepared for the oil sands area. The purpose of these reports is to provide baseline air quality baseline information to mid-1995. The specific reports are as follows:

- **Report 1** **Source Characterization**

  Identifies and quantifies anthropogenic air emissions in the Fort McMurray - Fort McKay corridor which include industrial point, fugitive, traffic and residential sources. Emissions of interest are SO_2, NO_x, CO, VOC, TRS, particulates and CO_2.

- **Report 2** **Ambient Air Quality Observations**

  Summarizes ambient air quality monitoring undertaken in the Fort McMurray - Fort McKay airshed. The sources include quantitative data from the Suncor, Syncrude and AEP networks as well as qualitative data associated with other monitoring programs.

- **Report 3** **Meteorology Observations**

  Summarizes meteorological data which describe the transport, dispersion and deposition of emissions in the area. The focus in on the meteorological data collected by Suncor from the Lower Camp and Mannix towers. A review of the terrain in the region and its effect on meteorology is provided.

- **Report 4** **Air Quality Modelling**

  Concurrent source, air quality and meteorological data are used to select an optimum dispersion modeling approach resulting in predictions which compare favourably with observations. The modelling will complement the ambient monitoring by providing local and regional short and long-term air quality changes associated with the current operations in the area.

These reports serve as background reports which can be used by industry to assist with future plant applications and by other stakeholders to assist with the review of these applications. Furthermore, these reports can also be used by RAQCC in support of their regional air quality related initiatives.

1.2 Report 3 (Meteorology Monitoring)

1.2.1 *Objectives*

The management of an airshed that is shared by multiple users requires an understanding of the meteorological processes that affect the transport and dilution of products vented to the atmosphere. The objectives of Report 3 (Meteorological Monitoring) are as follows:

- Identify the current meteorological monitoring programs in the oil sands airshed.
- Summarize the observations that describe the transport and dispersion processes.
- Identify diurnal and seasonal trends in atmospheric behaviour.
- Provide meteorological data that can be used by dispersion models.

The end-product of Report 3 is an understanding of meteorological dispersion processes in the Athabasca oil sands airshed that can be used as a basis for further air quality assessments.

1.2.2 *Approach*

Suncor maintains two stations that collect enhanced meteorological data in the vicinity of their plant. Data are collected from an instrumented 167 m tall tower located in the Athabasca River Valley at Lower Camp and from an instrumented 75 m tall tower located above the river valley at Mannix. This monitoring program represents an enhancement over other meteorological monitoring programs in the vicinity of the plant that are limited to collecting wind data 10 to 15 m above the ground.

Data from the Lower Camp and Mannix towers for the 20 month period starting November 1, 1993 to June 30, 1995 have been reviewed in this report. The report concludes by providing a summary and recommendations.

1.2.3 *Definition of Terms*

Given the technical nature of this report, it is useful to identify terminology used to facilitate a common understanding. Table 1.2 provides definitions of technical terms relating to meteorological monitoring which are used in the report. As with many scientific descriptions, symbols are used to represent selected parameters. The air pollution meteorology symbols used in this report as shown in Table 1.3.

1.2.4 *Report Organization*

Section 2 provides an overview of the enhanced meteorological monitoring program conducted by Suncor. The terrain features in the vicinity of the monitoring program are described in Section 3. The subsequent sections summarize the observations on a parameter-by-parameter basis:

Section	Parameters
4	Wind direction, wind speed, power-law exponent and surface roughness length
5	Horizontal and vertical turbulence, atmospheric stability indicators, Monin-Obukhov length and friction velocity
6	Temperature and potential temperature gradient
7	Net Radiation and mixing height
8	Relative humidity and precipitation

Section 9 provides a summary and recommendations, and Section 10 identifies the references. An analysis of wind data from other monitoring programs in the area is presented in Appendix A. The documentation of all computer files used for the terrain grids and the analysis of the meteorological data is presented in Appendix B.

Table 1.2 Definition of commonly used meteorological terms.

Term	Definition
Atmospheric Boundary Layer	The vertical extent to which the daytime heating and nighttime cooling cycle influences atmospheric behaviour. This is the layer closest to the earth's surface, and within which pollutants are released and dispersed.
Atmospheric Dispersion	Gases and small particles released into the atmosphere become dispersed or separated by random eddy motions or turbulence. Turbulence results in the dilution of a plume as it is mixed with the ambient air and carried downwind from the release point.
Season	For the purposes of this report, the four seasons are defined as fixed three month periods: winter is defined by December, January and February; spring is defined by March, April and May; summer is defined by June, July and August; and fall is defined by September, October and November.
Wind Direction	The direction of the mean air flow over a given averaging period. The wind direction is expressed between 0 and 360 degrees and is the direction from which the wind is blowing. For example, a 90° wind is blowing from the east.
Wind Speed	The wind speed is frequently reported in either kilometres per hour (km/h) or metres per second (m/s) (note: 1 m/s = 3.6 km/h). Wind speeds generally increase with increasing height above the ground because of reduced frictional effects between the air motion and the surface of the earth.
Power Law Exponent	A power-law relationship used to extrapolate wind speeds from a measured level to a level at which no information is available.
Surface Roughness	The surface roughness length characterizes the roughness of a surface and forms the boundary layer in dispersion models.
Horizontal Turbulence	The random turbulent motions that produce the crosswind spread of a plume as it moves downwind. The standard deviation of the wind direction provides a measure of the horizontal turbulence. The standard deviation is often expressed as σ_θ (sigma theta) in units of degrees.

Table 1.2 Continued.

Term	Definition
Vertical Turbulence	The random turbulent motions that produce the vertical spread of a plume as it moves downwind. Vertical spread below the plume centreline results in a plume being brought down to surface. The standard deviation of the vertical wind angle is expressed as σ_ϕ (sigma phi) in units of degrees.
Stability Class	A method of classifying the level of turbulence generation (or suppression) in the atmosphere. Pasquill-Gifford (PG) stability classes range from unstable (Classes A, B and C) through neutral (Class D) to stable (Classes E and F).
Unstable Conditions	Periods when convective turbulence dominates. Unstable conditions are characterized by strong daytime heating and low wind speed conditions.
Neutral Conditions	Periods when mechanical turbulence dominates. Neutral conditions are characterized by high wind speeds.
Stable Conditions	Periods when turbulence is suppressed by the radiation cooling of the earth's surface during the night. Stable conditions are characterized by clear skies and low wind speed conditions. Mechanical turbulence dominates in a layer 5 to 100 m in depth during stable conditions.
Friction Velocity	This is a velocity based on surface stress. The friction velocity is representative of turbulence fluctuations in the lowest layer of the atmospheric boundary layer.
Monin-Obukhov Length	This is the height at which the generation or suppression of thermal turbulence by heating or cooling is equal to the generation of turbulence by mechanical means.

Table 1.2 Continued.

Term	Definition
Temperature Gradient	Temperature normally decreases with increasing height above the earth's surface. Temperature gradients are defined as positive for decreasing values with increasing heights and negative for increasing values with increasing heights. The temperature gradient is expressed in units of degrees Kelvin per metre of elevation (K/m). For neutral atmospheric conditions, this rate of cooling is about 1 C° (1 K) for every 100 m in elevation increase (e.g., 0.01 K/m). During unstable conditions, the temperature gradients are greater than 0.01 K/m, (e.g., 0.03 K/m). During stable conditions, the temperature gradients are less than 0.01 K/m (e.g., -0.01 K/m).
Potential Temperature Gradient	A value of 0.01 K/m is added to the temperature gradient to "normalize" the temperature gradient. Neutral atmospheres are therefore characterized by a potential temperature gradient of 0.0 K/m. Positive potential temperature gradient values correspond to unstable conditions, while negative values correspond to stable conditions.
Net Radiation	Net radiation is defined as the difference between the incoming radiation from the sun and the outgoing radiation from the earth's surface. During the day, net radiation is positive and during the night net radiation is negative. Net radiation provides a measure of the production of convective turbulence during the day and the suppression of turbulence by cooling during the night.
Inversion	A stable atmospheric condition caused when the temperature increases with increasing height above the ground. An elevated inversion can produce a barrier that inhibits vertical dispersion and hence acts as a lid.
Mixing Height	A near-neutral or convective layer near the ground that is capped by an inversion. The mixing height can vary from typical nighttime values of 100 to 200 m to daytime values of up to 1000 to 2000 m during the day.
Mechanical Turbulence	Turbulence created by the action of the wind blowing over a rough irregular surface. Mechanical turbulence is greatest with a rough surface and high wind speeds.

Table 1.2 Concluded.

Term	Definition
Mechanical Mixing Height	The turbulent layer that is produced by mechanical interaction of wind with the earth's surface. The mixing height is determined by mechanical processes during the night and during the day when high wind speeds occur.
Convective Turbulence	Turbulence in the atmosphere can be created by the sun heating the earth's surface. Convective turbulence is greatest on a hot summer day.
Convective Mixing Height	The turbulent layer that is produced by convective activity resulting from daytime surface heating. The mixing height is dominated by convective processes during the day under strong solar heating conditions.

Table 1.3 Meteorological symbols.

Symbol	Definition
θ or Theta	Wind direction
U	Wind speed
p	Power-law exponent
Z	Height above ground
Z_o	Surface roughness length
σ_U or Sigma U	Standard deviation of hourly wind speed
σ_ϕ or Sigma Phi	Standard deviation of wind elevation angle
σ_w or Sigma W	Standard deviation of vertical wind
σ_θ or Sigma Theta	Standard deviation of wind direction
U*	Friction velocity
L	Monin-Obukhov length
ψ_m	Stability correction function for momentum
$\partial T/\partial Z$	Temperature gradient
$\partial T/\partial Z + 0.01$	Potential temperature gradient
Z_i	Mechanical mixing layer depth
ϕ or Phi	Latitude
h	Convective mixing height
c_p	Specific heat of air at constant pressure
ρ	Density of ambient air
$\gamma_d = 0.1$ K/m	Adiabatic lapse rate
$\gamma = -\partial T/\partial Z$	Lapse rate
H	Surface heat flux
R_{net}	Net radiation

2.0 MONITORING OVERVIEW

Meteorology controls the transport and dispersion of gaseous and particulate emissions which have been vented into the atmosphere. This report summarizes meteorological data collected in the Athabasca oil sands area of Alberta. Figure 2.1 shows the location of various meteorological monitoring stations in the Fort McMurray - Fort McKay area. The main focus of this report is on meteorological data collected between November 1, 1993 and June 30, 1995 by the Suncor Inc. Oil Sands Group at their Lower Camp and Mannix monitoring stations. In some cases, data from other monitoring locations have been included in Appendix A for comparison.

2.1 Current Suncor Monitoring Program

In 1993, Suncor Inc. Oil Sands Group identified a need to establish an enhanced meteorological monitoring program as part of their commitment to Alberta Environmental Protection to substantially reduce SO_2 emissions by July 1, 1996. This date reflects the time required to design and implement appropriate emission control technology for the Suncor facilities. In the interim, Suncor initiated a supplementary emission control (SEC) system. This system is based on the assumption that certain meteorological conditions are associated with ground-level air quality exceedences. The SEC system uses meteorological data and emission data as input to a dispersion model which then predicts the resulting ambient air quality. These predictions, in conjunction with ambient air quality monitoring observations, are used to determine the time periods during which Suncor modifies their plant operations to reduce emissions.

Suncor currently maintains a network of five ambient air quality monitoring stations in the vicinity of their operations. In the summer of 1993, the meteorological instrumentation at the Lower Camp and Mannix stations was upgraded for the program associated with the SEC system and also to meet the needs of a regional-based meteorological monitoring program. The purpose of the enhanced meteorological monitoring program is to gain a better understanding of plume-level air flow and dispersion characteristics in the vicinity of the Fort McMurray oil sands operations. As previously stated, the main focus of this report is on the hourly meteorological data collected from the enhanced monitoring program at the Lower Camp and Mannix stations between November 1993 and June 1995.

Figures 2.2 and 2.3 show the location of the Lower Camp and Mannix monitoring stations, respectively. The Lower Camp station is situated in the valley to the north of the Suncor facility, while the Mannix station is located on the west side of the Suncor access road just to the south of the Suncor facility. The base elevations of the Lower Camp and Mannix towers are approximately 245 and 334 m AMSL, respectively. As such, these two stations were chosen for the enhanced monitoring program since the data could be used to compare in-valley and above-valley meteorology. Details on the monitoring hardware at both sites are presented in BOVAR-CONCORD Environmental (1994).

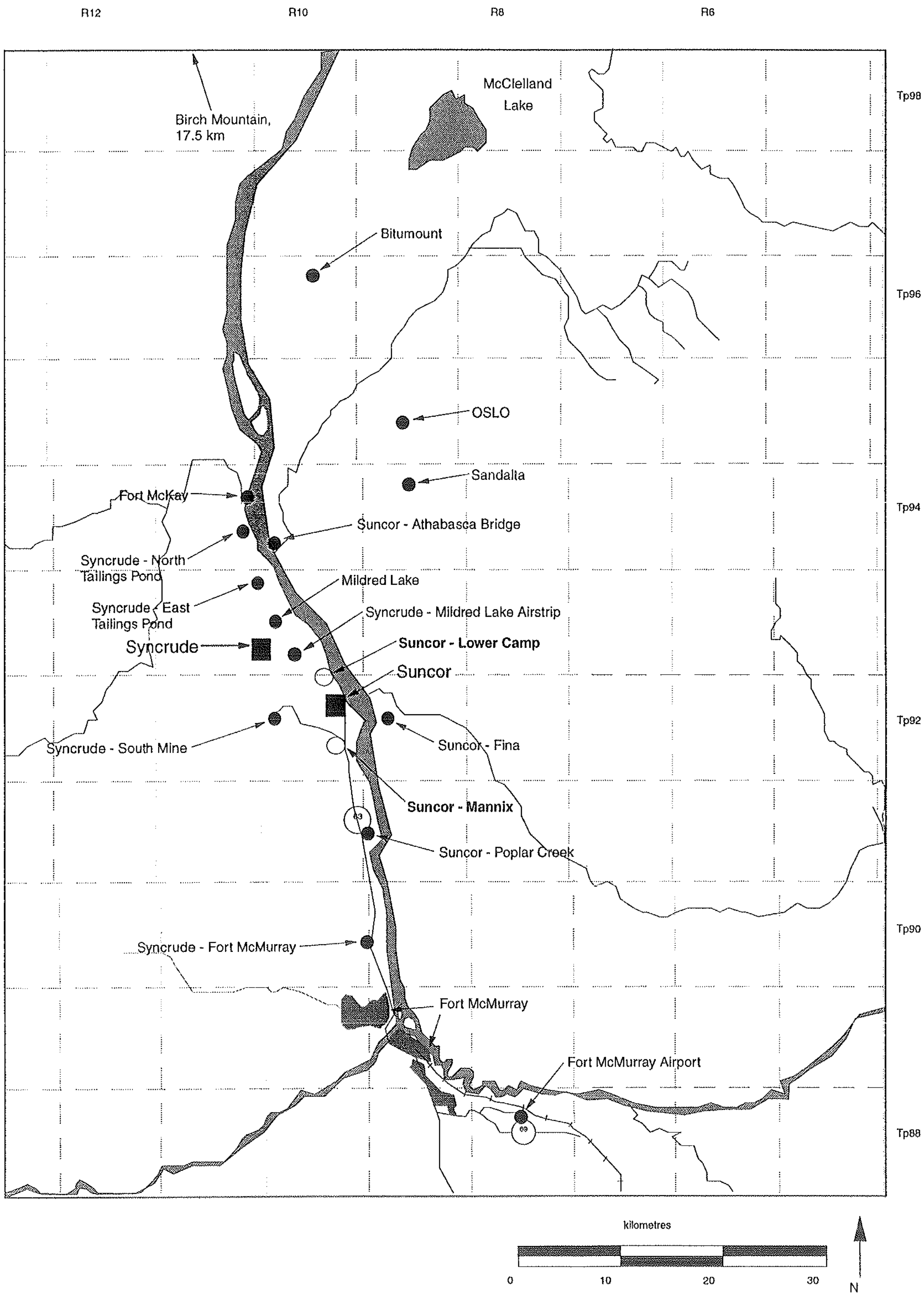

Figure 2.1 Location of monitoring stations.

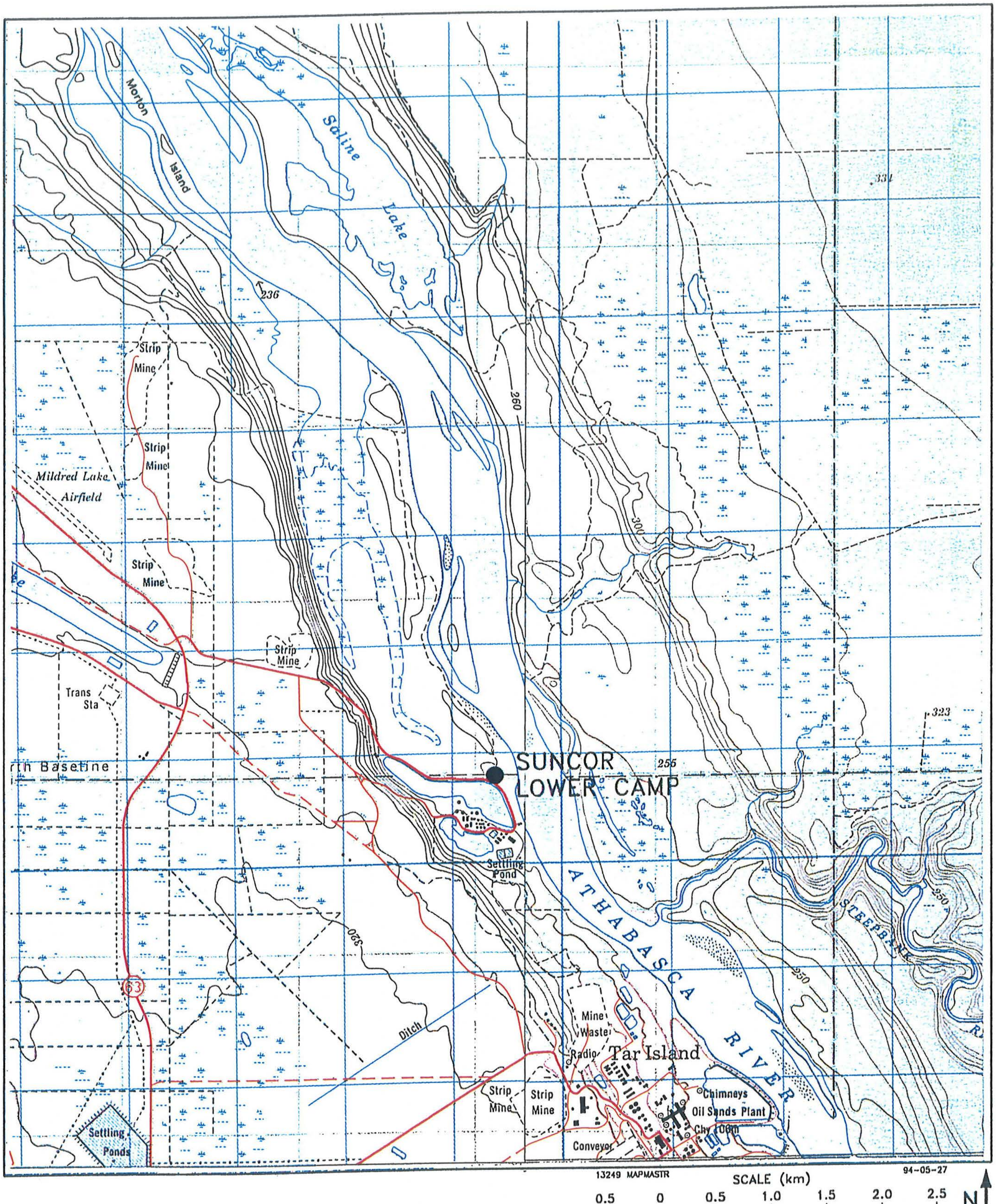

Figure 2.2 Location of **Suncor Lower Camp** air quality monitoring station.

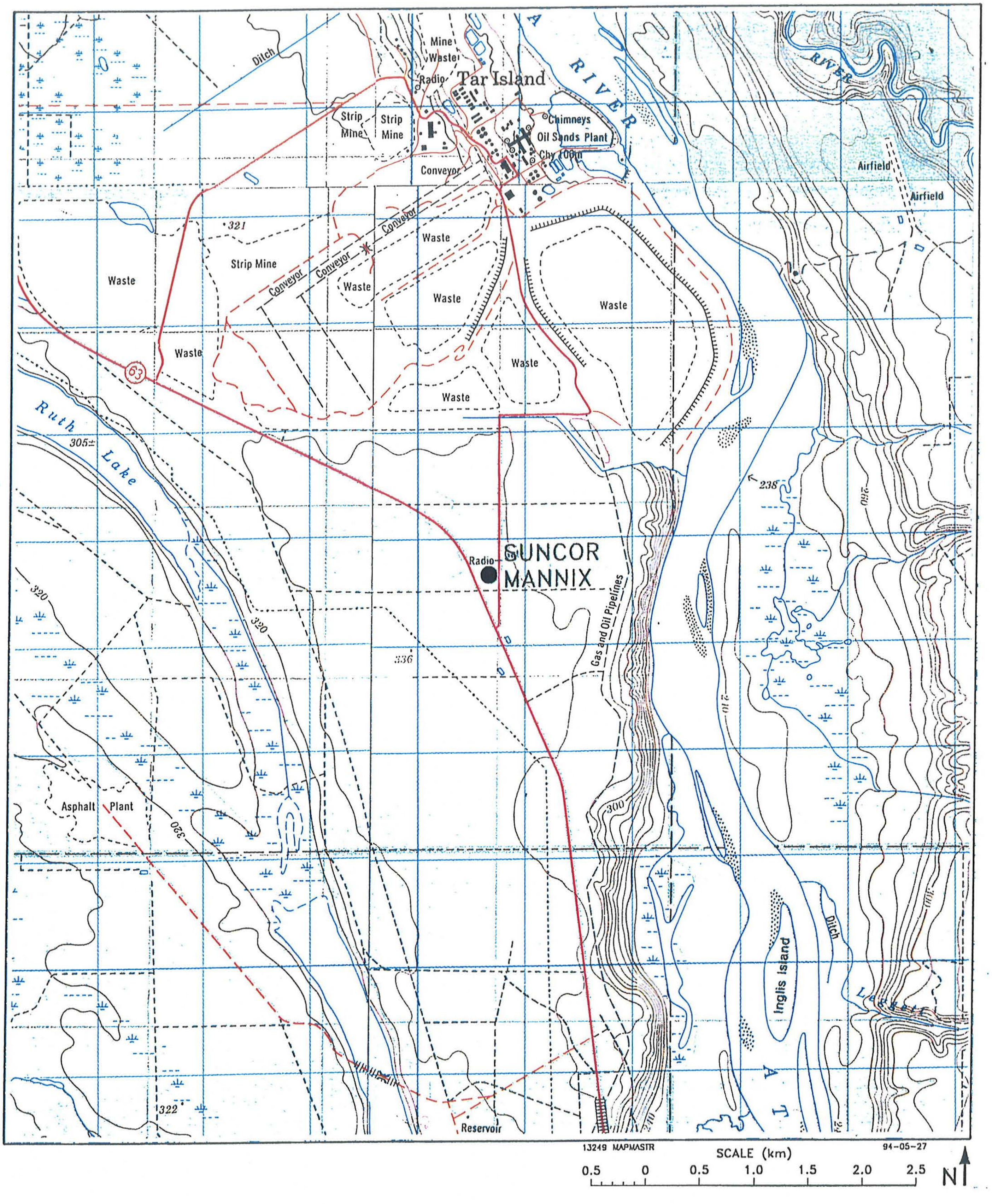

Figure 2.3 Location of the **Suncor Mannix** air quality monitoring station.

Table 2.1 and Figure 2.4 summarize the parameters that are collected on the Lower Camp and Mannix towers:

- Wind direction; wind speed; standard deviations of wind direction, wind speed and vertical wind; and temperature gradient are collected at four levels on the Lower Camp tower and at three levels on the Mannix tower.

- Net radiation and relative humidity are collected at the Mannix site.

Based on the data collected, additional meteorological parameters required for dispersion modelling assessments can be calculated. These other parameters include power-law exponent, mixing height, PG stability class, friction velocity, surface roughness and Monin-Obukhov length.

2.1.1 *Data Validation*

Prior to performing analysis for this report, all Suncor data were subjected to a quality assurance and quality control inspection program to eliminate unrealistic data from the file. Typically, unrealistic data result from mechanical problems (e.g., worn bearings in wind speed instruments), meteorological causes (e.g., frozen instrumentation on the towers, lightening strikes), power failures, or improper programming of the data-logger.

Various screening tests were conducted on the 20 months of data from the Lower Camp and Mannix monitoring stations to identify unrealistic data. A few typical examples of these tests include the following:

- Screening to identify data which fell beyond realistic ranges (e.g., relative humidity less than 10% or greater than 100%, negative wind speeds).

- Screening to identify data that failed a rate of change test (e.g., wind directions that varied by less than 1° for three or more consecutive hours).

- Screening to identify inconsistencies in vertical profiles for multiple sensors located on a tower.

2.1.2 *Data Collection Efficiency*

Table 2.2 shows the data recovery efficiency for each of the meteorological parameters monitored at the Lower Camp and Mannix stations from November 1, 1993 to June 30, 1995. The data recovery efficiency is based on the data which passed the scrutiny of the quality assurance and quality control program. The maximum possible number of valid observations is 14568 (i.e., 100% efficiency).

Table 2.1 Meteorological parameters measured at the Lower Camp and Mannix stations.

Variable Number	Parameter[a] Recorded	Variable Number	Parameter[a] Recorded
1	Year	25	Lower Camp Vertical Wind Std. Dev_{20}
2	Month	26	Lower Camp Vertical Wind Std. Dev_{45}
3	Day	27	Lower Camp Vertical Wind Std. Dev_{100}
4	Hour	28	Lower Camp Vertical Wind Std. Dev_{167}
5	Lower Camp T_{20}	29	Mannix WS_{20}
6	Lower Camp ΔT_{45-20}	30	Mannix WS_{45}
7	Lower Camp ΔT_{100-20}	31	Mannix WS_{75}
8	Lower Camp ΔT_{167-20}	32	Mannix Std. Dev. WS_{20}
9	Lower Camp Std. Dev. WS_{20}	33	Mannix Std. Dev. WS_{45}
10	Lower Camp Std. Dev. WS_{45}	34	Mannix Std. Dev. WS_{75}
11	Lower Camp Std. Dev. WS_{100}	35	Mannix Vertical Wind Std. Dev_{20}
12	Lower Camp Std. Dev. WS_{167}	36	Mannix Vertical Wind Std. Dev_{45}
13	Lower Camp WD_{20}	37	Mannix Vertical Wind Std. Dev_{75}
14	Lower Camp WD_{45}	38	Mannix T_{20}
15	Lower Camp WD_{100}	39	Mannix ΔT_{45-20}
16	Lower Camp WD_{167}	40	Mannix ΔT_{75-20}
17	Lower Camp Std. Dev. WD_{20}	41	Mannix Net Radiation
18	Lower Camp Std. Dev. WD_{45}	42	Mannix WD_{20}
19	Lower Camp Std. Dev. WD_{100}	43	Mannix WD_{45}
20	Lower Camp Std. Dev. WD_{167}	44	Mannix WD_{75}
21	Lower Camp WS_{20}	45	Mannix Std. Dev. WD_{20}
22	Lower Camp WS_{45}	46	Mannix Std. Dev. WD_{45}
23	Lower Camp WS_{100}	47	Mannix Std. Dev. WD_{75}
24	Lower Camp WS_{167}	48	Mannix Relative Humidity

(a) Subscript indicates height on tower in metres.

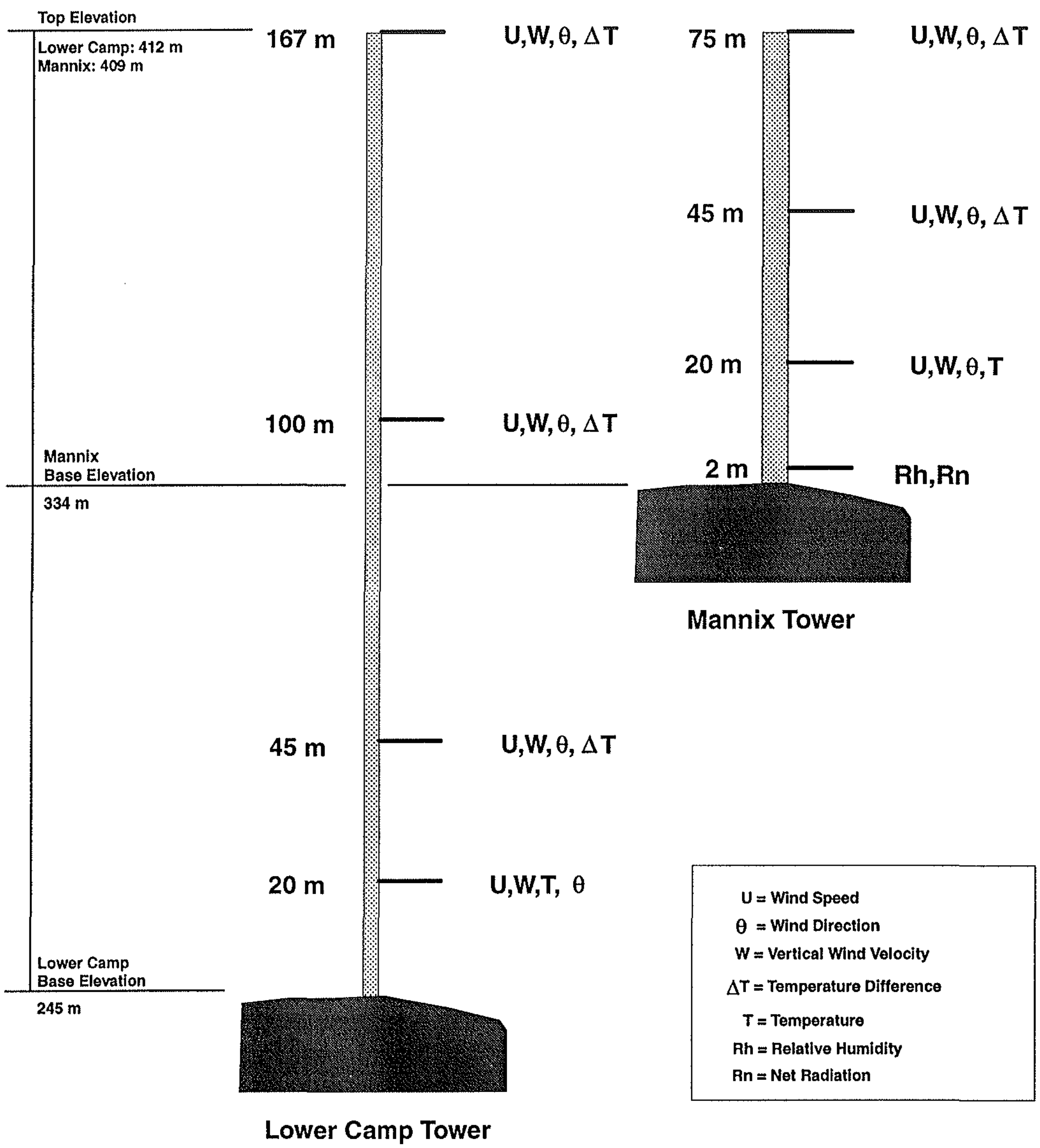

Figure 2.4 Schematic of the meteorological sensor placement at the Lower Camp and Mannix monitoring stations.

Table 2.2 Number of valid hourly observations and data recovery efficiencies for meteorological parameters measured at the Lower Camp and Mannix monitoring stations from November 1, 1993 to June 30, 1995.

Parameter	Lower Camp		Mannix	
	Number	Efficiency (%)	Number	Efficiency (%)
Wind Direction and Standard Deviation[a]				
167 m level	14206 (14176)	97.5 (97.3)	-	-
100 m level[b]	14222 **(9430)**	97.6 **(64.7)**	-	-
75 m level	-[c]	-	14233 (14207)	97.7 (97.5)
45 m level	**8263 (8215)**	**56.7 (56.4)**	14233 (14205)	97.7 (97.5)
20 m level	14191(14077)	97.4 (96.6)	14148 (14072)	97.1 (96.6)
Wind Direction and Standard Deviation				
167 m level	14121 (14121)	96.9 (96.9)	-	-
100 m level	14209 (14209)	97.5 (97.5)	-	-
75 m level	-[c]	-	14232 (14232)	97.7 (97.7)
45 m level	14213 (14213)	97.6 (97.6)	**8057 (8057)**	**55.3 (55.3)**
20 m level	13468(13468)	92.4 (92.4)	13949 (13949)	95.8 (95.8)
Temperature				
20 m level	14301	98.2	14245	97.8
Delta Temperature				
167 to 20 m	13610	93.4	-	-
100 to 20 m	14301	98.2	-	-
75 to 20 m	-	-	14245	97.8
45 to 20 m	14301	98.2	14245	97.8
Net Radiation	-	-	14150	97.1
Relative Humidity	-	-	**5461**	**37.5**
Standard Deviation of Vertical Wind				
167 m level	14243	97.8	-	-
100 m level	14252	97.8	-	-
75 m level	-	-	14221	97.6
45 m level	14252	97.8	14221	97.6
20 m level	13160	90.3	14221	97.6

(a) Standard deviations greater than or equal to 90° were not included.
(b) Boldface type indicates data recovery efficiencies less than 90%.
(c) Parameter was not measured at this level and/or station.

As indicated in the table, data recovery efficiencies are in excess of 90% for most parameters, with the exception of the following:

- Lower Camp Standard Deviation of Wind Direction at 100 m level. The recovery efficiency for this parameter is 64.7% Time series plots of the data indicated that all data after and including December 1, 1994 were recorded as being equal to the Lower Camp wind direction at 100 m. The cause for this data loss may be due to improper programming of the data-logger.

- Lower Camp Wind Direction at the 45 m level. The recovery efficiency for this parameter is 56.7%. This is due to several instances when the 45 m level wind direction at the Lower Camp station did not change for periods in excess of three hours. This was also indicated by the standard deviation for this parameter which remained at zero for extended periods of time. The cause is unknown, but may be due to a frozen instrument.

- Mannix Wind Speed at 45 m level. The recovery efficiency for this parameter is 55.3%. Time series plots of the 45 m level data indicate that it is exactly the same as the 75 m level data for various periods ranging from 350 hours to more than 6000 hours. This is highly unlikely and again, the probable cause may be due to improper programming of the data-logger.

- Mannix Relative Humidity. The recovery efficiency for this parameter is 37.5%. This is due to the fact that all data from April 11, 1994 to April 26, 1995 were recorded as 0% humidity. The cause for this data loss is unknown.

2.2 Other Data Sources in the Oil Sands Region

In addition to the ongoing data collection at Suncor, various other meteorological monitoring programs have been conducted in the oil sands area. When applicable, selected data from these other programs are presented in Appendix A of this report for comparative purposes.

3.0 TERRAIN

The path followed by a plume and the turbulence levels that result in the dilution of the plume can be affected by terrain features such as valleys and hills. The magnitude of the terrain effects is dependent on factors such as terrain elevation, the slope of the terrain feature, the relative height of the plume with respect to the terrain and the meteorological conditions.

Step-like terrain features can cause complex recirculating flow patterns in their immediate vicinity, while a valley can generate its own air flow path independent of the regional winds above the valley. In some cases, the plume will flow around dominant terrain features while in other cases the plume will flow over the terrain. In extreme cases, the plume may impinge directly on the terrain feature in its path.

Terrain information is required by the dispersion models that are used to simulate ambient air quality changes. In the past, these terrain values have been manually extracted from 1:50,000 topographic maps from Energy Mines & Resources Canada. Recently, digital terrain maps have become available from Forestry Lands and Wildlife, Lands Information Services Division. These digital maps are available in a 1:20,000 scale with a resolution ranging from 25 to 50 m. Figure 3.1 shows the area for which digital terrain maps were obtained. The digital maps (or digital elevation models, DEM) for the area were supplemented with digital terrain data from Suncor and Syncrude. The Suncor and Syncrude DEMs reflect changes in the land forms due to mining and tailings pond operations. For distances beyond the region for which maps were obtained, terrain was extracted from 1:50,000 scale topographic maps.

3.1 Local Terrain

Figures 3.2 and 3.3 show the terrain contours in the immediate vicinity of the Suncor and Syncrude plants. The origin (i.e., 0, 0) of the figures refers to the location of the proposed Suncor FGD stack. The corresponding UTM coordinates of this location are 471090.4E, 6317586.8N. Figure 3.2 is plotted as terrain contours superimposed over a shaded relief representation of the terrain. Figure 3.3 shows a three-dimensional representation with the Suncor stacks, the Syncrude stack, the Lower Camp tower and the Mannix tower indicated in the diagram. The dominant terrain features in the vicinity of the plants are the Athabasca River Valley, the Suncor #1 tailings pond and the Syncrude tailings pond.

3.2 Regional Terrain

Figure 3.4 shows the terrain on a regional scale. The dominant terrain features on a regional scale include:

- The Athabasca River Valley which has a general north-south orientation in the vicinity of the plants.

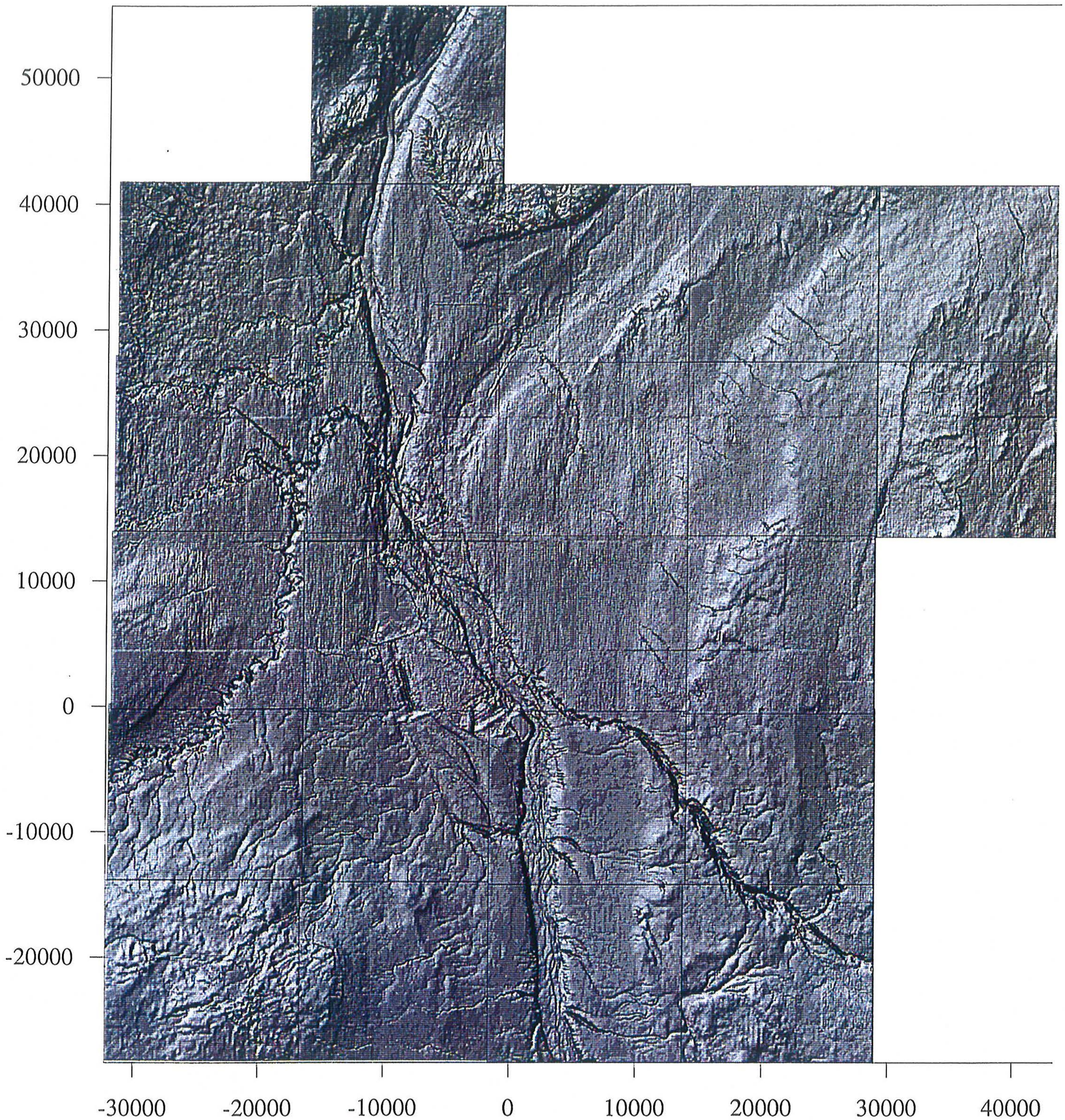

Figure 3.1 Area for which digital terrain maps were available.

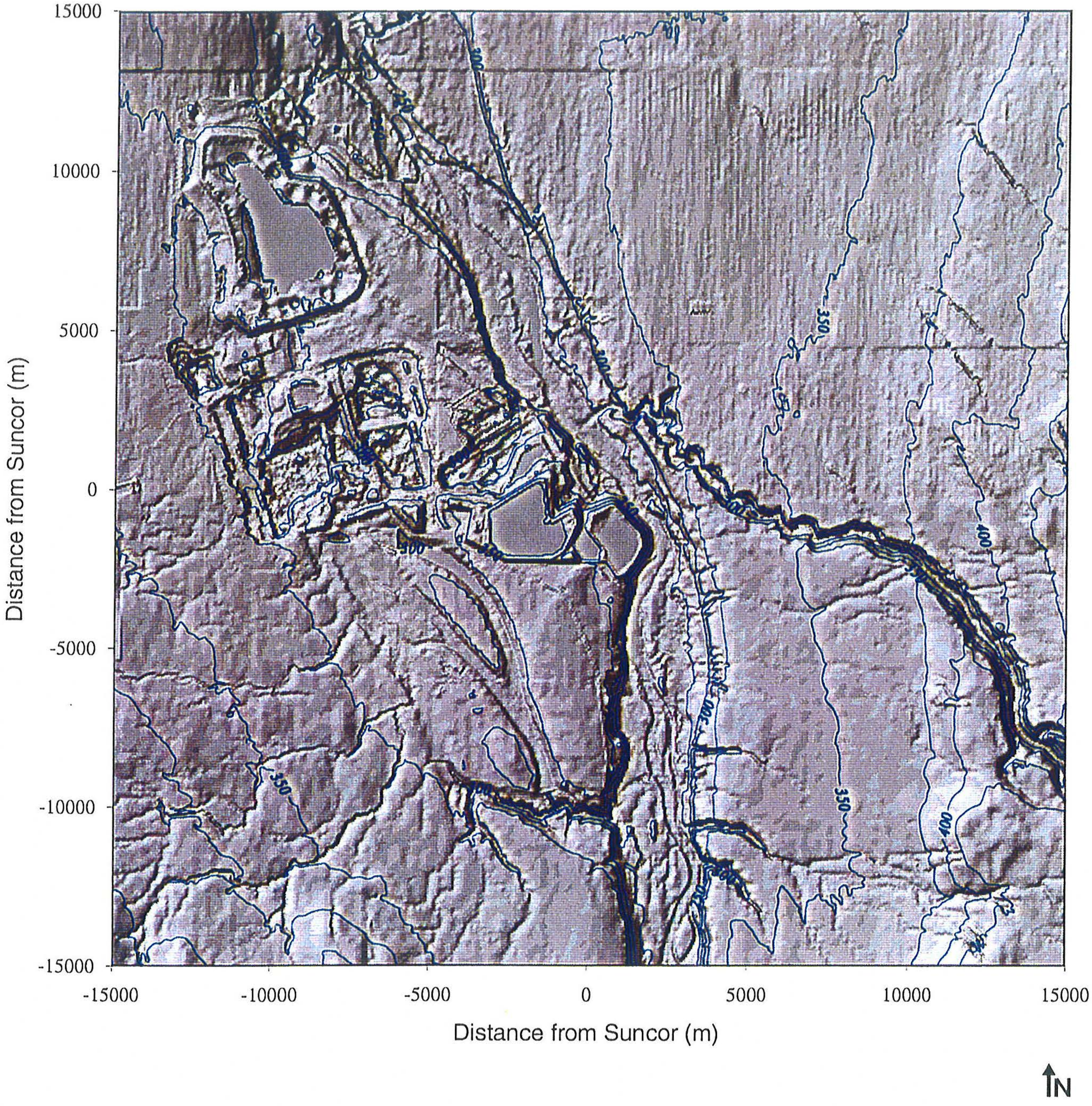

Figure 3.2 Local terrain contours in the vicinity of the Suncor and Syncrude plants (contour interval = 25 m AMSL).

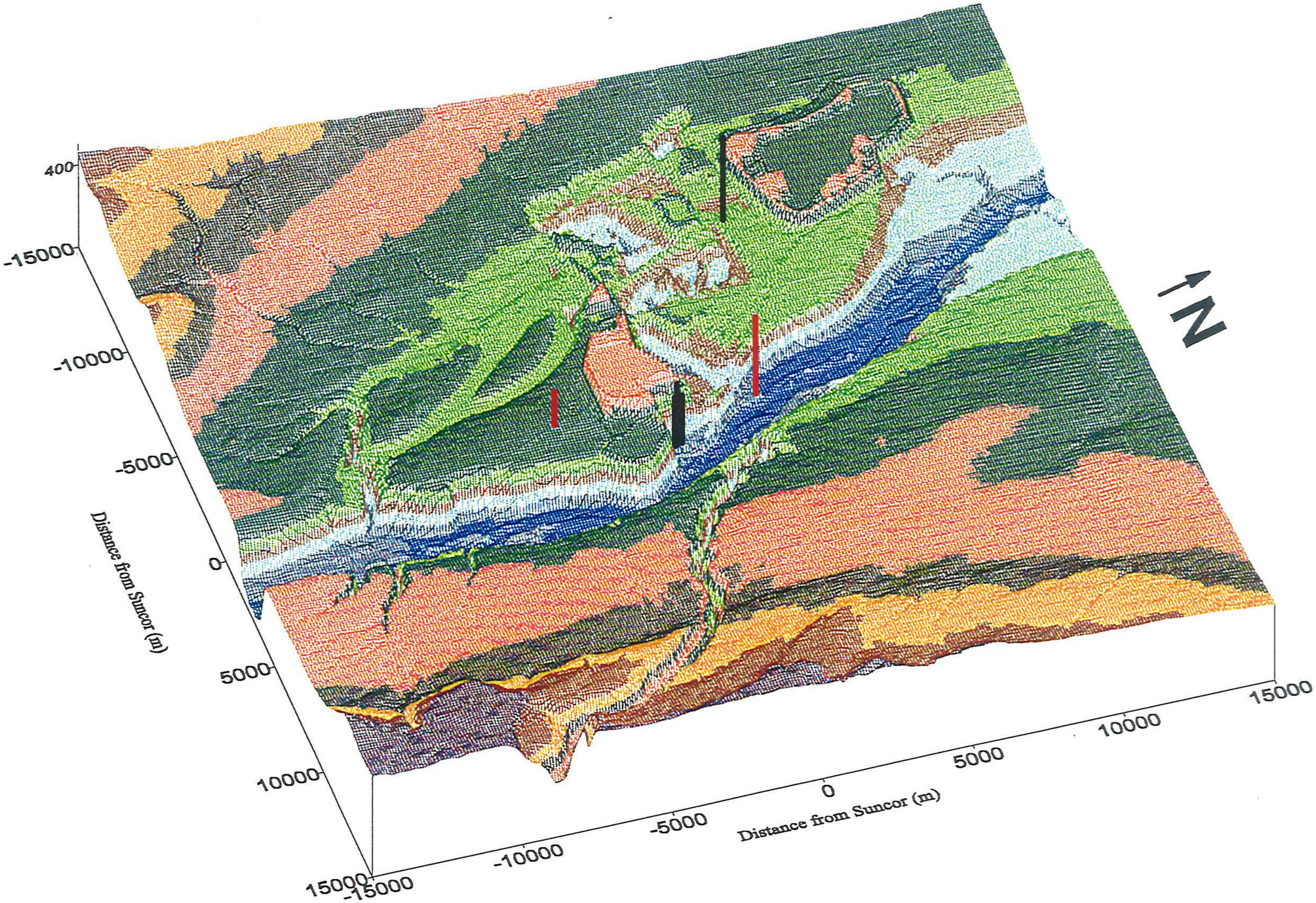

Figure 3.3 Three-dimensional representation of local terrain in the vicinity of the Suncor and Syncrude plants.

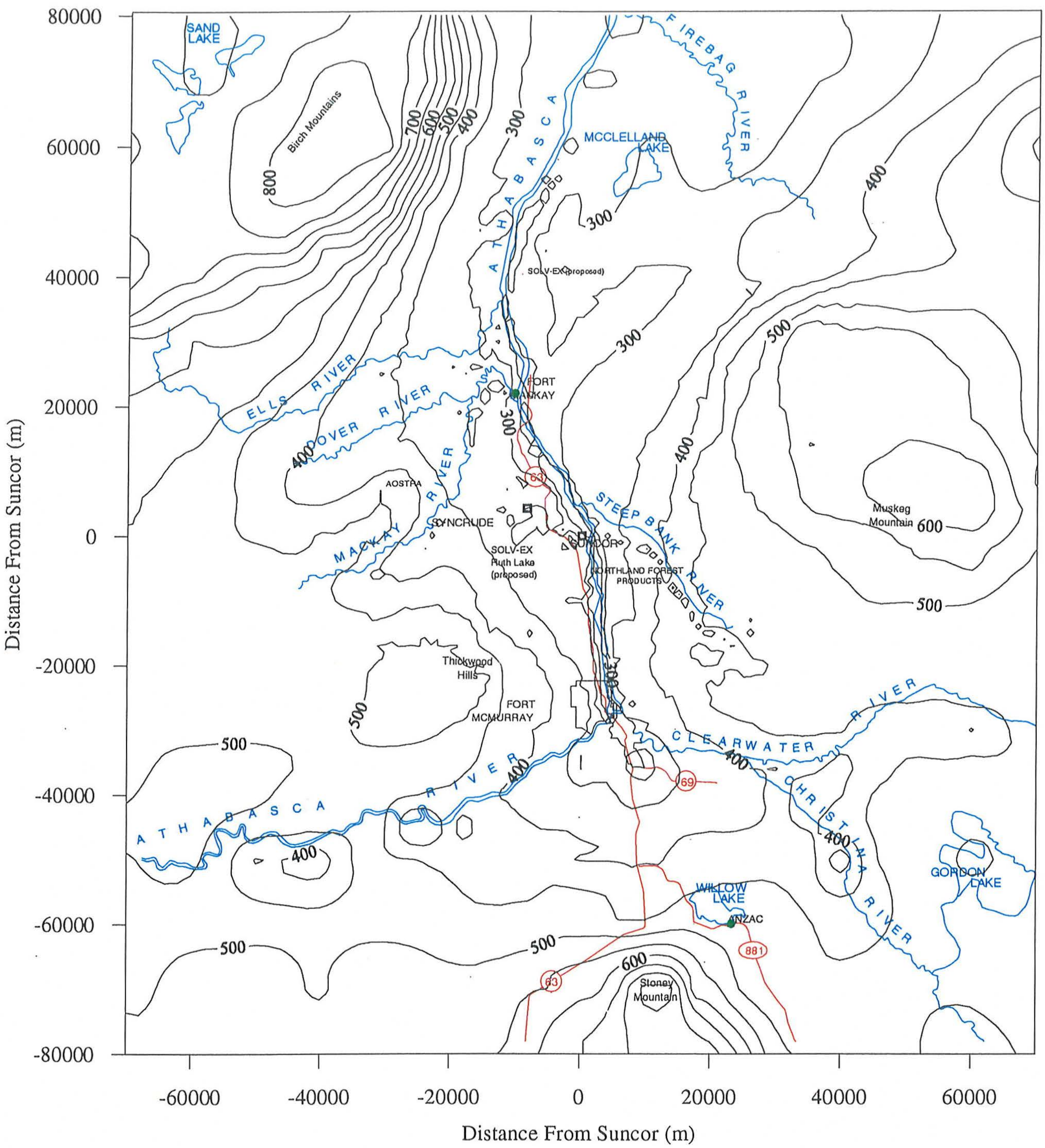

Figure 3.4 Regional terrain contours in the vicinity of the Suncor and Syncrude plants (contour interval = 50 AMSL).

- The Clearwater River Valley which has a general east-west orientation.

- The highest elevations are associated with the Birch Mountains which occur 50 km to the northwest of the plant area. At a distance of 75 km to the northwest, these mountains reach an elevation of 820 m AMSL.

- Muskeg Mountain is about 40 km to the east of the plant area. At a distance of 55 km, this mountain reaches an elevation of 665 m AMSL.

- Stoney Mountain is about 60 km to the south of the plant area. At a distance of 65 km, this mountain rises to an elevation of 760 m AMSL.

- The Thickwood Hills are about 20 km to the southwest of the plant area. At a distance of 25 km, these hills rise to an elevation of 515 m AMSL.

For the purposes of comparison, the base elevation of the Suncor plant stacks is about 259 m AMSL and the base elevation of the Syncrude plant stack is about 304 m AMSL.

3.3 Surface Features

The roughness and smoothness of a vegetation canopy affect the wind speed and turbulence profiles. The oil sands area is located in the Boreal Forest Region which supports a variety of upland and lowland vegetation. The area is characterized by forest associations of white spruce, black spruce, jackpine, balsam fir, tamarack, aspen, balsam poplar and white birch.

Mature tree heights range from 10 m for black spruce in low-lying areas to 30 m for jackpine located on sandy soils. Mature white spruce and aspen forest stands tend to be 25 and 15 m in height, respectively. Due to differing soil types and drainage patterns, the vegetation cover is non-uniform within the region.

4.0 WIND

The transport of gaseous and particulate emissions is controlled by the meteorology in the region. The two main parameters which affect the transport of a plume are wind direction and wind speed. Summaries of these two parameters are presented in the following sections.

4.1 Wind Direction (θ)

Wind direction was measured at four levels at the Lower Camp monitoring station (i.e., 167, 100, 45 and 20 m) and at three levels at the Mannix monitoring station (i.e., 75, 45 and 20 m). Wind direction data can be compared by plotting the frequency distribution as a "windrose". Each windrose consists of rays extending from an inner circle towards the outer edge of the diagram. The total length of each ray indicates the percent frequency of wind from the direction represented.

Figure 4.1 shows the annual windrose diagrams for each of the monitoring levels at Lower Camp. The 45 m level winds show a high frequency of south-southeast winds. This may be due to the low data recovery efficiency for this level (i.e., 56.7% as indicated in Table 2.2). The 20 m level winds tend to blow more frequently across the valley than those at higher elevations. When compared to longer-term Lower Camp wind data (Appendix A, Figure A.5), the observations at the 20 m level of the tower indicate a much higher frequency of crosswind air flow. It is not clear whether this is due to local tree canopy effects or instrument problems. Further investigation is warranted.

Figure 4.2 shows the annual windrose diagrams for each of the monitoring levels at Mannix. Although the predominant wind direction is south-southeast at all three monitoring levels, the percentage of south-southeast winds decreases with increased monitoring height. This may be due to reduced influences from the surrounding terrain.

The following table summarizes the most frequently observed wind direction at each level for the two monitoring locations:

Level	Lower Camp	Mannix
167 m	S	-
100 m	S	-
75 m	-	SSE
45 m	SSE	SSE
20 m	E	SSE

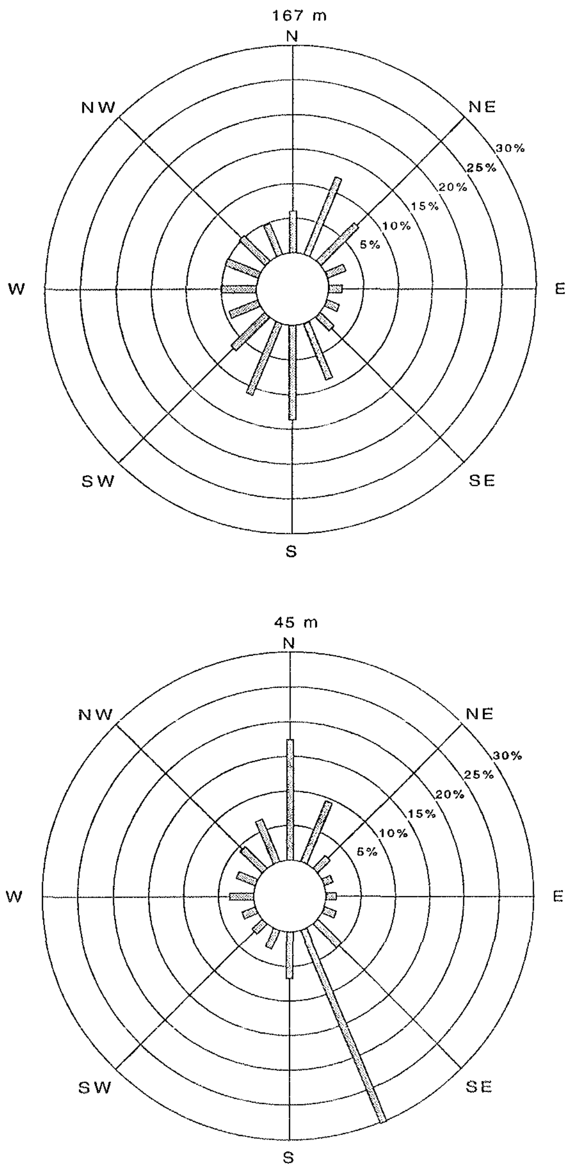

Figure 4.1 Annual windrose diagrams for the 167, 100, 45 and 20 m levels at the Lower Camp monitoring station.

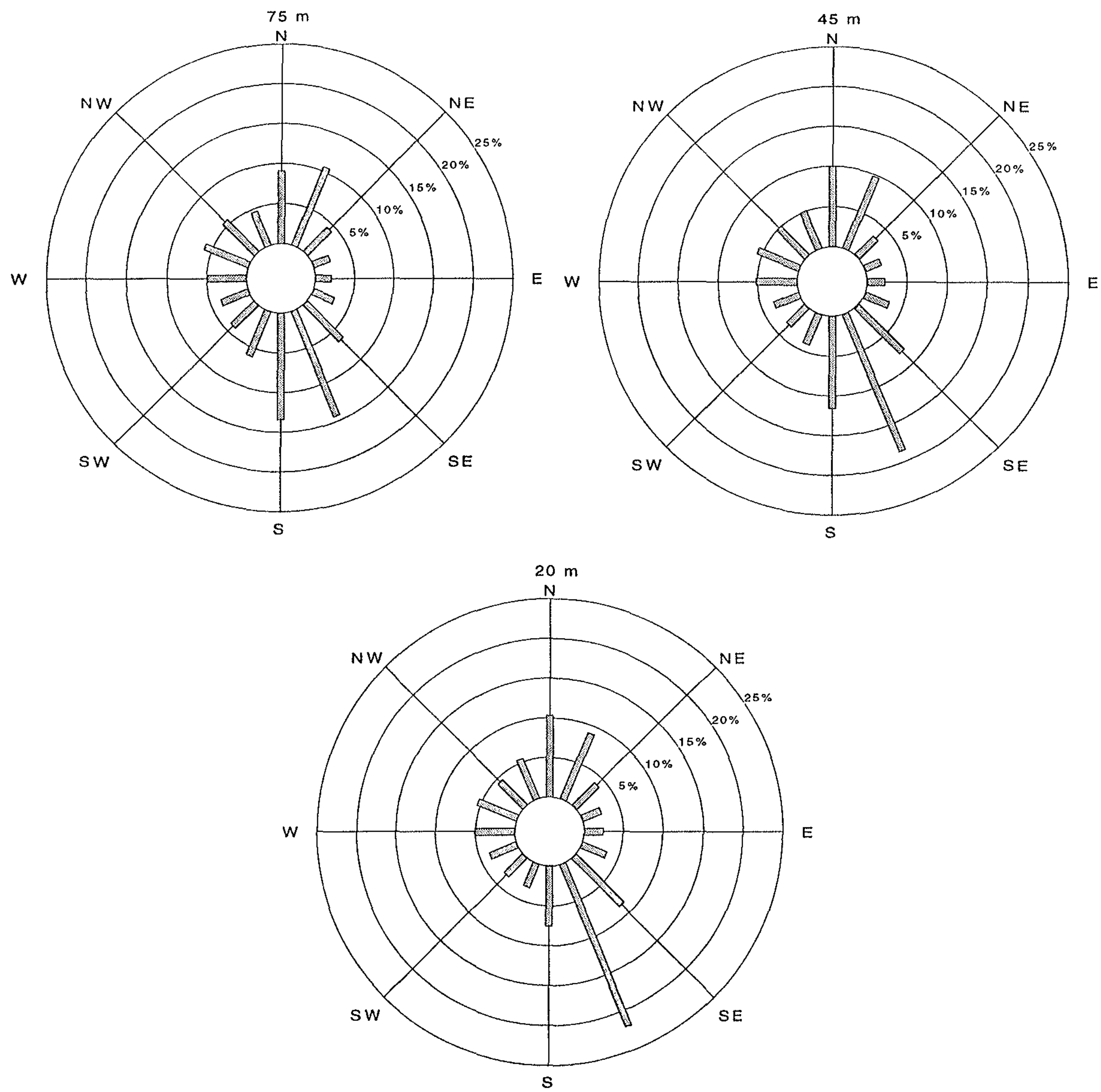

Figure 4.2 Annual windrose diagrams for the 75, 45 and 20 m levels at the Mannix monitoring station.

Figures 4.3 and 4.4 show the seasonal windroses for the 167 m level winds at Lower Camp and the 75 m level winds at Mannix, respectively. The most frequent or prevailing winds at these levels are as follows:

Season	Lower Camp	Mannix
Winter	S	S
Spring	NNE	SSE
Summer	S	SSE
Fall	S	S

Wind directions observed at the Lower Camp and Mannix upper levels reflect the along-valley flow as influenced by the surrounding terrain and the Athabasca River valley.

Figure 4.5 compares the annual windroses for Lower Camp (167 m) and Mannix (75 m). The windrose for Lower Camp indicates that winds from the south occur most frequently, while the predominant wind direction at Mannix is south-southeast, but again with a high frequency of south winds present. However, in general, the Lower Camp and Mannix windroses compare favourably, with a high frequency of wind indicated from the south and north-northeast at both stations.

Wind data have been collected in the past by various other monitoring programs in the Athabasca Oil Sands area. Analysis and windroses for some of these data sets are presented in Appendix A for comparative purposes. As indicated in Appendix A, wind roses associated with monitoring programs located in the Athabasca River Valley generally show the influence from the terrain within the valley and are therefore comparable to the data collected at Lower Camp and Mannix. The wind roses presented in Appendix A which do not compare as favourably with the Lower Camp and Mannix data (i.e., do not show the influence of the Athabasca River Valley) include the following:

- Fort McMurray Airport (Figure A3). This wind rose shows the influence of the Clearwater River Valley, with a predominance for east-west winds.
- Mildred Lake Pibal Data. These data were collected at 400 m level and show a predominance for westerly winds. The 400 m level height may be beyond the level influenced by the flow patterns which exist closer to the surface within the Athabasca River Valley.
- Birch Mountain. Data collected at Birch Mountain show a predominance for winds in the west to northwest sector. Birch Mountain is located approximately 50 km to the northwest of the Suncor facility. The Birch Mountain monitoring station was therefore at an elevation and distance removed from the influences of the Athabasca River Valley.

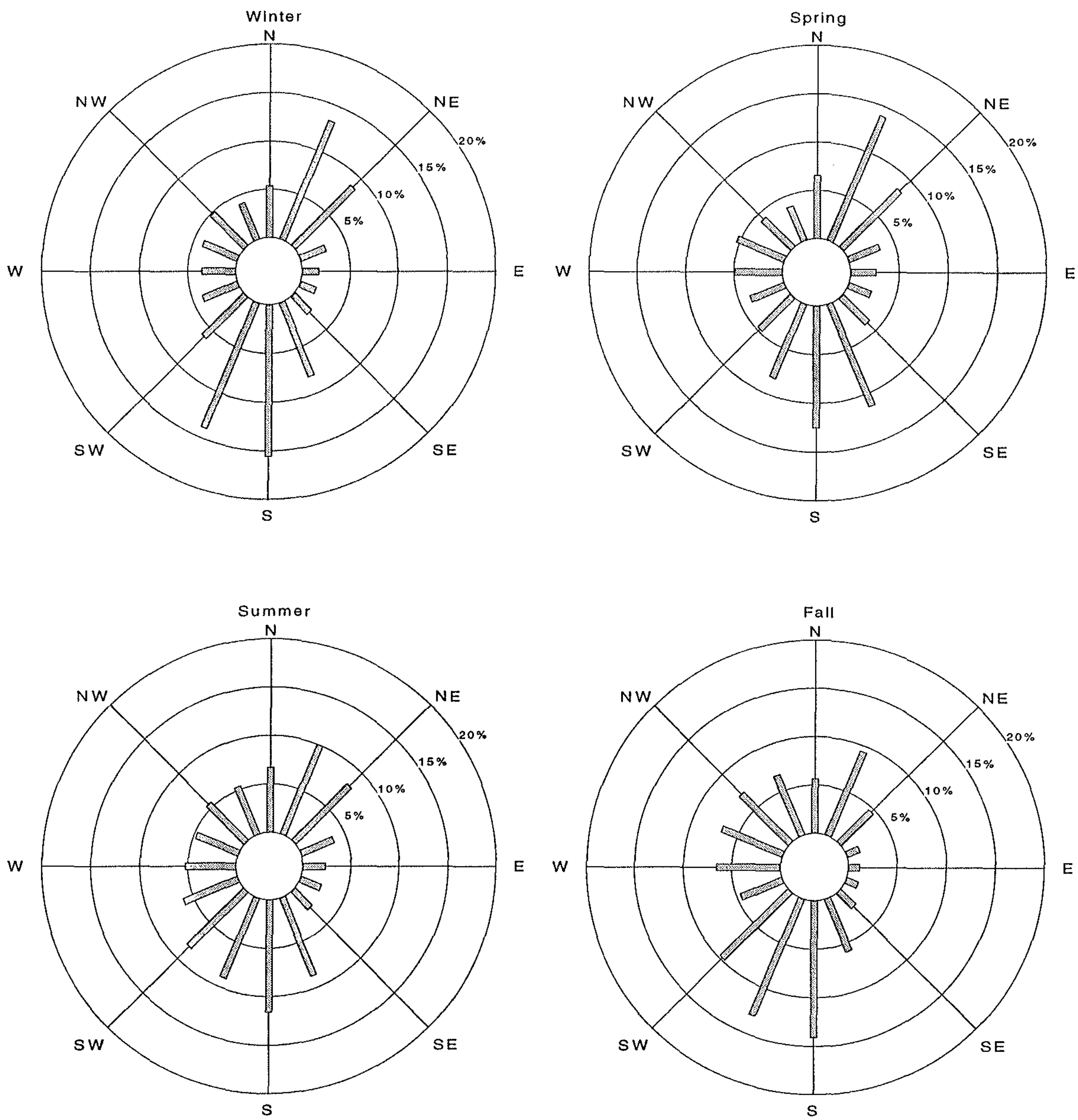

Figure 4.3 Seasonal windroses for the 167 m level winds at Lower Camp.

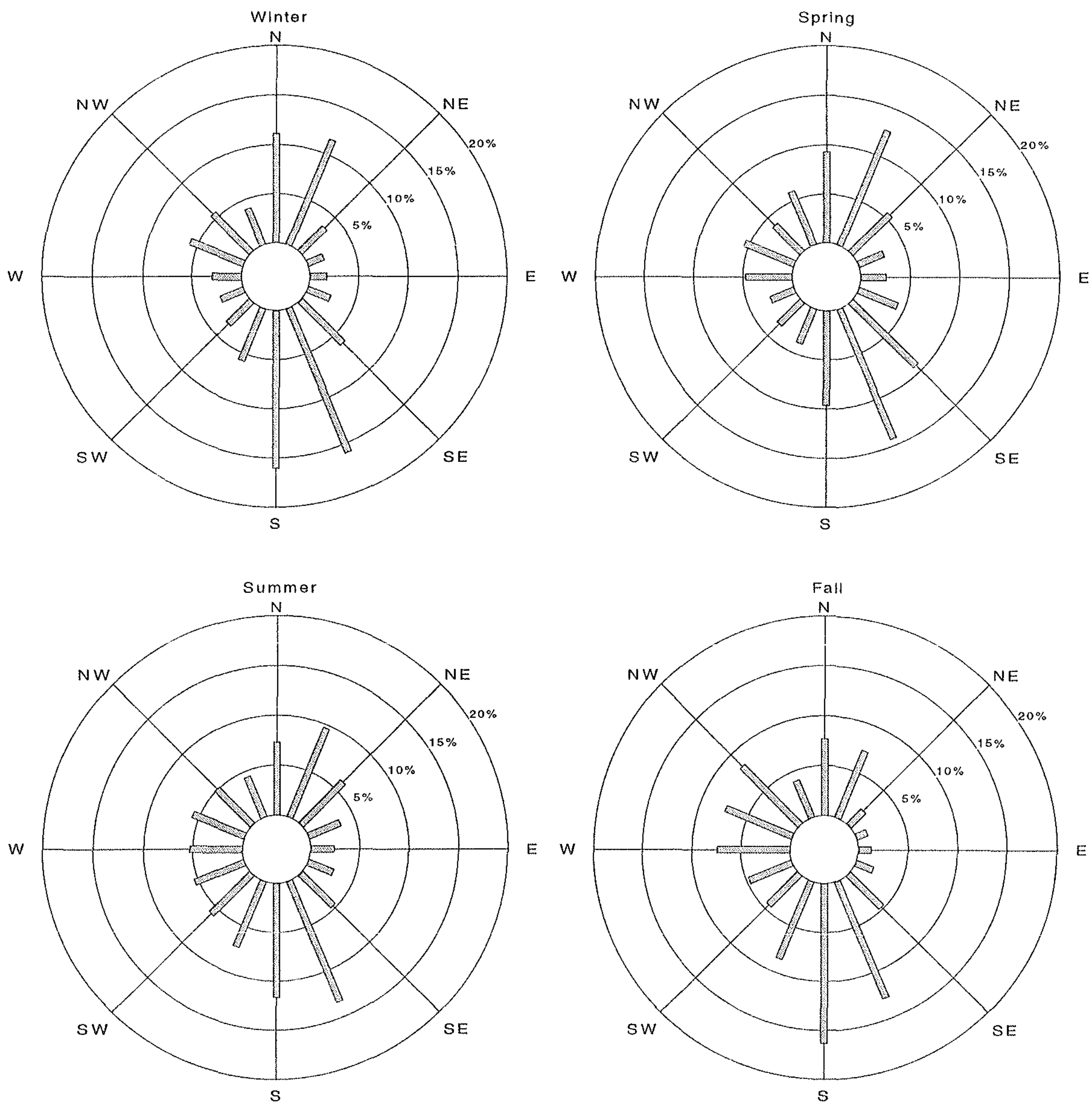

Figure 4.4 Seasonal windroses for the 75 m level winds at Mannix.

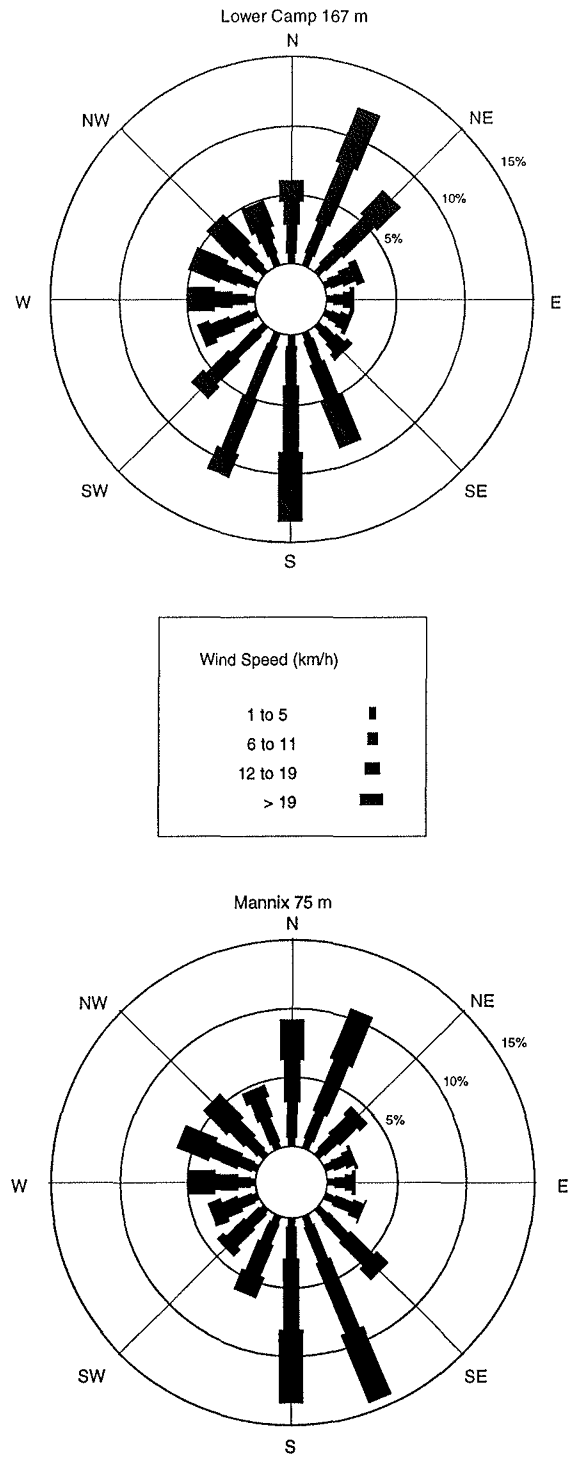

Figure 4.5 Annual windroses for Lower Camp (167 m) and Mannix (75 m).

4.2 Wind Speed (U)

Wind speed was measured at four levels at the Lower Camp monitoring station (i.e., 167, 100, 45 and 20 m) and at three levels at the Mannix monitoring station (i.e., 75, 45 and 20 m). Wind speed is important with respect to plume dispersion for the following reasons:

- The along-wind dilution is proportional to the wind speed.
- The height of the plume above the ground is inversely proportional to the wind speed.
- Wind flow interaction with surface features creates turbulence.

Table 4.1 provides the basic statistics associated with wind speeds at each monitoring level for Lower Camp and Mannix. The mean and median wind speeds increase with height above ground for each of the monitoring levels at the two stations. At the Lower Camp station, the median wind speed ranges from 7.9 km/h at the 20 m level to 14.2 km/h at the 167 m level. Similarly, at Mannix, the median wind speed ranges from 7.6 km/h at the 20 m level to 14.5 km/h at the 75 m level.

Figures 4.6 and 4.7 show the 25, 50 (median) and 75 percentile wind speeds at Lower Camp and Mannix, respectively, for each of the monitoring levels as a function of time of day. At the 20 and 45 m levels at Lower Camp and the 20 m level at Mannix, wind speeds tend to peak between 13:00 and 14:00 hours. For the upper levels at both stations, the wind speeds tend to peak after 20:00 hours.

Figures 4.8 and 4.9 show the 25, 50 (median) and 75 percentile wind speeds at Lower Camp and Mannix, respectively, for each of the monitoring levels as a function of month. No data are available for the months of July to October, inclusive, at the Mannix 45 m level. In general, the highest median wind speeds tended to occur during the months of September and October, with the exception of the highest median occurring in March for the 20 m level winds at Mannix. Wind speeds higher than the annual median also occurred during the months of March and May at all monitoring levels. At the Lower Camp 20 m level, the lowest median wind speed occurred in February. At all other monitoring levels at both Lower Camp and Mannix, the lowest median wind speeds occurred in January.

Figures 4.10 and 4.11 show seasonal and annual wind speed frequency distributions for each of the monitoring levels at Lower Camp and Mannix, respectively. In general, the data for the Lower Camp 167 m level and Mannix 75 m level compare favourably. On an annual basis, wind speeds less than 12 km/h occurred approximately 38% of the time at the 167 m level at Lower Camp and approximately 36% of the time at the 75 m level at Mannix.

At the 20 m levels, calm winds occurred approximately 4 times more frequently on an annual basis at Lower Camp than at Mannix, and wind speeds in excess of 19 km/h occurred almost 3 times more frequently at Lower Camp than at Mannix. Wind speeds less than 12 km/h occurred approximately 69% and 77% of the time at Lower Camp and Mannix, respectively.

Table 4.1 Basic statistics associated with wind speeds (km/h) observed from November 1, 1993 to June 30, 1995 at Lower Camp and Mannix monitoring stations.

Statistic	Lower Camp				Mannix		
	20 m	45 m	100 m	167 m	30 m	45 m	75 m
Number	13 468	14 213	14 209	14 121	13 949	8057	14 232
Mean	8.6	9.7	12.9	15.6	8.3	12.1	15.2
Minimum	0.0	0.3	0.3	0.1	0.0	0.1	0.2
25 Percentile	3.6	5.3	6.9	8.7	4.9	7.6	9.2
Median[a]	7.9	8.9	11.4	14.2	7.6	11.7	14.5
75 Percentile	12.5	13.0	17.6	21.2	11.0	16.2	20.6
Maximum	38.8	36.8	52.2	58.0	34.0	39.3	50.3

[a] Median = 50 percentile.

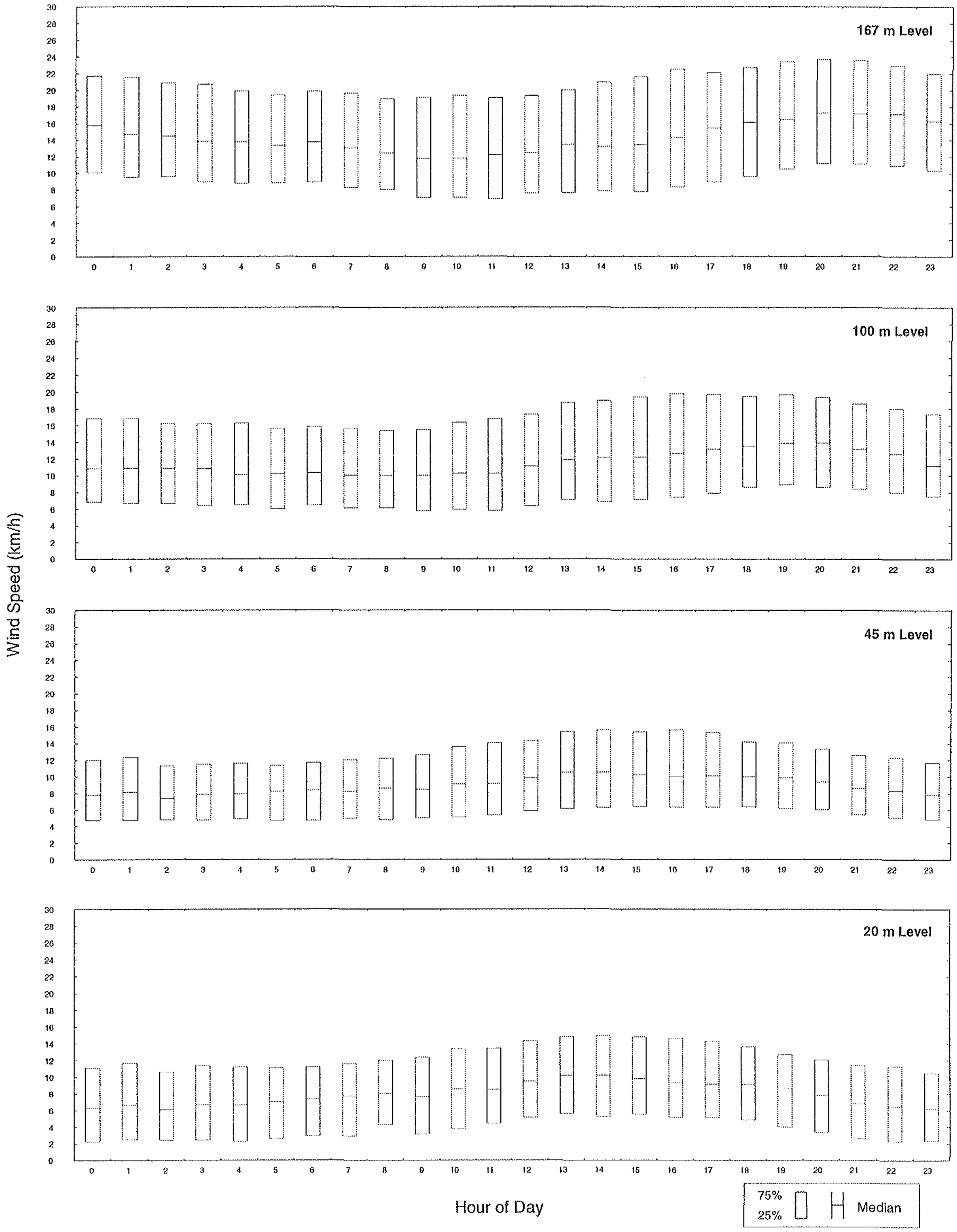

Figure 4.6 Wind speeds observed at Lower Camp monitoring station as a function of hour of day.

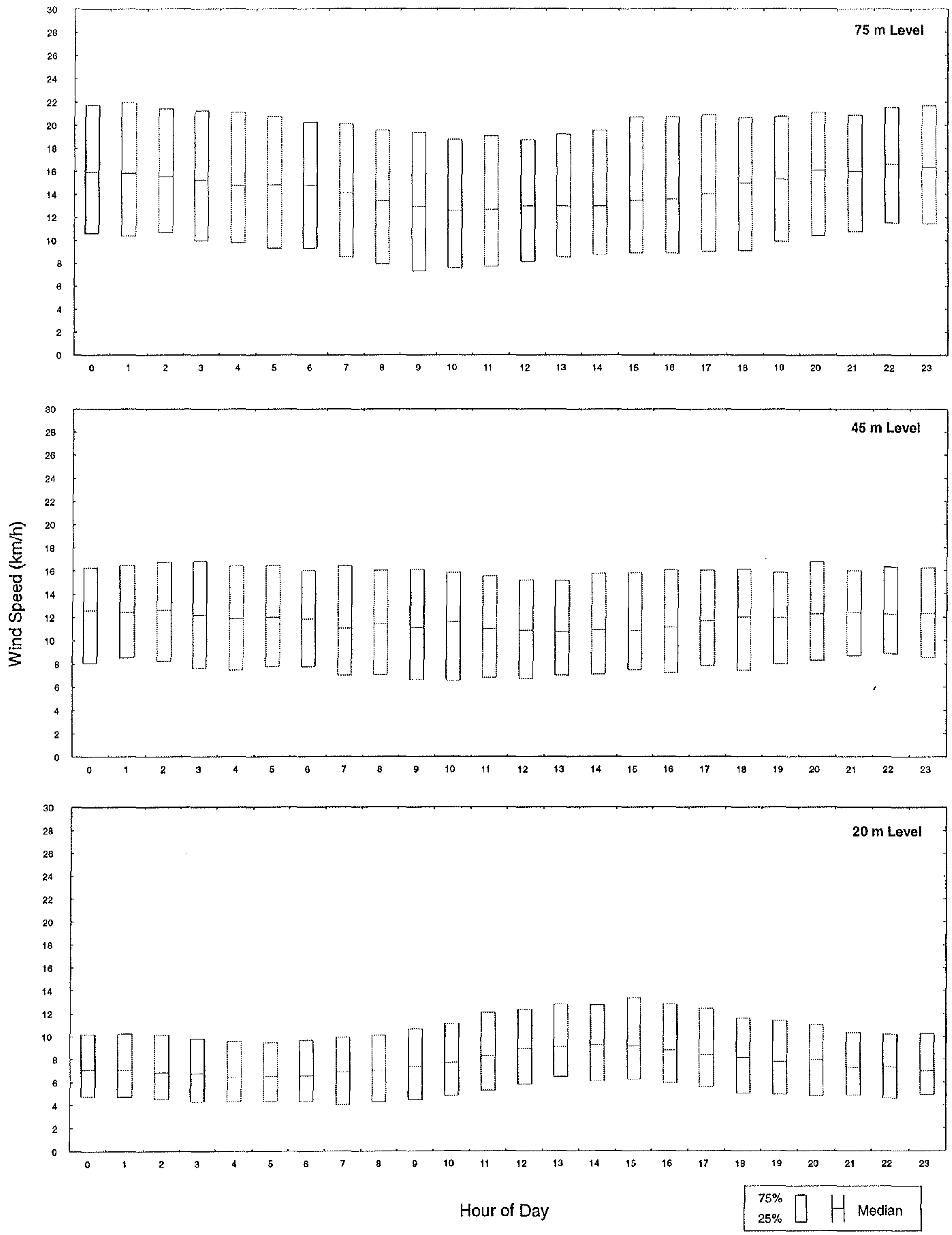

Figure 4.7 Wind speeds observed at Mannix monitoring station as a function of hour of day.

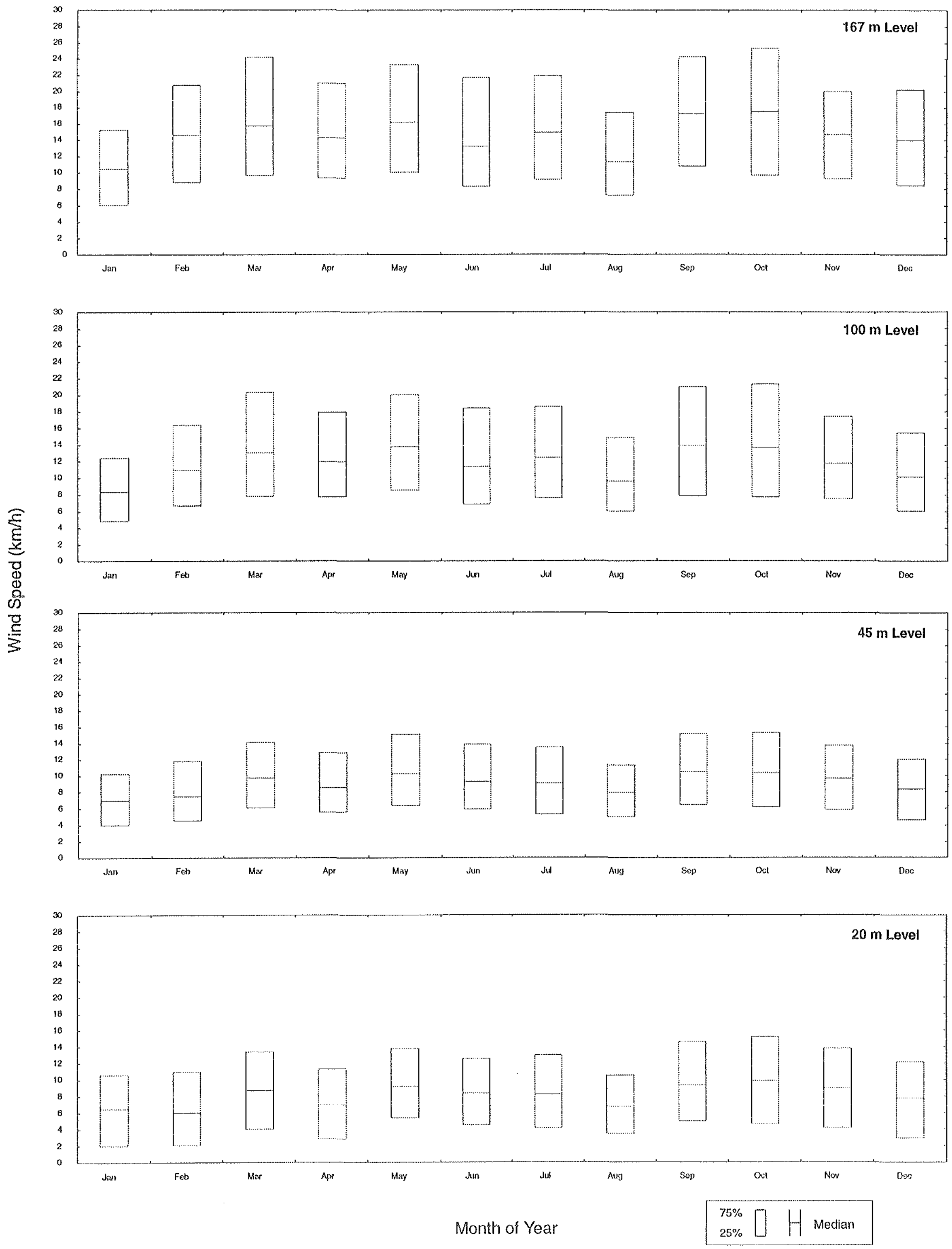

Figure 4.8 Wind speeds observed at Lower Camp monitoring station as a function of month.

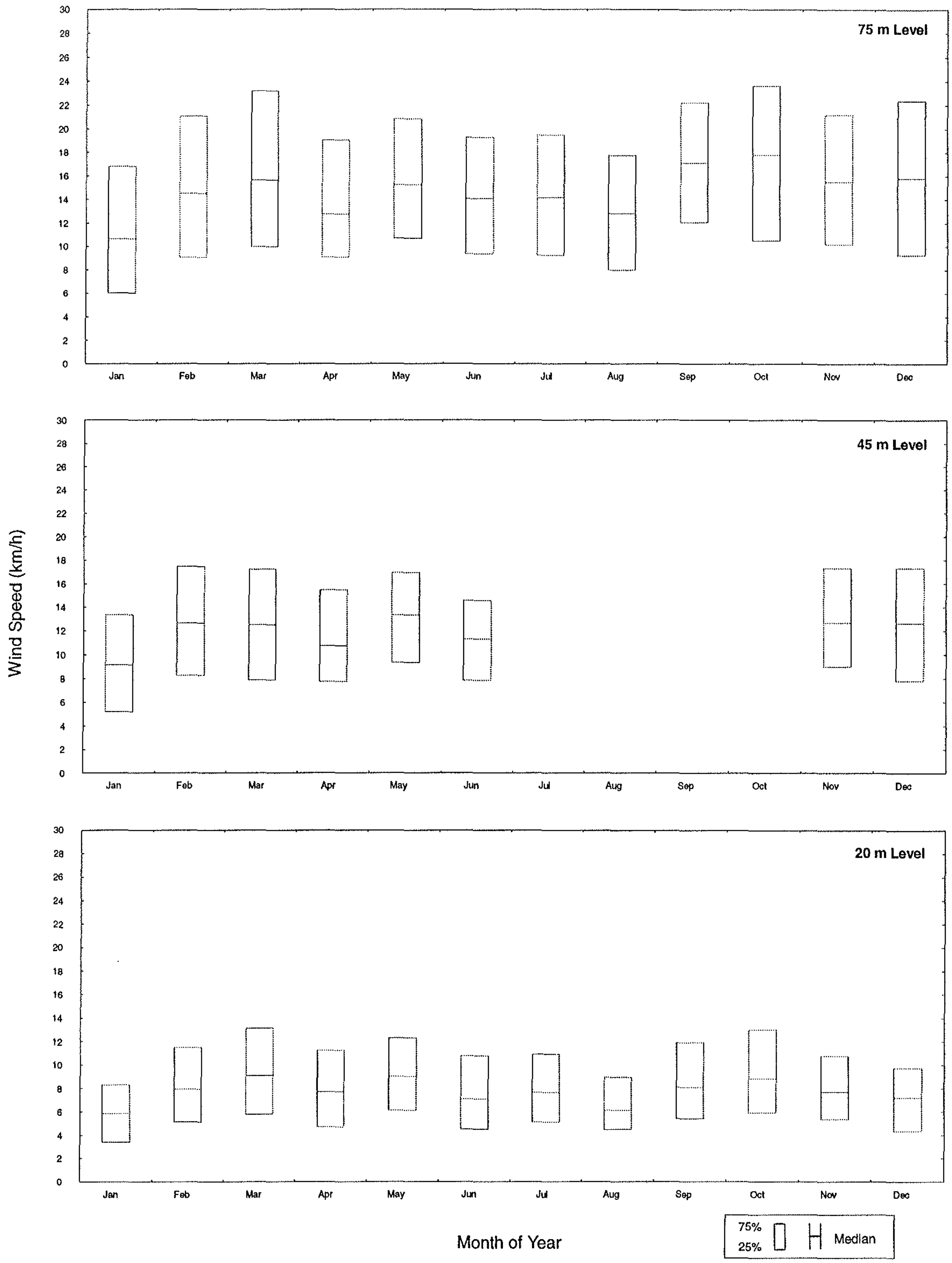

Figure 4.9 Wind speeds observed at Mannix monitoring station as a function of month.

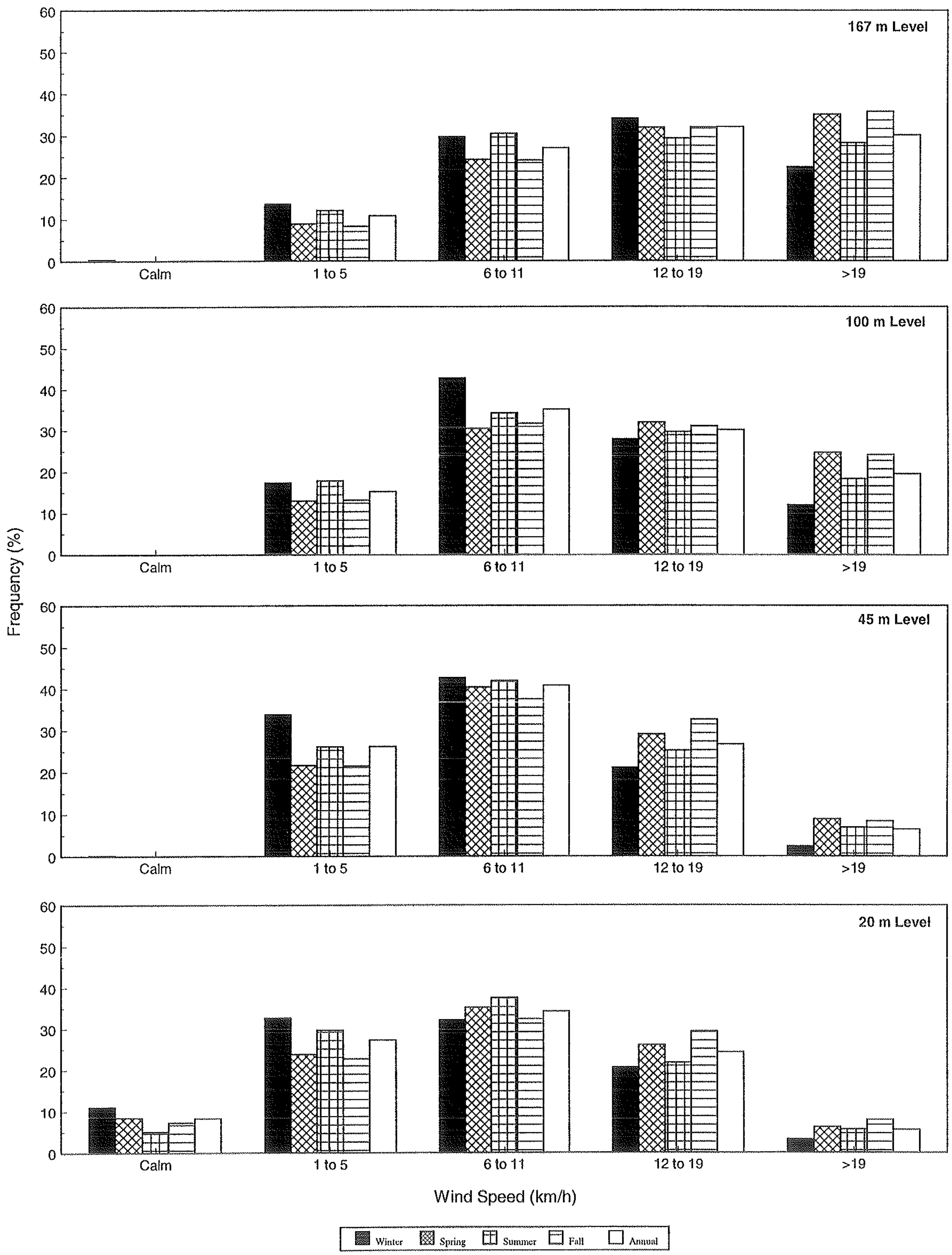

Figure 4.10 Seasonal and annual wind speed frequency distributions for Lower Camp.

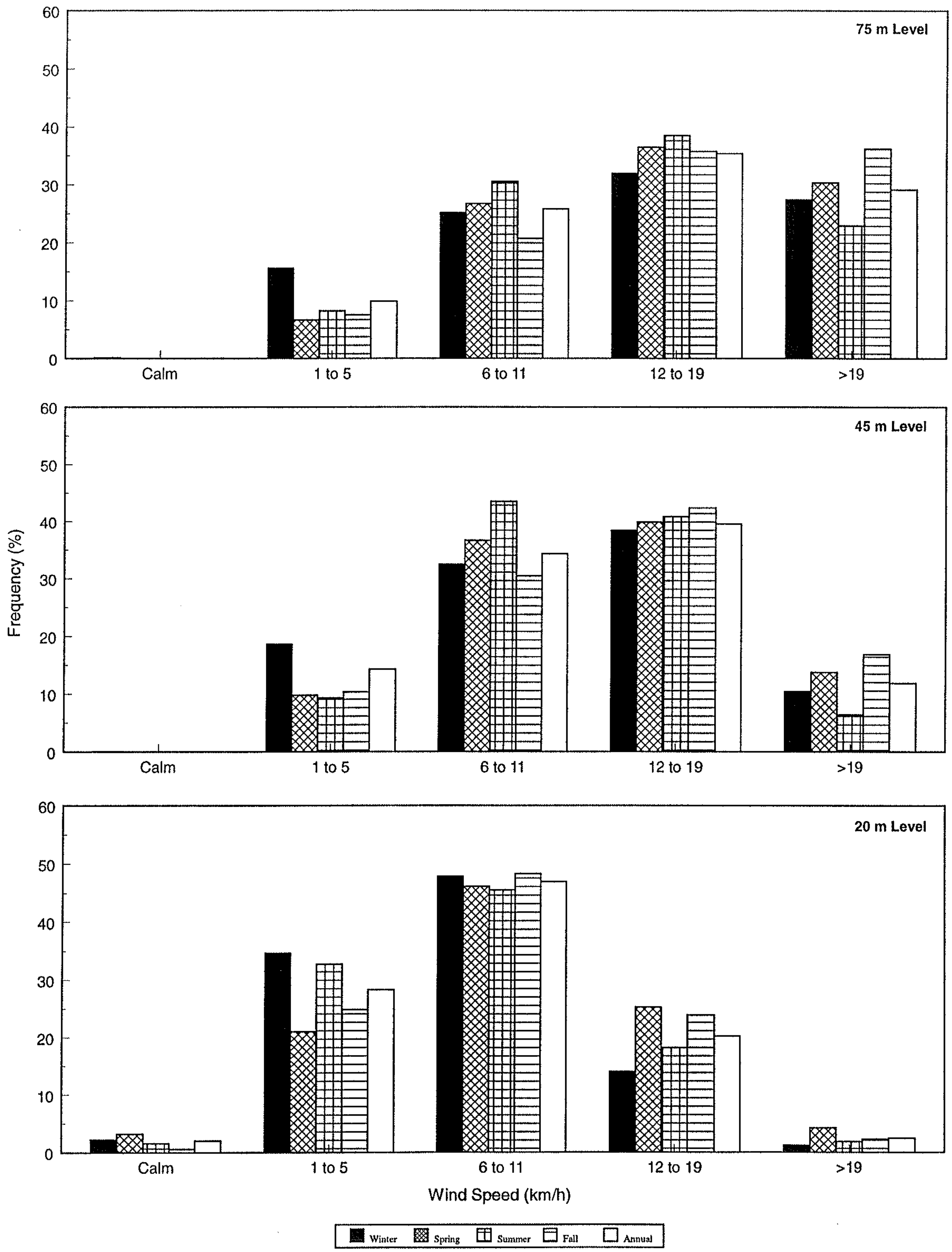

Figure 4.11 Seasonal and annual wind speed frequency distributions for Mannix.

At the Lower Camp 167 m level and Mannix 75 m level, the frequency distributions are very comparable. Calm wind speeds occurred less than 1% of the time and wind speeds > 19 km/h occurred about 30% of the time at both sites on an annual basis. Wind speeds less than 12 km/h occurred approximately 39% and 37% of the time at Lower Camp (167 m) and Mannix (75 m), respectively.

For comparative purposes, wind speed frequency data from various other monitoring programs were analyzed in Appendix A. The following summarizes the annual results of the analysis:

- The Suncor SODAR 150 m level data compare most favourably with the Lower Camp 45 m level and Mannix 20 m level data.

- The SandAlta 46 m level data compare most favourably with the Mannix 45 m level data. The SandAlta data compare reasonably well with the Lower Camp 100 m and 167 m level data for wind speeds < 12 km/h. However, the Lower Camp 100 m and 167 m level data indicate that wind speeds > 19 km/h occurred 20 and 30% of the time, respectively, whereas the SandAlta data indicate only 12% of the time.

- The Environment Canada Mildred Lake data compare most favourably with the Lower Camp and Mannix 20 m level data.

4.3 Power Law Exponent (p)

A power-law relationship is frequently used to extrapolate wind speeds from a measured level to a level at which no measurement is available. This relationship may be approximated using the following formula:

$$U_Z = U_R\left(\frac{Z}{Z_R}\right)^p$$

where: U_Z = the wind speed at an arbitrary height (Z)
U_R = the wind speed at a reference height (R)
p = the power-law exponent.

The power-law exponent (p) is a best fit value and is dependent on atmospheric stability, surface roughness and height above the ground. The value of p typically ranges from 0.1 on a sunny afternoon to 0.6 during a cloudless night (U.S. EPA 1987).

Rearranging the preceding equation to solve for p gives the following:

$$p = \frac{\ln(U_h) - \ln(U_l)}{\ln(Z_h) - \ln(Z_l)}$$

where: the subscript h refers to the higher of the two levels
the subscript l refers to the lower of the two levels.

The preceding relationship was used to calculate power-law exponents for the Lower Camp and Mannix data. The calculations were performed using wind speeds ≥ 1 m/s (3.6 km/h) at the Lower Camp 167 and 100 m levels and the Mannix 75 and 20 m levels. The following table shows the basic statistics for the calculated power-law exponents:

	Valid N	Mean	Minimum	Percentile			Maximum
				25	50 (Median)	75	
Lower Camp	12 784	0.4	-2.6	0.1	0.3	0.6	3.2
Mannix	11 732	0.4	-0.6	0.3	0.4	0.6	1.4

The analysis indicated that about 26% of the calculated values of Lower Camp and 20% of the values for Mannix were less than zero. The presence of these negative values indicates a wind speed decrease with increasing height. Figure 4.12 presents a frequency distribution of the negative power-law exponents (i.e., $p < 0$) as a function of stability class. As indicated in the figure, approximately 48% and 41% of the negative values occurred under D stability (neutral conditions) at Lower Camp and Mannix, respectively.

Figure 4.13 shows the diurnal variations for the calculated power exponent values for the Lower Camp and Mannix locations. As expected, smaller values occur during the day and larger values during the night.

The following table compares the median on-site p values for each PG stability class with the default values used in regulatory models (U.S. EPA 1987, Alberta Environment 1992):

Stability Class	Site-Specific p-Values			Valid n	
	Lower Camp	Mannix	Modelling Range	Lower Camp	Mannix
A	0.12	0.21	0.05 to 0.17	184	100
B	0.07	0.21	0.06 to 0.17	277	291
C	0.10	0.23	0.06 to 0.20	1256	1346
D	0.28	0.40	0.12 to 0.27	7751	7516
E	0.59	0.62	0.30 to 0.38	2289	2091
F	0.57	0.50	0.30 to 0.61	484	368

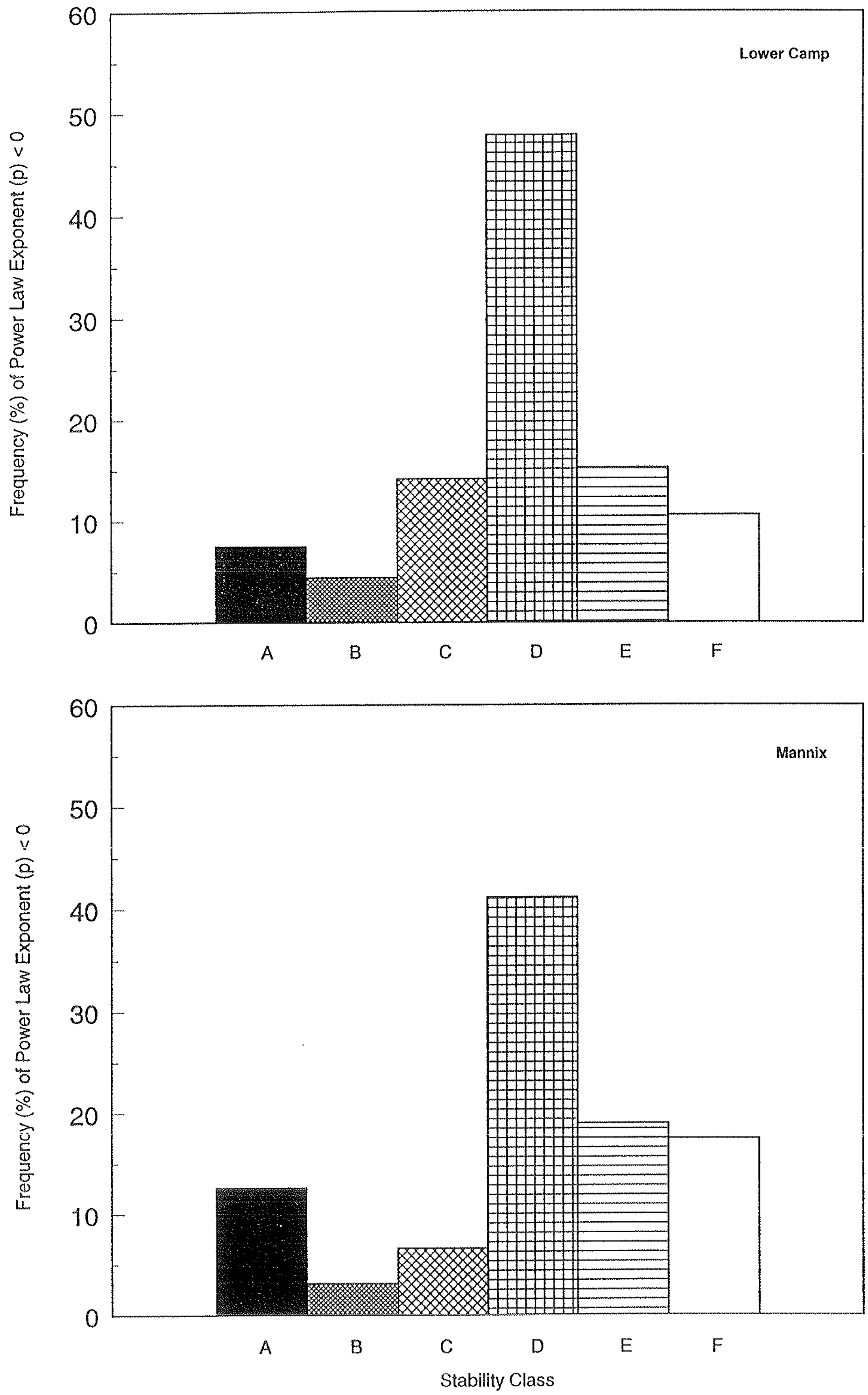

Figure 4.12 Frequency distributions of calculated negative "p" values (i.e., p<0) as a function of stability class data.

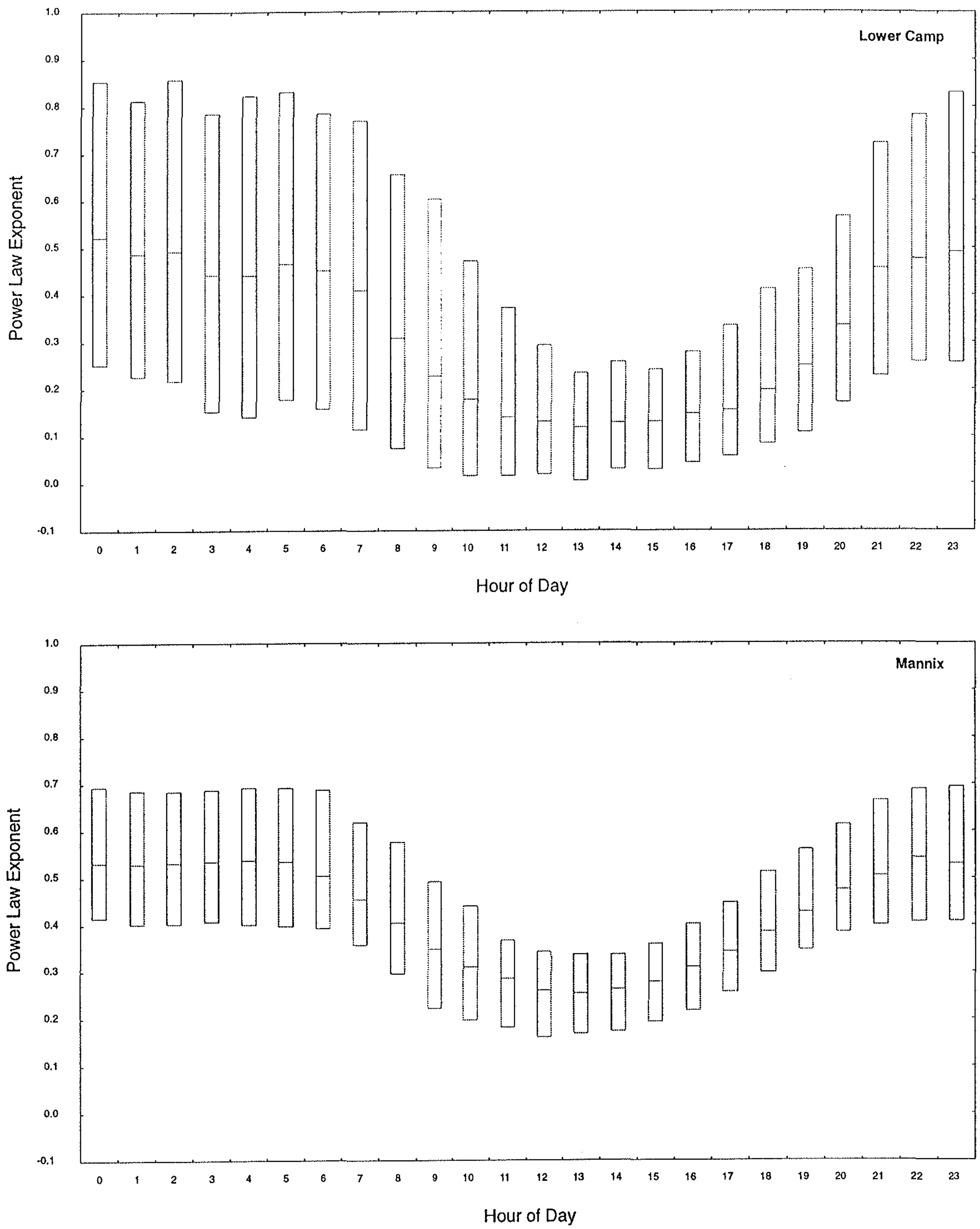

Figure 4.13 Diurnal variation of "p" values calculated for the Lower Camp and Mannix data.

Although most of the on-site p values fall within the typical range mentioned earlier (0.1 to 0.6), some values tend to be higher than those used in regulatory models, with the Mannix site showing the greatest discrepancies. This may be due to the following:

- The model default p values were derived based on tower data over flat terrain with a lower surface roughness than at Lower Camp and Mannix.

- Tree canopy and/or terrain effects at Mannix could cause a steeper wind speed gradient than at Lower Camp.

4.4 Surface Roughness Length

The aerodynamic surface roughness length (Z_o) characterizes the roughness of a surface and forms the lower boundary in dispersion models. In theory, the roughness length is the height at which the wind speed is zero. The effective roughness length may be determined using gustiness, which is calculated by $\sigma_U/\overline{U}$ (U.S. EPA 1987). The relationship between $\sigma_U/\overline{U}$ and Z_o is as follows:

$$Z_o = Z_R \exp\left(-\frac{\overline{U}}{\sigma_U}\right)$$

where:

Z_o = surface roughness length
Z_R = reference height
σ_U = standard deviation of the wind speed at Z_R
$\overline{U}$ = mean wind speed at Z_R

For this assessment, Z_o was calculated for neutral conditions (i.e., D stability class) with wind speeds greater than 18 km/h (5 m/s). Surface roughness lengths were calculated for the 20, 45 and 100 m levels of the Lower Camp tower and for the 20 and 75 m levels of the Mannix tower. Due to the low data recovery efficiency for wind speed at the Mannix 45 m level, no calculation for surface roughness length was made at this level. The following table indicates the median surface roughness values (m) which were calculated for each season:

		Season				
		Winter	Spring	Summer	Fall	Annual
Lower Camp	20 m	0.6	0.8	0.9	0.8	0.8
	45 m	0.3	0.7	0.8	0.5	0.6
	100 m	0.2	0.3	0.4	0.4	0.3
Mannix	20 m	0.9	1.1	1.4	1.3	1.2
	75 m	0.1	0.2	0.3	0.1	0.2

At Lower Camp, the lowest surface roughness values occur during the winter, while the highest values occurred during the summer for the 20 and 45 m levels, and during the summer and fall for the 100 m level. At Mannix, the highest values occurred during the summer, while the lowest values occurred in the winter. This trend is to be expected as a result of reduced foliage and vegetation cover during the winter months.

5.0 TURBULENCE

5.1 Horizontal Turbulence

Horizontal turbulence is responsible for the cross-wind spreading of a plume released into the atmosphere. A measure of the horizontal turbulence is the standard deviation of the wind direction (sigma theta or σ_θ), which is expressed in degrees. The σ_θ horizontal turbulence is a measure of the relative turbulence and is computed by the on-site data logger at the Lower Camp and Mannix monitoring stations.

Figures 5.1 and 5.2 show the variation of σ_θ with respect to wind speed for the Lower Camp and Mannix stations, respectively. The diagrams show that the highest σ_θ values tend to be associated with low wind speeds. At low wind speeds, large values of σ_θ are expected during the day due to increased convective turbulence, and at night due to increased meander. At wind speeds in excess of approximately 20 km/h, the median σ_θ values tend to converge to the following values:

	Lower Camp				Mannix		
	20 m	45 m	100 m	167 m	20 m	45 m	75 m
σ_θ (°)	14.5	11.7	8.9	7.0	20.7	11.2	8.9

These values are typical of those associated with a neutral well-mixed atmosphere. The σ_θ values decrease with increased height above ground due to the reduced influence of surface effects.

5.2 Vertical Turbulence

Vertical turbulence is responsible for the vertical spreading of a plume released into the atmosphere. One measure of the vertical turbulence is the standard deviation of the wind elevation angle (sigma phi or σ_ϕ). The σ_ϕ values were calculated using the following:

$$\sigma_\phi = \left(\frac{180}{\pi}\right)\tan^{-1}\left(\frac{\sigma_W}{U}\right)$$

where σ_W is the standard deviation of the vertical wind and U is the wind speed. The 180/π factor converts the calculated values from radians to degrees.

Figures 5.3 and 5.4 show the variation of σ_ϕ with respect to wind speed for the Lower Camp and Mannix stations, respectively. The diagrams show that the highest σ_ϕ values tend to be

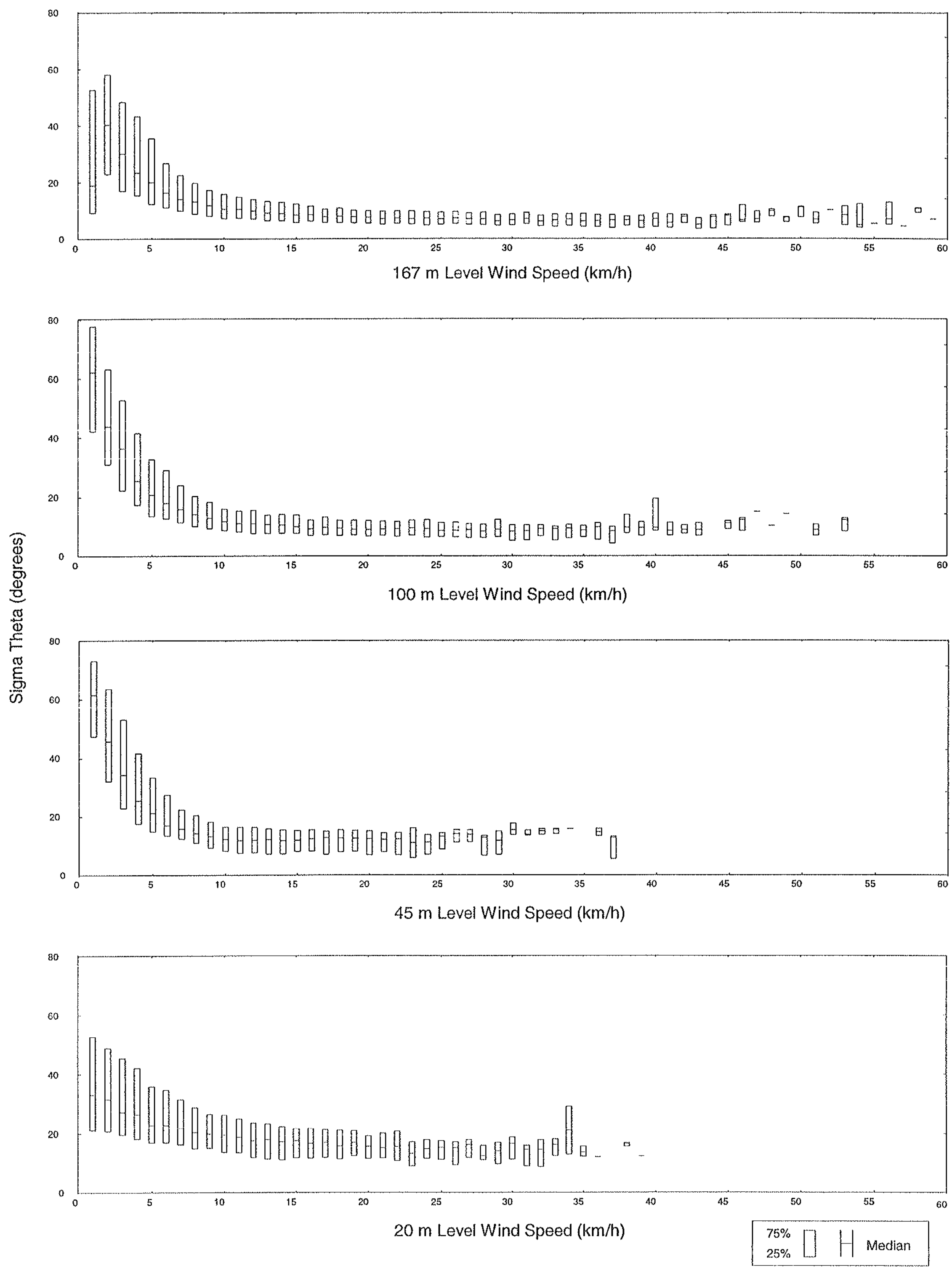

Figure 5.1 Variation of Sigma Theta (σ_θ) with respect to wind speed for the Lower Camp monitoring station.

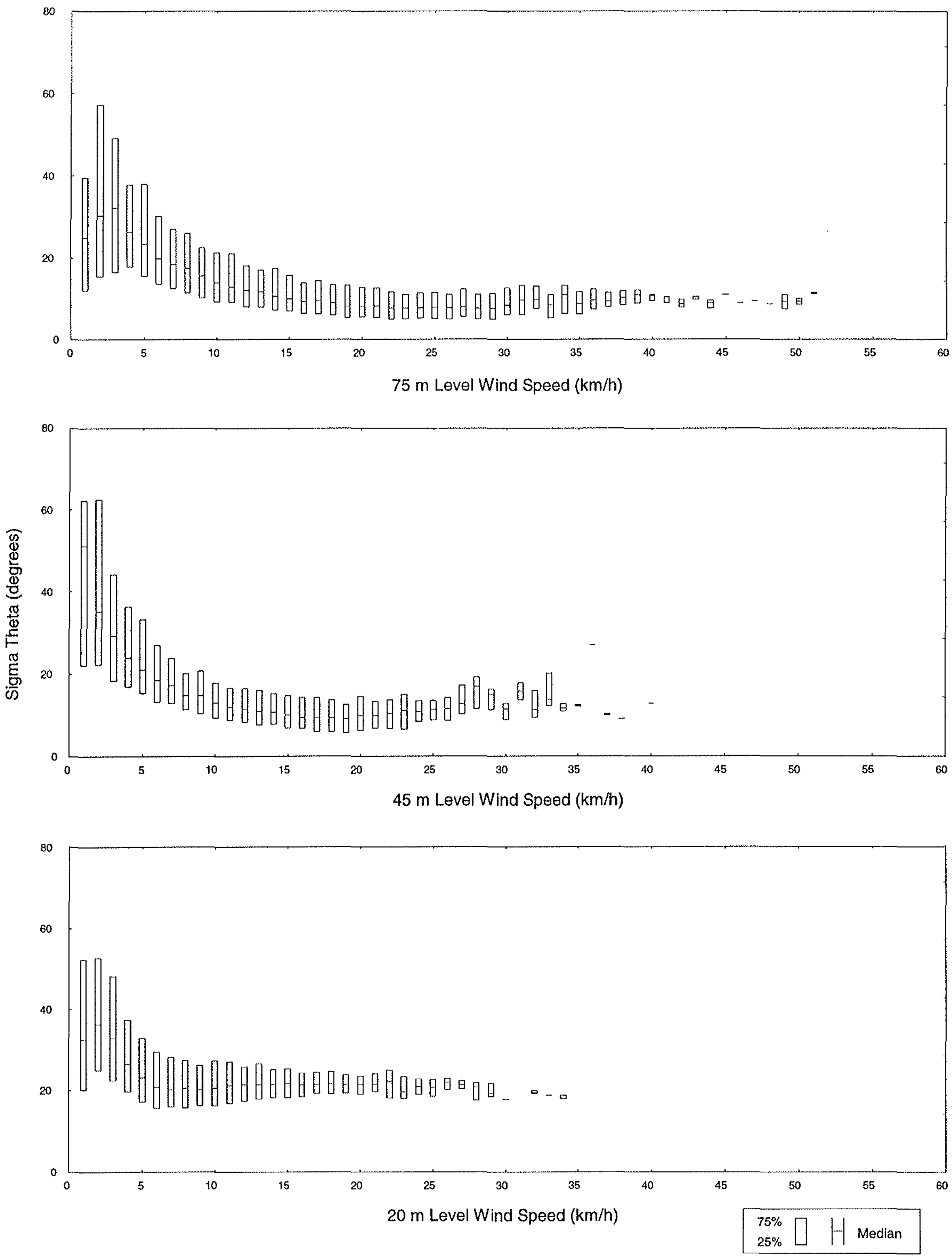

Figure 5.2 Variation of Sigma Theta (σ_θ) with respect to wind speed for the Mannix monitoring station.

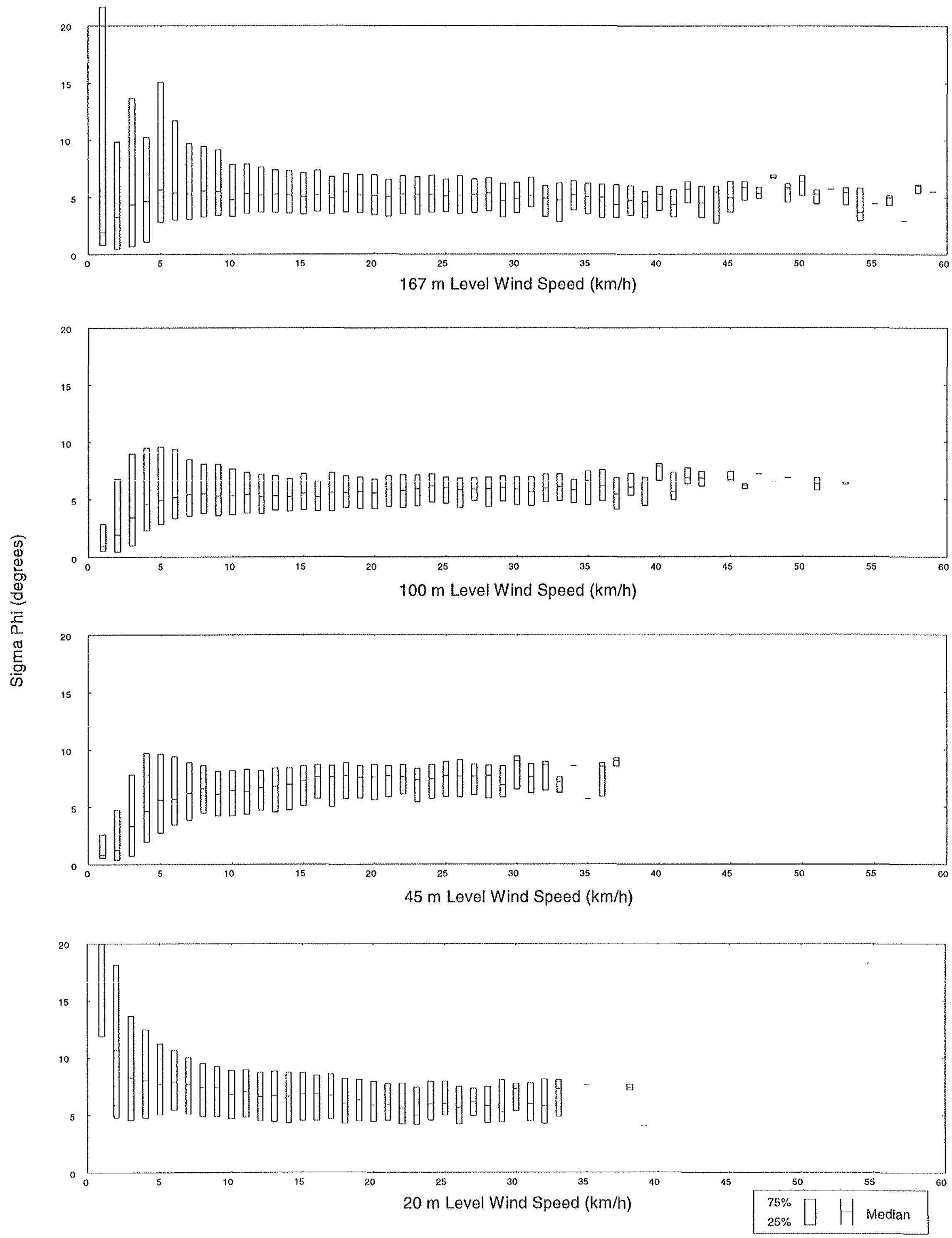

Figure 5.3 Variation of Sigma Phi (σ_ϕ) with respect to wind speed for the Lower Camp monitoring station.

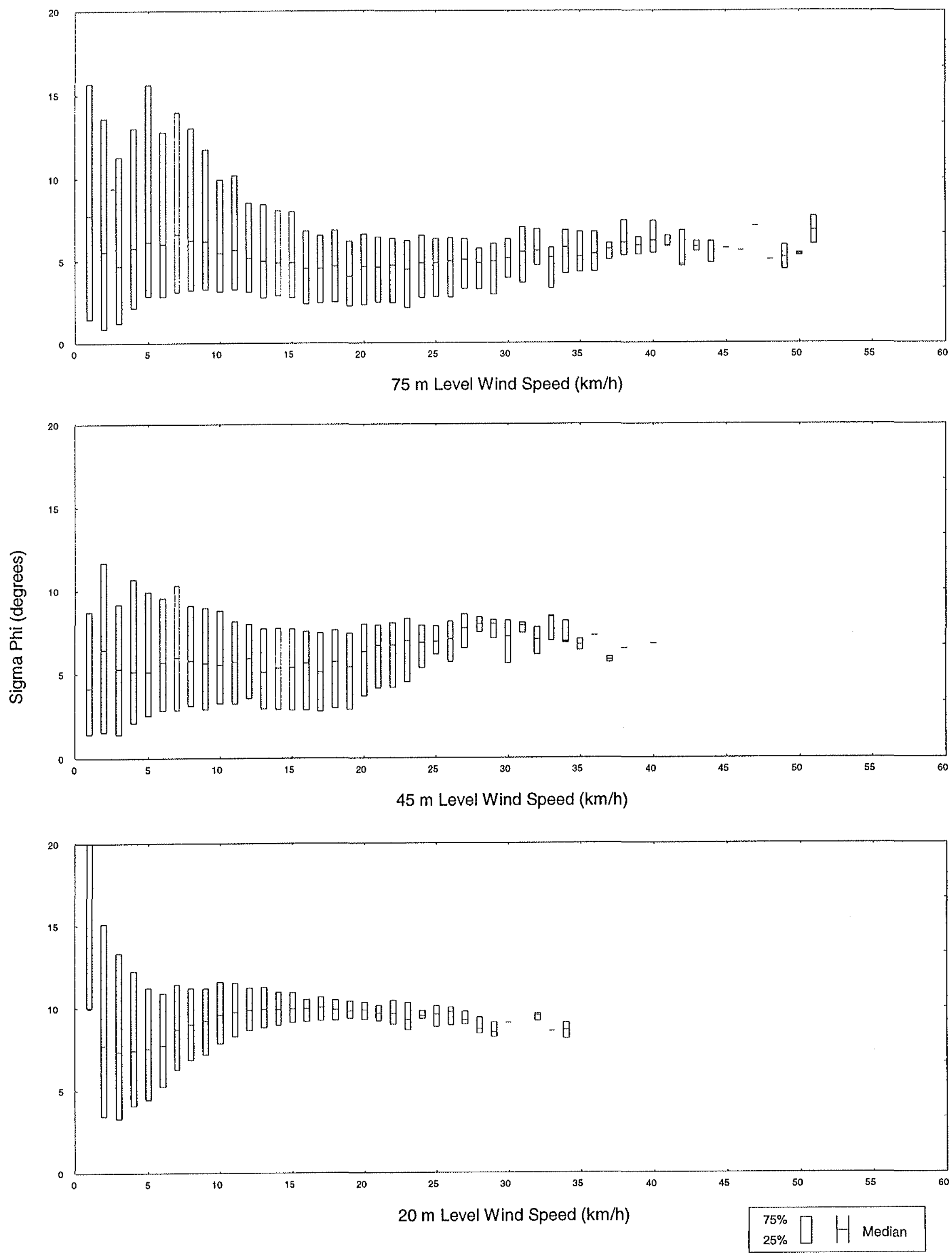

Figure 5.4 Variation of Sigma phi (σ_ϕ) with respect to wind speed for the Mannix monitoring station.

associated with low wind speeds. At wind speeds in excess of approximately 20 km/h, the median σ_ϕ values tend to converge to the following values:

	Lower Camp				Mannix		
	20 m	**45 m**	**100 m**	**167 m**	**20 m**	**45 m**	**75 m**
σ_ϕ (°)	5.8	7.7	5.8	4.6	9.8	7.1	5.8

These values are typical of those associated with a neutral well-mixed atmosphere. The σ_ϕ values tend to decrease with increased height above ground due to the reduced influence of surface effects.

5.3 Stability Class

Meteorologists frequently use the Pasquill-Gifford (PG) stability scheme when classifying the amount of turbulence present in the atmosphere. These classes range from **Unstable** (Stability Classes A, B and C) through **Neutral** (Stability Class D) to **Stable** (Stability Classes E and F). Unstable conditions are primarily associated with daytime heating which results in enhanced turbulence levels. Stable conditions are associated primarily with nighttime cooling which results in suppressed turbulence levels. Neutral conditions are primarily associated with high wind speeds.

A number of turbulence typing schemes have been developed to relate meteorological observations to the Pasquill-Gifford Stability Classes A through F. Selected schemes recommended by different groups include the following:

- The Turner (1964) STAR scheme which uses routine airport observations of wind speed and cloud cover.

- The solar radiation and wind speed method by Bowen *et al.* (1983).

- The temperature gradient method ($\delta T/\delta Z$) which is based on temperature measurements from the upper and lower tower observations (U.S. NRC 1972). Methods based on temperature gradient are useful for determining stable versus unstable conditions, but present difficulties when applied to determine individual classes (Coulter 1994).

- The standard deviation of the wind direction (σ_θ) (U.S. EPA 1984).

- The standard deviation of the vertical wind angle (σ_ϕ) (U.S. EPA 1984).

For this assessment, the method which was uses standard deviation of the vertical wind angle (σ_ϕ) was applied to the 20 m level observations at Mannix using day/night constraints. The day/night determination was made using sunrise and sunset data for the time of year and specific latitude. During the day, stability was limited to stability classes A to D, while stability classes D to F were only permitted to occur during the night.

Table 5.1 presents the criteria for the σ_ϕ method. The U.S. EPA criteria are based on a 10 m observation height and a surface roughness of 0.15 m. The median surface roughness length estimated for the Lower Camp 20 m level was 0.8 m. Similarly, for the Mannix 20 m level, the median surface roughness was 1.2 m. Therefore, for this assessment, a surface roughness length of 1.0 m was used. As indicated in Table 5.1, adjustments were made for the Suncor observation height of 20 m and for a surface roughness length of 1.0 m. As indicated in Section 5.2, the calculated σ_ϕ value for the Mannix 20 m level data was 9.8° for neutral stability. This is within the range shown in Table 5.1 (i.e., 7.3° to 12.2°).

Figure 5.5 shows the annual and seasonal distribution of stability class for the 20 m level observations at Mannix as compared to the long-term observations made from 1975 to 1984 at the Fort McMurray Airport. The following summarizes the data depicted in this figure:

- **Unstable Conditions.** The Mannix data show a higher frequency of A stability than the Fort McMurray data, while the Fort McMurray data show a higher frequency of B stability than the Mannix data. With respect to C stability, the Mannix and Fort McMurray data compare favourably.

- **Neutral Conditions.** The Mannix data show a slightly higher frequency of D stability than the Fort McMurray data.

- **Stable Conditions.** The Mannix data show a higher frequency of E stability than the Fort McMurray data, particularly in the winter season when the frequency of E stability at Mannix was nearly twice that observed at Fort McMurray. The Fort McMurray data show a substantially higher frequency of F stability than Mannix (i.e. 3 to 8 times higher).

Figure 5.6 depicts the diurnal variation of the seasonal Mannix stability class data. As previously discussed, the data were calculated allowing unstable conditions (Stability Classes A, B and C) to occur only during daylight hours and stable conditions (Stability Classes E and F) to occur only during the nighttime.

5.4 Similarity Parameters (U*, L)

Some dispersion models require the friction velocity (U*), a characteristic velocity based on surface stress. The value U* is representative of the turbulent fluctuations in the lowest layer of the atmospheric boundary layer. Other models require the Monin-Obukhov length (L) as a measure of stability. The Monin-Obukhov length is the height at which the generation (or

Table 5.1 Criteria used to determine PG stability class based on observation of σ_ϕ (degrees).

Observation Height (m)	**10[(a)]**	**20[(b)]**	**20[(c)]**
Surface Roughness (m)	**0.15**	**0.15**	**1.0**
A	> 11.5	> 13.9	> 20.2
B	10.0 to 11.5	11.5 to 13.9	16.7 to 20.2
C	7.8 to 10.0	8.4 to 11.5	12.2 to 16.7
D	5.0 to 7.8	5.0 to 8.4	7.3 to 12.2
E	2.4 to 5.0	2.2 to 5.0	3.2 to 7.3
F	< 2.4	< 2.2	< 3.2

(a) Criteria recommended by U.S. EPA for an observation height of 10 m and a surface roughness of 0.15 m.

(b) Criteria adjusted for a 20 m observation height.

(c) Criteria adjusted for a 20 m observation height and a 1.0 m surface roughness. These criteria were applied to the Suncor Mannix observations.

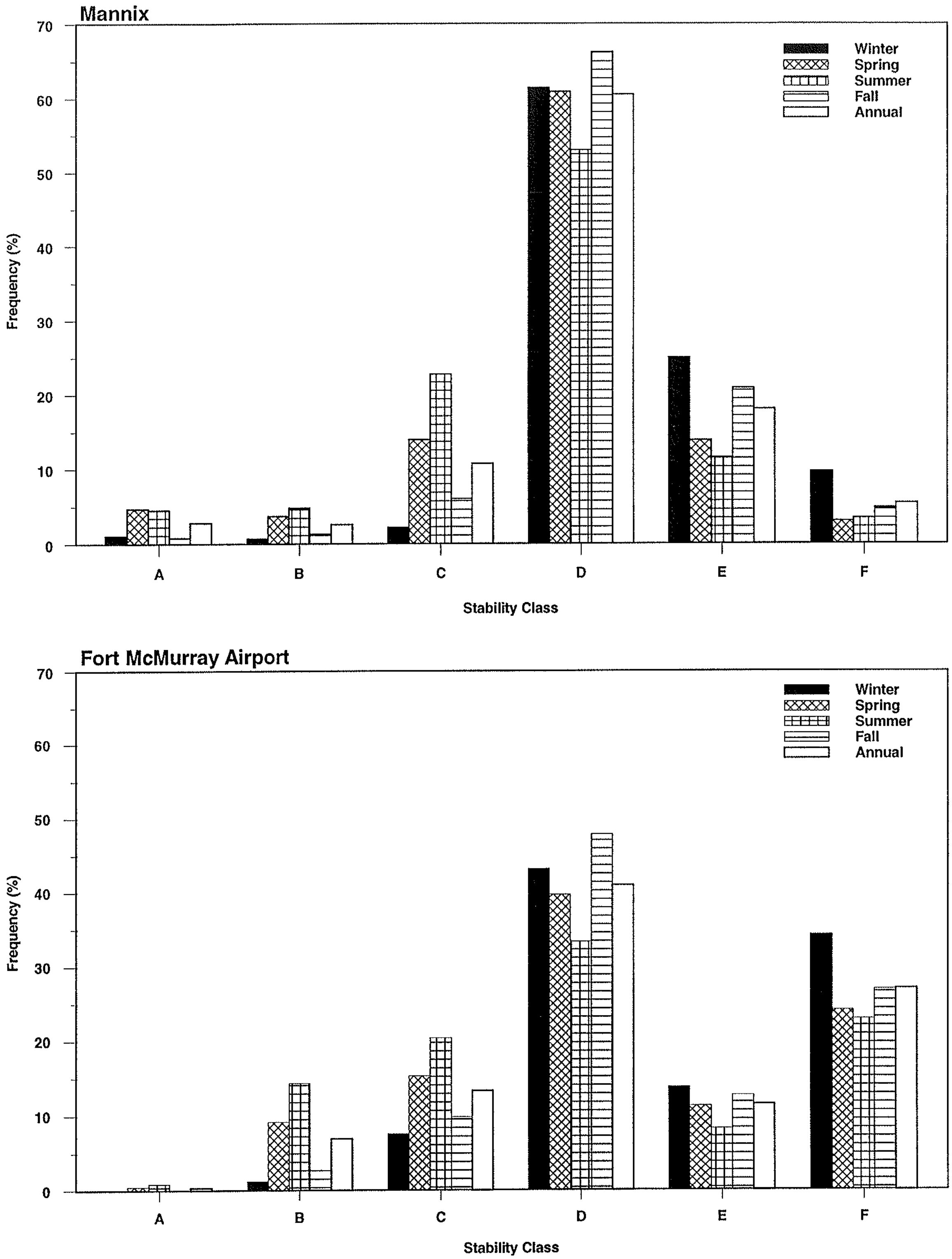

Figure 5.5 Seasonal stability class frequency distribution for Mannix (November 1, 1993 to June 30, 1995) and Fort McMurray Airport (1975 to 1984) monitoring stations.

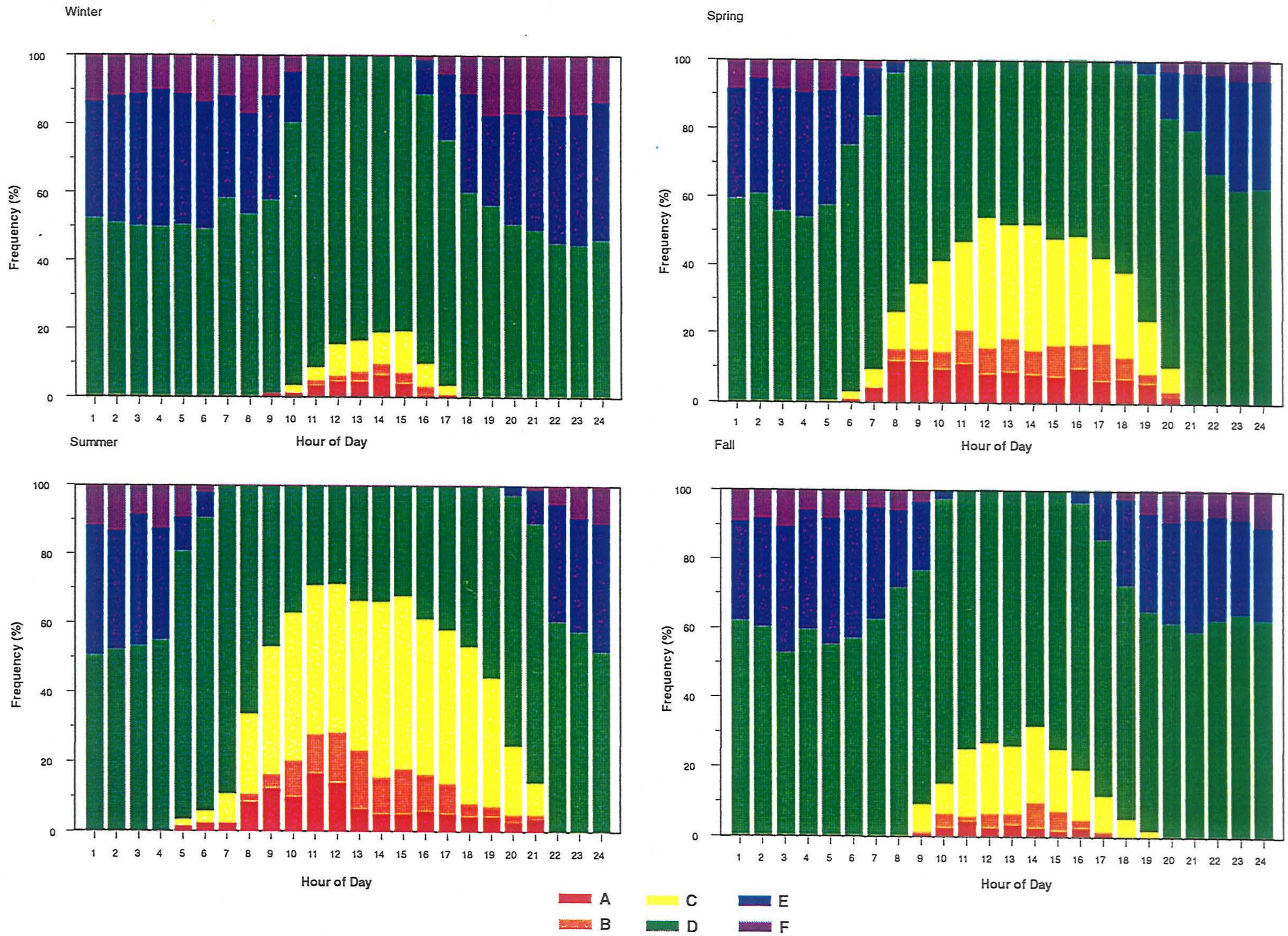

Figure 5.6 Seasonal variation of stability class as a function of hour of day at the Mannix monitoring station.

suppression) of thermal turbulence by surface heating (or cooling) is equal to the generation of turbulence by mechanical means. Negative values of L are associated with unstable atmospheres and positive values are associated with stable atmospheres. Large values of |L| (greater than 100 m) are associated with atmospheres in which almost all of the ground-level turbulence is generated by mechanical means.

5.4.1 *Monin-Obukhov Length*

The Monin-Obukhov lengths (L) were calculated according to the method outlined in the Alberta Environment ADEPT2 Users' Guide (Alberta Environment 1992). In this method, the Monin-Obukhov length is determined as a function of stability and roughness length as indicated in the following equation:

$$L = \frac{1}{a Z_o^b}$$

where: L = Monin-Obukhov length
Z_o = Surface roughness length

The "a" and "b" constants were derived by Liu and Durran (1977) and vary as a function of stability class. The median surface roughness length estimated for the Lower Camp 20 m level was 0.8 m. Similarly, for the Mannix 20 m level, the median surface was 1.2 m. Therefore, for this assessment, a surface roughness length of 1.0 m was used. The following table presents the "a" and "b" constants in conjunction with the Monin-Obukhov lengths (L) calculated for the Suncor data.

Stability Class	a	b	L
A	-0.1135	-0.1025	-9
B	-0.0385	-0.1710	-26
C	-0.0081	-0.3045	-123
D	0	-0.5030	$\pm\infty$
E	0.0081	-0.3045	123
F	0.0385	-0.1710	26

5.4.2 *Friction Velocity*

The friction velocities (U*) were calculated according to the following equation (Alberta Environment 1992):

$$U^* = \frac{kU}{\ln\left(\frac{Z_r}{Z_o}\right) - \psi_m}$$

where:	U*	=	Friction velocity
	k	=	Von Karman's constant (k = 0.4)
	U	=	Wind speed (m/s) at reference height Z_r (Z_r = 20 m)
	Z_o	=	Surface roughness (Z_o = 1 m)
	ψ_m	=	Correction function for momentum
	L	=	Monin-Obukhov length

The stability correction functions for momentum (ψ_m) were calculated using the following:

Stability Class	ψ_m
Unstable (A, B, C)	$\exp\left[0.032 + 0.448\ln\left(\frac{-Z_r}{L}\right) - 0.132\left(\ln\left(\frac{-Z_r}{L}\right)\right)^2\right]$
Neutral (D)	0
Stable (E, F)	$\frac{-5Z_r}{L}$

For this assessment, the preceding U* equation may be simplified to the following:

$$U^* = cU$$

where: c = $\frac{0.4}{\ln(20) - \psi_m}$

The following table presents the constant "c" and median U* values calculated for the Suncor data using the 20 m level wind speeds observed at Mannix:

	A	B	C	D	E	F
c	0.24	0.19	0.15	0.13	0.11	0.06
U*	0.14	0.28	0.33	0.34	0.18	0.06

The median U* value calculated for unstable conditions (stability classes A, B and C) with wind speeds ranging from 1 to 4 m/s is 0.3. This value lies within the range of 0.1 to 0.5 m/s used by the U.S. EPA CTSCREEN model (Perry *et al.* 1990).

6.0 TEMPERATURE

6.1 Ambient Temperature

The temperature in the Fort McMurray area is typical of that found in a northern continental region and is characterized by cool summers and long cold winters, with short spring and fall transition periods. Figure 6.1 compares the mean and extreme temperatures observed at the Fort McMurray Airport between 1961 and 1990 (Atmospheric Environment Service 1995) with ambient temperature data collected at the Lower Camp and Mannix monitoring stations from November 1, 1993 to June 30, 1995. The mean temperature ranges from -18.1°C in February to 20.1°C in July at Lower Camp and from -17.5°C in February to 19.0°C in July at Mannix for the same monitoring period. At the Fort McMurray Airport, the mean temperature ranges from -19.8°C in January to 16.6°C in July. Therefore, the temperatures recorded for Lower Camp and Mannix tended to be slightly higher than those reported over the long term at the Fort McMurray Airport.

Mean daily maximum temperatures in excess of 20°C were reported from May to September at Lower Camp and from May to August at Mannix, but only during the months from June to August at the Fort McMurray Airport. Mean daily minimum temperatures less than -20°C were reported from December to February at all three stations.

Extreme maximum temperatures in excess of 30°C occurred in the months from May to September at Lower Camp, in the months of May, July and August at Mannix, and from the months of April to September over the long term at the Fort McMurray Airport. Extreme minimum temperatures less than -30°C occurred from the months of November to March at Lower Camp and Mannix, and from the months of November to April over the long term at the Fort McMurray Airport.

The following table shows the mean seasonal and annual temperature observed at Lower Camp, Mannix and the Fort McMurray Airport during the monitoring periods as outlined previously:

Season	Temperature °C		
	Lower Camp	Mannix	Fort McMurray Airport
Winter	-16.1	-15.5	-17.3
Spring	4.5	3.8	1.7
Summer	18.7	17.1	15.5
Fall	1.6	1.0	1.1
Annual	0.3	0.2	0.2

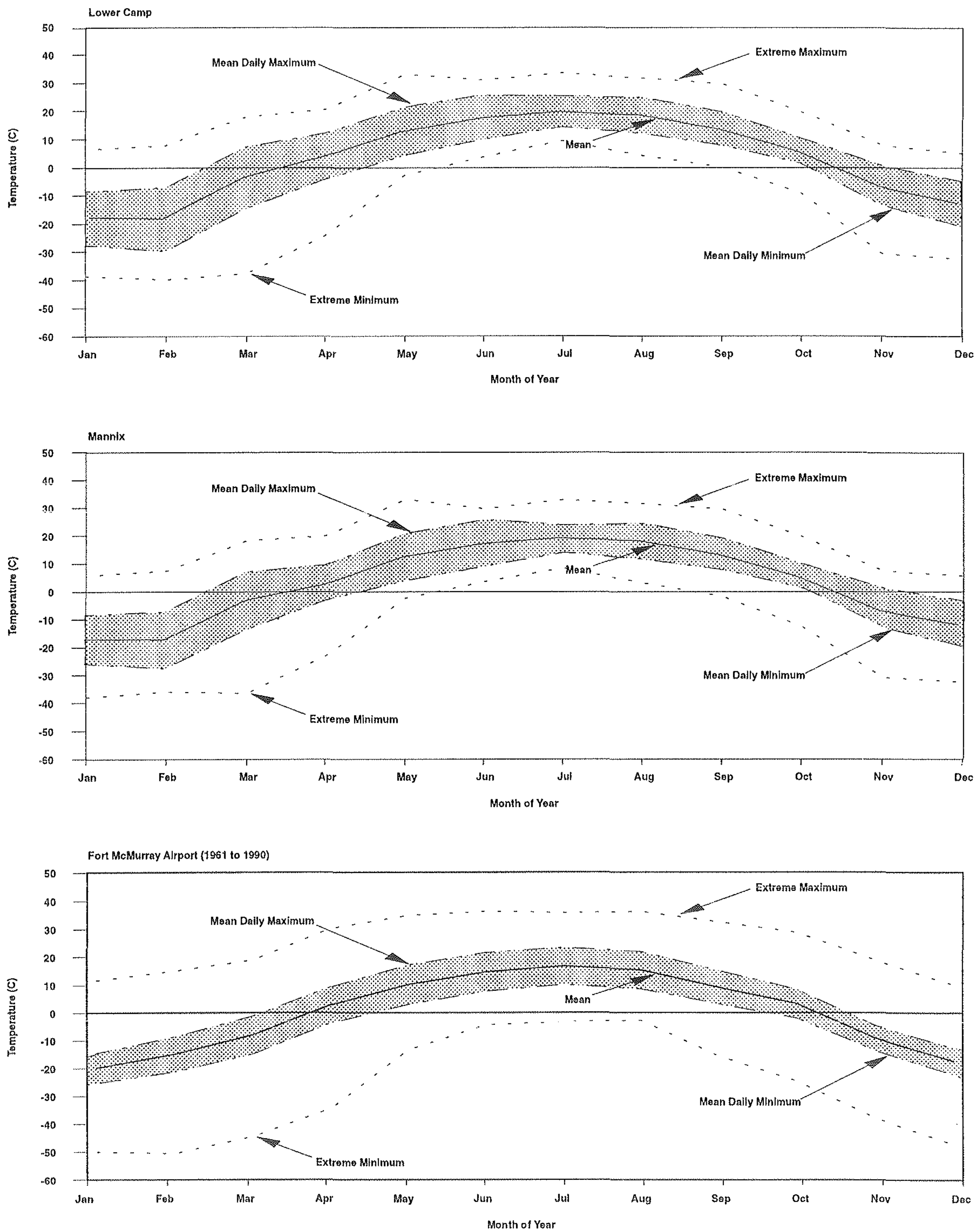

Figure 6.1 Mean and extreme temperatures (C) observed at the Lower Camp and Mannix monitoring stations from November 1, 1993 to June 30, 1995 and at the Fort McMurray Airport from 1961 to 1990.

6.2 Potential Temperature Gradient ($\partial T/\partial Z + 0.01$ K/m)

The temperature gradient indicates the change in temperature with respect to the difference in monitoring level height above ground. The potential temperature gradient is equivalent to the temperature gradient ($\partial T/\partial Z$) plus the adiabatic lapse rate (0.01 K/m).

The temperature gradient or potential temperature gradient can be related to the stability of the atmosphere. The relationship between these gradients and stability is dependent on the height and vertical spacing of the temperature sensors. For the purposes of display, potential temperature gradients less than -0.01 K/m were arbitrarily assumed to be associated with unstable atmospheric conditions. Similarly, values greater than +0.01 K/m were assumed to be associated with stable conditions. Potential temperature gradient values nearly equal to 0 K/m (i.e., $\geq$ -0.01 K/m and $\leq$ 0.01 K/m) were assumed to be associated with neutral atmospheric conditions.

Figure 6.2 shows the seasonal variation in potential temperature gradients ($\Delta T_{45\text{ to }20\text{ m}}$) as a function of time of day at the Lower Camp monitoring station. During the winter, the median potential temperature gradients generally indicate neutral atmospheric conditions. In the summer months, neutral conditions occur mainly during the transition period between stable nighttime conditions and unstable daytime conditions. Summer conditions best demonstrate the presence of unstable conditions that would be expected during the day and stable conditions that would be expected during the night.

Figure 6.3 presents the seasonal variation in potential temperature gradient ($\Delta T_{100\text{ to }20\text{ m}}$) as a function of time of day at the Lower Camp monitoring station. During the winter, stable conditions are predominant. The summer diagram indicates stable atmospheric conditions at night with neutral conditions occurring in association with daytime heating (i.e., between 8:00 and 21:00 hours).

Figure 6.4 shows the seasonal potential temperature gradient data for ΔT between 167 and 20 m as a function of time of day at the Lower Camp monitoring station. On average, the atmospheric conditions are more stable at the upper level.

The gradients observed for $\Delta T_{45\text{ to }20\text{ m}}$ are more intense than those observed over a deeper layer (i.e., 100 to 20 m or 167 to 20 m). The stronger gradients nearer the ground reflect the heating and cooling of the ground as the driving force for energy exchange with the atmosphere.

Figures 6.5 and 6.6 indicate the seasonal potential temperature gradients for the Mannix station for $\Delta T_{45\text{ to }20\text{ m}}$ and $\Delta T_{75\text{ to }20\text{ m}}$, respectively. On average, stable conditions are indicated during the nighttime, with neutral conditions during the day. The lack of negative values associated with $\Delta T_{45\text{ to }20\text{ m}}$ at Mannix is noted. For the most part, the temperature gradients indicate a trend for stable conditions (i.e., positive values) at night moving to less stable conditions during the day. The trend for more intense values near the ground is also noted. The information presented, however, tend to suggest a bias towards stable conditions. It should be noted that only 50% of the data are representative in these figures. Nonetheless, a review of the data and data collection methods is recommended.

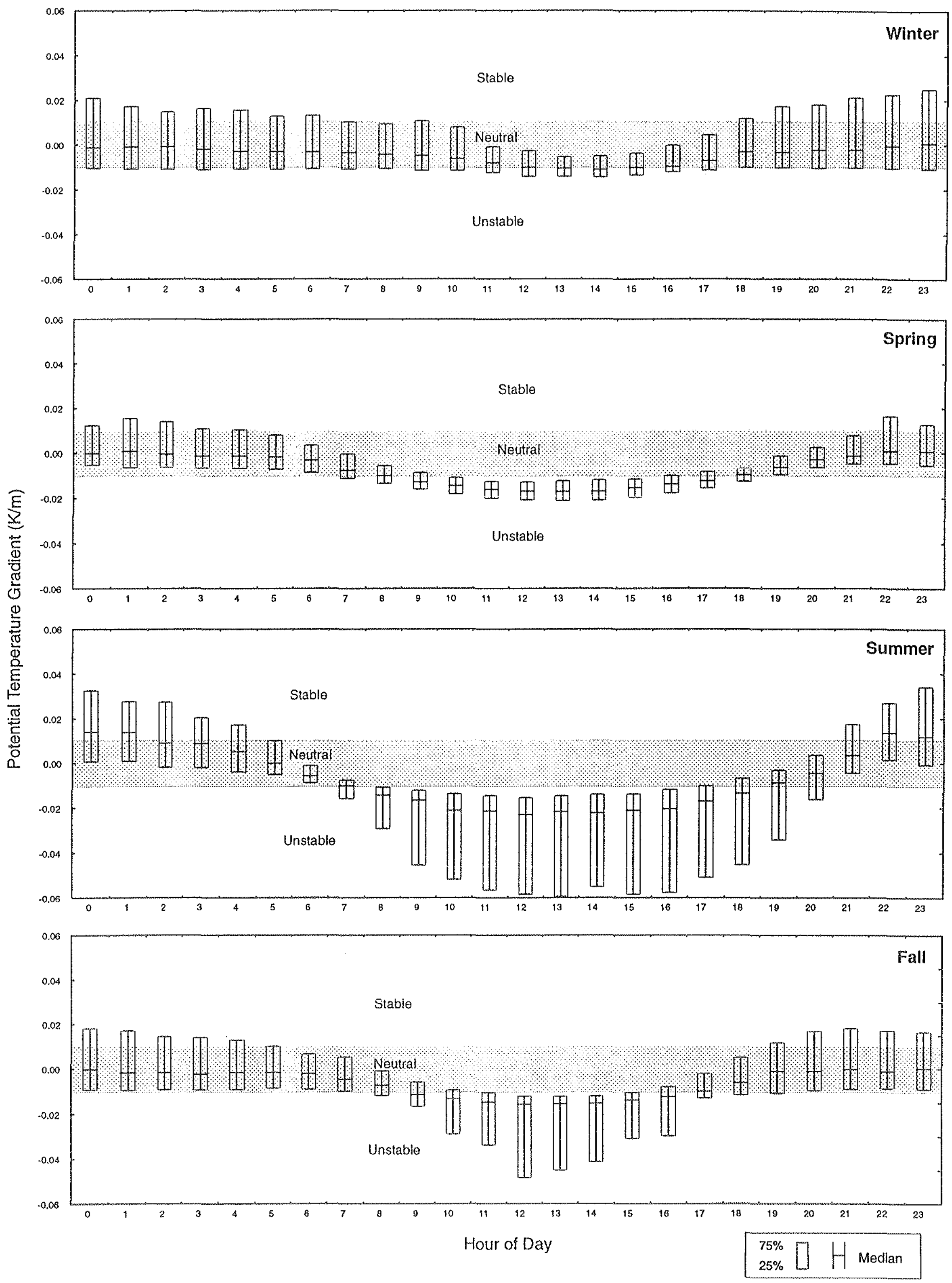

Figure 6.2 Seasonal variation of potential temperature gradients (K/m) observed at the Lower Camp monitoring station with respect to time of day for $\Delta T_{45\ \mathrm{to}\ 20\ \mathrm{m}}$.

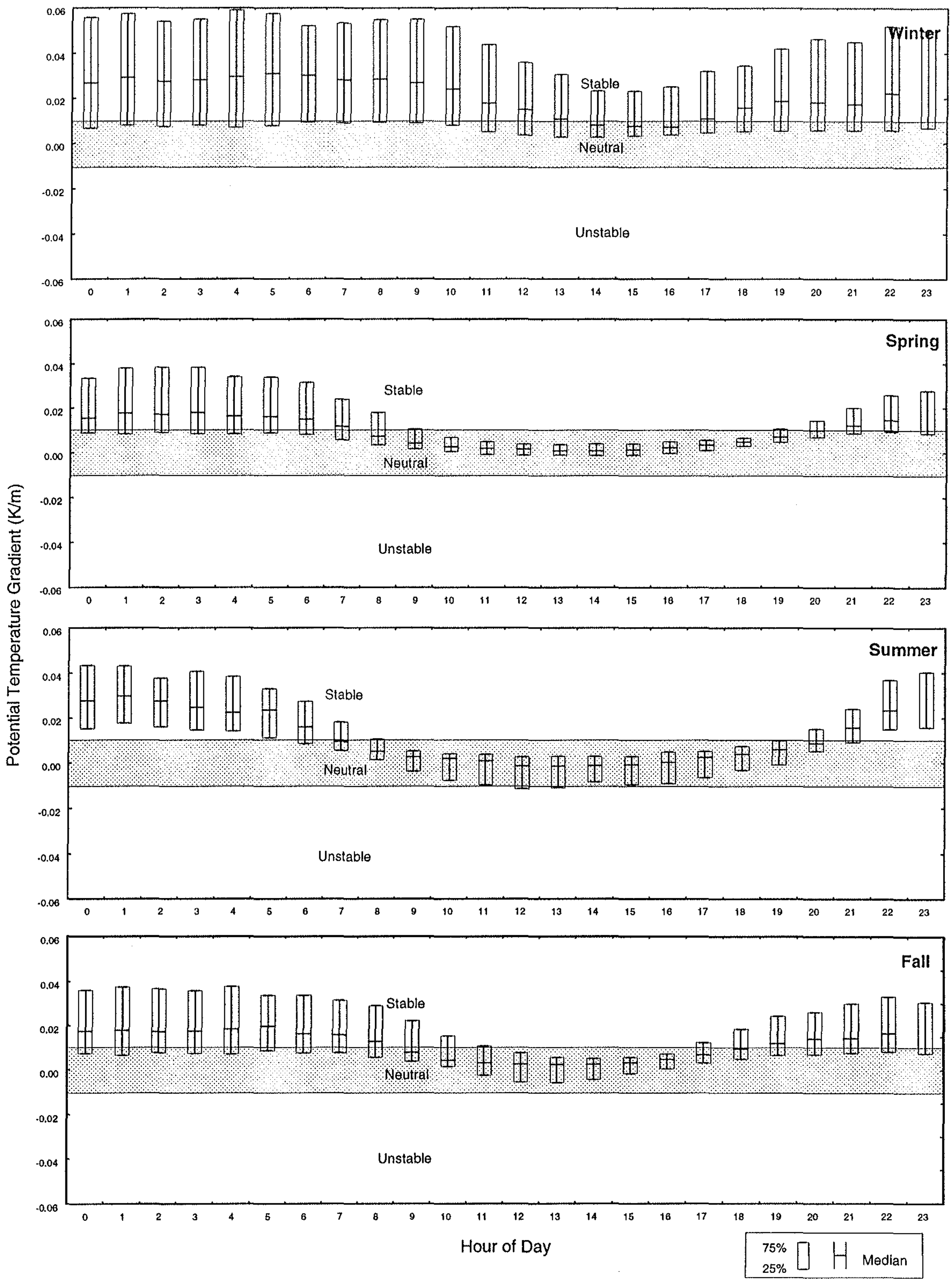

Figure 6.3 Seasonal variation of potential temperature gradients (K/m) observed at the Lower Camp monitoring station with respect to time of day for $\Delta T_{100\text{ to }20\text{ m}}$.

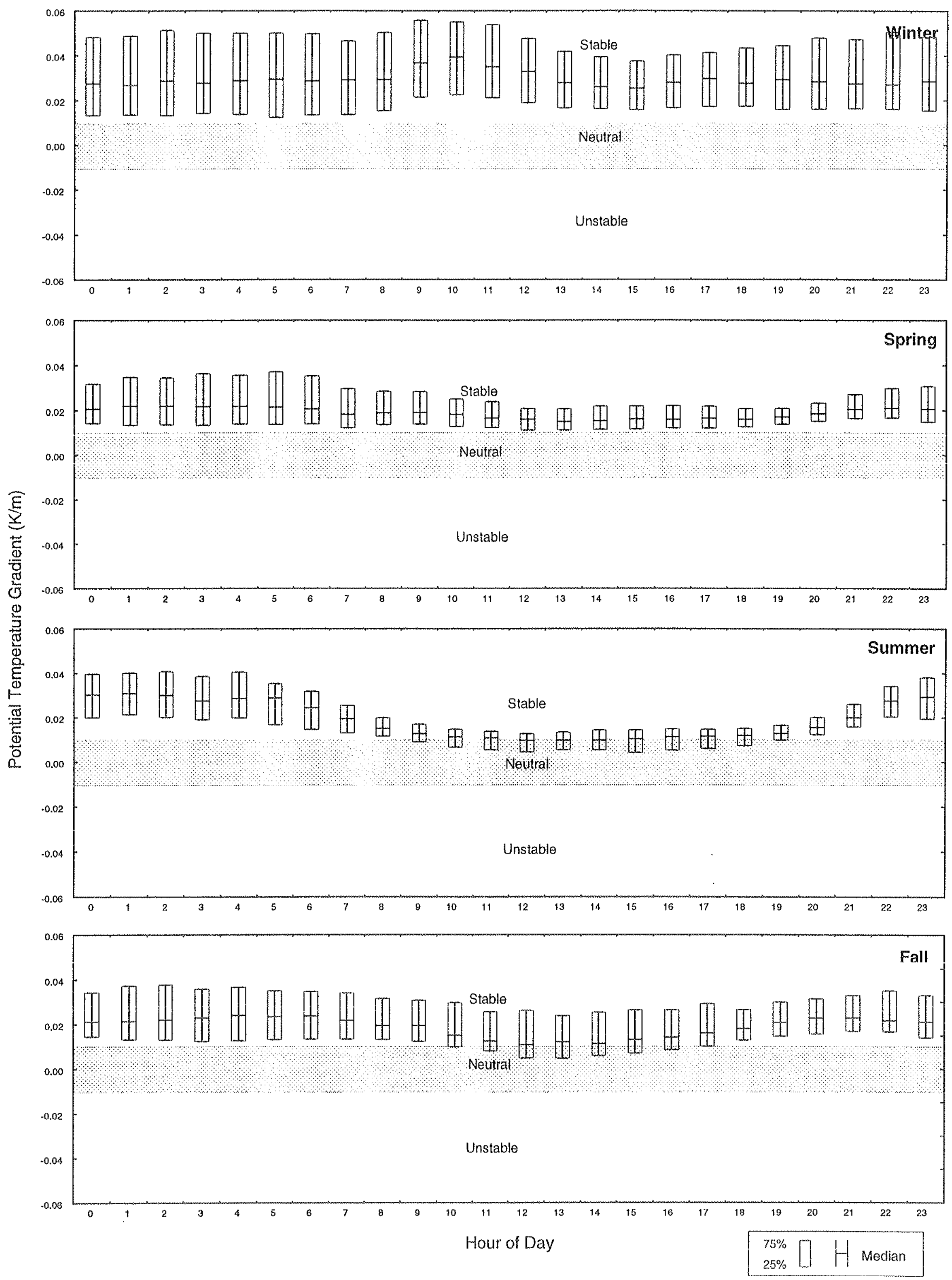

Figure 6.4 Seasonal variation of potential temperature gradients (K/m) observed at the Lower Camp monitoring station with respect to time of day for $\Delta T_{167 \text{ to } 20 \text{ m}}$.

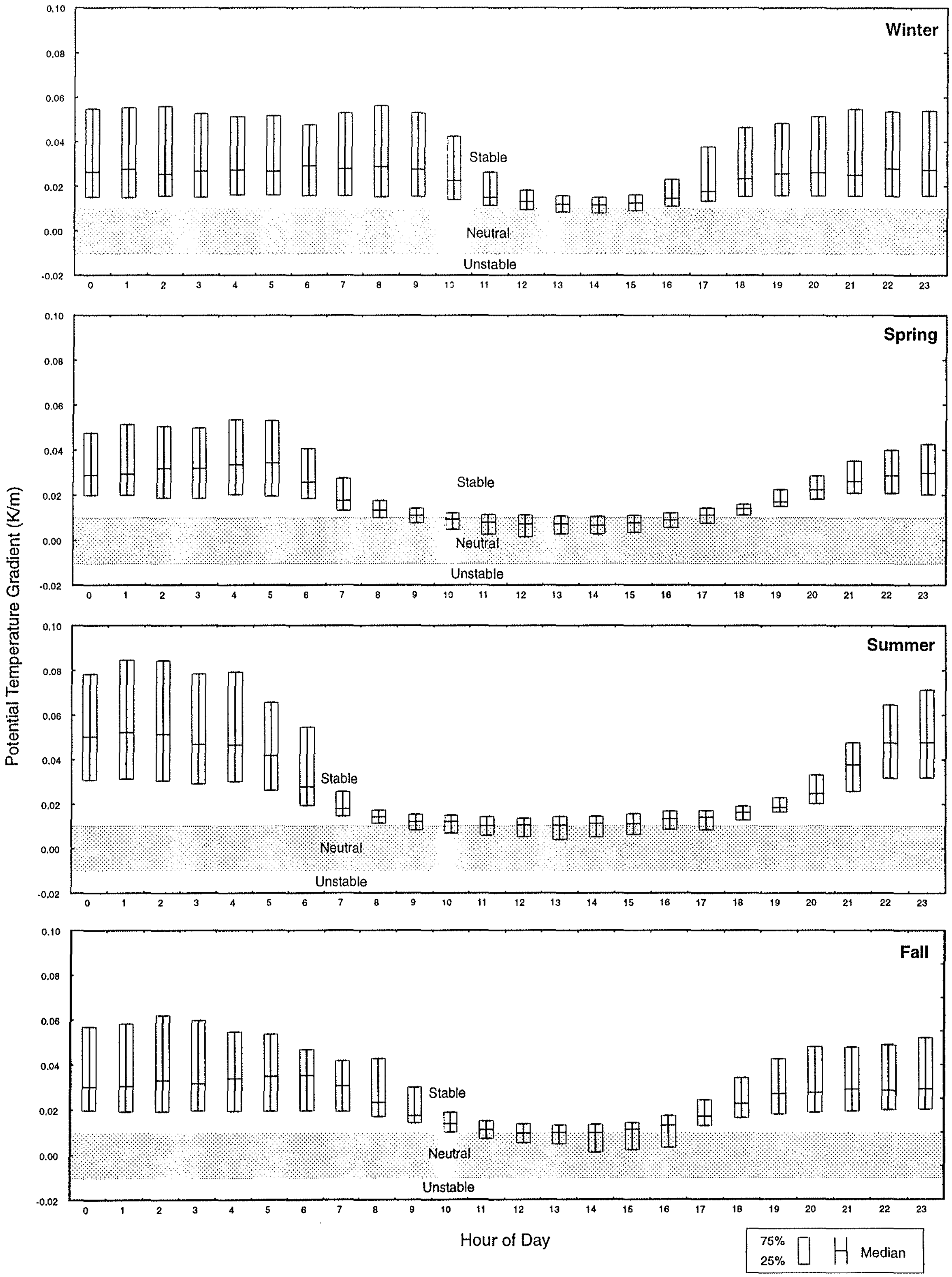

Figure 6.5 Seasonal variation of potential temperature gradients (K/m) observed at the Mannix monitoring station with respect to time of day for $\Delta T_{45 \text{ to } 20 \text{ m}}$.

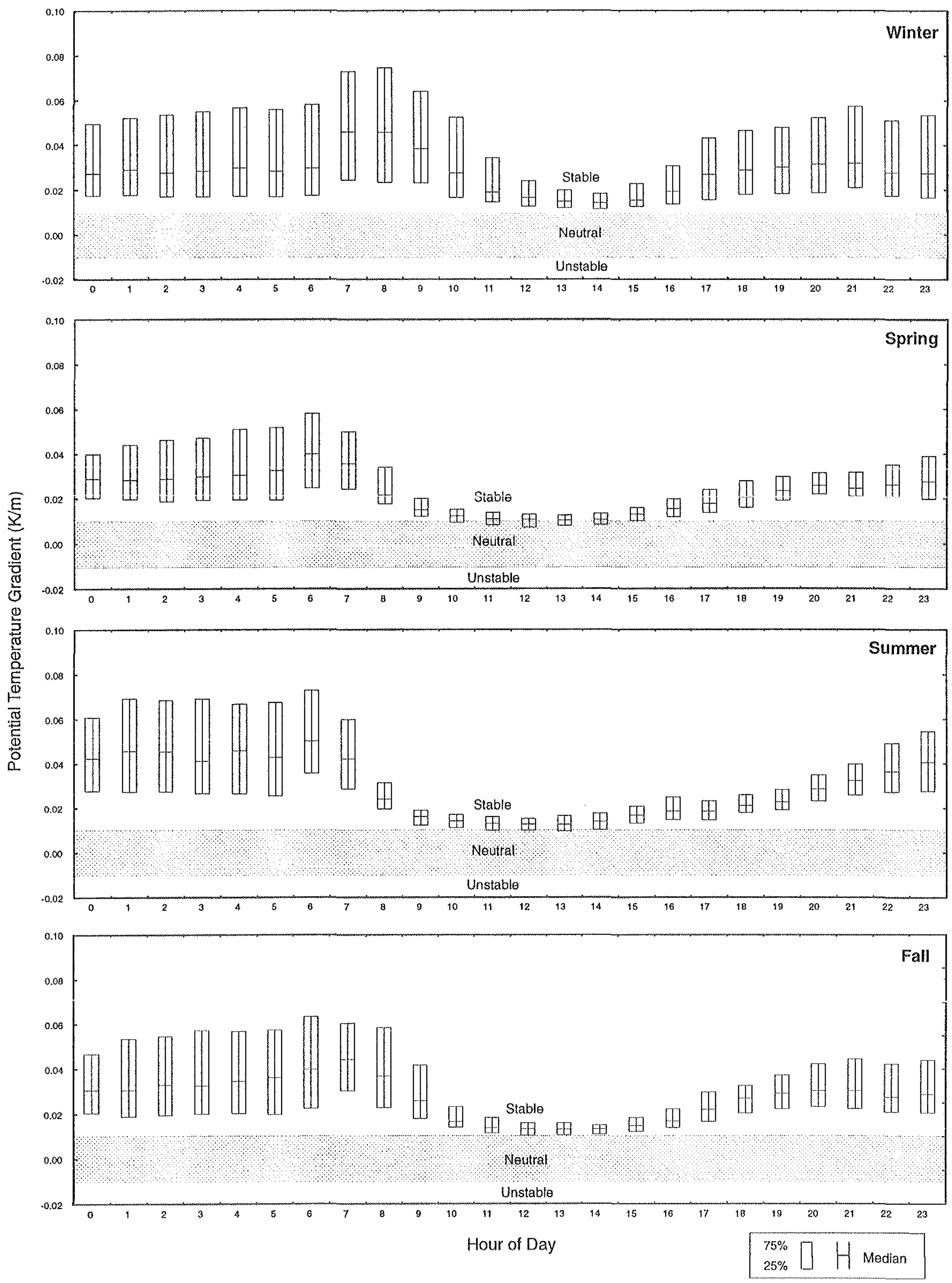

Figure 6.6 Seasonal variation of potential temperature gradients (K/m) observed at the Mannix monitoring station with respect to time of day for $\Delta T_{75\text{ to }20\text{ m}}$.

7.0 NET RADIATION AND MIXING HEIGHT

7.1 Net Radiation

The stability of the atmosphere is driven by the heating and cooling of the surface. Solar radiation is the primary means of energy input and was measured only at the Mannix station. Figure 7.1 shows the seasonal net radiation as a function of time of day. The following should be noted with respect to the net radiation data:

- Prior to March 7, 1994, all measurements in excess of 100 W/m^2 were "capped" or recorded by the data-logger as 100 W/m^2. This resulted in 48 hours of data being capped between December 1, 1993 and March 7, 1994.

- After March 7, 1994, all measurements in excess of 500 W/m^2 were "capped" or recorded by the data-logger as 500 W/m^2. This resulted in 55 hours of data being capped between May 14 and August 12, 1994.

- All nighttime values are expected to be less than zero. However, as identified in Figure 7.1, this is not the case for some of the data collected during the winter months. The reason for this inconsistency is unknown.

The following table summarizes the mean net radiation values (W/m^2) for each season:

Season	Mean Net Radiation (W/m^2)		Mean Net Radiation[c] (W/m^2)
	Daytime[a]	Nighttime[b]	
Winter	18.5	3.4	11.0
Spring	153.0	-4.6	72.5
Summer	227.1	5.9	115.2
Fall	61.9	-8.1	26.9
Annual	107.8	-0.7	53.1

(a) 6:00 to 17:59 h, inclusive.
(b) 18:00 to 5:59 h, inclusive.
(c) All hours.

7.2 Mixing Height

A temperature increase with height is referred to as an inversion. For a ground-level inversion, a two-layered atmosphere is created. The lower layer is well-mixed and is characterized by neutral or unstable conditions. The depth of this lower layer is referred to as the mixing height. The upper layer tends to be characterized by stable conditions. The vertical transfer of mass between these two layers is minimal.

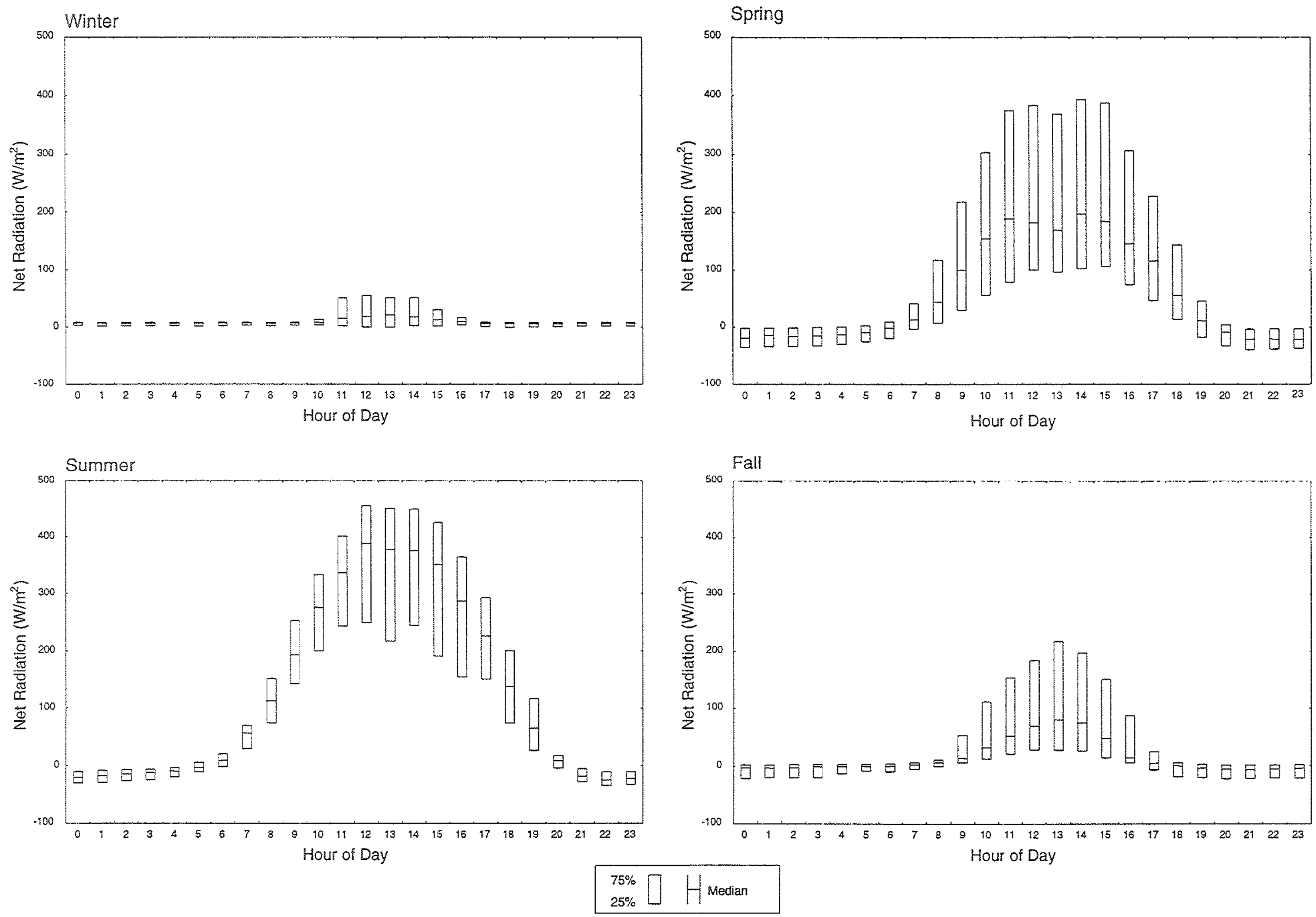

Figure 7.1 Seasonal variation of net radiation (W/m²) observed at Mannix monitoring station with respect to time of day.

7.2.1 *Mechanical Mixing*

During the night or under overcast conditions, the mixing layer is determined by mechanical interactions of wind with surface features. The mixing layer depth is related to wind speed through the following theoretical relationship:

$$Z_i = \frac{a\,U^*}{f}$$

where:
- Z_i = mechanical mixing layer height
- a = constant that has been reported to range from 0.15 to 0.30
- U^* = friction velocity
- f = Coriolis force
  = $2\,\Omega \sin\phi$
- Ω = $7.29 \times 10^{-5}\ s^{-1}$
- ϕ = latitude (57°)

For neutral conditions U^* is given by:

$$U^* = \frac{0.4\,U_z}{\ln\left(Z/Z_o\right)}$$

where:
- U_z = wind speed at height Z
- Z_o = surface roughness

These two relationships can be combined to produce a single expression for Z_i:

$$Z_i = \frac{a\,0.4}{2\,\Omega \sin\phi \ln\left(Z/Z_o\right)}\,U_z$$

$$= \frac{3271\,a}{\ln\left(Z/Z_o\right)}\,U_z$$

For this assessment, the 20 m level wind speeds from Mannix were used in the analysis (i.e., Z = 20 m) with a surface roughness of 1 m. The equation therefore reduces to the following:

$$Z_i = 1092\,a\,U_{20}$$

The multiplier "1092 a" ranges from 164 to 327, depending on the value of "a" selected. Benkley and Schulman (1979) specifically recommend a value for "a" of 0.185 which corresponds to a multiplier of 202. Therefore, for this assessment, the following relationship was used to estimate mechanical mixing heights:

$$Z_i = 200\ U_{20}$$

where: U_{20} = the three hour centre average 20 m level wind speed (m/s) at Mannix.

7.2.2 *Convective Mixing*

During summer conditions, surface heating will produce a well-mixed layer. A simplified expression for predicting the convective mixing height is as follows:

$$h = \left[\frac{2}{c_p\, \rho(\gamma_d - \gamma)} \int_{t_o}^{t} H\ dt \right]^{1/2}$$

where:
- h = convective mixing height (m)
- c_p = specific heat of air at constant pressure (1005 J/kg K)
- ρ = ambient density of air (kg/m^3)
- γ_d = adiabatic lapse rate
- γ = lapse rate at sunrise
- H = surface heat flux (W/m^2)

From a simplified perspective, the surface heat flux can be assumed to be directly proportional to the net radiation. This assumption ignores latent heat and ground effects. An empirical relationship was used to relate the mean afternoon mixing height values to net radiation. Table 7.1 shows the mixing height values and accumulated net radiation values for Stony Plain, Norman Wells and Whitehorse. Figure 7.2 shows the best mathematical fit between these two parameters as described by the following:

$$Z_i = 512\ (R_{net})^{0.527}$$

Given the assumed equivalency between R_{net} and $\int_{t_o}^{t} H\, dt$, it is comforting that the empirical exponent is approximately equal to 0.5.

7.2.3 *Summary*

The mechanical mixing height can be estimated from the relationship:

$$Z_i = 200\ U_{20}$$

where: U_{20} = the three hour centre average 20 m level wind speed (m/s) at Mannix.

Table 7.1 Data used in the estimation of convective mixing heights for accumulated net radiation.

Month	Mixing Heights (m)[a]			Accumulated Net Radiation (MJ/m^3)[b]		
	Edmonton Stony Plain	Norman Wells	Whitehorse	Edmonton Stony Plain	Norman Wells	Whitehorse
January	227	155	182	-	-	-
February	295	247	329	0.635	-	-
March	696	474	936	2.231	-	-
April	1578	812	1588	8.516	-	5.211
May	2396	1237	2019	11.020	10.279	9.936
June	2185	1555	2366	11.891	11.592	10.893
July	1954	1448	1841	11.926	10.666	9.957
August	1563	1117	1761	9.993	7.404	7.861
September	1322	758	1205	6.234	3.646	4.500
October	998	355	760	3.140	0.497	1.301
November	420	180	290	0.641	-	-
December	208	135	190	-	-	-

(a) Mean maximum afternoon mixing height. From Table B1 in Portelli (1977).

(b) Only positive values are accumulated. From Pages 1-38, 44 and 48 in Phillips and Aston (1980).

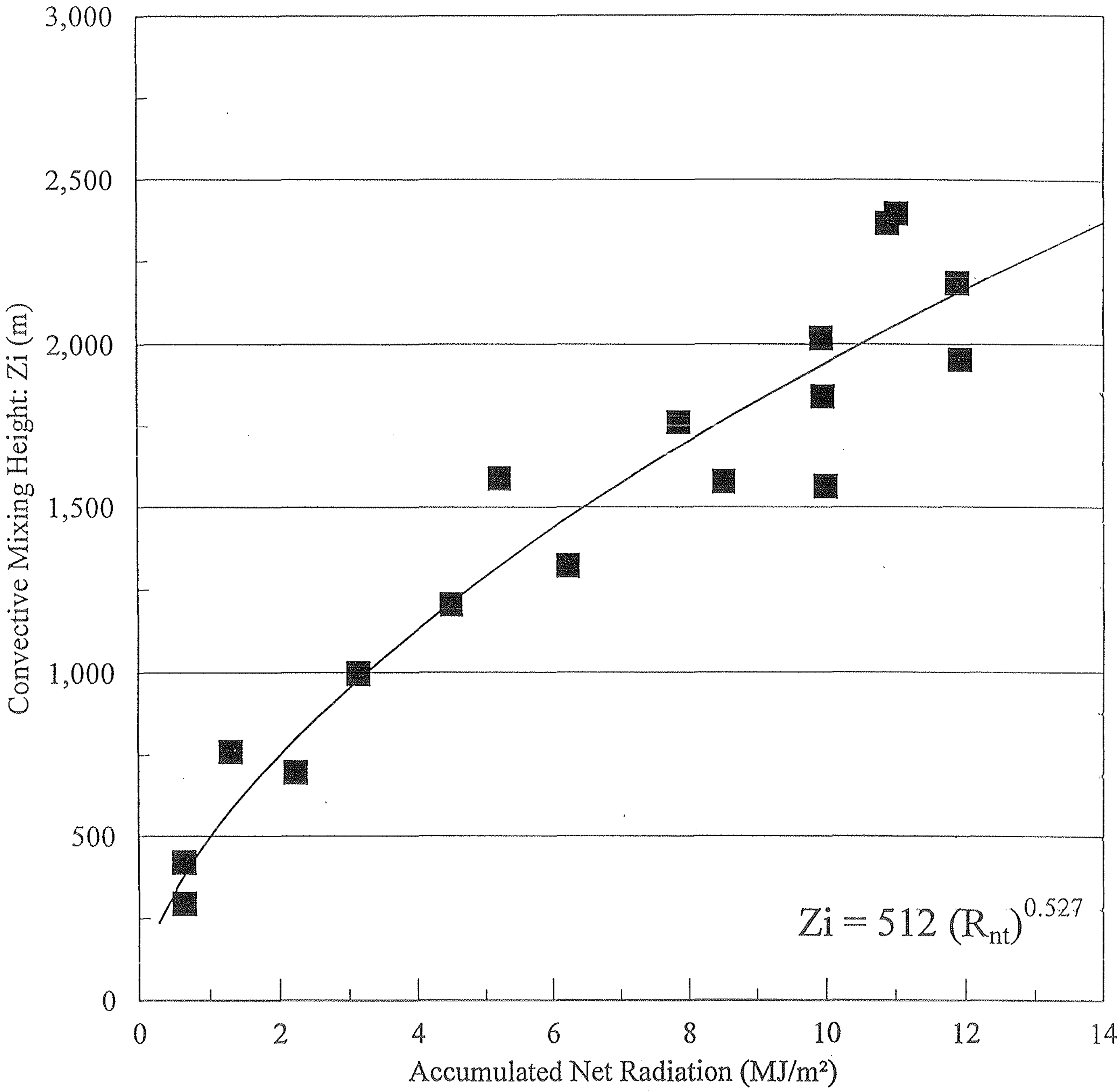

Figure 7.2 Empirical relationship used to estimate convective mixing height.

The convective mixing height can be estimated from the relationship:

$$Z_i = 512\ (R_{net})^{0.527}$$

where: R_{net} is the net accumulated value of positive radiation since sunrise.

For an individual hour, the mixing height is taken as the maximum of the mechanical and convective values.

7.2.4 *Calculated Mixing Heights*

The mixing heights based on the Mannix 20 m level wind speed and the net radiation observations were calculated using the methods described in the previous sections. Figure 7.3 shows the seasonal and diurnal variation of median mixing heights. The largest predicted mixing heights are associated with late afternoon, spring and summer hours. These values are in the 1600 to 2000 m range. During the night and in the winter, the mixing height values tend to be in the 400 to 500 m range.

The following table compares the median seasonal maximum mixing heights for the Mannix data with median values reported for the Athabasca Oil Sands by Davison et al. (1981) and mean maximum values reported by Portelli (1977).

		Athabasca Oil Sands	
	Mannix	**(a)**	**(b)**
Winter	490	270	260
Spring	1390	1000	1230
Summer	1780	1000	1725
Fall	850	800	760

(a) Davison *et al.* 1981.
(b) Portelli 1977.

As indicated in the table, the values calculated from the Suncor data tend to be slightly higher than the previously reported values for the winter, spring and summer months. The Suncor fall values are essentially equivalent to the previously reported values.

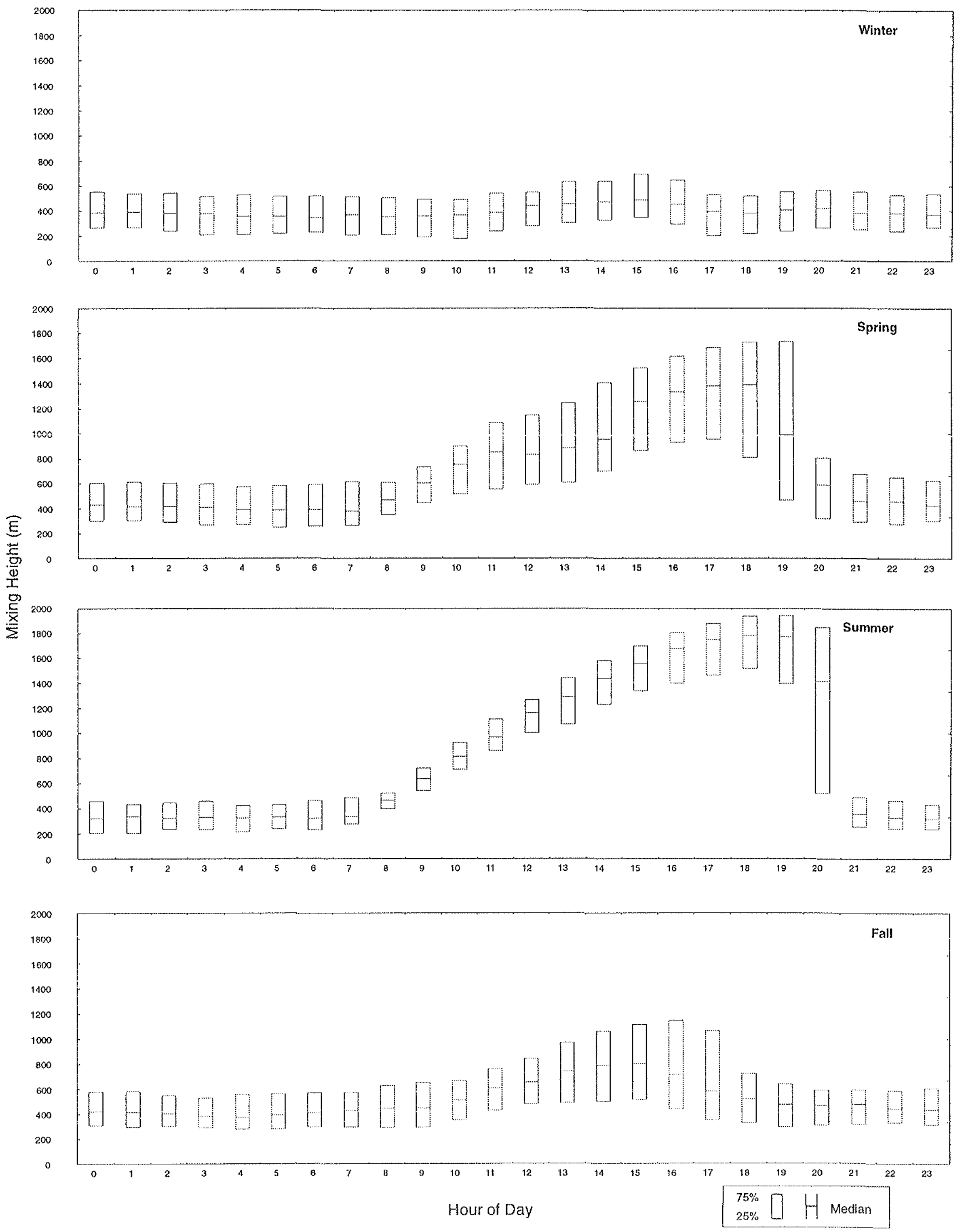

Figure 7.3 Variation in seasonal mixing heights for Mannix monitoring station with respect to hour of day.

8.0 RELATIVE HUMIDITY AND PRECIPITATION

8.1 Relative Humidity

Relative humidity was monitored at the Mannix monitoring station from November 1, 1993 to June 30, 1995. As previously discussed, no valid data are available from April 11, 1994 to April 26, 1995. Relative humidity was not monitored at the Lower Camp station.

Figure 8.1 presents the median hourly relative humidity for Mannix as a function of time of day. As indicated in the figure, there is very little diurnal variation of the median relative humidity during the winter. This is due to only small temperature changes during the day. The winter values range from approximately 78 to 82%. During the spring and summer months, when there are large variations in diurnal temperatures, the median relative humidity ranges from approximately 31% during the day to 76% during the night. The range of median relative humidity values during the fall is less in magnitude than the spring values, but greater than the winter values. During the fall, the mean relative humidity ranges from approximately 77 to 88%. As expected, the minimum relative humidity tends to occur during the mid-afternoon period during all seasons, which is when the ambient temperatures tend to be the highest.

8.2 Precipitation

Figure 8.2 shows the mean rainfall (mm), snowfall (cm) and total precipitation (mm) observed at the Fort McMurray Airport (1961 to 1990) (Atmospheric Environment Service 1995). The maximum mean rainfall of 79.1 mm occurred in July. The maximum mean snowfall of 33.1 cm occurred in November.

Figure 8.3 shows the maximum 24-hour rainfall, snowfall and total precipitation observed at the Fort McMurray Airport (1961 to 1990) The maximum 24-hour rainfall (94.5 mm) and total precipitation occurred in August. The maximum 24-hour snowfall (29.7 cm) occurred in March.

Figure 8.4 shows the mean number of days with measurable precipitation at the Fort McMurray Airport (1961 to 1990). On average, Fort McMurray has 142 days per year with measurable precipitation.

Dispersion models often require rainfall intensity data for contaminant removal rates. The following table indicates the total precipitation and percent frequency of precipitation as a function of season at the Fort McMurray Airport. Precipitation occurs most frequently (44.6% of the time) during the summer, and least frequently during the spring months (30.4% of the time). The highest intensity of precipitation occurs during the summer months, while the lowest occurs during the winter. For comparative purposes, total precipitation data from the Environment Canada Mildred Lake station were also analyzed. The seasonal total precipitation values for Mildred Lake (November 1993 to August 1995) tend to be lower than the long-term values for the Fort McMurray Airport (1961 to 1990).

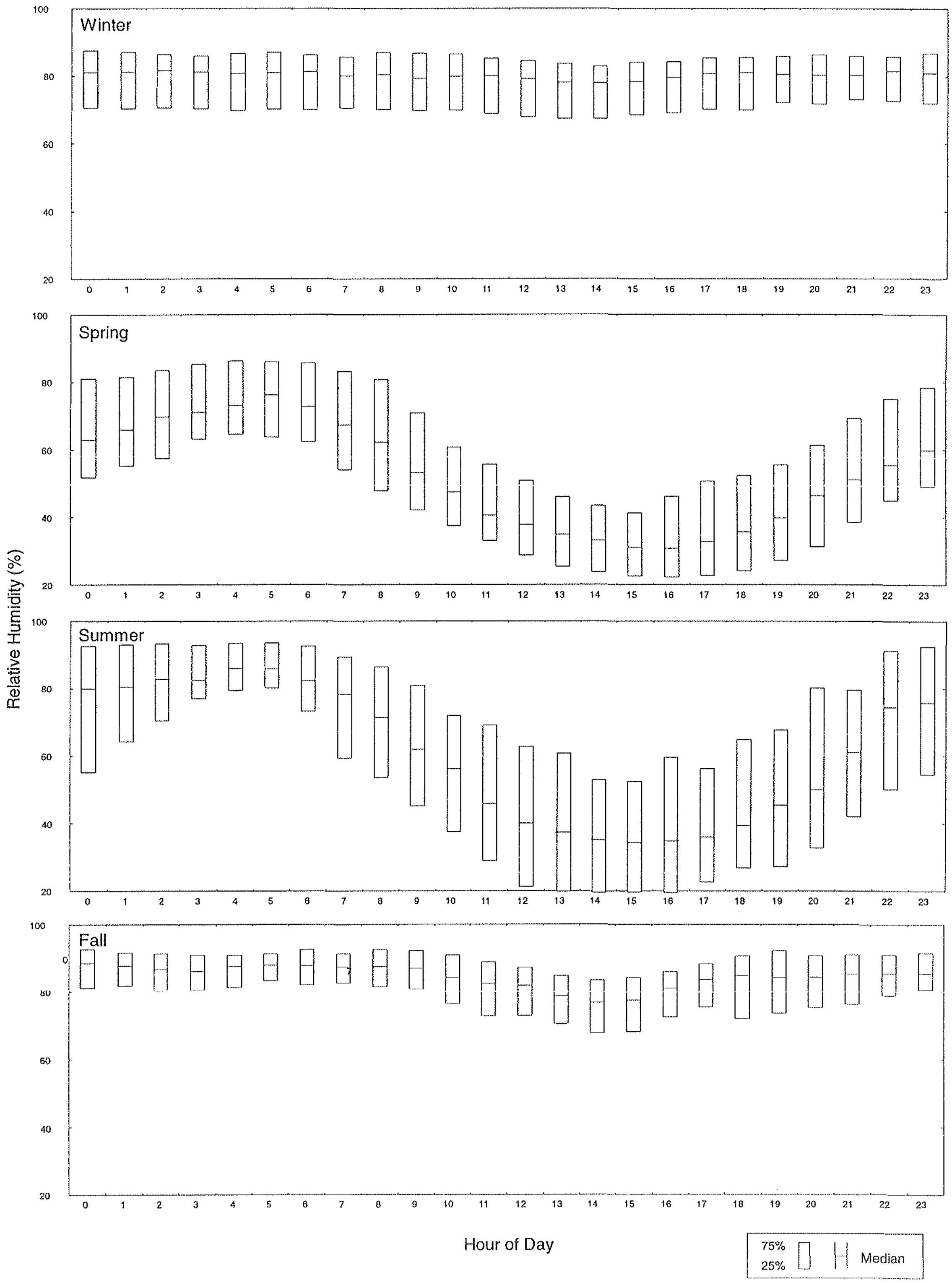

Figure 8.1 Relative humidity observed at Mannix monitoring station.

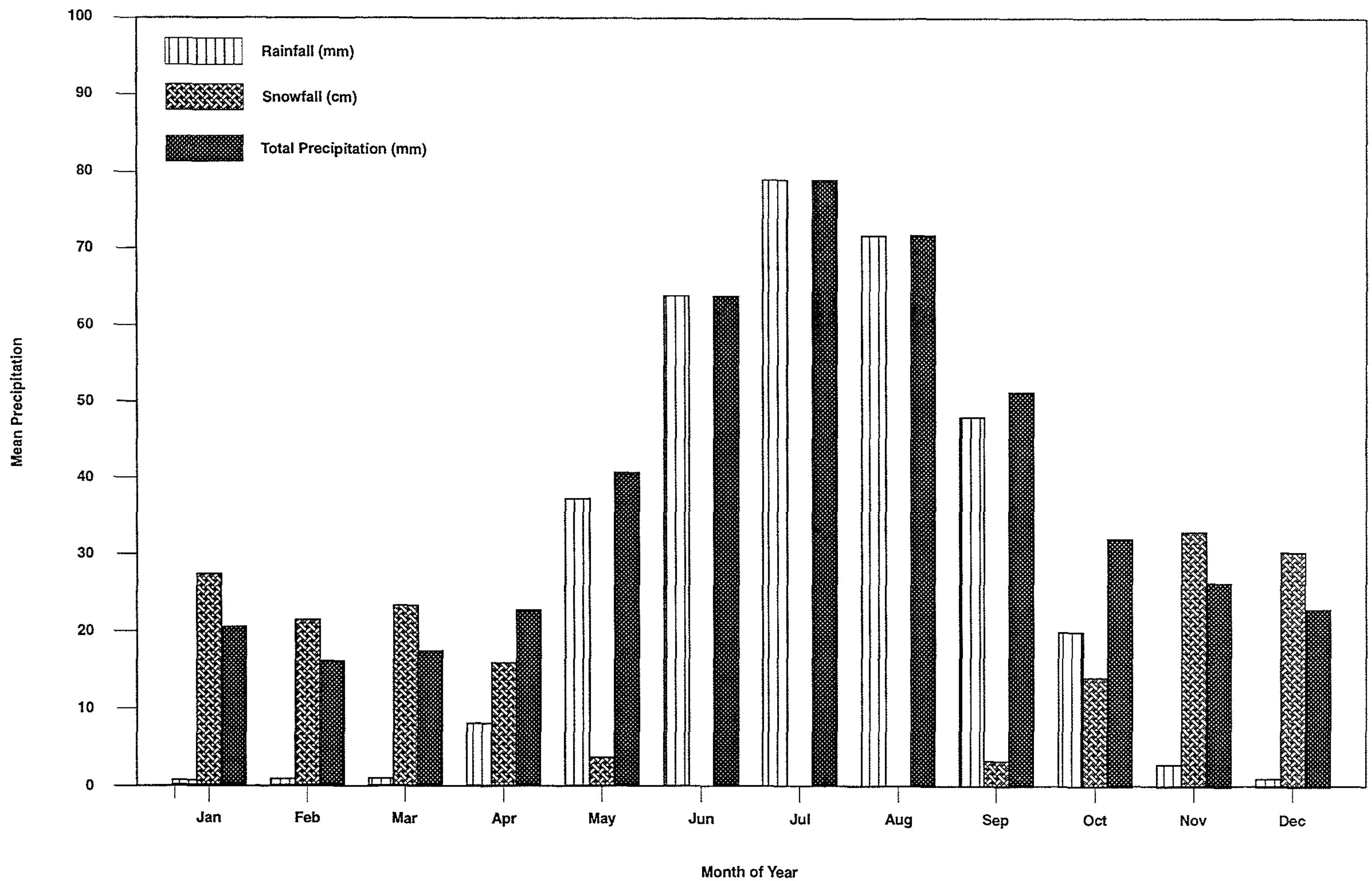

Figure 8.2 Mean rainfall (mm), snowfall (cm) and total precipitation (mm) observed at Fort McMurray Airport (1961 to 1990).

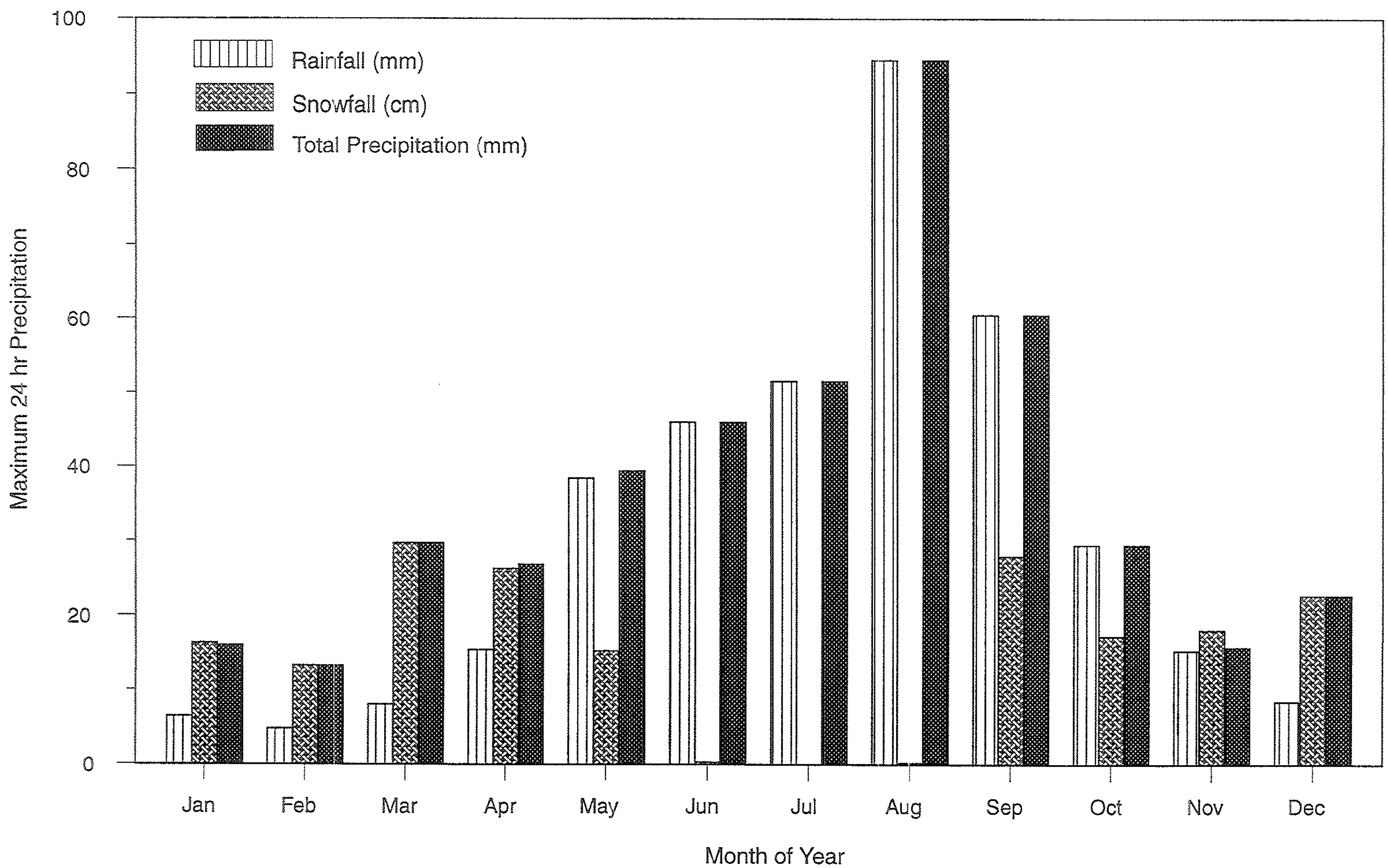

Figure 8.3 Maximum 24-hour rainfall (mm), snowfall (cm) and total precipitation (mm) observed at Fort McMurray Airport (1961 to 1990).

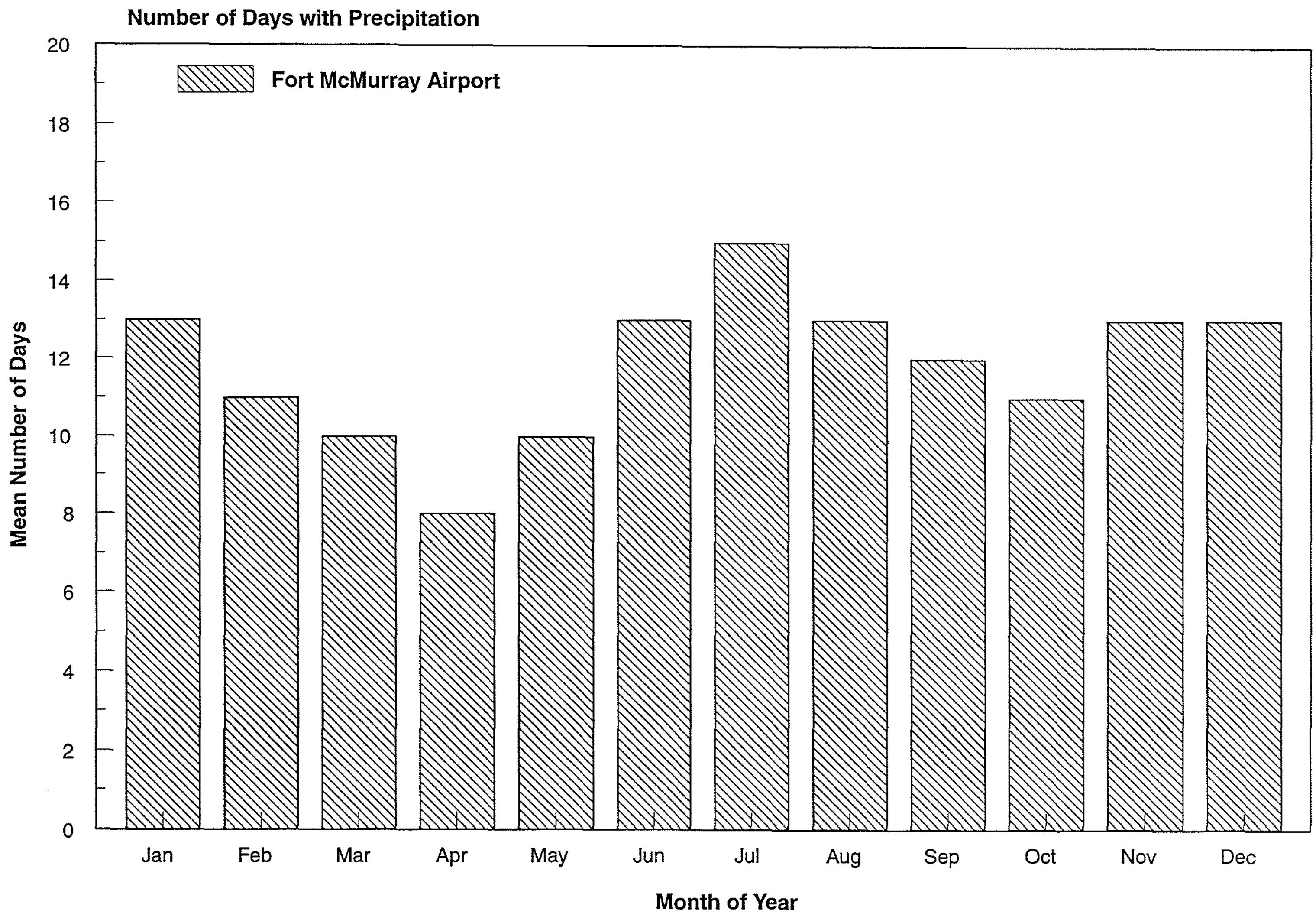

Figure 8.4 Mean number of days with precipitation observed at the Fort McMurray Airport (1961 to 1990).

Season	Fort McMurray Airport			Mildred Lake
	Total Precipitation (mm)	Frequency (%)	Intensity[a] (mm/h)	Total Precipitation (mm)
Winter	59.4	41.0	0.094	26.0
Spring	80.6	30.4	0.282	51.8
Summer	214.8	44.6	0.901	193.2
Fall	110.0	39.6	0.319	58.8
Annual	464.8	38.9	0.339	329.8

[a] Based on Fort McMurray Airport data from 1951 to 1980.

9.0 SUMMARY AND RECOMMENDATIONS

This report concludes by providing a summary of the monitoring program and results of the meteorological data analysis. Recommendations are also presented based on the data evaluation.

9.1 Summary

Suncor initiated an enhanced meteorological monitoring program at the Lower Camp and Mannix air quality monitoring stations. The Lower Camp station is comprised of a communications tower that is instrumented at the 20, 45, 100 and 167 m levels. The Mannix station is comprised of a communications tower that is instrumented at the 20, 45 and 75 m levels. This report evaluated data for the 20 month period, from November 1, 1993 to June 30, 1995, inclusive.

As the meteorological parameters can be affected by local terrain features, the terrain in the vicinity of the monitoring stations was reviewed. The primary terrain feature is the Athabasca River Valley which has a general north-south orientation in the vicinity of the meteorological monitoring station. The Lower Camp tower has a base elevation of 245 m ASL and is located in the valley. The Mannix tower has a base elevation of 334 m ASL and is located above the river valley. The top of both towers are located at approximately the same elevation (Lower Camp 412 m ASL and Mannix at about 409 m ASL).

The following presents a parameter-by-parameter summary of the data collected by the meteorological program:

Section 4 - Wind

- Wind Direction. Wind directions at both sites tend to be from either the south-southwest to south-southeast sector or from the north to north-northeast sector. These two sectors represent the orientation of the Athabasca River Valley. The only exception is the Lower Camp 20 m level which tends to indicate crossvalley flows. This data and/or instrumentation at this level warrant further investigation.

- Wind Speed. Median wind speeds at Lower Camp range from 8 km/h at the 20 m level to 14 km/h at the 167 m level. At Mannix, median wind speeds range from 8 km/h at the 20 m level to 14 km/h at the 75 m level. Wind speeds less than 11 km/h (3 m/s) occur one-third of the time at the Mannix 75 m and Lower Camp 167 m levels. The fall season has the highest frequency of wind speeds greater than 19 km/h (5 m/s).

- Power Law Exponent. Table 9.1 summarizes the power law exponent as a function of stability class. As indicated in the table, the median power law exponent as a function of stability class ranges from 0.1 to 0.6 for Lower Camp and from 0.2 to 0.6 at Mannix.

Table 9.1 Summary of selected turbulence parameters as a function of stability class.

Stability Class	Potential Temperature Gradients (K/m)		Power Law Exponent		Surface Roughness Length (m)	Monin-Obukhov Length (m)	Friction Velocity (m)
	Lower Camp (167 to 100 m)	Mannix (75 to 20 m)	Lower Camp	Mannix			
A	-	-	0.12	0.21	1.0	-9	0.14
B	-	-	0.07	0.21	1.0	-26	0.28
C	-	-	0.10	0.23	1.0	-123	0.33
D	-	-	0.28	0.40	1.0	$\pm\infty$	0.34
E	0.03	0.04	0.59	0.62	1.0	123	0.18
F	0.04	0.05	0.57	0.50	1.0	26	0.06

- Surface Roughness Length. The median surface roughness lengths for Lower Camp and Mannix are 0.8 and 1.2 m, respectively. For the purpose of modelling, a value of 1.0 m will be used as representative for the area.

Section 5 - Turbulence

- Horizontal Turbulence. The largest values of σ_θ tend to be associated with light wind speeds due to convective turbulence during the day and increased meander during nighttime. The neutral values for σ_θ at the 20 m level were 14 and 21 degrees, respectively, at the Lower Camp and Mannix sites.

- Vertical Turbulence. The largest values of σ_ϕ tend to be associated with light winds. The neutral convergence values for σ_ϕ at the 20 m level were 6 and 10 degrees, respectively, for the Lower Camp and Mannix sites.

- Stability Class. The stability class determination was made based on the Mannix data using the U.S. EPA σ_ϕ method. The calculated stability class frequencies compared reasonably well with stability classes from Fort McMurray Airport observations. On an annual basis, the Suncor σ_ϕ based stability classes yielded 16% unstable, 61% neutral and 23% stable atmospheric conditions.

- Monin-Obukhov Length. The Monin-Obukhov lengths were calculated for a surface roughness length of 1.0 m. Table 9.1 presents the calculated values as a function of stability class.

- Friction Velocity. Table 9.1 presents the calculated friction velocities as a function of stability class. The values range from approximately 0.1 to 0.3 m/s, with an overall median value of 0.3 m/s.

Section 6 - Temperature

- Temperature. Mean temperatures at the Mannix and Lower Camp sites ranged from approximately -18°C in February to 20°C in July. Extreme temperatures in excess of 30°C and below -30°C were observed in the months from May to September and November to March, respectively. The annual average temperature was approximately 0°C.

- Temperature Gradient. Temperature gradients at lower levels exhibit stronger gradients than those at elevated levels due to the heating and cooling processes at the ground. Winter temperature gradients have more stable values while summer gradients have more neutral and unstable values.

Section 7 - Net Radiation and Mixing Heights

- Net Radiation. The mean net radiation values observed for each season are 11, 72, 115, and 27 W/m^2 for winter, spring, summer and fall, respectively. An empirical relationship between net radiation and convective mixing height is presented as $Z_i = 512 (R_{net})^{0.527}$.

- Mixing Heights. Mechanical and convective mixing height values were estimated for the Mannix station using the 20 m level wind speeds and a surface roughness of 1 m. The larger of these two values was used for each hour of data. In late afternoon in spring and summer, the largest predicted mixing heights are in the 1600 to 2000 m range. During nighttime hours and in winter, predicted mixing heights are in the 400 to 500 m range.

Section 8 - Relative Humidity and Precipitation

- Relative Humidity. Winter median relative humidity values range from 78 to 82%. Spring and summer median values range from 31 to 76%. Fall median values range from 77 to 88%. The largest relative humidity values are associated with nighttime conditions and the lowest with the mid-afternoon period.

- Precipitation. The most precipitation in the area occurs in summer months and the least in winter. Summer has the highest frequency of precipitation and spring the least.

9.2 Recommendations

During the data analysis process, a number of issues were identified that need to be addressed. Until further investigation takes place, it is not known whether the data associated with these issues are real, a product of faulty instrumentation or a product of faulty programming. The issues identified include the following:

- A possible programming difficulty, since after December 1, 1994, the Lower Camp 100 m level. Wind direction standard deviation is equal to the actual wind direction.

- Difficulty with data collection involving the Lower Camp 45 m level wind direction.

- Difficulty with the Mannix 45 m level wind speed sensor.

- Difficulty with the Mannix relative humidity sensor.

- Uncertainty in the high occurrence of crossvalley wind direction flows reported by the Lower Camp 20 m wind direction sensor.

- Uncertainty in the potential temperature gradients reported at some levels of the tower. Although the values show a consistent diurnal variation, the bias to positive values suggests that unstable conditions do not exist.

- Uncertainty caused by some of the net radiation data being capped at 500 W/m^2 during the summer. The absence of negative values during the winter also warrants further investigation.

To address these difficulties and uncertainties, BOVAR Environmental recommends the following:

- An audit program be conducted to confirm satisfactory operation of all sensors and the correct programming for all instrumentation.

- A formalized data validation program on either a monthly or quarterly basis be implemented to provide ongoing quality control of the data collected.

- The outcome of the data validation procedure be a finalized archiving and integration of the meteorological data with other air quality data that are collected by the oil sands plants.

- The wind data collected at the upper levels of both towers are equivalent to the 105 m level of the Syncrude stack which is 183 m in height. As the Syncrude plume is expected to be in the range of 200 to 400 m above stack base, there is a question as to whether or not the wind data collected are representative of the air flow for Syncrude. An enhancement of the wind program would help resolve this issue.

The implementation of these recommendations will result in increased confidence for all data collected and will provide a database that will meet the needs of all stakeholder interests in the airshed. Not withstanding the identification of uncertainties and the corresponding recommendations, data collected from multiple levels of multiple towers do provide a redundancy. This redundancy produces a level of confidence that the data collected can be used for evaluating air quality changes resulting from emissions from the two oil sands plants.

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APPENDICES

APPENDIX A

Additional Meteorological Monitoring Programs

APPENDIX A.

Wind Direction

Wind direction data for comparative purposes are available from various other monitoring programs in the Athabasca Oil Sands area. These additional data sources include:

- Suncor SODAR Data. These data were collected during 1988 at a nominal 150 m level using a Doppler acoustic wind sensor.

- OSLO Data. These surface observations were collected at the proposed OSLO extraction site for the period March 1988 to December 1989 (Concord Environmental 1990).

- SandAlta Data. This data is based on observations conducted at the proposed SandAlta lease site from April 1984 to March 1985 (Western Research 1985). Wind data are presented for observations made at 11 m and 46 m above the ground.

- Fort McMurray Airport. Environment Canada routinely collects data at airports across the country. The data presented in this report represent 10 m level observations at the Fort McMurray Airport conducted from 1975 to 1984, inclusive.

- Mildred Lake. Environment Canada initiated a monitoring program at Mildred Lake in November 1993. The data presented in this report were collected from November 1993 to August 1995, inclusive.

- Pibal Data. A total of 2344 pibal observations were taken in the Mildred Lake area from 1975 to 1978. A portion of the presented data are from a continuous program which involved two to four pibal releases per day, while the remainder of the pibal data are from more intensive programs varying over one or two weeks and involving up to 20 releases per day.

- Mildred Lake, Birch Mountain and the Bitumount Tower data were analyzed for Canstar (Western Research 1981). These data were collected from September 1976 to March 1979, inclusive.

- Compliance Monitoring. Suncor, Syncrude and Alberta Environmental Protection (AEP) compile data from 12 monitoring trailers in the Athabasca Oil Sands area. A list of these sites and the dates of monitoring period used in this analysis are presented in the following table:

Monitoring Program	Monitoring Period Analyzed
Suncor Stations:	
Mannix	January 1, 1990 to September 20, 1995
Lower Camp	January 1, 1990 to September 20, 1995
Fina	January 1, 1990 to September 20, 1995
Poplar Creek	July 20, 1990 to September 20, 1995
Athabasca Bridge	September 28, 1990 to September 20, 1995
Syncrude Stations:	
South Mine	January 1, 1990 to August 9, 1995
Fort McMurray	January 1, 1990 to August 8, 1995
Mildred Lake Airstrip	January 1, 1990 to August 9, 1995
North Tailings Pond	January 1, 1990 to August 9, 1995
East Tailings Pond	January 1, 1990 to August 9, 1995
AEP Stations:	
Fort McKay	January 1, 1990 to June 30, 1995
Fort McMurray	January 1, 1990 to June 30, 1995

Figure A.1 shows the location of the previously mentioned monitoring stations with respect to the Lower Camp and Mannix monitoring stations.

Figure A.2 shows the windroses for the Suncor SODAR (150 m), OSLO (10 m), SandAlta (11 m) and SandAlta (46 m) data. As shown in the diagrams, the Suncor SODAR data indicate that north winds occurred most frequently, while the OSLO data indicate north-northeast and south-southeast winds as being most frequent. The SandAlta winds show a predominance for southeasterly winds. The windroses for these monitoring stations show influence of the Athabasca River Valley and as such, are comparable to the windroses shown in Figures 4.2 and 4.3 for Mannix and Lower Camp, respectively.

Figure A.3 shows the data collected at the Fort McMurray Airport and Mildred Lake by Environment Canada, and the pibal data collected at Mildred Lake. The Fort McMurray Airport data indicate a strong east-west predominance which may be due to the influence of the Clearwater River Valley. The Environment Canada Mildred Lake surface data show a predominance for northerly and southeasterly winds, indicative of influences from the Athabasca River Valley. In contrast, the upper level Mildred Lake pibal data indicate a predominance for west and west-southwest winds. In summary, while the surface levels winds at Mildred Lake are comparable to the data collected at Mannix and Lower Camp, the upper level pibal data and data collected at the Fort McMurray Airport, do not show the Athabasca River Valley influences and therefore, are not comparable.

Figure A.4 shows the Mildred Lake, Birch Mountain and Bitumount Tower data analyzed for Canstar. These data clearly illustrate the difference in the various wind flow patterns in the area. The Birch Mountain winds show a strong dominance in the west to northwest sector, while the

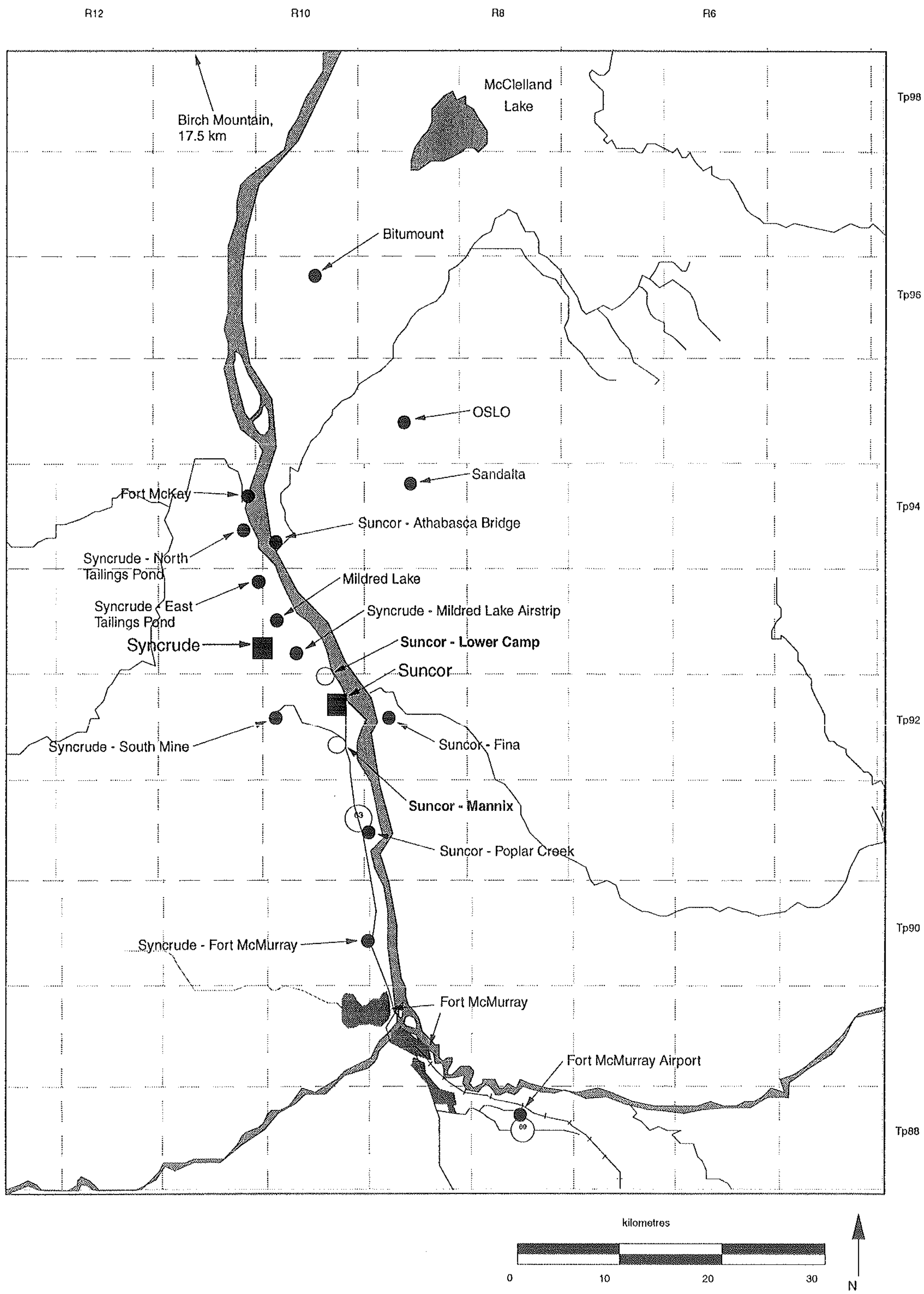

Figure A.1 Location of monitoring stations.

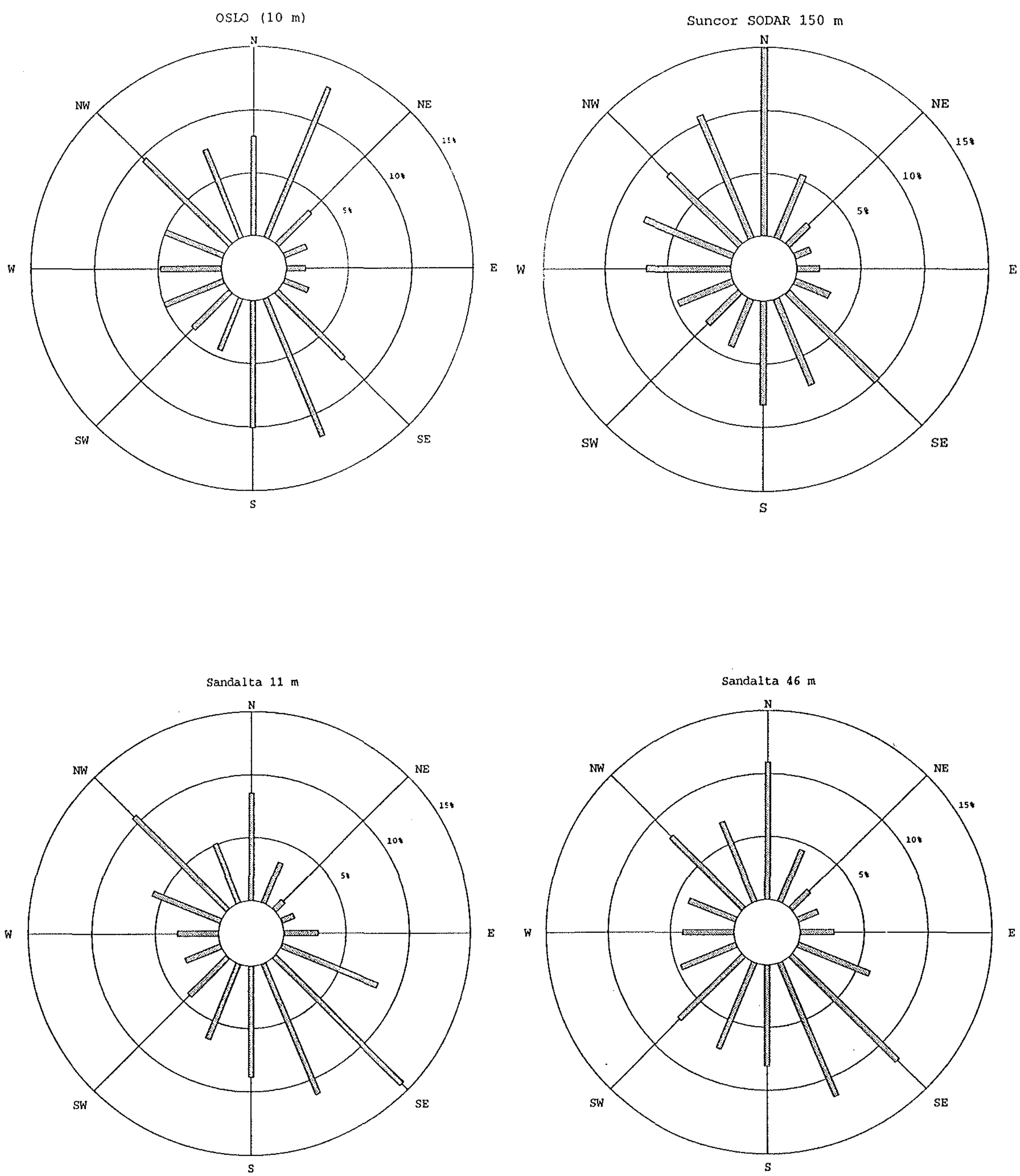

Figure A.2 Windroses for Suncor SODAR (150 m), OSLO (10 m), SandAlta (11 m) and SandAlta (46 m) data.

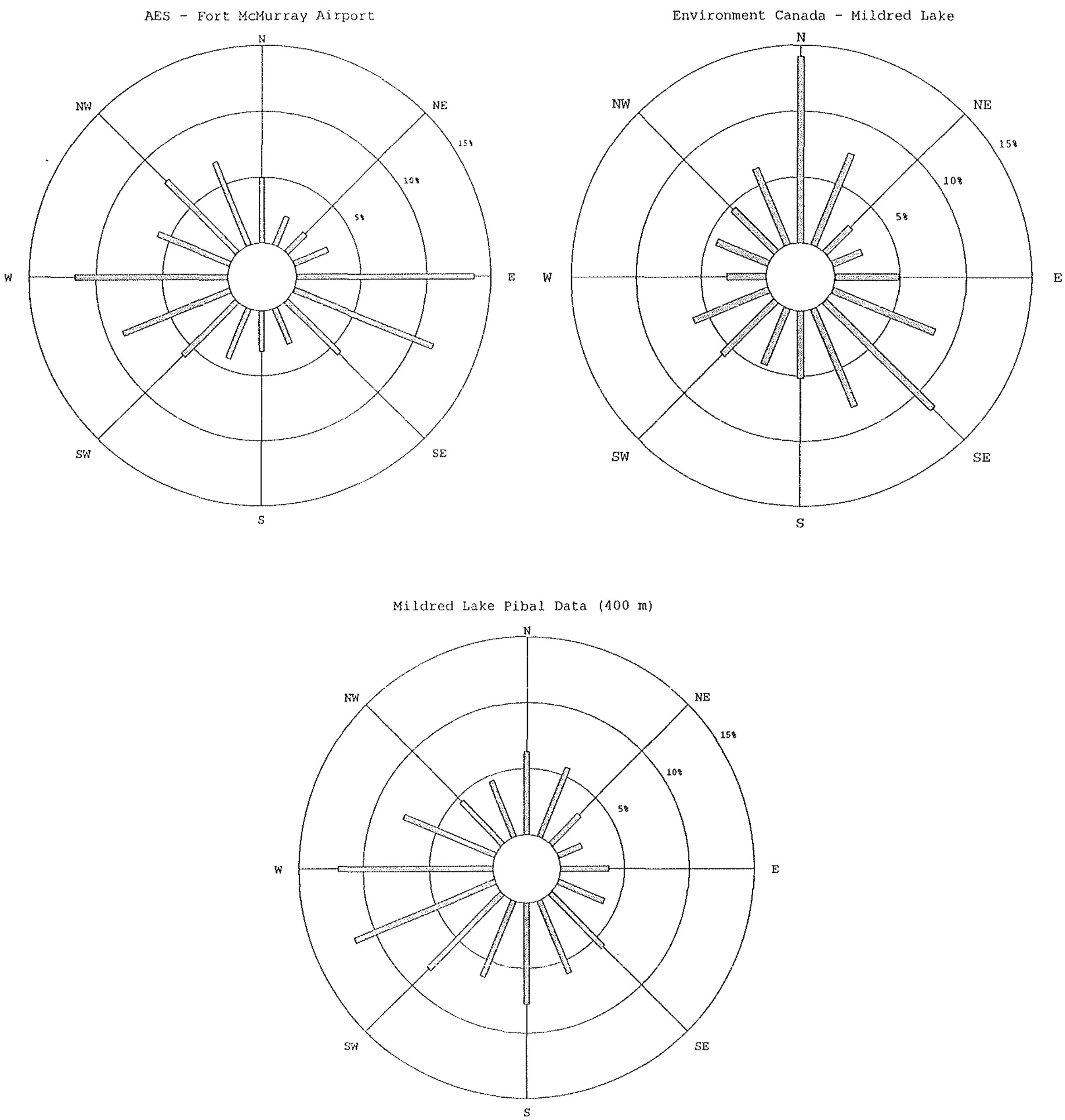

Figure A.3 Windroses for Environment Canada Fort McMurray Airport and Mildred Lake monitoring stations and Mildred Lake pibal data.

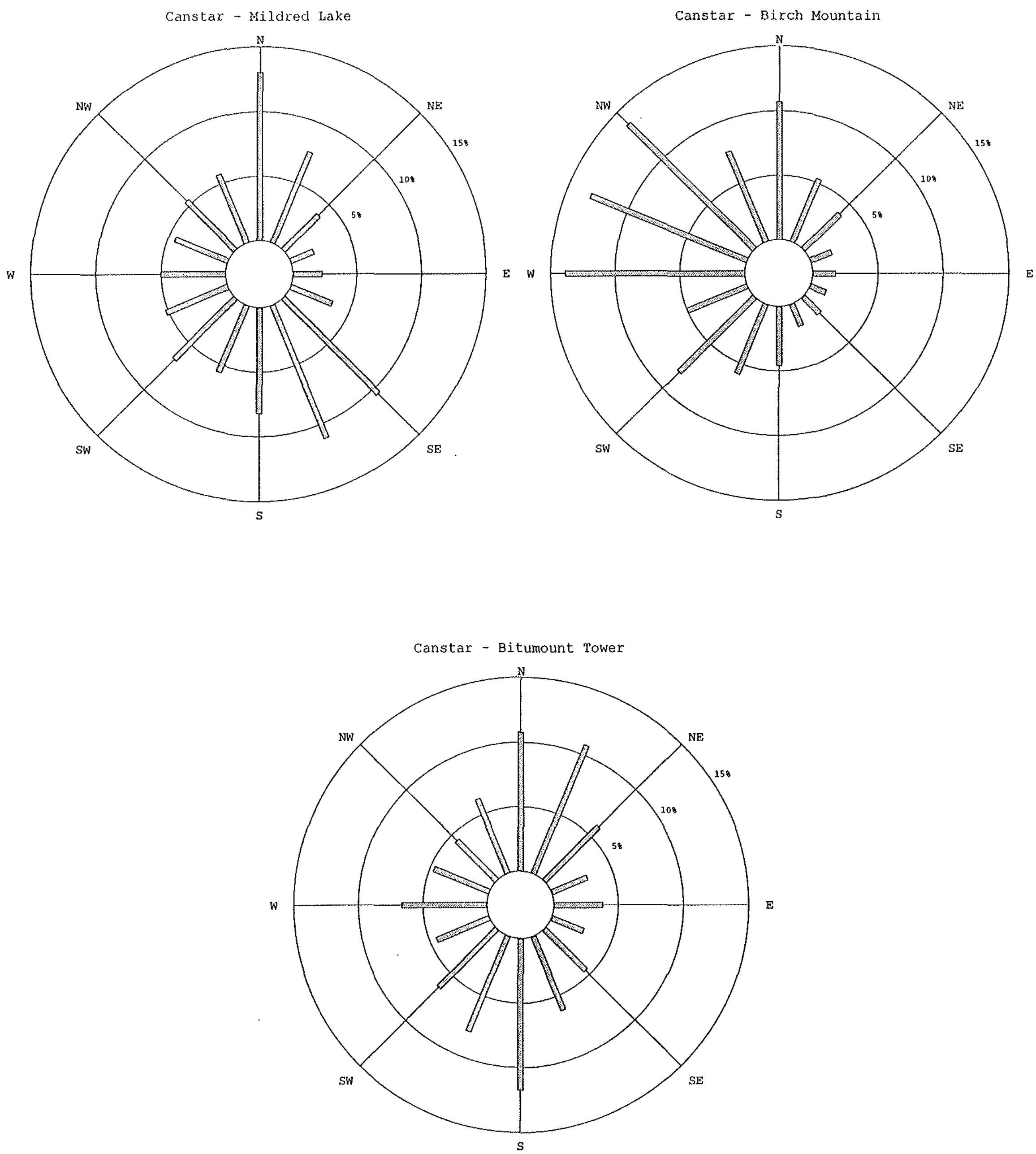

Figure A.4 Windroses for Mildred Lake, Birch Mountain and Bitumount Tower data.

Bitumount Tower and Mildred Lake winds appear to be more influenced by the Athabasca River Valley and are therefore, more comparable to the Mannix and Lower Camp data.

Figures A.5 to A.7 show the windroses for the 12 data sources compiled by AEP. The following table shows the most predominant wind direction for each of these windroses:

Monitoring Program	Predominant Wind Direction
Suncor Stations:	
Mannix	SSE
Lower Camp	SE
Fina	N
Poplar Creek	S
Athabasca Bridge	SSE
Syncrude Stations:	
South Mine	SSE
Fort McMurray	SSE
Mildred Lake Airstrip	SSE
North Tailings Pond	N
East Tailings Pond	N
AEP Stations:	
Fort McKay	N
Fort McMurray	N

Again, due to their proximity to the Athabasca River, these stations indicate the presence of valley influences on the wind flow.

In summary, due to their removed location from the Athabasca River Valley, the Birch Mountain winds, upper level pibal data and Fort McMurray Airport winds are not comparable to the Mannix and Lower Camp winds. The other monitoring stations, which were located within the Athabasca River Valley, show the influence of the valley terrain.

Wind Speed

Figure A.8 presents frequency distributions for the Suncor SODAR, SandAlta and Environment Canada Mildred Lake data. The Suncor SODAR and Mildred Lake data indicate that wind speeds occur most frequently in the 6 to 11 km/h category, while the SandAlta data indicate that wind speeds occur most frequently in the 12 to 19 km/h category.

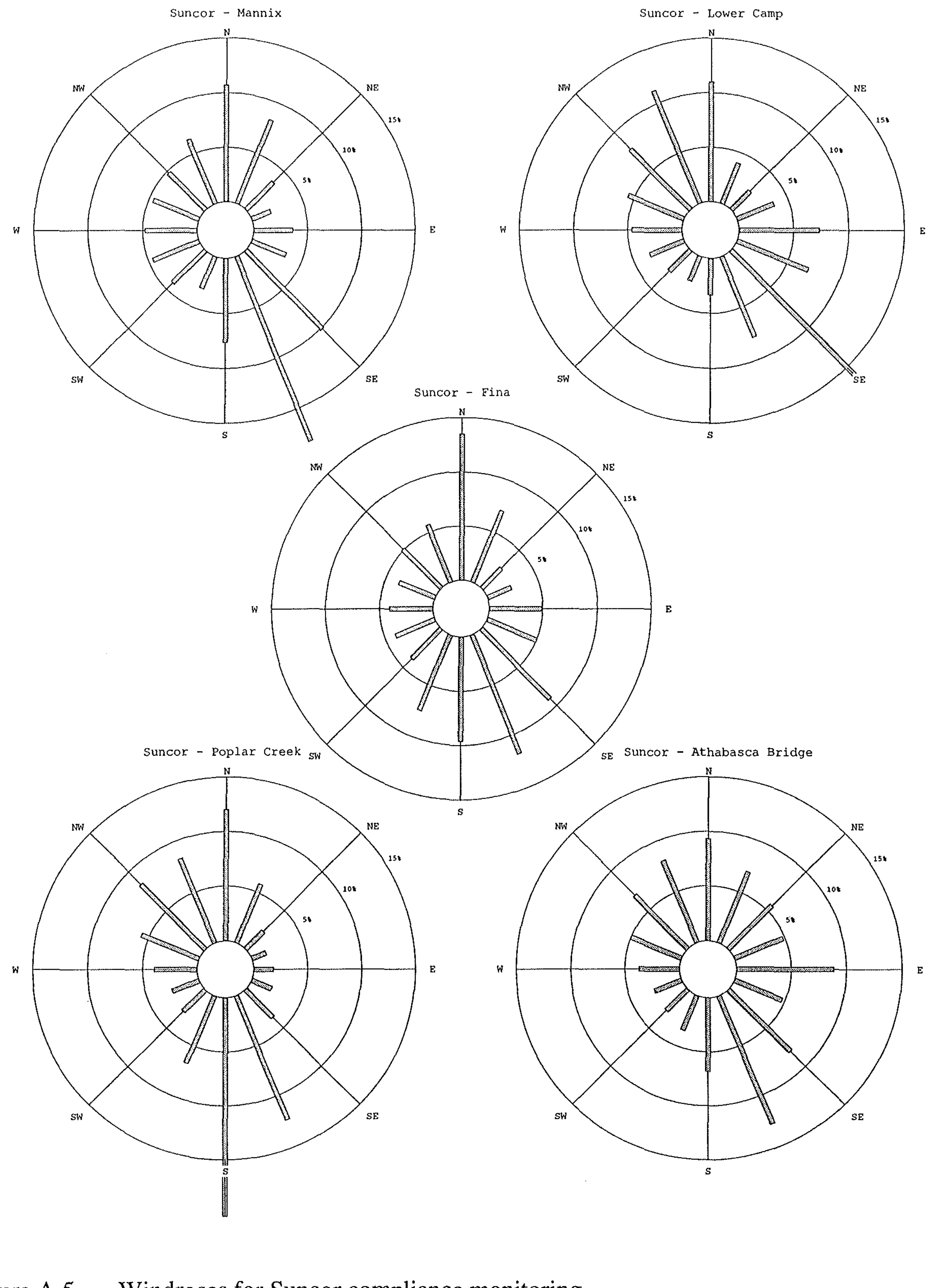

Figure A.5 Windroses for Suncor compliance monitoring.

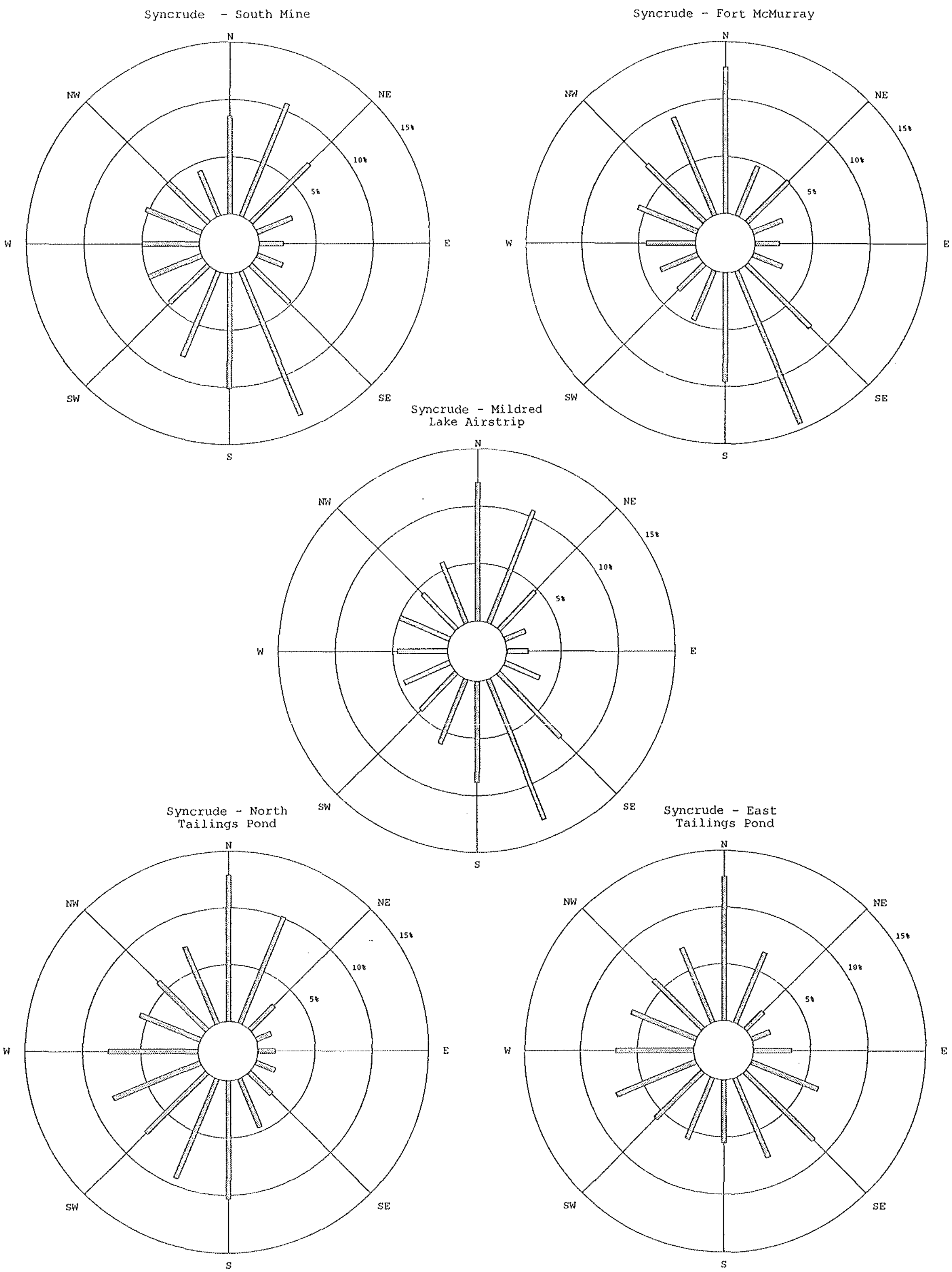

Figure A.6 Windroses for Syncrude compliance monitoring.

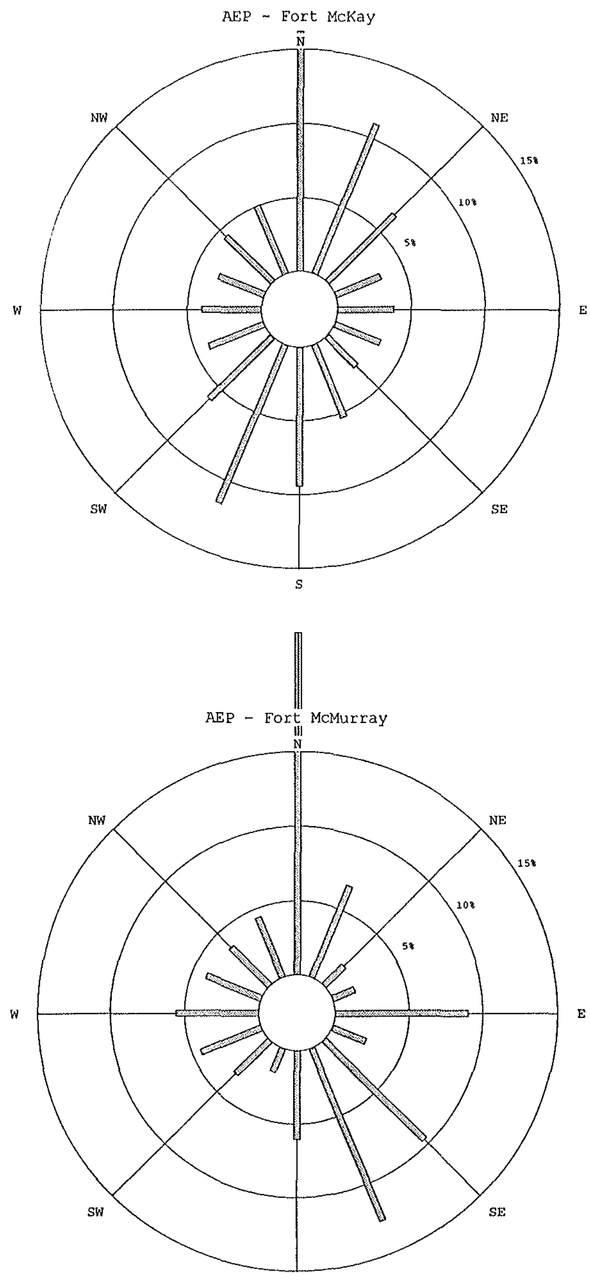

Figure A.7 Windroses for Alberta Environmental Protection monitoring stations at Fort McKay and Fort McMurray.

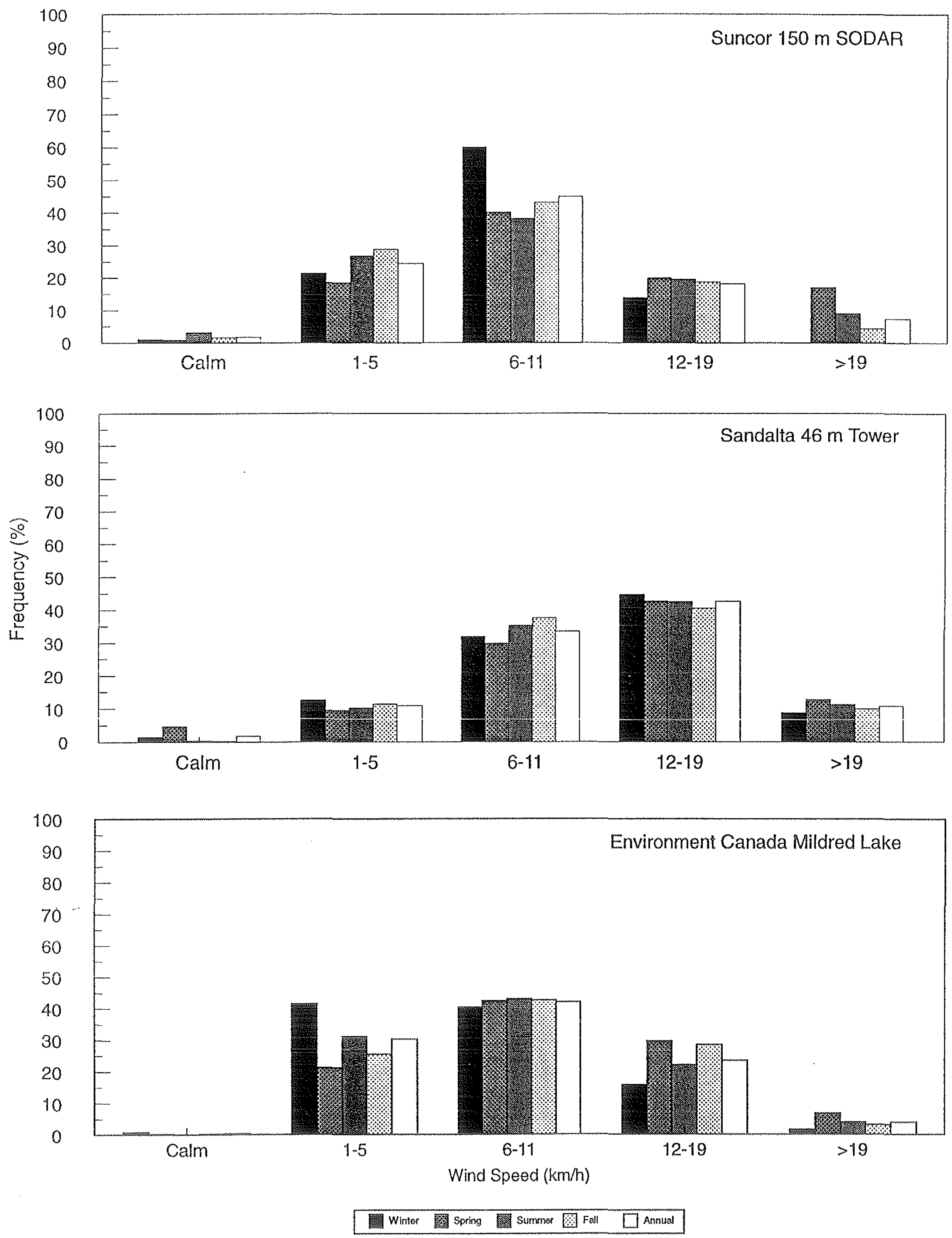

Figure A.8 Wind speed frequency distributions for the Suncor SODAR (150 m), SandAlta (46 m) and Environment Canada Mildred Lake data.

The following table summarizes the percent frequency of wind speeds on an annual basis for comparison with the Lower Camp and Mannix data:

		Wind Speed (km/h)				
		Calm	**1 to 5**	**6 to 11**	**12 to 19**	**> 19**
Suncor SODAR	(150 m)	2	24	45	20	9
SandAlta	(46 m)	2	12	32	42	12
Mildred Lake	(10 m)	< 1	30	42	34	4
Lower Camp	(167 m)	<1	11	27	32	30
	(100 m)	< 1	15	35	30	20
	(45 m)	< 1	26	41	27	6
	(20 m)	8	27	34	24	6
Mannix	(75 m)	< 1	10	26	35	29
	(45 m)	< 1	14	34	40	12
	(20 m)	2	28	47	20	2

As indicated in the preceding table, the Suncor SODAR data compare most favourably with the Lower Camp 45 m level and Mannix 20 m level data. The SandAlta 46 m level data compare most favourably with the Mannix 45 m level data and with the Lower Camp 100 m and 167 m level data, but only for wind speeds < 12 km/h. The Environment Canada Mildred Lake data compare most favourably with the Lower Camp and Mannix 20 m level data.

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APPENDIX B

File Documentation

APPENDIX B. File Documentation

An important part of any project is file management. The computer files associated with the project include the following types:

- Meteorological data files
- Terrain data files
- Report text and graphics files.

The purpose of this Appendix is to identify these files and the associated formats. The data text and graphics files were all prepared using standard off-the-shelf commercial MS-DOS/ WINDOWS software.

B.1 Meteorological Data Files

The statistical analysis and data management program STATISTICA for WINDOWS (Release 5.0) (Statsoft, Tulsa, Oklahoma) was used as the primary analytical tool for the meteorological data. A single time-series data file with 14 568 records (one hour per record) and 87 variables was compiled:

- File Name: SUNMETRV.STA
- File Size: 10145472 bytes
- Date: February 12, 1996 (4:14:58 p.m.)

A corresponding common delimited ASCII file was created from this file for use by other software packages. File specifications for the ASCII file are as follows:

- File Name: SUNMETRV.ASC
- File Size: 9540510 bytes
- Date: February 13, 1996 (11:22:32 a.m.)

The 87 variable fields contained in these files are identified in Table B.1.

B.2 Dispersion Model Meteorological Input Files

The meteorological data were used to create two types of input files for dispersion modelling: sequential time series and climatological STAR formats. Specifically, sequential time series files were prepared for the ISCST3 and RTDM models. Because of the differing locations of the two plants, data from different sources were used. The files created are listed in Table B.2 and the formats of the ISCST3, RTDM and STAR meteorological files are provided in Tables B.3, B.4 and B.5, respectively.

Table B.1 Identification of fields for meteorological data collected at the Suncor Lower Camp and Mannix stations.

Code Name		Station	Variable Description	Monitoring Level (m)	Units
1	YEAR	Both	Year	All	n/a
2	MON	Both	Month	All	n/a
3	DAY	Both	Day	All	n/a
4	HOUR	Both	Hour	All	n/a
5	LT20	Lower Camp	Temperature	20	°C
6	LT4520	Lower Camp	ΔT	45 to 20	C°
7	LT10020	Lower Camp	ΔT	100 to 20	C°
8	LT16720	Lower Camp	ΔT	167 to 20	C°
9	LWSSD20	Lower Camp	Standard Deviation of Wind Speed	20	km/h
10	LWSSD45	Lower Camp	Standard Deviation of Wind Speed	45	km/h
11	LWSSD100	Lower Camp	Standard Deviation of Wind Speed	100	km/h
12	LWSSD167	Lower Camp	Standard Deviation of Wind Speed	167	km/h
13	LWD20	Lower Camp	Wind Direction	20	degrees
14	LWD45	Lower Camp	Wind Direction	45	degrees
15	LWD100	Lower Camp	Wind Direction	100	degrees
16	LWD167	Lower Camp	Wind Direction	167	degrees
17	LWDSD20	Lower Camp	Standard Deviation of Wind Direction	20	degrees
18	LWDSD45	Lower Camp	Standard Deviation of Wind Direction	45	degrees
19	LWDSD100	Lower Camp	Standard Deviation of Wind Direction	100	degrees
20	LWDSD167	Lower Camp	Standard Deviation of Wind Direction	167	degrees
21	LWS20	Lower Camp	Wind Speed	20	km/h
22	LWS45	Lower Camp	Wind Speed	45	km/h
23	LWS100	Lower Camp	Wind Speed	100	km/h
24	LWS167	Lower Camp	Wind Speed	167	km/h
25	LWVSD20	Lower Camp	Standard Deviation of Vertical Wind	20	m/s
26	LWVSD45	Lower Camp	Standard Deviation of Vertical Wind	45	m/s
27	LWVSD100	Lower Camp	Standard Deviation of Vertical Wind	100	m/s
28	LWVSD167	Lower Camp	Standard Deviation of Vertical Wind	167	m/s
29	MWS20	Mannix	Wind Speed	20	km/h
30	MWS45	Mannix	Wind Speed	45	km/h
31	MWS75	Mannix	Wind Speed	75	km/h
32	MWSSD20	Mannix	Standard Deviation of Wind Speed	20	km/h

Table B.1 Continued.

Code Name	Station	Variable Description	Monitoring Level (m)	Units
33 MWSSD45	Mannix	Standard Deviation of Wind Speed	45	km/h
34 MWSSD75	Mannix	Standard Deviation of Wind Speed	75	km/h
35 MWVSD20	Mannix	Standard Deviation of Vertical Wind	20	m/s
36 MWVSD45	Mannix	Standard Deviation of Vertical Wind	45	m/s
37 MWVSD75	Mannix	Standard Deviation of Vertical Wind	75	m/s
38 MT20	Mannix	Temperature	20	°C
39 MT4520	Mannix	ΔT	45 to 20	C°
40 MT7520	Mannix	ΔT	75 to 20	C°
41 MNETRAD	Mannix	Net Radiation	2	W/m^2
42 MWD20	Mannix	Wind Direction	20	degrees
43 MWD45	Mannix	Wind Direction	45	degrees
44 MWD75	Mannix	Wind Direction	75	degrees
45 MWDSD20	Mannix	Standard Deviation of Wind Direction	20	degrees
46 MWDSD45	Mannix	Standard Deviation of Wind Direction	45	degrees
47 MWDSD75	Mannix	Standard Deviation of Wind Direction	75	degrees
48 MRH	Mannix	Relative Humidity	2	percent
49 LCSGV20	Lower Camp	Sigma V	20	m/s
50 LCSGV45	Lower Camp	Sigma V	45	m/s
51 LCSGV100	Lower Camp	Sigma V	100	m/s
52 LCSGV167	Lower Camp	Sigma V	167	m/s
53 MSGV20	Mannix	Sigma V	20	m/s
54 MSGV45	Mannix	Sigma V	45	m/s
55 MSGV75	Mannix	Sigma V	75	m/s
56 LCSGP20	Lower Camp	Sigma Phi	20	degrees
57 LCSGP45	Lower Camp	Sigma Phi	45	degrees
58 LCSGP100	Lower Camp	Sigma Phi	100	degrees
59 LCSGP167	Lower Camp	Sigma Phi	167	degrees
60 MSGP20	Mannix	Sigma Phi	20	degrees
61 MSGP45	Mannix	Sigma Phi	45	degrees
62 MSGP75	Mannix	Sigma Phi	75	degrees
63 LDTDZ45	Lower Camp	Potential Temperature Gradient	45	K/m
64 LDTDZ100	Lower Camp	Potential Temperature Gradient	100	K/m
65 LDTDZ167	Lower Camp	Potential Temperature Gradient	167	K/m

Table B.1 Concluded.

Code Name	Station	Variable Description	Monitoring Level (m)	Units
66 MDTDZ45	Mannix	Potential Temperature Gradient	45	K/m
67 MDTDZ75	Mannix	Potential Temperature Gradient	75	K/m
68 NOSTAB	Mannix	Stability Class (no day/night constraints)	20	n/a
69 STAB2	Mannix	Stability Class (with day/night constraints	20	n/a
70 MIXHGT	Mannix	Mixing Height	20	m
71 LPLE	Lower Camp	Power Law Exponent	167 to 100	n/a
72 MPLE	Mannix	Power Law Exponent	75 to 20	n/a
73 M20RGH	Mannix	Surface Roughness	20	m
74 LC20RGH	Lower Camp	Surface Roughness	20	m
75 LC45RGH	Lower Camp	Surface Roughness	45	m
76 LC100RGH	Lower Camp	Surface Roughness	100	m
77 M75RGH	Mannix	Surface Roughness	75	m
78 L	Both	Monin-Obukhov Length	20	m
79 MCORABC	Mannix	Momentum Correction Functions[(a)]	20	n/a
80 MCORD	Mannix	Momentum Correction Functions[(b)]	20	n/a
81 MCOREF	Mannix	Momentum Correction Functions[(c)]	20	n/a
82 USABC	Mannix	Friction Velocity[(a)]	20	m/s
83 USD	Mannix	Friction Velocity[(b)]	20	m/s
84 USEF	Mannix	Friction Velocity[(c)]	20	m/s
85 USTAR	Mannix	Friction Velocity[(d)]	20	m/s
86 LDTDZTOP	Mannix	Potential Temperature Gradient	167 to 100	K/m
87 MDTDZTOP	Mannix	Potential Temperature Gradient	75 to 45	K/m

(a) For unstable conditions only.
(b) For neutral conditions only.
(c) For stable conditions only.
(d) For all stability classes.

Table B.2 Meteorological files created for dispersion modelling.

File	Model	Description	Size	Date	Time
ILC167.MET	ISCST3	Based on 167 m winds from Lower Camp	728434	Dec. 7, 1995	8:20 a.m.
IMAN75.MET	ISCST3	Based on 75 m winds from Mannix	728434	Dec. 7, 1995	9:38 a.m.
RLC167.MET	RTDM32	Based on 167 m winds from Lower Camp	1194576	Dec. 7,1995	11:03 a.m.
RMAN75.MET	RTDM32	Based on 75 m winds from Mannix	1194576	Dec. 7, 1995	11:50 a.m.
L167STAR.DAT	STAR[a]	Based on 167 m winds from Lower Camp	24507	Aug. 24, 1995	1:31 p.m.
M75STAR.DAT	STAR[a]	Based on 75 m winds from Mannix	24507	Aug 24. 1995	1:11 p.m.

(a) STAR data can be used by ADEPT2 or ISCST3 models.

Table B.3 Format of hourly meteorological data required by ISCST3 model.

Variable	Format
Year (last 2 digits)	I2
Month (01 to 12)	I2
Day (01 to 31)	I2
Hour (01 to 24)	I2
Flow Vector (degrees)	F9.4
Wind Speed (m/s)	F9.4
Ambient Temperature (K)	F6.1
Stability Class (1 to 6)	I2
Rural Mixing Height	F7.1
Urban Mixing Height	F7.1
Wind Profile Exponent	F8.4
Vertical Temperature Gradient (K/m)	F8.4
Friction Velocity (m/s)	F9.4
Monin-Obukhov Length (m)	F10.1
Surface Roughness Length (m)	F8.4
Precipitation Code (00 to 45)	I4
Precipitation Rate (mm/h)	F7.2

Table B.4 Format[a] of hourly meteorological data required by RTDM32 model.

Parameter	Columns	Comments
Year	1-2	Last 2 digits (1982=82)
Julian Day	3-5	1-366
Hour	6-7	Time at end of hour (01-24)
Wind Direction	9-14	In degrees, direction from which wind is blowing
Wind Speed (#1)	15-20	Units converted to m/sec with USCALE
Mixing Height	21-26	In metres
Stability Class	27-32	Turner (1964) method recommended
Ambient Temperature	33-38	Degrees Fahrenheit
Turbulence Intensity, y-component	39-44	Convert σ_θ to radians, use T_y directly
Turbulence Intensity, z-component	45-50	convert σ_ϕ to radians, or use T_z directly
VPTG, plume rise	51-56	Use data near stack-top location and elevation, °C/m
VPTG, H_{crit}	57-62	Use data near terrain obstacle of interest, °C/m
Horizontal wind shear	63-68	Use data as close to typical plume height as possible, degrees/metre
Wind Speed Profile exponent	69-74	See subsection 2.4 of RTDM Manual
Alternate Wind Speed	75-80	Used for plume dilution, if available (in user units)

(a) Year, Julian day and hour are in fixed point format. All other variables are in floating point format.

Table B.5 Format of seasonal and annual STAR data.

Line No.	Variable	Column No.	Format
1	Header = 'STAR DATA'	1 to 10	A4
2	Subheader = 'ECHO'	11 to 20	A4
3	Subheader = 'DATA'	11 to 20	A4
	Winter Data Block - A Stability		
4	Wind Direction = N	2 to 4	A3
4	Frequency that N winds occur under A stability for each of 6 wind speed categories	8 to 14 15 to 21 22 to 28 29 to 35 36 to 42 43 to 49	F7.5 F7.5 F7.5 F7.5 F7.5 F7.5
5 to 19	Repeat line 4 for other wind directions using right justified 1 to 3 letter code to specify direction (e.g., NNE, SE, W)		
	Winter Data Blocks - B to F Stabilities		
20 to 35	Repeat lines 4 to 20 for winter data, B stability		
36 to 51	Repeat lines 4 to 20 for winter data, C stability		
52 to 67	Repeat lines 4 to 20 for winter data, D stability		
68 to 84	Repeat lines 4 to 20 for winter data, E stability		
85 to 100	Repeat lines 4 to 20 for winter data, F stability		
	Spring, Summer, Fall and Annual Blocks		
101 to 196	Repeat lines 4 to 100 for spring data		
197 to 293	Repeat lines 4 to 100 for summer data		
294 to 389	Repeat lines 4 to 100 for fall data		
390 to 485	Repeat lines 4 to 100 for annual data		

B.3 Terrain Data Files

Digital Elevation Model (DEM) files were obtained from Forestry, Lands and Wildlife, Land Information Services Division, Mapping (Edmonton, Alberta). The 1:20 000 DEM mapsheets that were obtained for the Athabasca Oil Sands area are identified in Table B.6 and Figure B.1. The 1:20 000 data were provided on a regular 50 m grid spacing. These data were supplemented with digital terrain data from Suncor and Syncrude, which were provided on a regular 25 m grid spacing.

A BOVAR Environmental custom program was used to extract the data from the Alberta DEM mapsheets to produce an "x,y,z" format where x = easting coordinate, y = northing coordinate and z = terrain elevation (m AMSL). The "x,y,z" files were then imported into the SURFER (Version 6) contouring and 3D surface mapping program (Golden Software, Golden, Colorado). The shaded relief maps, terrain contours and 3D surface maps presented in this report were prepared with SURFER.

BOVAR Environmental custom software uses the gridded SURFER files to produce receptor files required by dispersion models such as ISC3, RTDM and ADEPT2. This custom software is designed to select the "worst-case" terrain required for the models. Worst case is defined as selecting the highest elevation for the region that the receptor represents. Table B.7 presents the input (*.IN) and output (*.REC) files used to produce terrain grid for ISC3 modelling purposes. Each of the grids is represented graphically in Figure B.2.

Table B.8 presents the input (*.IN) and output (*.TER) files used to produce terrain grids for RTDM modelling purposes. Each of the grids is represented graphically in Figure B.3.

B.4 Report Files

The word processing program, WORD (Version 6) by Microsoft Corporation was used to prepare this report. The figures were prepared using a number of different graphics packages: Lotus Development Corporation's FREELANCE Graphics for Windows (Release 2.01) and Golden Software's SURFER (Version 6). Table B.9 identifies the WORD text files and Table B.10 identifies the graphics files that comprise this report.

Table B.6 Identification of DEM mapsheets used for the Athabasca oil sands area.

Map	NTS Reference	Scale
1	74 D 13 NW	1:20 000
2	74 D 13 NE	1:20 000
3	74 D 13 SE	1:20 000
4	74 D 13 SW	1:20 000
5	74 D 14 NW	1:20 000
6	74 D 14 NE	1:20 000
7	74 D 14 SE	1:20 000
8	74 D 14 SW	1:20 000
9	74 E 03 NW	1:20 000
10	74 E 03 NE	1:20 000
11	74 E 03 SE	1:20 000
12	74 E 03 SW	1:20 000
13	74 E 04 NW	1:20 000
14	74 E 04 NE	1:20 000
15	74 E 04 SE	1:20 000
16	74 E 04 SW	1:20 000
17	74 E 02 NW	1:20 000
18	74 E 05 NE	1:20 000
19	74 E 05 SE	1:20 000
20	74 E 05 SW	1:20 000
21	74 E 06 SE	1:20 000
22	74 E 06 SW	1:20 000
23	74 E 07 SW	1:20 000

NTS = National Topographic System.

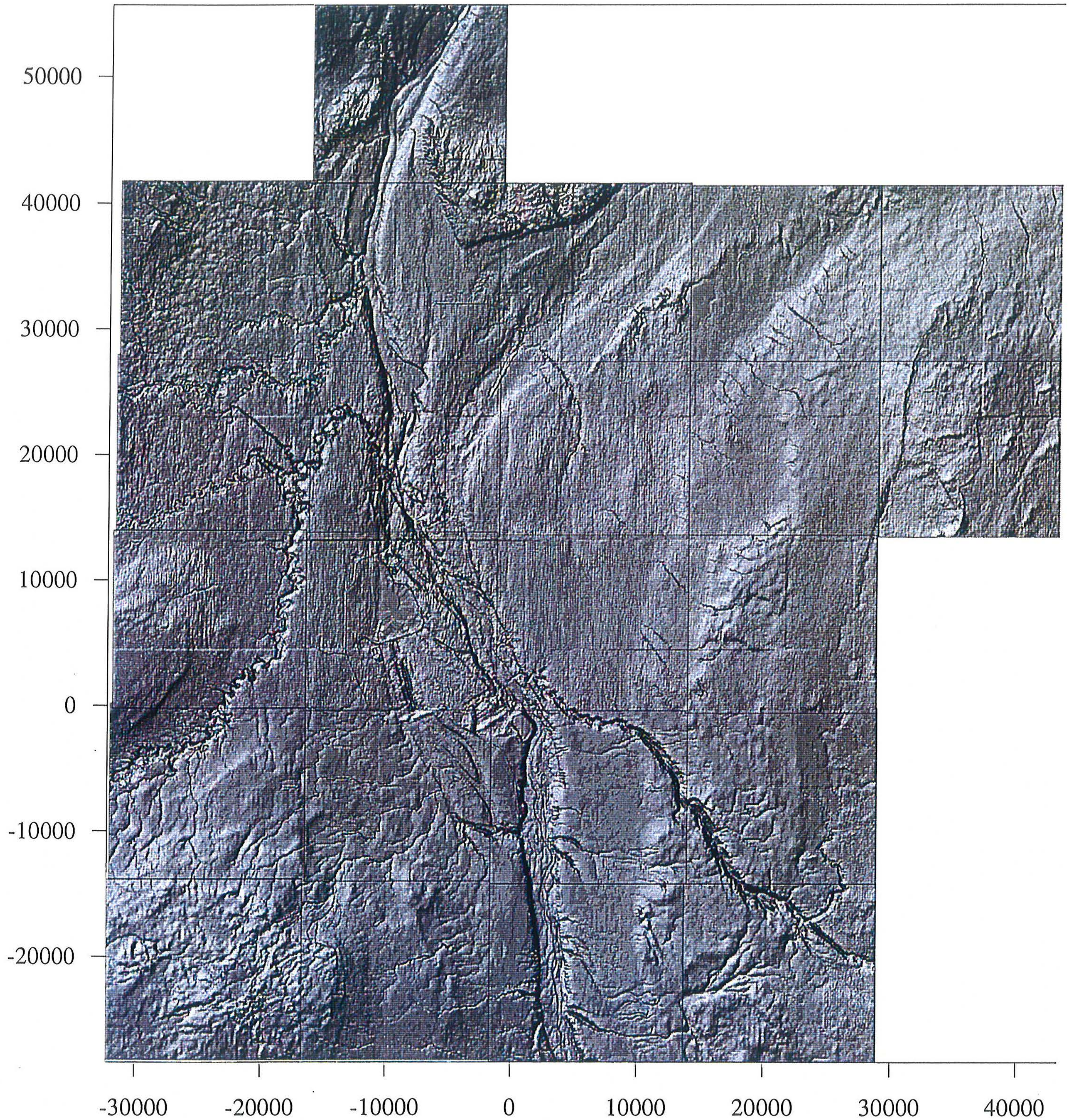

Figure B.1 Area for which digital terrain maps were available.

Table B.7 Files used to generate various terrain grids for ISC3 modelling.

File Name	File Size (Bytes)	Date	Time	Description
Input: ISC3.IN Output: SYNMAIN.REC	1998 19404	Oct. 1, 1995 Jan. 12, 1996	08:17:50 a.m. 03:32:14 p.m.	This grid file has 400 receptors which cover a 4000 m by 4000 m area, with 200 m grid spacing around the Syncrude Main Stack. The receptors are shown in bright red as a small area on Figure B.2.
Input: IS3MAIN1.IN Output: SYNMAIN1.REC	2059 15840	Jan. 12, 1996 Jan. 12, 1996	11:30:08 a.m. 03:34:06 p.m.	This grid file has 336 receptors which cover a 10 000 m by 10 000 m area, with 500 m grid spacing around the Syncrude Main Stack. No receptors are included for the area which overlaps with SYNMAIN.REC. The receptors are shown in light yellow (surrounding bright red) on Figure B.2.
Input: ISC3FGD.IN Output: SYNFGD.REC	1988 19404	Jan. 10, 1996 Jan. 12, 1996	08:20:56 a.m. 03:34:36 p.m.	This grid file has 400 receptors which cover a 4000 m by 4000 m area, with 200 m spacing around the Suncor FGD stack. The receptors are shown in bright yellow as a small area on Figure B.2.
Input: ISC3FGD1.IN Output: SYNFGD1.REC	2078 13728	Jan. 15, 1996 Jan. 15, 1996	07:22:24 a.m. 07:37:12 a.m.	This grid file has 303 receptors which cover a 10 000 m by 10 000 m area, with 500 m spacing around Suncor FGD stack. No receptors are included for the areas which overlap with SYNMAIN1.REC and SYNFGD.REC. The receptors are shown in bright green (surrounding the bright yellow) on Figure B.2.
Input: ISC3FGD2.IN Output: SYNFGD2.REC	2375 64768	Jan. 12, 1996 Jan. 12, 1996	04:48:42 p.m. 05:09:02 p.m.	This grid file has 1405 receptors which cover a 40 000 m by 40 000 m area, with 1000 m grid spacing around the Suncor FGD stack. No receptors are included for the areas which overlap with the preceding four grid files. The receptors are shown in blue on Figure B.2.

Table B.7 Concluded.

File Name	File Size (Bytes)	Date	Time	Description
Input: ISC3FGD3.IN Output: SYNFGD3.REC	2025 9152	Jan. 12, 1996 Jan. 12, 1996	03:12:26 p.m. 04:10:52 p.m.	This grid file has 192 receptors which cover an 80 000 m by 80 000 m area, with 5000 m grid spacing around the Suncor FGD Stack. No receptors are included for the areas which overlap with the preceding five grid files. The receptors are shown in dark green on Figure B.2.
Input: ISC3FGD4.IN Output: SYNFGD4.REC	2067 12320	Jan. 10, 1996 Jan. 12, 1996	10:31:26 a.m. 04:11:06 p.m.	This grid file has 260 receptors which cover a 180 000 m by 180 000 m area, with 10 000 m grid spacing around the Suncor FGD Stack. No receptors are included for the areas which overlap with the preceding six grid files. The receptors are shown in brown in Figure B.2.

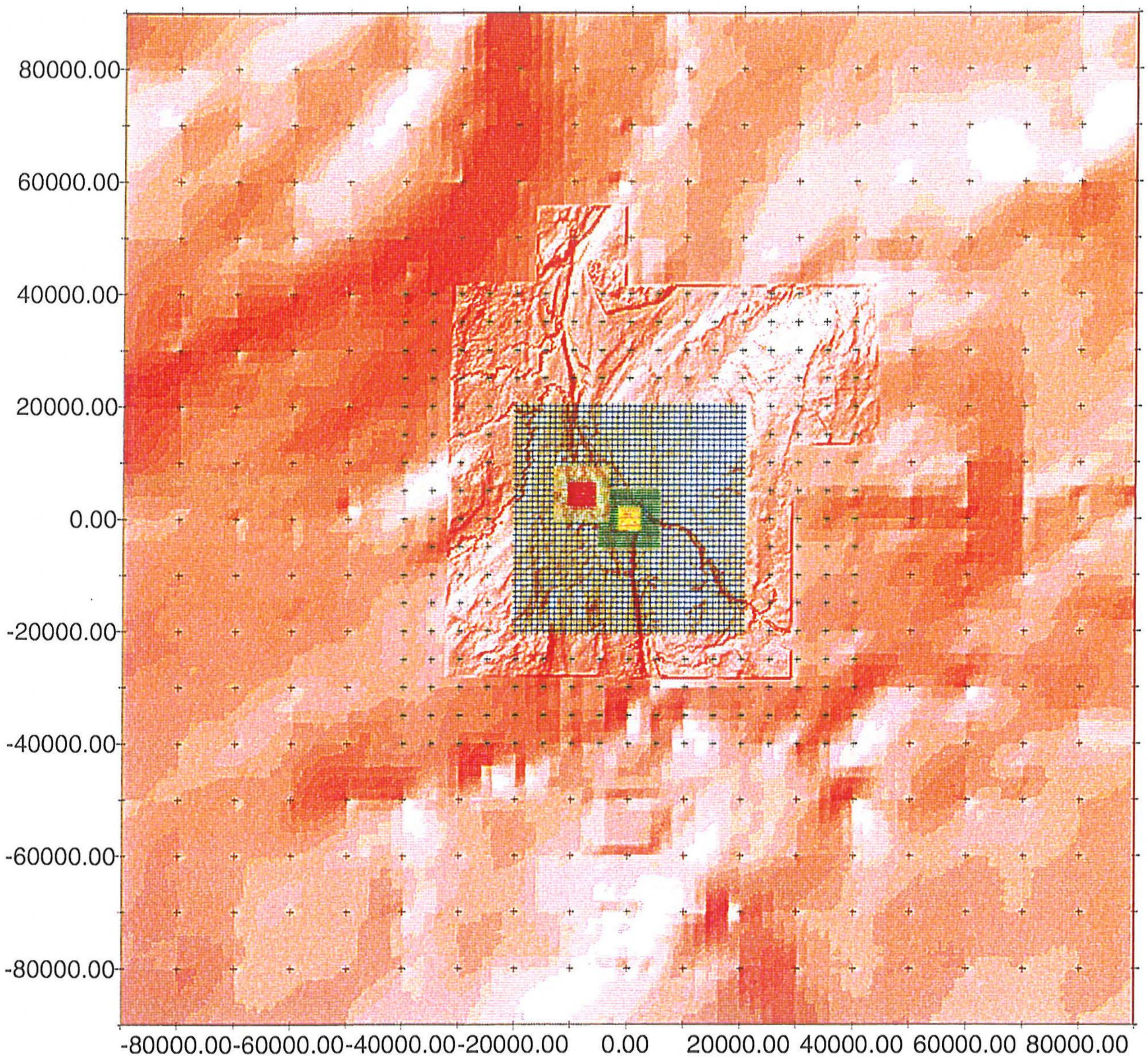

Figure B.2 Receptor grids generated for ISC3 modelling.

Table B.8 Files used to generate various terrain grids for RTDM modelling.

File Name	File Size (Bytes)	Date	Time	Description
Input: RTDMFGD1.IN Receptor: RTFGD1.REC	768 51240	Jan. 17, 1996 Feb. 6, 1996	03:16:30 p.m. 03:59:26 p.m.	This grid file has 1221 receptors which cover an area within a 10 000 m radius. The minimum distance between receptors is 1.25 km. The maximum terrain height is 360 m ASL. The grid area is shown on Figure B.3 in bright yellow.
Input: RTDMFGD2.IN Receptor: RTFGD2.REC	768 51660	Jan. 17, 1996 Feb. 6, 1996	04:03:36 p.m. 04:09:04 p.m.	This grid file has 1231 receptors which cover an area within a 30 000 m radius. The minimum distance between receptors is 3.75 km. The maximum terrain height is 555 m ASL. The grid area is shown on Figure B.3 in blue.
Input: RTDMFGD3.IN Receptor: RTFGD3.REC	782 48678	Jan. 21, 1996 Feb. 6, 1996	07:29:00 a.m. 04:14:28 p.m.	This grid file has 1160 receptors which cover an area within a 90 000 m radius. The minimum distance between receptors is 7.50 km. The maximum terrain height is 800 m ASL. The grid area is shown on Figure B.3 in red.

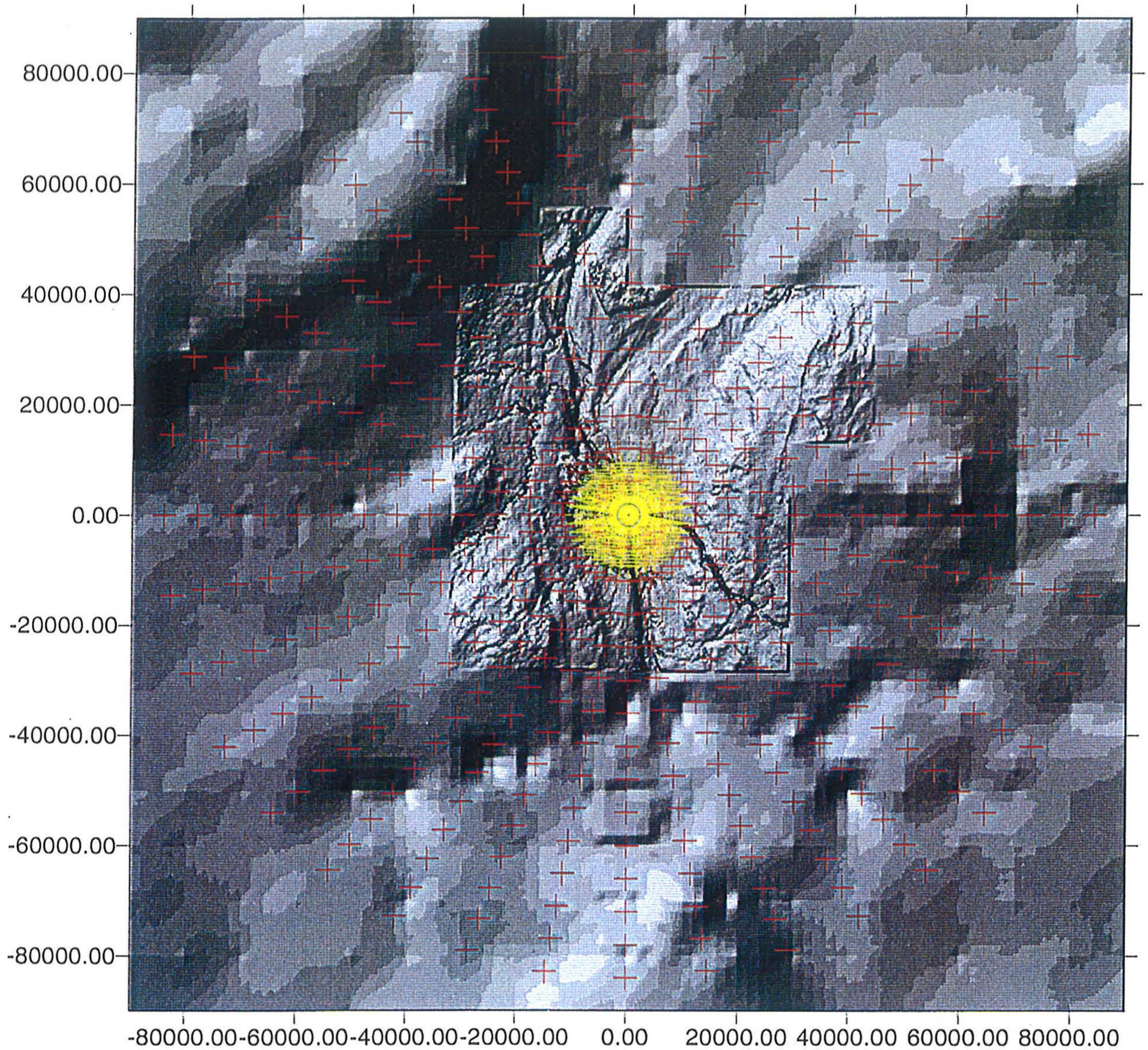

Figure B.3 Receptor grids generated for RTDM modelling.

Table B.9 Report 3 text files.

Section	File Name	File Size	Date	Time
1	sec-1.doc	47104	Feb. 14, 1996	10:48:40 a.m.
2	sec-2.doc	51200	Feb. 13, 1996	1:00:40 p.m.
3	sec-3.doc	30208	Feb. 14, 1996	10:02:52 a.m.
4	sec-4.doc	281600	Feb. 14, 1996	10:40:30 a.m.
5	sec-5.doc	69120	Feb. 14, 1996	10:00:46 a.m.
6	sec-6.doc	30208	Feb. 14, 1996	10:08:06 a.m.
7	sec-7.doc	62976	Feb. 14, 1996	11:52:08 a.m.
8	sec-8.doc	37376	Feb. 14, 1996	11:48:06 a.m.
9	sec-9.doc	43520	Feb. 14, 1996	11:36:16 p.m.
10	sec-10.doc	~22700	May 8, 1996	2:31:12 p.m.
Appendix A	app-a.doc	~ 97000	May 8, 1996	2:48:28 p.m.
Appendix B	app-b.doc	~ 79500	May 8, 1996	~ 3:30 p.m.

Table B.10 Report 3 graphics files.

Figure	Software	File	File Size	Date	Time
2.1	Freelance Graphics	MONMAP2.PRE	47904	2/14/96	10:20:32 a.m.
2.2	Hard Copy Only	Project No. 4313244	n/a	n/a	n/a
2.3	Hard Copy Only	Project No. 4313244	n/a	n/a	n/a
2.4	Freelance Graphics	TOWERS.PRE	21140	2/14/96	11:00:52 a.m.
3.1	SURFER	RELIEF.SRF	12352570	2/14/96	8:34:02 p.m.
3.2	SURFER	SUNSYN2.SRF	3121766	2/14/96	9:39:42 p.m.
3.3	SURFER	SYNC3DM1.SRF	366613	1/25/96	7:23:40 a.m.
3.4	SURFER	SUNOVLAY.SRF	205135	2/14/96	7:48:56 p.m.
4.1	Freelance Graphics	LCANNWR.PRE	23121	10/10/95	3:49:30 p.m.
4.2	Freelance Graphics	MANANNWR.PRE	20712	10/11/95	9:43:18 a.m.
4.3	Freelance Graphics	LC167SWR.PRE	22513	10/10/95	4:01:18 p.m.
4.4	Freelance Graphics	MAN75SWR.PRE	22513	10/10/95	4:05:32 p.m.
4.5	Freelance Graphics	WRALL.PRE	65104	2/12/96	5:26:50 p.m.
4.6	Freelance Graphics	LCWSHR.PRE	82539	2/9/96	12:52:00 p.m.
4.7	Freelance Graphics	MANWSHR.PRE	65209	2/9/96	12:50:22 p.m.
4.8	Freelance Graphics	LCWSMTH.PRE	81136	2/9/96	1:09:54 p.m.
4.9	Freelance Graphics	MANWSMTH.PRE	64656	2/9/96	12:50:22 p.m.
4.10	Freelance Graphics	LCWSFRE.PRE	85400	2/12/96	2:32:04 p.m.
4.11	Freelance Graphics	MANWSFRE.PRE	40889	2/9/96	4:26:20 p.m.
4.12	Freelance Graphics	-PLEFRE.PRE	32075	2/12/96	4:00:42 p.m.
4.13	Freelance Graphics	LCMPLEMR.PRE	45173	2/9/96	9:25:34 p.m.
5.1	Freelance Graphics	LSIGT.PRE	195963	2/14/96	10:25:04 a.m.
5.2	Freelance Graphics	MANSIGT.PRE	141409	2/14/96	10:31:02 a.m.
5.3	Freelance Graphics	LSIGP.PRE	190303	2/14/96	10:31:00 a.m.
5.4	Freelance Graphics	MANSIGP.PRE	136313	2/14/96	10:37:58 a.m.
5.5	Freelance Graphics	STBMANFM.PRE	53657	1/31/96	4:11:58 p.m.
5.6	Freelance Graphics	STABSTCK.PRE	295956	2/14/96	3:56:08 p.m.

Table B.10 Concluded.

Figure	Software	File	File Size	Date	Time
6.1	Freelance Graphics	TEMPALL.PRE	89895	2/12/96	8:57:24 p.m.
6.2	Freelance Graphics	LCPTG45.PRE	517753	2/12/96	11:29:28 a.m.
6.3	Freelance Graphics	LCPTG100.PRE	460288	10/19/95	9:47:22 a.m.
6.4	Freelance Graphics	LCPTG167.PRE	578992	10/19/95	9:28:28 p.m.
6.5	Freelance Graphics	MPTG45.PRE	523532	2/5/96	1:09:50 p.m.
6.6	Freelance Graphics	MPTG75.PRE	368663	2/12/96	10:30:46 a.m.
7.1	Freelance Graphics	NETRAD.PRE	263862	11/10/95	4:22:42 p.m.
7.2	Hardcopy Only	n/a	n/a	n/a	n/a
7.3	Freelance Graphics	MSEAHRHT.PRE	205310	2/13/96	9:59:18 a.m.
8.1	Freelance Graphics	RELHUM.PRE	178849	2/12/96	10:21:54 p.m.
8.2	Freelance Graphics	FMPREC.PRE	36796	2/13/96	10:40:40 a.m.
8.3	Freelance Graphics	FMMXPREC.PRE	51757	2/13/96	10:40:30 a.m.
8.4	Freelance Graphics	FMMXPREC.PRE	51757	2/13/96	10:40:30 a.m.
A.1	Freelance Graphics	WRFIGS.PRE	110079	2/14/96	11:45:34 a.m.
A.2	Freelance Graphics	WRFIGS.PRE	110079	2/14/96	11:45:34 a.m.
A.3	Freelance Graphics	WRFIGS.PRE	110079	2/14/96	11:45:34 a.m.
A.4	Freelance Graphics	WRFIGS.PRE	110079	2/14/96	11:45:34 a.m.
A.5	Freelance Graphics	WRFIGS.PRE	110079	2/14/96	11:45:34 a.m.
A.6	Freelance Graphics	WRFIGS.PRE	110079	2/14/96	11:45:34 a.m.
A.7	Freelance Graphics	WRFIGS.PRE	110079	2/14/96	11:45:34 a.m.
A.8	Freelance Graphics	WRFIGS.PRE	110079	2/14/96	11:45:34 a.m.
B.1	SURFER	RELIEF.SRF	12352618	2/14/96	12:10:40 p.m.
B.2	SURFER	SYNCGRID.SRF	1448862	2/14/96	1:29:14 p.m.
B.3	SURFER	RTD.SRF	1448330	2/14/96	12:16:02 p.m.