Ambient Air Quality 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.

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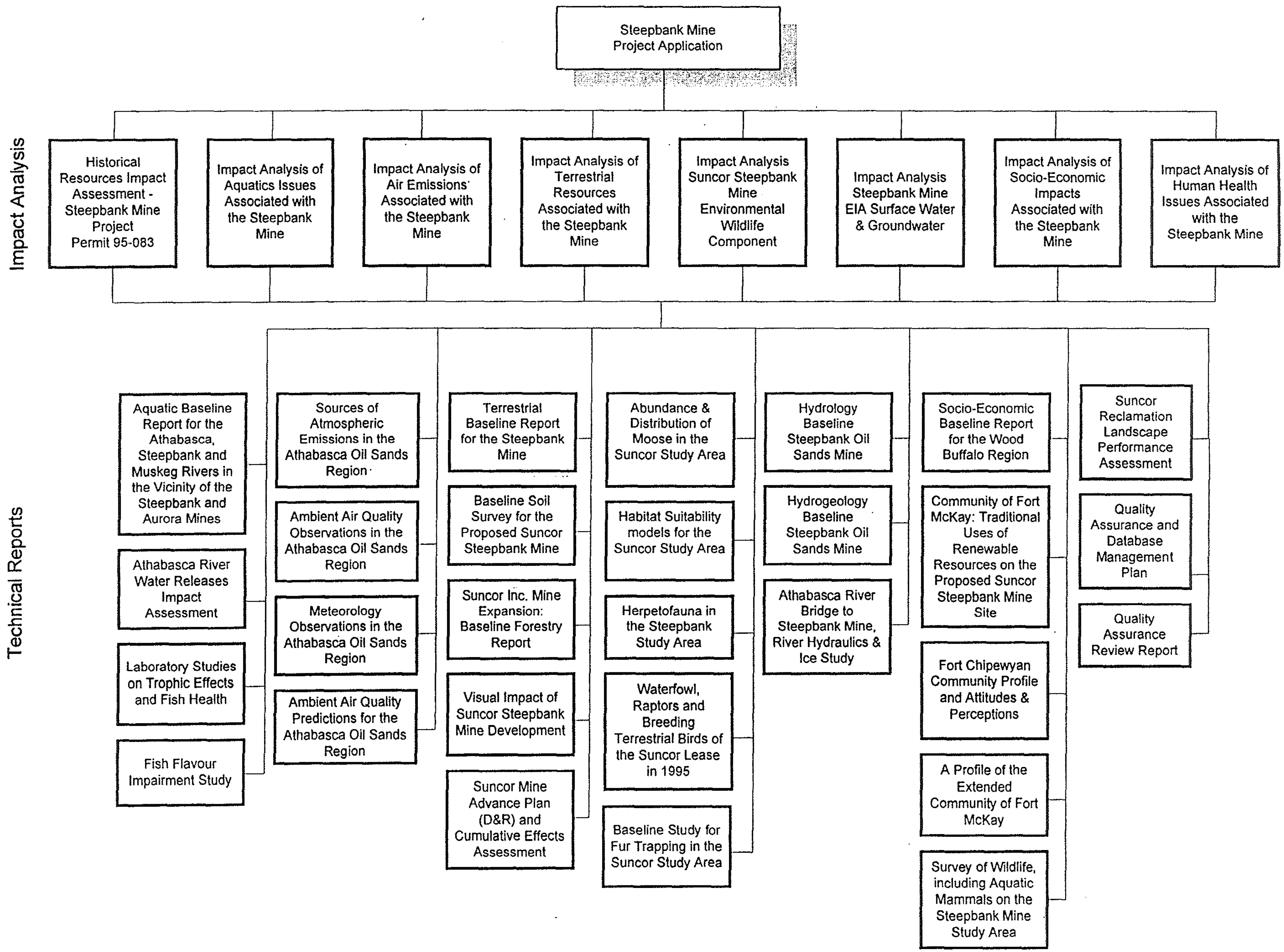

Reports Prepared for the Steepbank Mine Environmental Assessment

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AMBIENT AIR QUALITY OBSERVATIONS IN THE ATHABASCA OIL SANDS REGION

(Report 2)

Prepared for:

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

Prepared by:

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May 1996
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Attention: **Peter Koning**
New Lease Environmental Coordinator

Subject: **Air Quality Technical Report**

We are pleased to submit our report entitled *Ambient Air Quality Observations in the Athabasca Oil Sands Region.* This report summarizes ambient air quality monitoring undertaken in the Fort McMurray-Fort McKay airshed. The sources include quantitative data from Suncor, Syncrude and Alberta Environmental Protection networks as well as qualitative data associated with other monitoring programs.

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

Yours sincerely,

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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, Syncrude Canada Ltd., Alberta Environmental Protection and Environment Canada. BOVAR Environmental would like to thank the following individuals: Gordon Kemp, Rebecca Fabian and Sue Lowell from Suncor; John Ellingson and Rolf Hopkinson from Syncrude; Bob Myrick from AEP; and Mike Shaw from Environment Canada.

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 collection and analysis was carried out by Michael Brennand with support from Ivan Dorin. Report typing and formatting was provided 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 that 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 have plans 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 by atmospheric emissions associated with oil sands 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 multistakeholder 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 that 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.

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.*

- 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 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:

- **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.

- **Multistakeholder:** 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.

Multistakeholder 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*

A series of background air quality reports have been prepared for the oil sands area for the following reasons: oil sands will continue to play a significant role in Canada's energy requirements; air quality issues associated with oil sands mining, extraction and upgrading operations have a multistakeholder interest; and there have been several recent initiatives associated with addressing air quality issues in Alberta. The purpose of these reports is to provide baseline air quality information to mid 1995. The specific reports are as follows:

associated with addressing air quality issues in Alberta. The purpose of these reports is to provide baseline air quality information to mid 1995. The specific reports are as follows:

- **Report 1 Source Characterization**

  To identify and quantify anthropogenic air emissions in the Fort McMurray - Fort McKay corridor that include industrial point, fugitive, traffic and residential sources. Emissions of interest include SO_2, NO_x, CO, VOC, TRS, particulates and CO_2.

- **Report 2 Ambient Air Quality Observations**

  To summarize 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**

  To summarize the meteorological data that describe the transport, dispersion and deposition of emissions in the area. The focus is 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 modelling 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 operation in the area.

These reports serve as background reports that 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 2 (Ambient Air Quality Observations)

1.2.1 *Objectives*

The management of an airshed that is shared by multiple users requires an understanding of the air quality changes associated with the operation of emission sources. The objectives of Report 2 (Ambient Air Quality Observations) are to:

- Identify current ambient air quality monitoring programs in the Athabasca oil sands airshed.
- Summarize the current ambient air quality observations.
- Identify spatial and temporal trends and correlation with respect to meteorology.

The end-product of Report 2 is an understanding of the current air quality observed in the Athabasca oil sands airshed that can be used as a basis for further air quality assessments.

1.2.2 *Approach*

Suncor, Syncrude and Alberta Environmental Protection maintain ambient air quality monitoring programs in the oil sands region. These monitoring programs are comprised of both continuous and passive monitoring. The selected approach was based on reviewing the data collected by these programs for the 5-½ year period starting January 1, 1990 and finishing June 30, 1995. These data are supplemented by additional programs that were of limited duration. The report concludes by providing a summary and providing 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 ambient air quality that are used in the report.

1.2.4 *Report Organization*

Section 2 provide an overview of the current ambient air quality monitoring conducted in the region by Suncor, Syncrude and AEP. This is followed by a review of ambient air quality guidelines. The subsequent sections summarize the observations on a contaminant-by-contaminant basis:

Section	Contaminant
4	Sulphur dioxide (SO_2)
5	Hydrogen sulphide (H_2S)
6	Oxides of nitrogen (NO_x)
7	Ozone (O_3)
8	Carbon monoxide (CO)
9	Hydrocarbon (HC)
10	Particulate
11	Passive monitoring
12	Precipitation chemistry

Table 1.2 Definition of commonly used terms.

Term	Definition
Air Quality	A description of the type and amount of trace constituents in the ambient air that can be described as a contaminant. A contaminant (or pollutant) has the connotation of being derived from human activities.
Ambient Air	Ambient air refers to that portion of the atmosphere that can be described as the breathing zone for the inhabitants of the earth's surface. Contaminants contained in the ambient air are of concern because of their potential effects on human health, vegetation and materials. Ambient air does not usually include air quality in the workplace or in residences.
Ambient Air Quality Guidelines	An ambient air quality guideline is a numerical concentration intended to prevent deterioration of air quality. A guideline is generally based on the lowest-observable-effect on a sensitive receptor.
Airshed	A geographical region that shares one or more of the following: similar terrain, similar meteorology, similar sources, similar receptors. For the purposes of this report, the Athabasca oil sands region airshed was arbitrarily selected as the area located within 60 km of the Suncor and Syncrude oil sands operations. This airshed will likely be redefined by RAQCC.
Concentration	The amount of a given component of the atmosphere is usually expressed as a concentration on a volume basis as percent (%), parts per million (ppm) or parts per billion (ppb) or on a mass basis as micrograms per cubic metre of air ($\mu g/m^3$) or milligrams per cubic metre of air (mg/m^3).
Receptor	A biological or physical entity that is exposed to air emissions. Vegetation and humans are examples of biological receptors. Soils and water are examples of physical receptors.
Continuous Monitoring	A continuous monitoring station is comprised of commercially available analyzers enclosed in a heated/air conditioned shelter. An ambient air stream is drawn past a fast response detector whose electrical response is proportional to the concentration of a selected contaminant in the gas stream. The continuous concentration information is summarized as one-hour averages.

Table 1.2 Concluded.

Term	Definition
Passive Monitoring	A passive monitoring station is comprised of a reactive surface that is exposed to the ambient air for a nominal 30 day period. At the conclusion of the exposure period, the reactive material is analyzed to provide a measure of exposure.
Deposition	The contaminant removal rate from the atmosphere and precipitation chemistry relate to the long-term deposition of contaminants and potential acidifying effects (that is "acid rain") on surface water and soil systems. The sum of dry and wet deposition provides the cumulative loading to an ecosystem.
Dry Deposition	Contaminants can be removed from the atmosphere by direct contact with surface features (such as vegetation). This process is referred to as dry deposition and is usually expressed as a flux in units of kg/ha/a (kilograms of contaminant per hectare of land surface area per year (annum)).
Wet Deposition	Contaminants can also be removed from the atmosphere by precipitation. The precipitation chemistry is defined by the concentrations of various chemical species in the precipitation. These chemical species can result from naturally occurring particulate and gaseous compounds as well as from pollutant emissions. Wet deposition is expressed in the same units as dry deposition.
Precipitation Chemistry	Trace gases and particulates in the atmosphere can be dissolved in water droplets that ultimately form precipitation. The composition of the precipitation will be comprised of positively charged compounds (anions) and negatively charged compounds (cations).

Special monitoring studies of limited duration that have been conducted in the area are discussed in Section 13. This is followed by Section 14 that provides a summary and recommendations and by Section 15 that identifies the references listed in this report. The documentation of all computer files used for the analysis of the air quality data is discussed in the Appendix.

2.0 OVERVIEW OF MONITORING PROGRAMS

Ambient air quality monitoring in the region is comprised of continuous monitoring, passive monitoring, regional precipitation monitoring and specialized studies.

2.1 Continuous Monitoring

A considerable amount of monitoring activity has been undertaken in the oil sands area. Some of these monitoring sites are shown in Figure 2.1 and the programs include the following:

- Suncor has conducted continuous ambient air quality monitoring in the vicinity of their plant since 1975. They currently have five stations where they measure SO_2 (all five stations), H_2S (all five stations) and total hydrocarbons (THC) (four stations).

- Syncrude has conducted continuous ambient air quality monitoring in the vicinity of their plant since 1979. They currently have five stations where they measure SO_2 (all five stations), H_2S (all five stations), NO_x (one station) and THC (two stations).

- Alberta Environmental Protection has monitored ambient air quality at stations in Fort McMurray and Fort McKay since 1977 and 1983, respectively. Both stations measure H_2S, SO_2 and THC. The Fort McMurray station also measures NO_x, O_3 and CO.

- AOSERP established two ambient air quality monitoring stations at Birch Mountain and Bitumount in 1977. The Birch Mountain station measured SO_2 and O_3 and the Bitumount station measured O_3, SO_2, NO_2, CO, HC and H_2S. Both stations were shut down in 1980 (Strosher 1981).

- Ambient monitoring at the SandAlta lease has been undertaken by Gulf Canada Resources Ltd. and Alberta Environment. The monitoring undertaken by Gulf was from the period April 1981 to February 1982. The Alberta Environment monitoring period started May 1983 and continued until March 1986 (Morrow and Murray 1982, Murray 1984 and Hansen 1985, 1986).

- OSLO established an air quality monitoring program in March 1988 to collect air quality data at their proposed oil sands site. The program was completed in December 1989 (Concord Environmental Corporation 1990).

This assessment, however, will only focus on current programs (i.e., Suncor, Syncrude and Alberta Environmental Protection). Table 2.1 summarizes the periods that the Suncor, Syncrude and Alberta Environmental Protection monitoring stations have been in operation. The Suncor stations are identified by both a site name as well as a numerical designation, whereas the

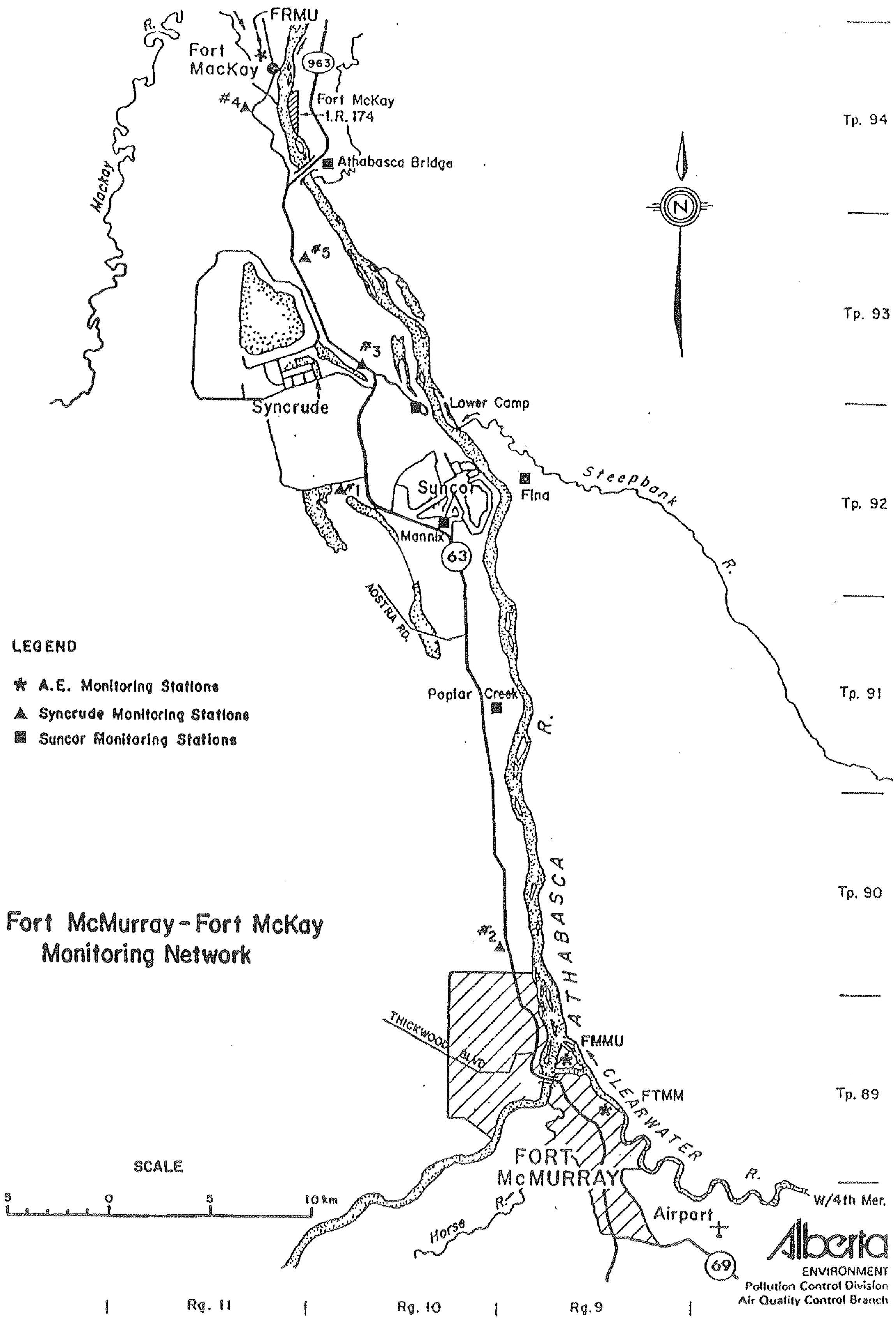


Figure 2.1 Fort McMurray - Fort McKay Monitoring Network.

Table 2.1 Continuous Ambient Air Quality Monitoring Programs operated by Suncor, Syncrude and Alberta Environmental Protection.

Operation Station / Site		Period
Suncor (■)		
Supertest Hill[a] (#1)		1975 to July 1990
Mannix (#2)		1975 to date
Ruth Lake[b] (#3)		1975 to October 1990
Lower Camp (#4)		1975 to date
Fina Airstrip (#5)		1975 to date
Poplar Creek[a] (#9)		July 1990 to date
Athabasca Bridge[b] (#10)		October 1991 to date
Syncrude (▲)		
AQS1	• South of Mine	1979 to July 1993
	• Moved 800 m West	July 1993 to date
AQS2	• Northwest of Tailings Pond	1979 to November 1990
	• Moved to Fort McMurray	November 1990 to date
AQS3	• Mildred Lake Airstrip	1979 to date
AQS4	• North of Tailings Pond	1979 to date
AQS5	• East of Tailings Pond	1979 to date
Alberta Environmental Protection (*)		
FMMU	Fort McMurray	1977 to date
FRMU	Fort McKay	1983 to date

(a) The Supertest trailer was moved to Poplar Creek in July 1990.
(b) The Ruth Lake trailer was moved to Athabasca Bridge in October 1991.

Syncrude stations are identified by a numerical designation. Both operators have relocated stations in the past 5 years as part of their network review with respect to current needs.

Table 2.2 summarizes the parameters that are currently being monitored at each station. The core parameters at each station include the contaminants SO_2 and H_2S and the meteorological parameters wind speed and wind direction. Selected stations also monitor NO_x (NO and NO_2), O_3, THC and CO.

Table 2.3 summarizes the locations of the current monitoring stations with respect to the powerhouse stack at Suncor and the main stack at Syncrude. Due to the valley location of the Suncor facility, many of the monitoring sites are located at higher elevations than those associated with the Suncor plant site.

2.2 Passive Monitoring

Suncor, Syncrude and AEP all maintain passive monitoring sites in the region for the purposes of measuring total sulphation and hydrogen sulphide. In 1991, Syncrude applied for and received permission to reduce their number of static monitoring stations from 40 to 30. The following outlines the number of passive stations in the area in 1994:

Operator:	Suncor	Syncrude	AEP
Number of Stations	40	30	6
Total Sulphation	Yes	Yes	Yes
H_2S	Yes	Yes	Yes

Figure 2.2 shows the locations of the passive sites. These sites are biased by the accessibility which is defined by the north-south road corridors. In areas to the east and to the west of the valley axis, the spatial distribution is very limited.

2.3 Precipitation Quality

Precipitation quality is measured at several locations in northern Alberta and Saskatchewan (Figure 2.3). The following table identifies these stations and their associated locations with respect to the Athabasca oil sands region of Alberta:

Table 2.2 Summary of parameters currently monitored on a continuous basis.

Operation	Station	U	θ	SO_2	H_2S	NO_x	THC	O_3	CO
Suncor	Mannix (#2)	✓	✓	✓	✓	×	✓	×	×
	Lower Camp (#4)	✓	✓	✓	✓	×	✓	×	×
	Fina Airstrip (#5)	✓	✓	✓	✓	×	×	×	×
	Poplar Creek (#9)	✓	✓	✓	✓	×	✓	×	×
	Athabasca Bridge (#10)	✓	✓	✓	✓	×	✓	×	×
Syncrude	AQS1 (Mine South)	✓	✓	✓	✓	×	×	×	×
	AQS2 (Fort McMurray)	✓	✓	✓	✓	×	✓	×	×
	AQS3 (Mildred Lake)	✓	✓	✓	✓	×	×	×	×
	AQS4 (Tailings North)	✓	✓	✓	✓	✓	✓	×	×
	AQS5 (Tailings East)	✓	✓	✓	✓	×	×	×	×
Alberta Environmental Protection	FMMU (Fort McMurray)	✓	✓	✓	✓	✓	✓	✓	✓
	FRMU (Fort McKay)	✓	✓	✓	✓	×	✓	×	×

✓ = currently being monitored
× = not being monitored
U = wind speed
θ = wind direction
SO_2 = sulphur dioxide
H_2S = hydrogen sulphide
NO_x = oxides of nitrogen
THC = total hydrocarbons
O_3 = ozone
CO = carbon monoxide

Table 2.3 Location of the ambient air quality monitoring stations with respect to the Syncrude main stack and the Suncor powerhouse stack.

Station	Syncrude				Suncor			
	Distance[a] (km)	Elevation Difference (m)	Direction[a]	Wind[b] (degrees)	Distance[a] (km)	Elevation Difference (m)	Direction[a]	Wind[b] (degrees)
Suncor								
Mannix	11.5	31	SE	314	3.8	76	S	7
Lower Camp	6.9	-60	E	278	3.8	-15	NNW	152
Fina	13.1	28	ESE	292	3.5	73	E	280
Poplar Creek	19.4	-55	SE	326	12	-10	S	353
Athabasca Bridge	11.3	-62	S	188	17	-17	SE	158
Syncrude								
AQS1 (Mine South)	5.5	2	SE	345	7.5	47	W	83
AQS2 (Fort McMurray)	29.0	35	SSE	335	22.0	80	S	355
AQS3 (Mildred Lake)	3.5	15	ENE	288	7.5	60	NW	135
AQS4 (Tailings North)	12.4	-39	N	175	19.3	6	NNW	150
AQS5 (Tailings East)	7.0	-30	N	179	14.3	15	NW	142
Alberta Environmental Protection								
Fort McMurray	42.9	-50	SSE	336	35.9	-5	SSE	346
Fort McKay	16.0	-60	N	178	22.3	-15	NNW	156

[a] Distances and directions with respect to powerhouse stack at Suncor and main stack at Syncrude.
[b] Wind direction required to advect plume from stack to the station.

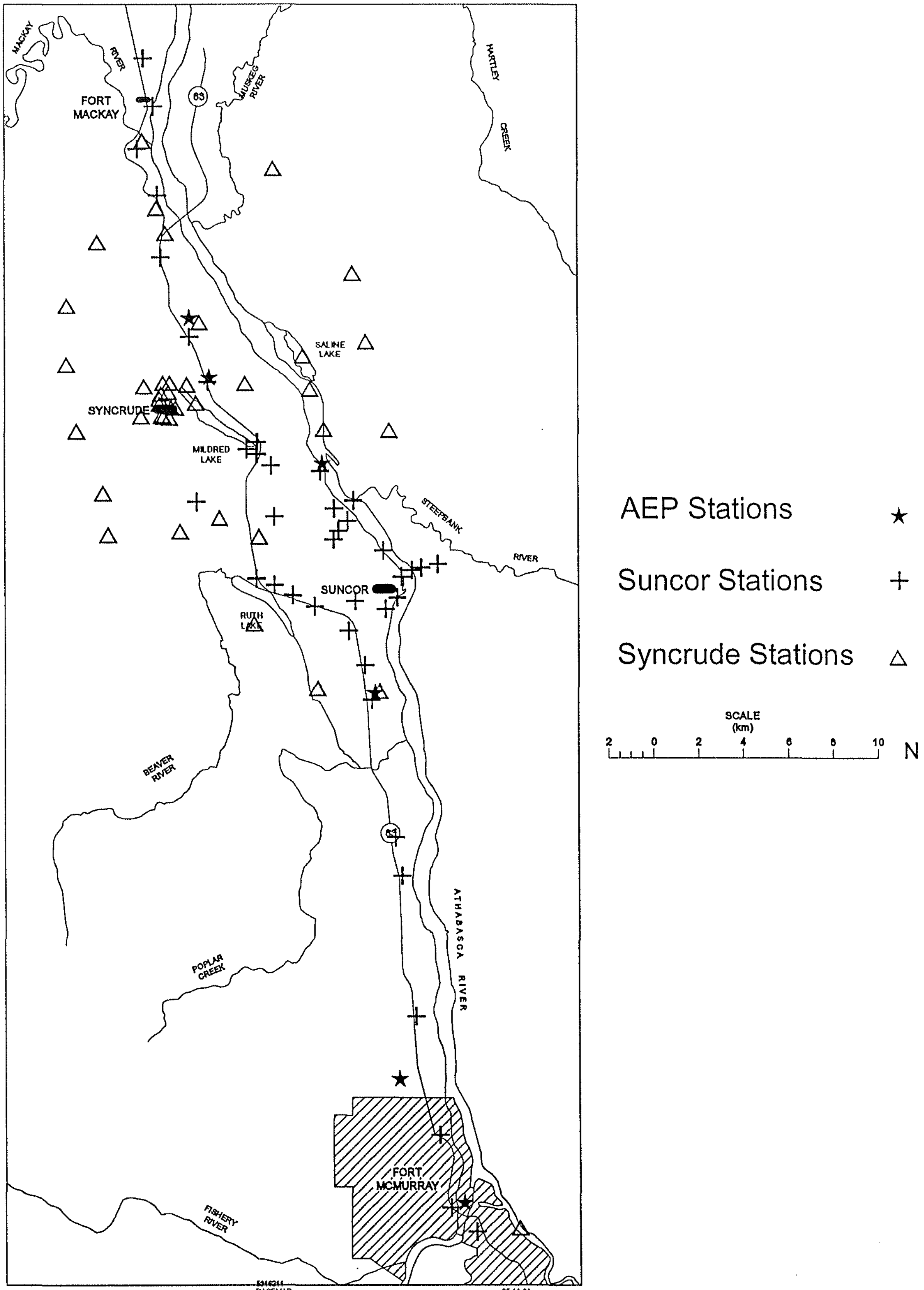


Figure 2.2 Location of the Suncor, Syncrude and Alberta Environmental Protection passive monitoring stations.

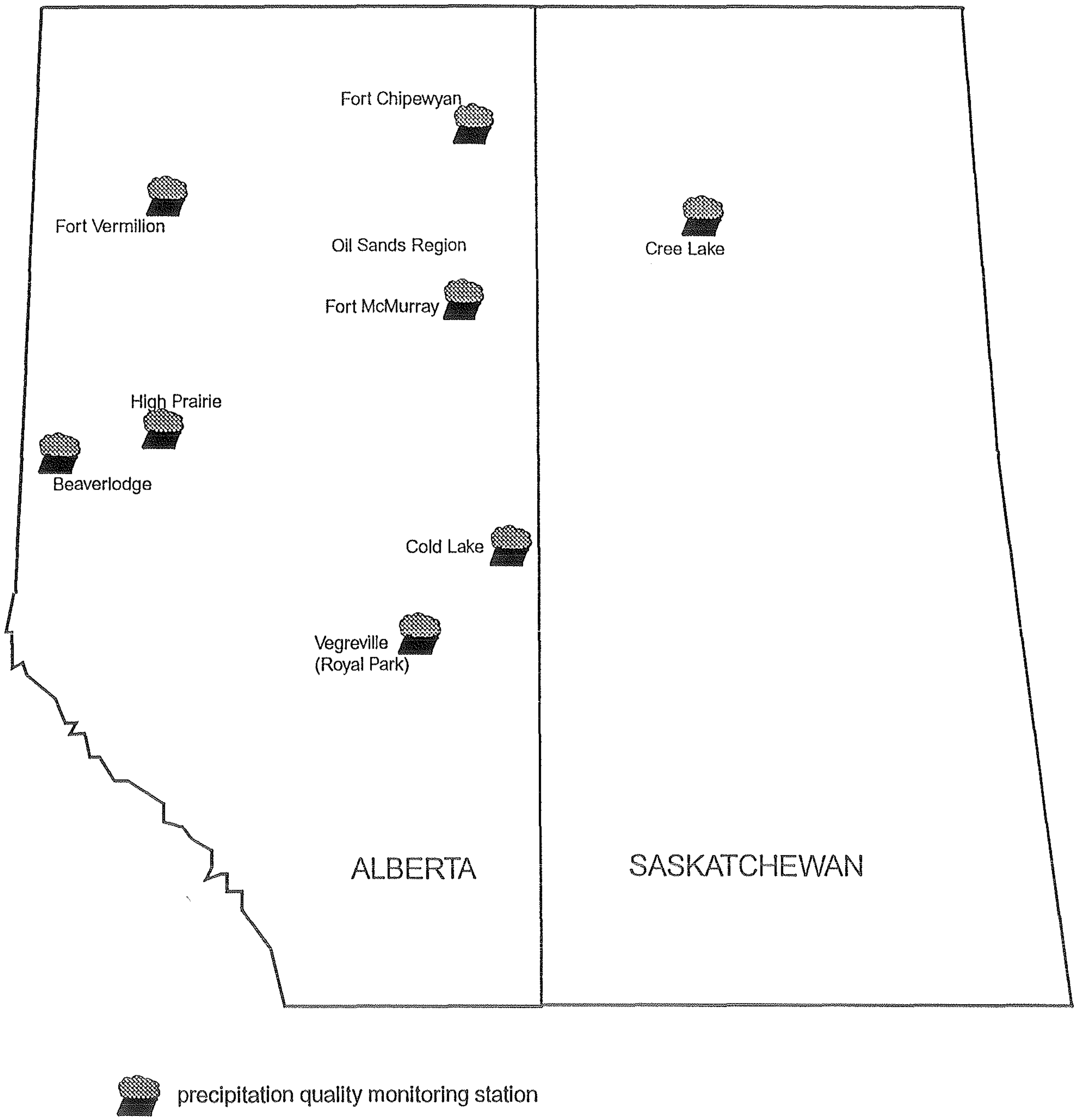


Figure 2.3 Location of precipitation quality monitoring stations in northern Alberta and Saskatchewan.

Location	Distance (km)	Direction degrees / sector	
Fort McMurray	36	166°	SSE
Fort Chipewyan	190	5°	N
Fort Vermilion	310	302°	WNW
High Prairie	360	242°	SW
Beaver Lodge	530	250°	SW
Cold Lake	300	162°	SSE
Vegreville	395	186°	S
Cree Lake	285	74°	ENE

All the stations except for Cree Lake are located in Alberta and operated by Alberta Environmental Protection. The Cree Lake station is located in Saskatchewan and is operated by Environment Canada.

Precipitation and snow pack samples were collected in the oil sands area during the period 1976 to 1984. These data have been critically reviewed by Davis *et al.* (1985). The efforts associated with this precipitation and snow pack sampling have been discontinued. The only sites with ongoing sampling in the region are the stations operated by Alberta Environmental Protection.

2.4 Specialized Studies

In addition to routine ambient air quality studies, a number of short-term specialized studies have been undertaken to characterize the air quality in the region. These include:

- A second ambient air quality station in Fort McMurray. This station was operated by AEP for the period October 1, 1991 to June 30, 1992.
- Measurements of ambient hydrocarbon (HC) and reduced sulphur (TRS) species compounds in the vicinity of the Suncor and Syncrude plants.
- Odour assessments associated with the operation of the Suncor plant.
- Qualitative odour assessments that have become a part of the operational procedures by RAQCC to identify odour events, track the sources and ensure follow-up corrective actions have taken place.

- Measurement of deposition through the use of throughfall and stemflow measurements of precipitation in the period 1975 to 1978.

While these specialized studies do not have the same continuity as the ongoing monitoring programs, they do provide period "snapshots" that enhance our understanding of regional air quality.

3.0 AIR QUALITY GUIDELINES

3.1 Ambient Concentrations

The impact of air contaminants introduced into the atmosphere by industrial activities can be broad. In humans, these contaminants can be directly inhaled and in the extreme, produce adverse health consequences. Furthermore, the contaminants can also have direct and indirect effects on animals, vegetation, soil, water and visibility. It is for this reason that environmental regulatory agencies have established maximum concentration limits in the atmosphere.

Table 3.1 presents the Alberta Provincial guidelines and the Canadian Federal Government air quality objectives for regulated contaminants. The contaminants include: sulphur dioxide (SO_2), hydrogen sulphide (H_2S), nitrogen dioxide (NO_2), carbon monoxide (CO), oxidants expressed as ozone (O_3) and suspended particulates. These guidelines and objectives refer to averaging periods ranging from one hour to one year. In addition, the Federal Government has established three levels of objectives (Environment Canada 1981). The levels are as follows:

- "The maximum **desirable** level defines the long-term goal for air quality and provides a basis for an anti-degradation policy for the unpolluted parts of the country and for the continuing development of control technology."
- "The maximum **acceptable** level is intended to provide adequate protection against adverse effects on soil, water, vegetation, materials, animals, visibility, personal comfort and well-being."
- "The maximum **tolerable** level denotes a concentration of an air contaminant that requires abatement without delay to avoid further deterioration to an air quality that endangers the prevailing Canadian life-style or ultimately, to an air quality that poses a substantial risk to public health."

In Alberta, the maximum concentrations of certain pollutants in ambient air are currently specified as guidelines. These pollutants include: SO_2, H_2S, NO_2, CO, oxidants expressed as O_3 and suspended particulates (Government of Alberta 1993).

With the exception of oxidants and the proposed Federal one-hour average objective for H_2S, the Alberta Environment guidelines are equal to the most stringent of the Federal objectives. The Alberta guidelines for oxidants are less strict when compared to the Federal Air Quality objectives since rural ozone concentrations in Alberta have been observed to exceed the Federal Desirable Level (Angle and Sandhu 1986, 1989).

Table 3.1 Maximum Permissible Levels[a] for the Province of Alberta Guidelines and Federal Air Quality Objectives.

	Alberta Guidelines		Federal Objectives		
			Desirable	Acceptable	Tolerable
SO_2 (µg/m³)					
Annual	30	(0.01 ppm)	30	60	n/a[b]
24-Hour	150	(0.06 ppm)	150	300	800
1-Hour	450	(0.17 ppm)	450	900	n/a
H_2S (µg/m³)					
24-Hour	4	(3 ppb)	n/a	5[c]	n/a
1-Hour	14	(10 ppb)	1[c]	15[c]	n/a
NO_2 (µg/m³)					
Annual	60	(0.03 ppm)	60	100	n/a
24-Hour	200	(0.11 ppm)	n/a	200	300
1-Hour	400	(0.21 ppm)	n/a	400	1000
CO (mg/m³)					
8-Hour	6	(5 ppm)	6	15	20
1-Hour	15	(13 ppm)	15	35	n/a
Oxidants (µg/m³)[d]					
Annual	n/a		n/a	30	n/a
24-Hour	50	(25 ppb)	30	50	n/a
1-Hour	160	(80 ppb)	100	160	300
Suspended Particulates (µg/m³)					
Annual[e]	60	(n/a)	60	70	n/a
24-Hour	100	(n/a)	n/a	120	400

(a) At a temperature and pressure of 25°C and 101.3 kPa, respectively.
(b) n/a = not applicable.
(c) Proposed.
(d) As ozone (O_3).
(e) As a geometric mean.

The World Health Organization (WHO) (1987) conducted a critical literature review to recommend air quality standards which could be applied to the European community. Their review focussed on the most recent scientific knowledge and the effects on human health and vegetation. The results of the WHO review are presented below for SO_2, H_2S, NO_2, CO, O_3 and total suspended particulates.

3.1.1 *Sulphur Dioxide (SO_2)*

The lowest-observed-effect level of a **human health** concern is 0.38 ppm as a 10-minute average. The WHO recommended guideline for SO_2 is 0.19 ppm as a 10-minute average, which provides a safety factor of two. The 0.19 ppm value as a 10-minute average corresponds to a calculated value of 0.13 ppm as a one-hour average. This guideline is more stringent than those proposed by our Federal and Provincial governments (0.17 ppm).

The WHO guidelines for protection of **forests** are based on the International Union of Forest Research Organizations (IUFRO) which developed two sets of criteria: one for areas where forest growth is poor due to environment stress and the second for areas with more equable or uniform growing conditions. For areas where forest growth is poor, the criteria are:

- Maximum annual average concentration of 0.009 ppm.
- The 24-hour average concentration should not exceed 0.019 ppm more than 12 times in six months.
- 97.5% of the 30-minute average growing season values should be less than 0.029 ppm. The 0.029 ppm value is equivalent to 0.025 ppm as a one-hour average concentration.

For conditions with more equable growing conditions, the recommended criteria are:

- Maximum annual average concentration of 0.019 ppm.
- The 24-hour average concentration should not exceed 0.038 ppm more than 12 times in six months.
- 97.5% of the 30-minute average growing season values should be less than 0.057 ppm. The 0.057 ppm value is equivalent to 0.050 ppm as a one-hour average concentration.

The WHO report concludes that these recommended values "are sufficient to protect forest trees". The WHO recommended guidelines for **vegetation** in general are summarized as:

- Maximum annual average SO_2 concentration of 0.011 ppm.
- Maximum 24-hour average SO_2 concentration of 0.038 ppm.

The annual average value is the same as that specified by Alberta Environment. The 24-hourly value is more stringent than the corresponding Alberta guideline of 0.06 ppm.

3.1.2 *Hydrogen Sulphide (H_2S)*

The lowest-adverse-effect level is 10 700 ppb (1.07%), which is when eye irritation is caused. The recommended health guideline for H_2S is 107 ppb, with an averaging time of 24 hours. In order to avoid odour complaints, however, the recommended guideline is decreased to 5 ppb as a 30-minute average. This latter value is more stringent than the Alberta one-hour guideline of 10 ppb.

3.1.3 *Nitrogen Dioxide (NO_2)*

The WHO recommends NO_2 guidelines of 0.21 ppm and of 0.08 ppm as one-hour and 24-hour averages, respectively. The one-hour value is based on the lowest-observed-effect level in asthmatics of 0.29 ppm. The 24-hour value was selected to create a margin of protection against chronic effects. The WHO 24-hour average guideline (0.08 ppm) is more stringent than that proposed by Alberta (0.11 ppm).

For vegetation, if the annual average SO_2 and ozone (O_3) concentrations are less than 0.01 ppm and 36 ppb respectively, then the recommended guideline for NO_2 is 0.015 ppm as an annual average. This value is selected to protect sensitive vegetation from the direct effects of NO_2. To protect vegetation against peak NO_2 concentrations, WHO recommended that NO_2 concentrations should not exceed 0.05 ppm as a 4-hour average concentration (in the presence of similar concentrations of SO_2). These values are more stringent than those recommended for Alberta.

3.1.4 *Carbon Monoxide (CO)*

The WHO recommendations for carbon monoxide (CO) are designed to protect non-smokers and are as follows:

- 87 ppm as a 15-minute average.
- 52 ppm as a 30-minute average.
- 26 ppm as a 1-hour average.
- 8.7 ppm as an 8-hour average.

The Alberta values of 13 ppm as a 1-hour average and 5 ppm as an 8-hour average are more stringent than the WHO recommendations.

3.1.5 *Particulates*

The effect of particulates on human health depends on the size range of the particulates:

- Total suspended particulates (TSP) includes all particulates that are suspended in the ambient air. These particulates can be as large as 30 μm in diameter. Larger particulates introduced into the air settle out quickly due to gravitational effects.

- Particulates smaller than 10 μm in diameter (PM_{10}) are readily inhaled into the upper respiratory tract.

- Particulates smaller than 2.5 μm in diameter ($PM_{2.5}$) can be inhaled deeply into pulmonary tissue.

In recognition of the greater sensitivity to smaller particles, air quality guidelines for particulates are being expressed in terms of PM_{10}. While Alberta has not adopted PM_{10} guidelines, B.C. has an interim PM_{10} guideline of 50 $\mu g/m^3$ which is based on the 24-hour objective adopted by California. The California objective recognizes that the U.S. National Primary Objective of 150 $\mu g/m^3$ may not be sufficient to protect human health. Most of the recent scientific literature relating to PM_{10} effects on human health was published after the WHO report.

3.1.6 *Ozone (O_3)*

Ozone is not directly emitted from industrial sources. Ozone is a strong oxidizing agent and can occur in the troposphere due to chemical reactions with oxides of nitrogen and hydrocarbons. The WHO recommended guidelines to prevent adverse human health effects are as follows:

- 75 to 100 ppb as a one-hour average.
- 50 to 60 ppb as an 8-hour average.

The recommended guidelines to prevent adverse effects on vegetation are as follows:

- 100 ppb as a one-hour average.
- 33 ppb as a 24-hour average.
- 30 ppb as a 100-day average (over a growing season).

These values are similar to those proposed for Alberta.

3.1.7 *Summary*

In summary, when comparing the WHO guideline values to those in Table 3.1, it can be seen that for some compounds (SO_2, H_2S and NO_2), the Alberta values are less stringent than the WHO values while for other compounds (CO), the Alberta values are more stringent. Both the Alberta and WHO guidelines fail to recognize PM_{10}. The WHO guidelines for vegetation reflect growing season averaging periods.

3.2 Deposition

Deposition includes both wet and dry processes and reflects the long-term accumulation of contaminants in aquatic and terrestrial ecosystems. Deposition of sulphur and nitrogen compounds to these systems has been associated with a change in water and soil chemistry and with the acidification of water and soil.

There are currently no limits on the rates of deposition for the Province of Alberta. Studies have been undertaken to define target loadings which can be used as part of an air quality management program.

3.2.1 *Total Sulphate Deposition*

The United States-Canada Memorandum of Intent (MOI) assessment document (1983) specifies a target loading value for wet sulphate deposition of 20 kg/ha/a to protect sensitive aquatic systems. This target loading concept is based on the following:

- Sulphuric acid is the dominant compound contributing to long-term water acidification.

- The sulphate ion (SO_4^{-2}) is a reasonably good surrogate for hydrogen (H^+) ion deposition. The latter results in the acidification.

- Sensitive aquatic systems are defined as those with a surface alkalinity of less than 200 µeq/L.

- For systems with a surface alkalinity greater than 200 µeq/L, higher loading rates were deemed to be acceptable.

The validity of extrapolating this target value to Western Canada has been questioned (Marmorek *et al.* 1986, Singleton *et al.* 1988, Interim Acid Deposition Critical Loadings Task Group 1990, Alberta Environment 1990). In Alberta and the rest of the Prairie Provinces, there is strong evidence to show that wet deposition is not correlated with SO_4^{-2}. If wet sulphate were acting as a good surrogate for H^+, then there would be a strong positive correlation between the two variables and a strong negative correlation between SO_4^{-2} and the pH (acidity) of precipitation (Summers 1986). In Western Canada, the very poor correlation that exists between SO_4^{-2} and H^+, and the much better correlation that exists between SO_4^{-2} and cations such as calcium (Ca^{+2}), magnesium (Mg^{+2}) and ammonium (NH_4^+), lead to the conclusion that windblown calcareous dust and SO_4^{-2} from other sources (e.g., soils) have altered the chemistry of the precipitation.

3.2.2 *Acidifying Potential (AP)*

The Interim Acid Deposition Critical Loadings Task Group (1990) defines an interim target loading based on wet deposition only. The target loading is expressed as an Acidifying Potential (AP) which is defined as:

$$AP = SO_4^{-2} - (Ca^{+2} + Mg^{+2})$$

where the individual components can be expressed in units of kmol H^+/ha/a. The committee recommended an interim critical range of 0.12 to 0.31 kmol H^+/ha/a to protect highly sensitive ecosystems. It appears that this interim range is based on protecting sensitive lake systems.

3.2.3 *Effective Acidity (EA)*

The Alberta Environment (1990) review for setting deposition limits in Alberta recommends a target loading based on the Effective Acidity (EA) approach. Turchenek *et al.* (1993) describe various programs that have been initiated to identify appropriate acidification loadings. These include:

- Artificial acidification of a field plot located 6 km south of Bitumount Forestry Look-out tower. A sensitive soil was identified and 0.3, 0.6, 1.2, 2.4 and 4.8 kmol H^+/ha/a acid was applied in 1991.

- Long-term site evaluations conducted by AEP in 1981. The Fort McMurray site was identified as an appropriate early warning indicator.

- Application of the ARC soil model to determine critical loads. Two Fort McMurray soils were selected and evaluated with acidification loadings of 0.22 and 0.86 kmol H^+/ha/a.

The soils from the Fort McMurray site were found to be the most sensitive. The predicted decrease of 0.5 pH units in 20 years was associated with 0.86 kmol H^+/ha/a loading. The authors indicate that their simulations are overestimating of actual conditions and that the model indicators suggest a critical load of 0.2 kmol H^+/ha/a may be appropriate for this sensitive soil type.

In a follow-up report by Turchenek *et al.* (1994), the following were noted:

- A weathering rate of 0.07 kmol H^+/ha/a can be applied to sandy, acid sensitive soils in Alberta.

- An evaluation of organic soils indicated depositions of less than 0.5 kmol H^+/ha/a would have a minimal effect on peatlands.

- After two years, the artificial acidification program indicated that levels of SO_4^{-2} in the soil has increased, however, an additional 2 years of exposure would be required for soil acidification model evaluation.

In addition to looking at soil response to acidification inputs, additional work has been undertaken reviewing methods to calculate the effective acidity input (Peake 1992). The methods proposed by Peake and those used in the previous Syncrude EIA (Concord Environmental 1991) are shown in Table 3.2 and a comparison of the methods as applied to the three ADRP sites is provided in Table 3.3. Some of Peake's conclusions relating to the calculation of EA are:

- Dry deposition of SO_2 and SO_4^{-2} can dominate EA values.

- Wet deposition of NH_4^+ is more important than H^+.

- Wet deposition of Ca^{+2} and Mg^{+2} should not be included as it is already accounted for in the H^+ measurement.

Table 3.3 indicates that wet deposition can be more important in remote areas located some distance from SO_2 sources (i.e. Fortress) while dry deposition processes can be more important in areas closer to SO_2 sources (Crossfield West and East).

In a follow-up workshop held in 1992, it was recommended that Approach Number 3 be used. This approach requires precipitation chemistry measurements of H^+, NH_4^+ and NO_3^- and ambient concentration measurements of gaseous SO_2 and NH_3, and particulate SO_4^{-2}, NH_4^+ and NO_3^-.

The Alberta Environment (1990) review defines three sensitivity classes for soil systems and preliminary effective acidity deposition limits for each class:

Sensitivity Class	Effective Acidity Deposition Limit (kmol H^+/ha/a)
Low	0.7 to 1.0
Medium	0.3 to 0.4
High	0.1 to 0.3

Table 3.2 Evaluation of alternative forms for estimating effective acidity (EA) and net acidifying potential (AP) (Peake 1992).

No.	Method	Wet Deposition	Dry Deposition
1	Coote *et al.* (1981) (EA)	$[H^{+}] + 1.15\ [NH_4^{+}] - 0.7\ [NO_3^{-}]$	None
2	Singleton *et al.* (1988) (EA)	$[H^{+}] + 1.15\ [NH_4^{+}] - 0.7\ [NO_3^{-}]$	$[SO_4^{-2} + SO_2]$
3[a]	Enhanced Coote to include dry deposition of nitrogen species (EA)	$[H^{+}] + 1.15\ [NH_4^{+}] - 0.7\ [NO_3^{-}]$	$[SO_4^{-2} + SO_2 + 1.15\ NH_4^{+} - 0.7\ NO_3^{-}]$
4	Enhanced Singleton to include dry deposition of nitrogen species (EA)	$[H^{+}] + 1.15\ [NH_4^{+}] - 0.7\ [NO_3^{-}]$	$[SO_4^{-2} + SO_2 + 0.15\ NH_4^{+} - 0.7\ NO_3 + 0.3\ NO_x]$
5	Enhanced Singleton to include wet (EA) alkaline deposition	$[H^{+}] + 1.15\ [NH_4^{+}] - 0.7\ [NO_3^{-}] - [Ca^{+2}] - [Mg^{+2}]$	$[SO_4^{-2} + SO_2]$
6	Enhanced Singleton to include dry deposition of alkaline particulates (EA)	$[H^{+}] + 1.15\ [NH_4^{+}] - 0.7\ [NO_3^{-}]$	$[SO_4^{-2} + SO_2 - Ca^{+2} - Mg^{+2}]$
7	Syncrude EIA (1991) (EA)	$[H^{+}] + 1.15\ [NH_4^{+}] - 0.7\ [NO_3^{-}]$	$[SO_2]$
8	Bridges and Summers (1989) (AP)	$[SO_4^{-2}] - [Ca^{+2}] - [Mg^{+2}] + 0.3\ [NO_3^{-}]$	None
9	Syncrude EIA (1991) (AP)	$[SO_4^{-2}] - [Ca^{+2}] - [Mg^{+2}]$	None

[a] Preferred Approach (1992 Workshop).

Table 3.3 Contributions of wet and dry depositions at the three ADRP sites (kmol H^+/ha/a).

Method	Fortress			Crossfield West			Crossfield East		
	Wet	+ Dry[(a)]	= Total	Wet	+ Dry[(a)]	= Total	Wet	+ Dry[(a)]	= Total
1	0.17	0	0.17	0.21	0	0.21	0.20	0	0.20
2	0.17	0.10	0.26	0.21	0.34	0.55	0.20	0.42	0.62
3[(b)]	0.17	0.11	0.28	0.21	0.50	0.81	0.20	0.79	0.99
4	0.17	0.07	0.24	0.21	0.31	0.52	0.20	0.38	0.58
5	-0.02	0.10	0.08	0.06	0.34	0.40	0.14	0.42	0.56
6	0.17	0.06	0.23	0.21	0.13	0.34	0.20	0.16	0.36
7 (EA)	0.17	0.09	0.26	0.21	0.30	0.51	0.20	0.38	0.58
8 (AP)	-0.06	0	-0.06	0.03	0	0.03	-0.03	0	-0.03
9 (AP)	-0.04	0	-0.04	0.06	0	0.06	0.02	0	0.02

(a) Assumed dry velocities

SO_2	0.7 cm/s
NO_x	0.1 cm/s
HNO_3	3.0 cm/s
HNO_2	3.0 cm/s
NH_3	1.5 cm/s
Fine particles	0.1 cm/s
Course particles	2.0 cm/s

(b) Preferred Approach (1992 Workshop).

Similarly, Alberta Environment also defines three sensitivity classes for aquatic systems and preliminary deposition limits for each class. These are as follows:

Sensitivity Class	Alkalinity (mg/L)	Effective Acidity Deposition Limit (kmol H^+/ha/a)
Low	> 21	> 0.3
Medium	11 to 20	> 0.3
High	0 to 10	0.1 to 0.3

3.3 Passive Monitoring Guidelines

Government of Alberta (1993) defines the following guidelines for passive total sulphation and hydrogen sulphide monitors:

- Total Sulphation — 0.50 mg SO_3^{-1} equivalent/day/100 cm^2 as a one-month cumulative loading.
- H_2S — 0.10 mg SO_3^{-1} equivalent/day/100 cm^2 as a one-month cumulative loading.

The selection of these guidelines does not appear to be based on potential environmental effects but on a subjective understanding of values that can occur in the vicinity of an SO_2 emitting source.

4.0 SULPHUR DIOXIDE (SO_2)

Air quality data from the continuous SO_2 analyzers were reviewed to determine the magnitudes and frequencies of relatively large SO_2 concentrations. In particular, all hours when the hourly average SO_2 concentration exceeded 0.17 ppm (450 $\mu g/m^3$) were identified. The observed SO_2 concentrations were compared to regulatory and WHO guidelines. Trends with respect to meteorology and time of occurrence were also determined. Finally, an estimation of a representative background SO_2 concentration was made.

The tables and figures in this section are based on computer databases provided by Syncrude, Suncor and AEP. Some discrepancies between values provided in the supplied computer database files and those contained in the respective annual and monthly reports were found. Follow-up discussions with Syncrude and Suncor were required to resolve these differences.

4.1 Comparison to Air Quality Guidelines

Table 4.1 provides a summary of the number of hours per year when the 0.17 ppm guideline as a one-hour average was exceeded for each station. Over the 5-½ year period, the average number of hourly exceedences is 59 per year with minimum and maximum annual totals of 26 and 95, respectively. Most of the exceedences are associated with the Fina (total = 114; average annual = 21) and Mannix (total = 71; average annual = 13) stations. The fewest exceedences are associated with AQS5 (Tailing East) (total = 1) and Fort McMurray (total = 1). In contrast to the single hourly exceedences observed in Fort McMurray, a total of 8 exceedences (average annual = 1) over the 5-½ year period were observed in Fort McKay.

Table 4.2 provides a summary of the number of hours per year when the 0.34 ppm (900 $\mu g/m^3$) SO_2 objective was exceeded on a station-by-station basis. Over the 5-½ year period, the average number of hourly exceedences is 5.3 per year with minimum and maximum yearly totals of 0 and 11, respectively. Most of the exceedences are associated with the Fina station (total = 13; average annual = 2.4).

Table 4.3 compares the SO_2 observations with the WHO SO_2 guidelines for vegetation. Based on the assumption of equable growing conditions, 97.5% of the hourly values during the growing season should be less than 0.050 ppm. Only two sites fail to meet this criterion: Mannix and Fina. For poor growing conditions, the equivalent criterion is 0.025 ppm. Eight of the 12 sites fail to meet this criterion. Based on the assumption of equable growing conditions, daily average values should not exceed 0.038 ppm more than 12 times in a 6 month period. All of the monitoring sites meet this criteria. For poor growing conditions, the equivalent criteria is based on 0.019 ppm. Two sites fail to meet this criteria (Mannix and Fina). The application of the WHO vegetation criteria confirm that the poorest air quality is experienced at the Mannix and Fina stations.

Table 4.1 Number of hourly SO_2 concentrations greater than 0.17 ppm (450 $\mu g/m^3$).

Station	1990	1991	1992	1993	1994	1995[a]	Total	Average
Mannix (#2)	21	7	5	9	21	8	71	13
Lower Camp (#4)	18	11	1	3	6	2	41	7
Fina (#5)	41	20	9	14	16	14	114	21
Poplar Creek (#9)	0	0	2	0	4	0	6	1
Athabasca Bridge (#10)	0	0	2	2	6	2	12	2
AQS1 (Mine South)	6	2	0	3	7	4	22	4
AQS2 (Fort McMurray)	1	2	0	0	5	0	8	2
AQS3 (Mildred Lake)	4	3	5	4	8	4	28	5
AQS4 (Tailing North)	4	2	1	0	3	3	13	2
AQS5 (Tailing East)	0	0	0	0	1	0	1	0.2
Fort McMurray (FMMU)	0	0	0	0	0	1	1	0.2
Fort McKay (FRMU)	0	2	1	1	2	2	8	2
Total	95	49	26	36	79	40	325	59

[a] To June 30, 1995.

Table 4.2 Number of hourly SO_2 concentrations greater than 0.34 ppm (900 $\mu g/m^3$).

Station	1990	1991	1992	1993	1994	1995[(a)]	Total	Average
Mannix (#2)	3	1	0	0	3	0	7	1.3
Lower Camp (#4)	4	1	0	0	0	0	5	0.9
Fina (#5)	4	4	1	3	0	1	13	2.4
Poplar Creek (#9)	0	0	0	0	1	0	1	0.2
Athabasca Bridge (#10)	0	0	0	0	0	0	0	0
AQS1 (Mine South)	0	0	0	0	2	0	2	0.4
AQS2 (Fort McMurray)	0	0	0	0	0	0	0	0
AQS3 (Mildred Lake)	0	0	0	0	1	0	1	0.2
AQS4 (Tailing North)	0	0	0	0	0	0	0	0
AQS5 (Tailing East)	0	0	0	0	0	0	0	0
Fort McMurray (FMMU)	0	0	0	0	0	0	0	0
Fort McKay (FRMU)	0	0	0	0	0	0	0	0
Total	11	6	1	3	7	1	29	5.3

(a) January to June.

Table 4.3 Comparison of SO_2 observations (January 1990 to January 1995) with the WHO SO_2 guidelines for vegetation.

	Frequency less than indicated value during growing season[c]		**Number of daily values greater than indicated values per 6 months**	
Concentration (ppm)	**0.050(a)**	**0.025(b)**	**0.038(a)**	**0.019(b)**
(ug/m³)	**130**	**65**	**100**	**50**
Station				
Mannix (#2)	**96.76**	**92.67**	5.3	**21.3**
Lower Camp (#4)	98.18	**94.81**	2.3	9.6
Fina (#5)	**97.15**	**94.44**	6.2	**19.2**
Poplar Creek (#9)	98.64	**95.68**	0.9	8.5
Athabasca Bridge (#10)	99.12	**97.38**	0.6	4.4
AQS1 (Mine South)	98.80	**96.51**	0.3	3.4
AQS2 (Fort McMurray)	98.32	97.51	0.6	4.5
AQS3 (Mildred Lake)	98.55	**95.68**	0.6	5.2
AQS4 (Tailing North)	98.94	**96.57**	0.1	4.9
AQS5 (Tailing East)	99.74	99.07	0.0	0.9
Fort McMurray (FMMU)	99.84	98.88	0.1	2.6
Fort McKay (FRMU)	99.36	97.80	0.3	4.9
Guideline	> 97.5	> 97.5	< 12	< 12

(a) For conditions with equable growing conditions.
(b) For conditions with poor forest growth.
(c) The growing season has been defined as the period April through September inclusive.

4.2 Trends with Time and Meteorology

SO_2 exceedence hours were classified according to concentration, month, time of day, wind speed and wind direction to help identify trends. The analysis results in a histogram format are presented on a station-by-station basis in the following figures:

- Figure 4.1 Suncor Mannix (#2)
- Figure 4.2 Suncor Lower Camp (#4)
- Figure 4.3 Suncor Fina (#5)
- Figure 4.4 Suncor Poplar Creek (#9)
- Figure 4.5 Suncor Athabasca Bridge (#10)
- Figure 4.6 Syncrude AQS1 (Mine South)
- Figure 4.7 Syncrude AQS2 (Fort McMurray)
- Figure 4.8 Syncrude AQS3 (Mildred Lake)
- Figure 4.9 Syncrude AQS4 (Tailing North)
- Figure 4.10 Syncrude AQS5 (Tailing East)
- Figure 4.11 Fort McMurray (FMMU)
- Figure 4.12 Fort McKay (FRMU)

SO_2 concentrations greater than 0.17 ppm and less than or equal to 0.18 ppm are plotted as 0.17 ppm and values greater than 0.18 ppm but less than 0.19 ppm are plotted as 0.18 ppm and so on. The wind directions and wind speeds shown in the figures were obtained from the wind sensors located at the respective monitoring stations. The figures also show the wind directions required to transport a plume from the two plants to the monitoring station in question.

Trends identified from the figures are summarized in Table 4.4 and repeated below:

- The largest hourly average SO_2 concentrations (greater than or equal to 0.5 ppm) were observed at Mannix (#2), Lower Camp (#4) and Fina (#5).

- The median exceedence values are in the 0.18 to 0.23 ppm range.

- Exceedences were observed most frequently in the late winter/spring (February, March, April, May) and summer (July, August) periods.

- Exceedences were observed most frequently during daytime hours (0900 to 1600 hours).

- Exceedences were associated with wind speeds less than 10 km/h (less than 3 m/s).

- In many cases, there was a clear downwind/upwind relationship between the location of the plant and the wind direction.

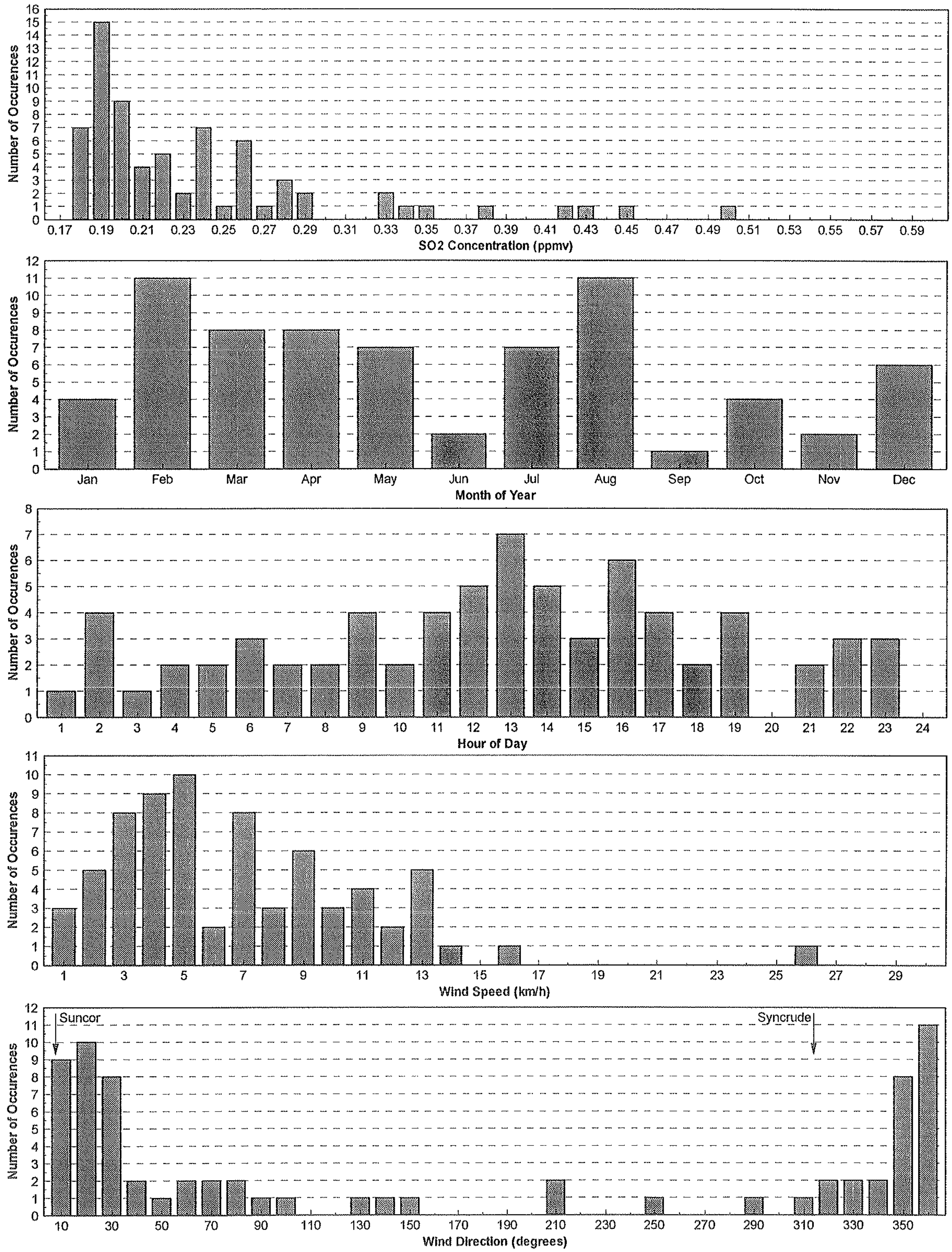


Figure 4.1 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Suncor (Station #2) Mannix (January 1990 to June 1995).

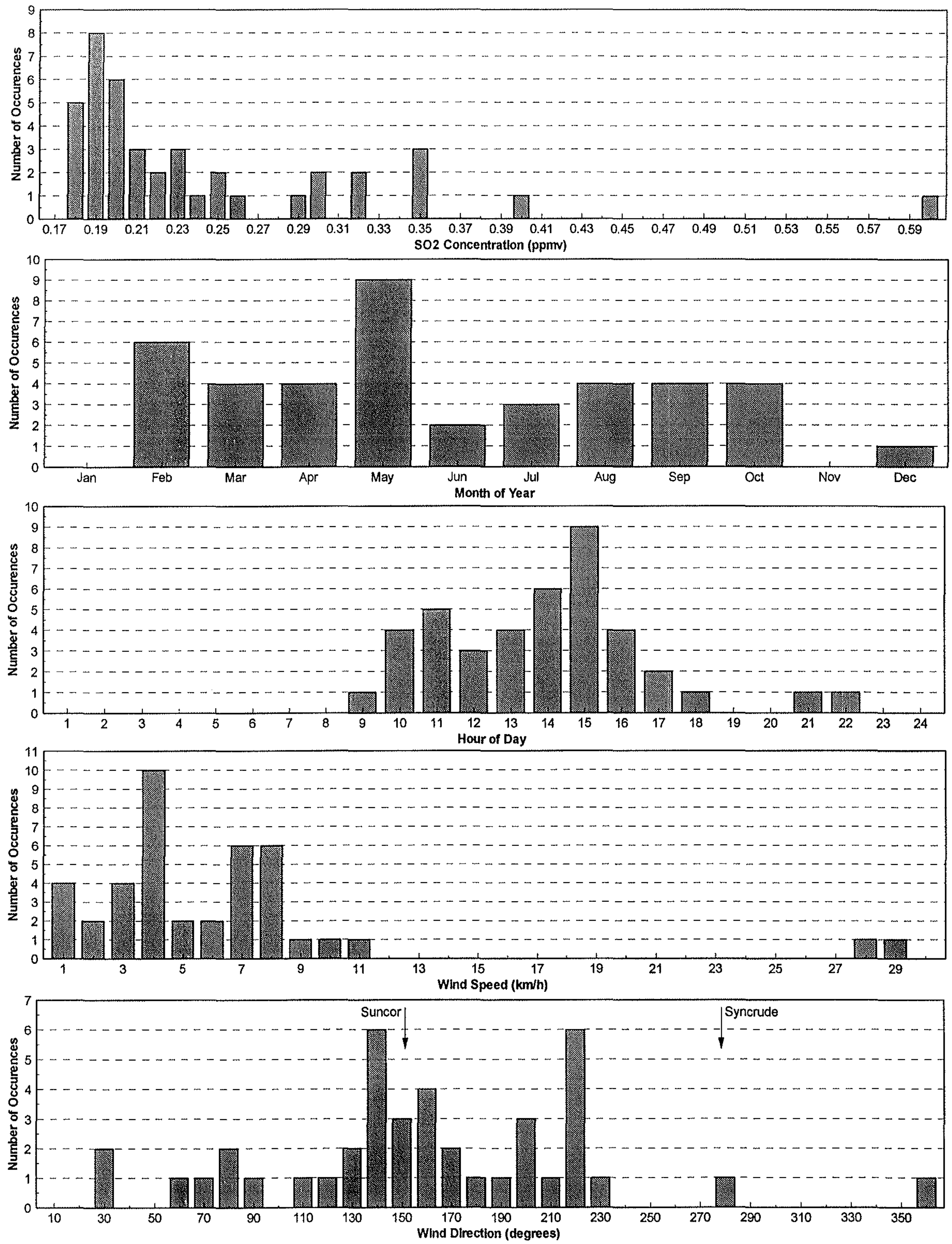


Figure 4.2 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Suncor (Station #4) Lower Camp (January 1990 to June 1995).

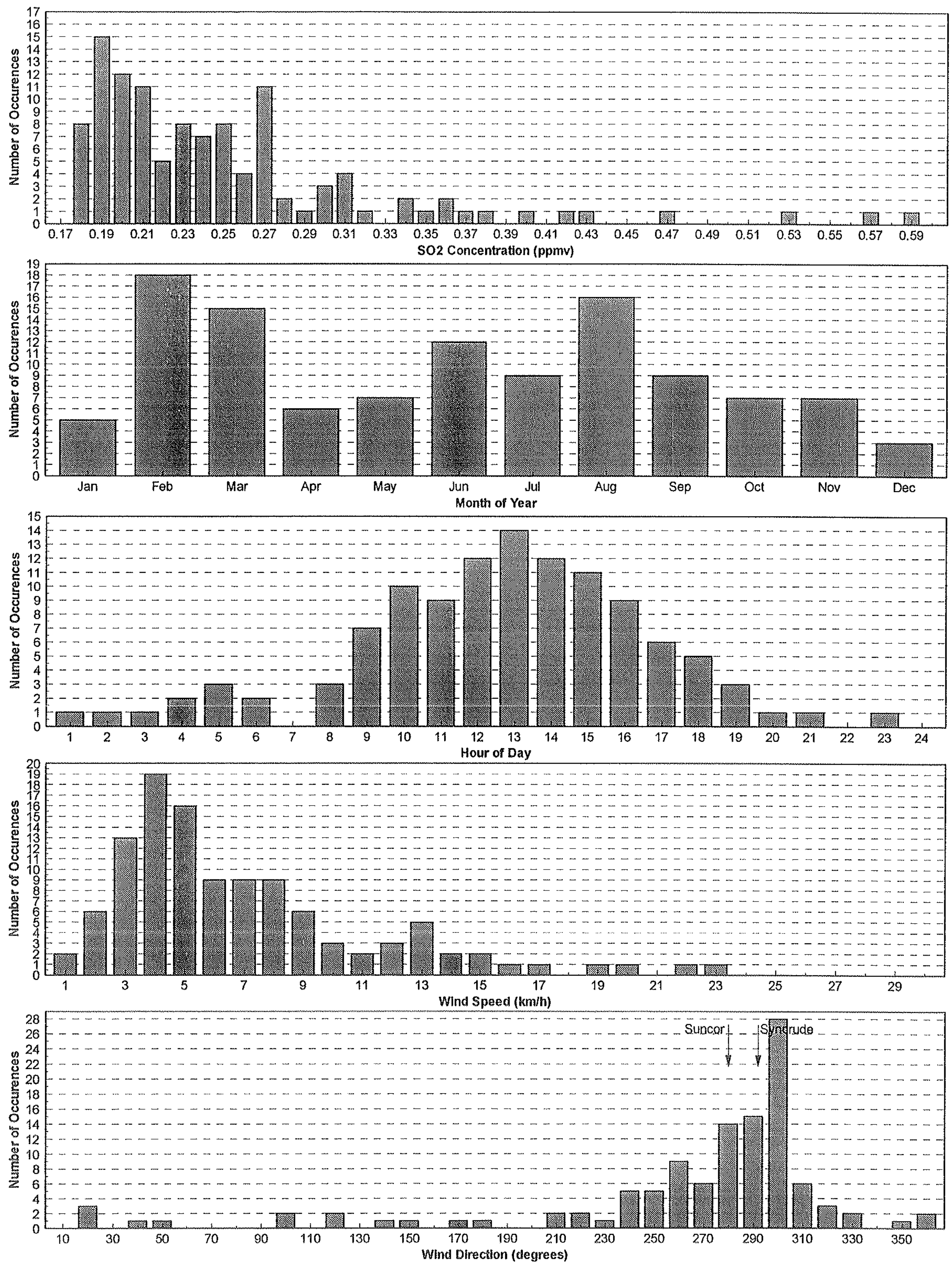


Figure 4.3 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Suncor (Station #5) Fina (January 1990 to June 1995).

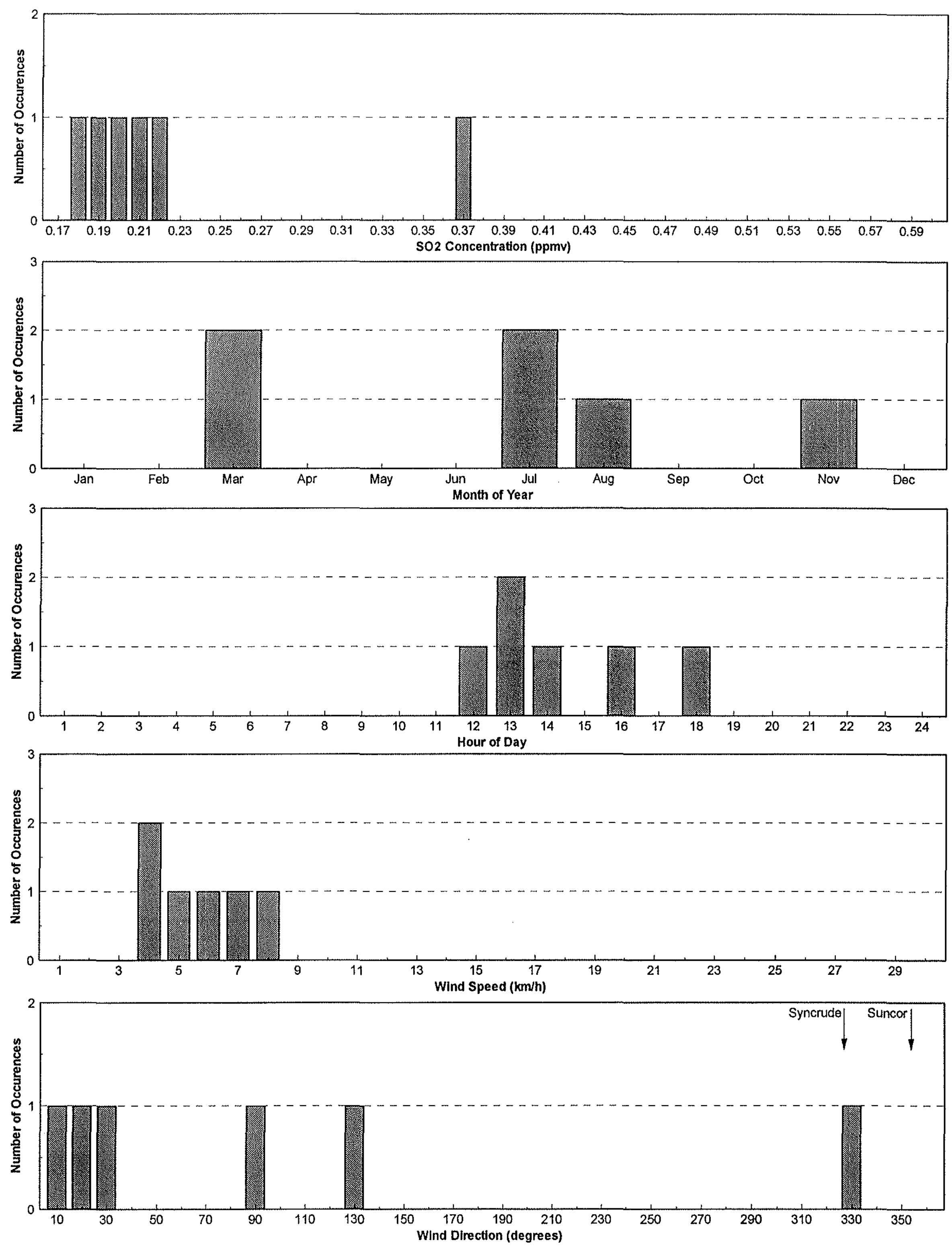


Figure 4.4 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Suncor (Station #9) Poplar Creek (January 1990 to June 1995).

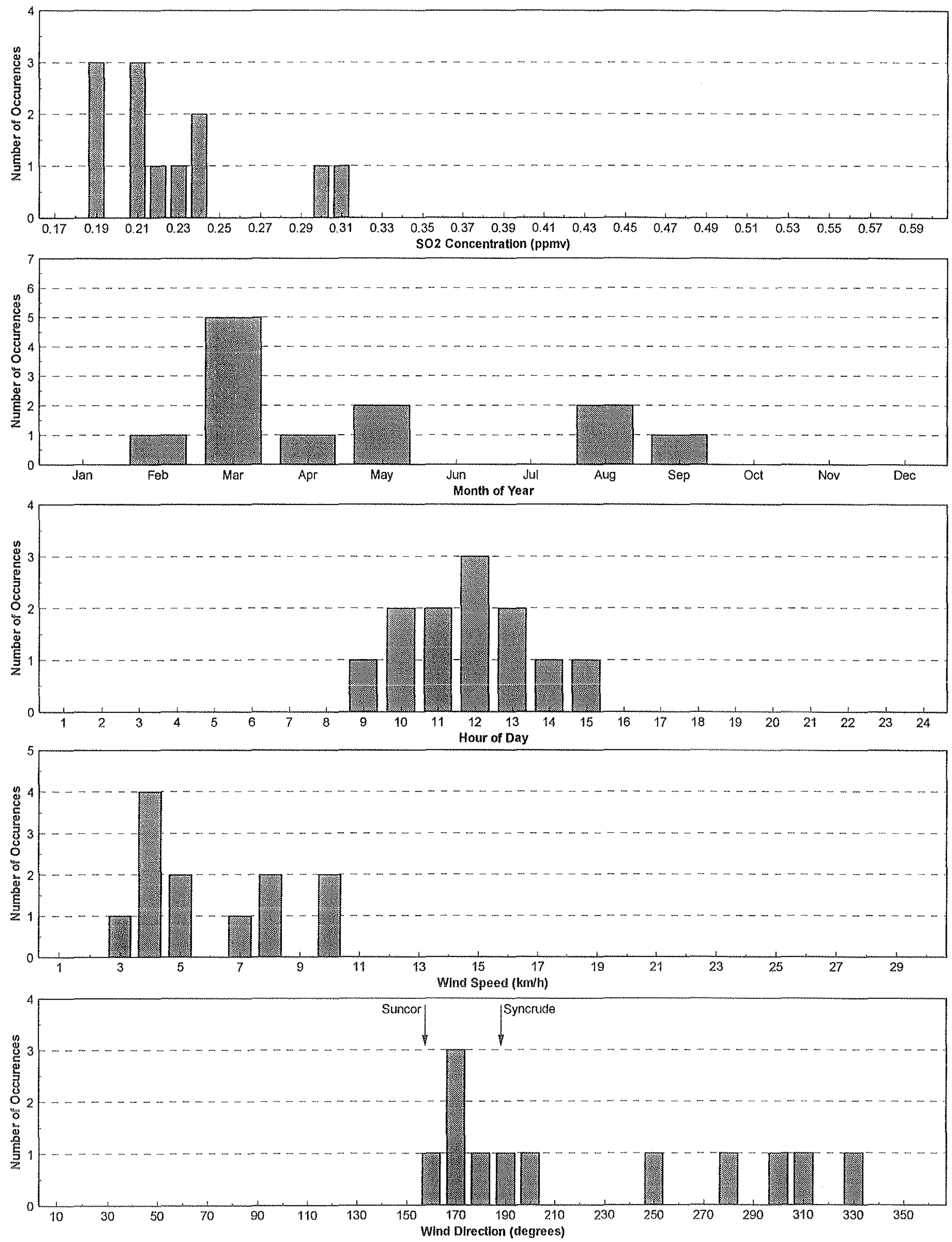


Figure 4.5 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Suncor (Station #10) Athabasca Bridge (January 1990 to June 1995).

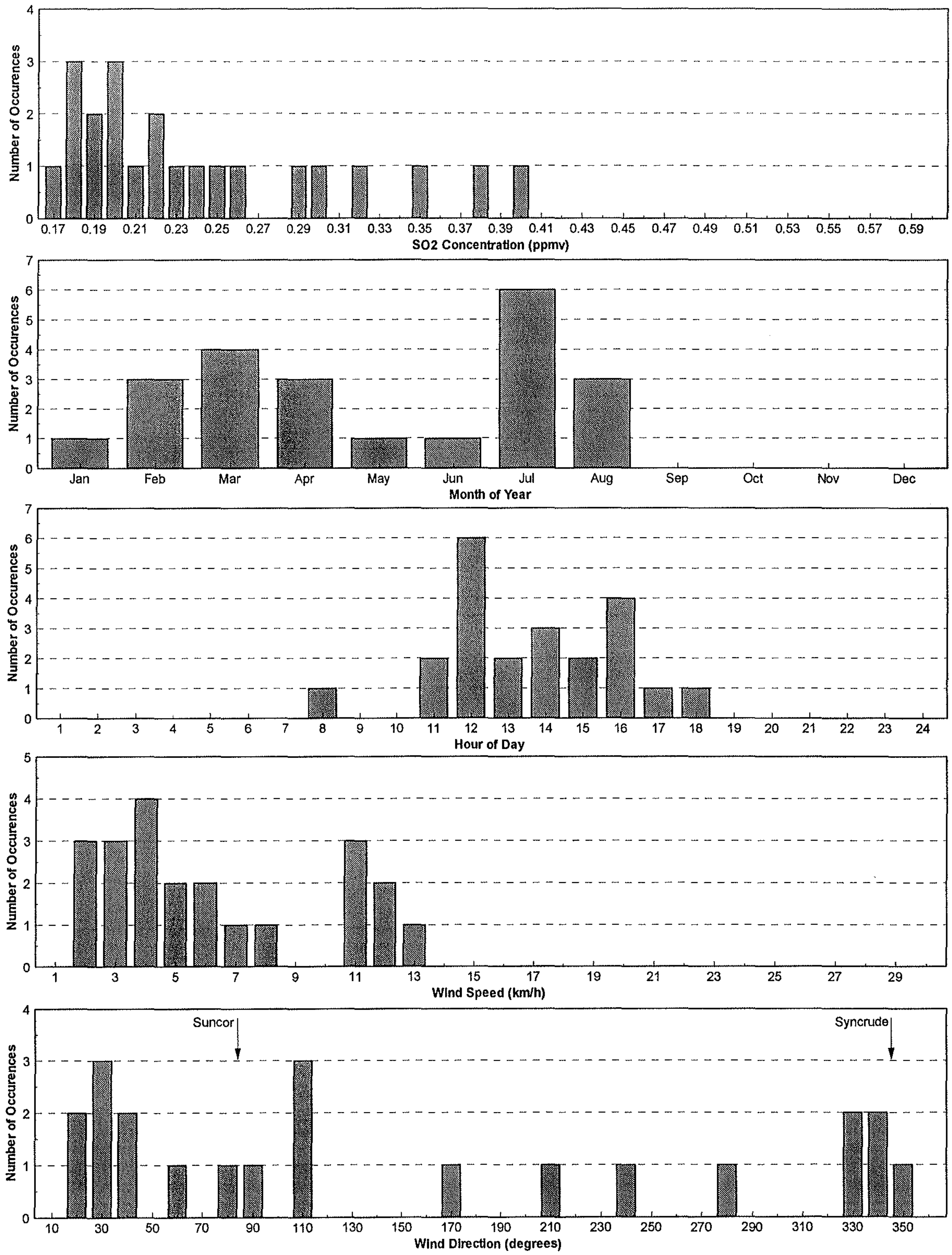


Figure 4.6 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Syncrude AQS1 (Mine South) (January 1990 to June 1995).

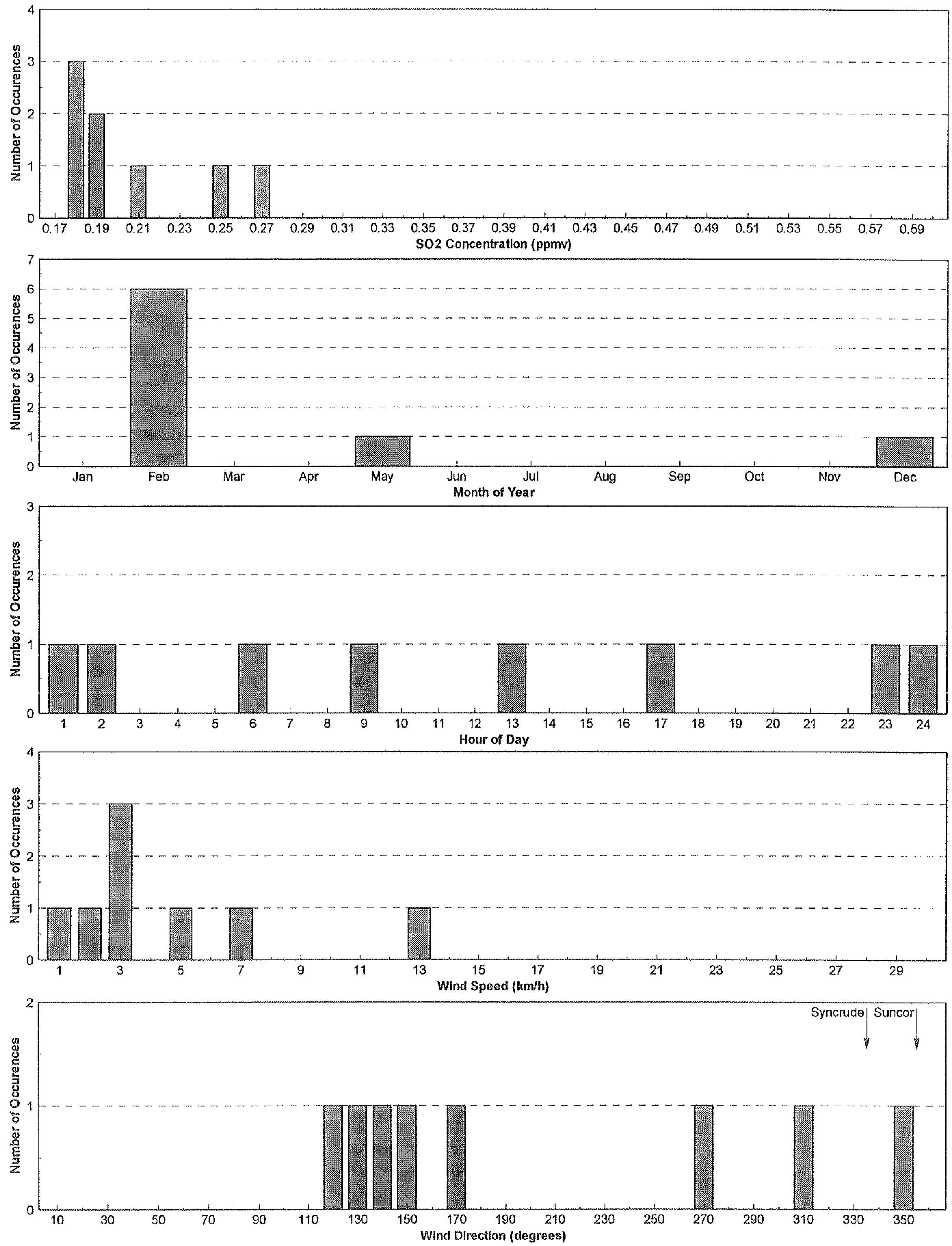


Figure 4.7 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Syncrude AQS2 (Fort McMurray) (January 1990 to June 1995).

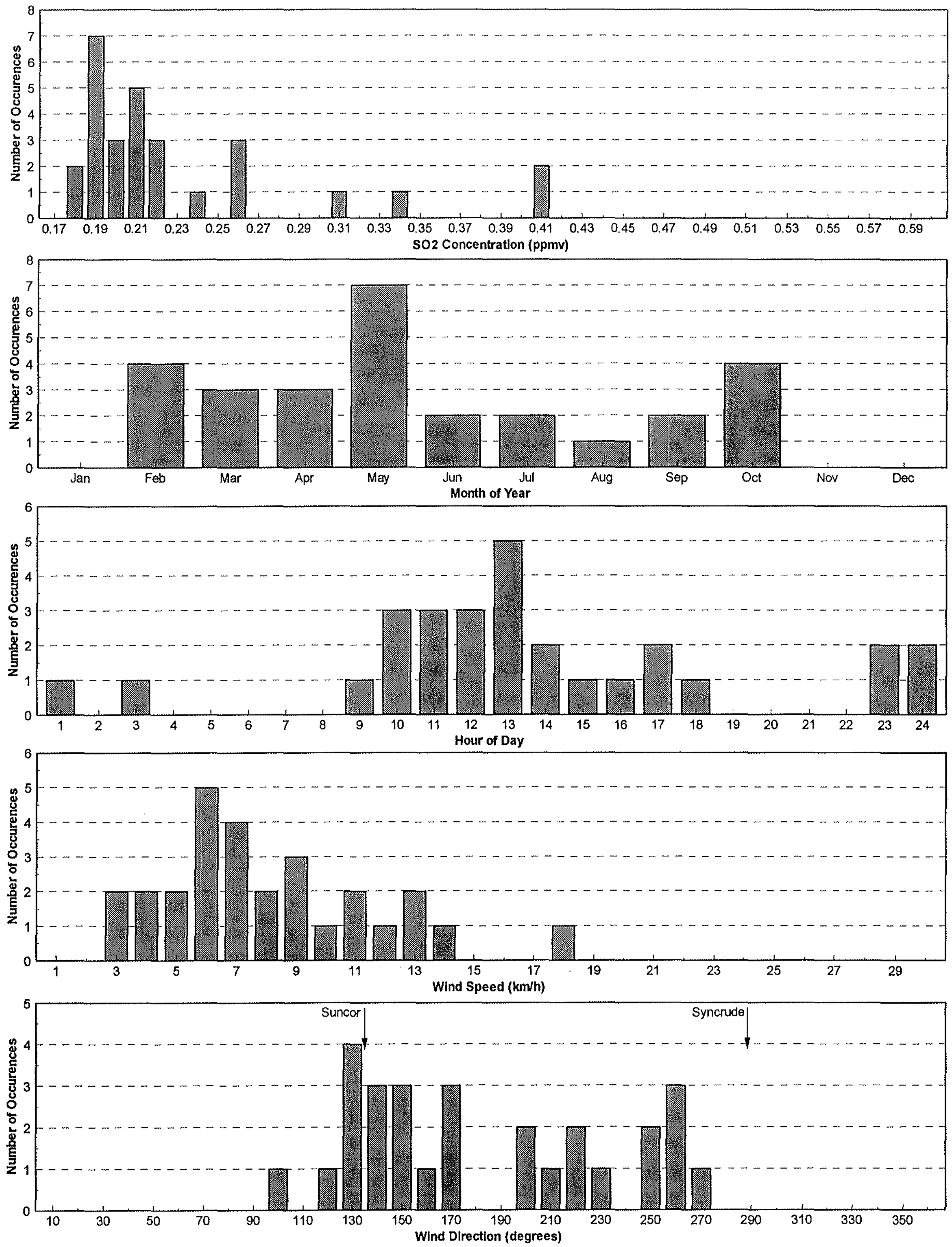


Figure 4.8 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Syncrude AQS3 (Mildred Lake) (January 1990 to June 1995).

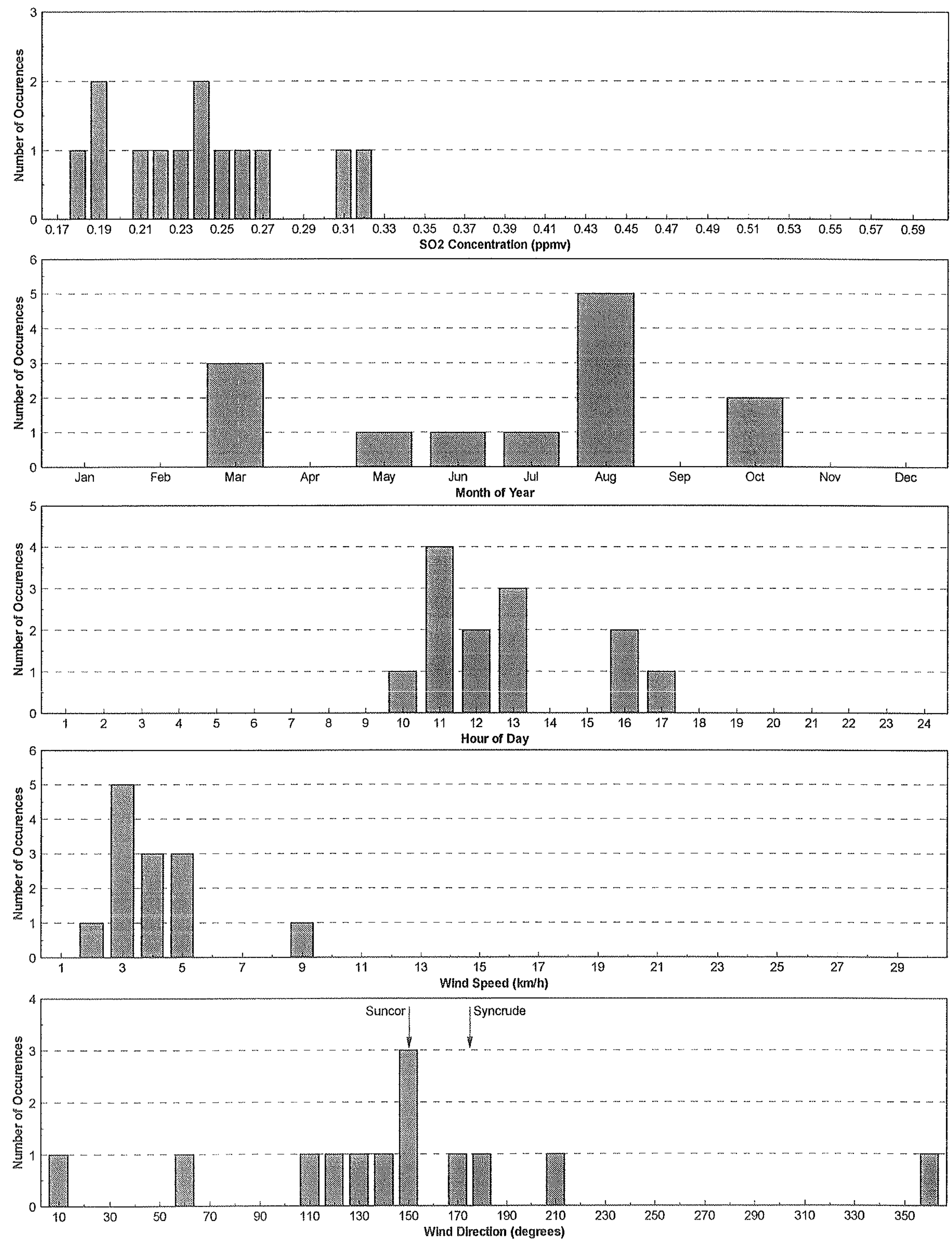


Figure 4.9 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Syncrude AQS4 (Tailings North) (January 1990 to June 1995).

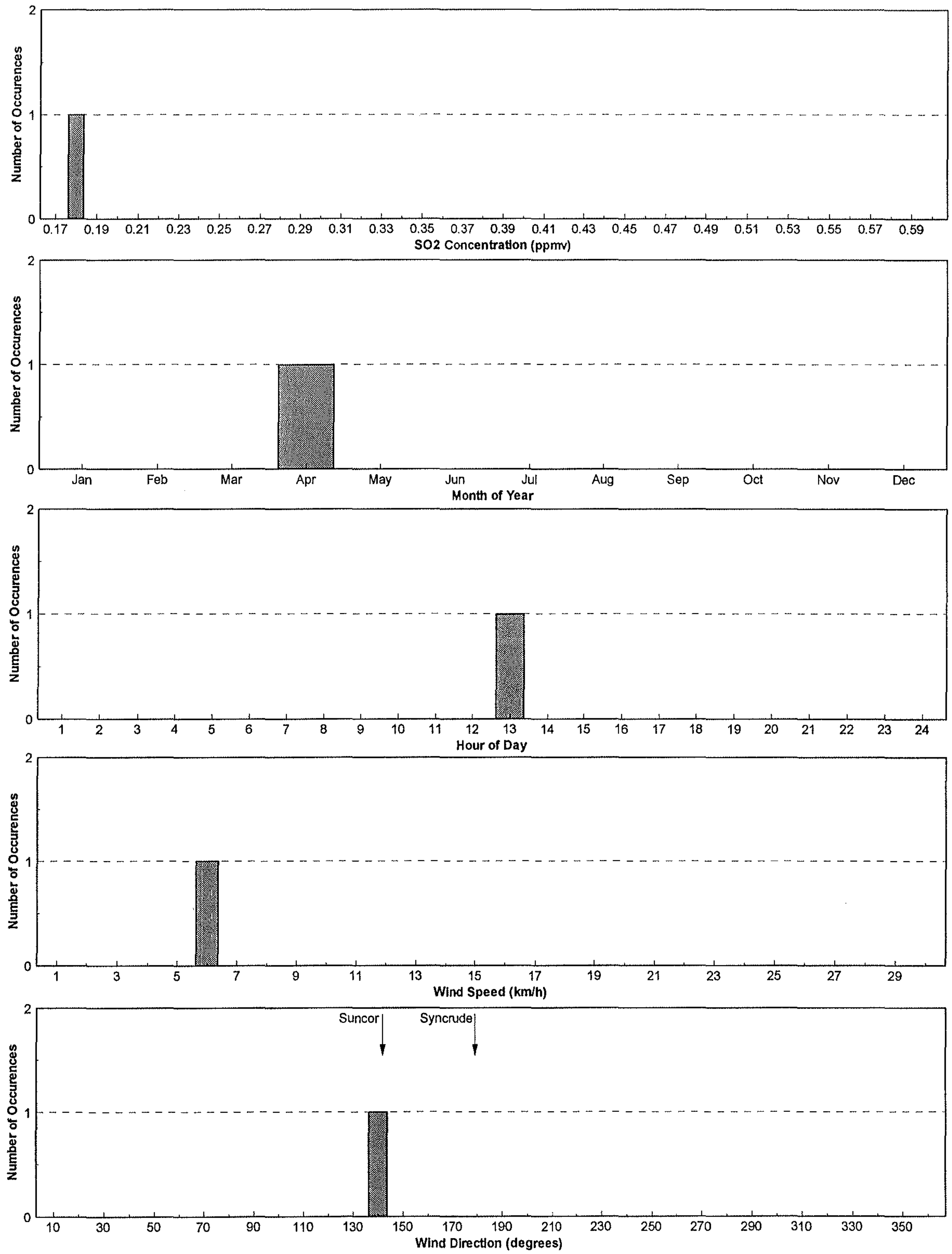


Figure 4.10 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Syncrude AQS5 (Tailings East) (January 1990 to June 1995).

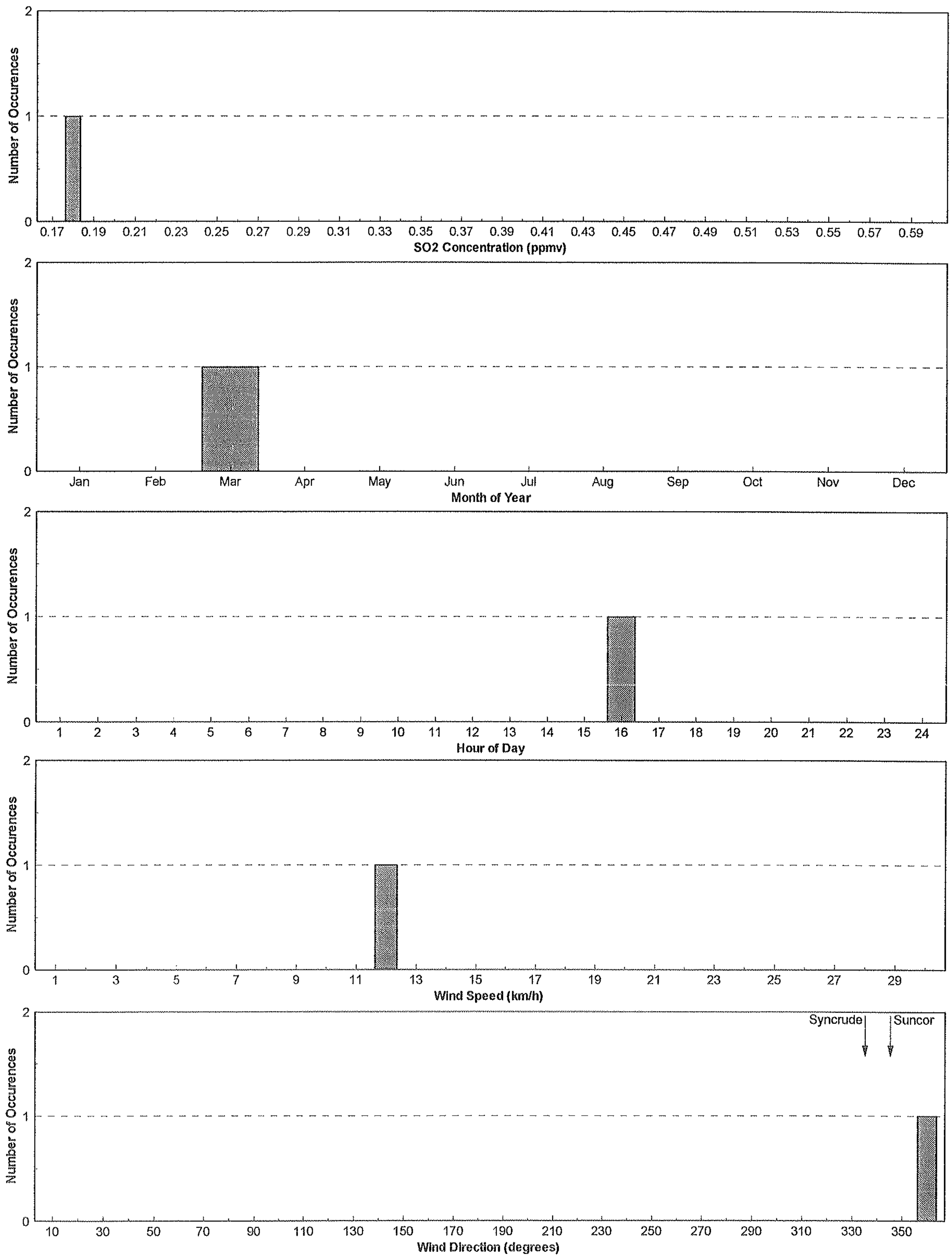


Figure 4.11 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Fort McMurray (FMMU) (January 1990 to June 1995).

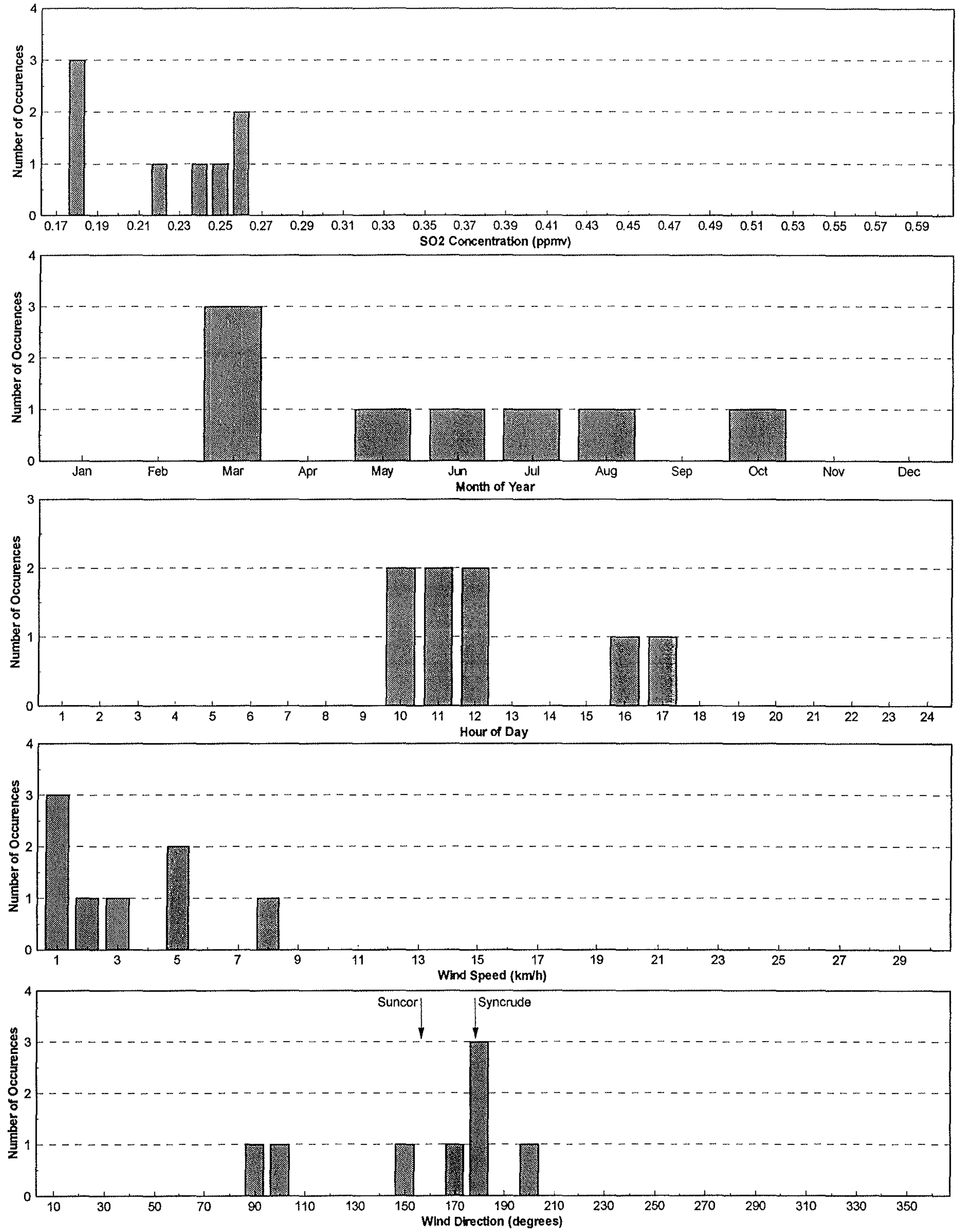


Figure 4.12 Hourly average SO_2 concentrations greater than 0.17 ppm and associated conditions at Fort McKay (FRMU) (January 1990 to June 1995).

Table 4.4 Summary of time and conditions associated with hourly average SO_2 concentrations in excess of 0.17 ppm (450 $\mu g/m^3$) for the 5-½ year period January 1, 1990 to June 30, 1995.

Station	Number of Exceedences (h)	Number of Exceedences (h/a)	Maximum Concentration (ppm)	Median Exceedence (ppm)	Month	Hour	Wind Speed (km/h)	Direction (degrees)
Suncor								
Mannix (#2)	71	13	0.50	0.21	Feb., Aug.	12 to 16	3 to 7	350 to 30
Lower Camp (#4)	41	7	0.60	0.21	May, Feb.	11 to 15	4 to 8	140 to 220
Fina (#5)	114	21	0.59	0.23	Feb., Aug.	9 to 17	3 to 5	260 to 300
Poplar Creek (#9)	6	1	0.37	0.20	Mar., July	13	4	330 to 30
Athabasca Bridge (#10)	12	2	0.31	0.22	Mar.	10 to 13	4 to 10	170
Syncrude								
AQS1 (Mine South)	22	4	0.40	0.22	July, Mar.	12 to 16	2 to 11	30 to 110
AQS2 (Fort McMurray)	8	2	0.27	0.18	Feb.	1 to 24	3	120 to 170
AQS3 (Mildred Lake)	28	5	0.41	0.21	May	10 to 13	6 to 9	130 to 170
AQS4 (Tailing North)	13	2	0.32	0.23	Aug.	11 to 13	3 to 5	150
AQS5 (Tailing East)	1	0.2	0.18	0.18	Apr.	13	6	140
AEP								
Fort McMurray	1	0.2	0.18	0.18	Mar.	16	12	360
Fort McKay	8	2	0.26	0.22	Mar.	10 to 12	1 to 5	180

- In other cases, the wind direction appears to be poorly correlated with the location of either plant. This is likely due to the change of wind direction with height as the wind sensors are located in the 10 to 15 m height range whereas the plumes are typically 100 to 300 m above the ground. Additionally, the plumes may not follow a linear trajectory towards the ambient air quality monitoring stations due to topographic features.

In summary, the high SO_2 concentrations that are observed in the region are, for the most part, well correlated with one of the two oil sands plants being clearly located upwind, with day-time hours and with wind speeds less than 10 km/h. High concentrations tend to occur more frequently in the late winter/spring and summer periods. The day-time occurrence of high SO_2 concentrations indicate that the convective and/or limited trapping meteorological conditions are responsible for the SO_2 events as most of the SO_2 emissions in the region result from relatively tall stacks at Suncor and Syncrude.

4.3 Background SO_2 and SO_4^{-2} Concentrations

It is difficult to define a regional background SO_2 concentration that would exist in the absence of the current oil sands operations. This is because the background values on average would be less than the level of detection of the SO_2 analyzers used in the monitoring program. For this reason, annual average and background concentrations derived from the current network will have limited meaning.

Integrated sampling allows low concentration measurements to be undertaken. These samplers draw a low volume of air through an absorbing medium for weekly or monthly periods. The absorbing medium is then analyzed and the average concentration for the exposure period can be determined. To determine representative background concentrations, data collected using this type of sampler at Cree Lake (Saskatchewan) and Vegreville were reviewed.

Environment Canada maintained a monitoring program in Cree Lake with the objective of obtaining background concentrations of gases and particulate compounds. Figure 4.13 and Tables 4.5 and 4.6 show the SO_2 and SO_4^{-2} values for 1990 up to the time in 1993 when the monitoring was cancelled. The data indicate:

- The smallest SO_2 values in the 0.3 to 0.8 $\mu g/m^3$ (0.1 to 0.3 ppb) range occur in the summer season.

- The largest SO_2 values in the 2 to 4 $\mu g/m^3$ (0.8 to 1.5 ppb) range occur in the winter season.

This difference is likely due to the more stable air masses during the winter that would result in the long-range transport of higher concentrations to greater distances. Furthermore, during winter the removal rate (i.e. deposition) is expected to be lower due to reduced vegetation activity. Similar seasonal trends are observed for SO_4^{-2} as for SO_2. On the average, the SO_4^{-2} values are about 74% of the SO_2 values.

Background monitoring for trace compounds was conducted in Vegreville (Royal Park) by the Alberta Research Council (Peake 1993). The results for 1992 based on the use of an annular denuder sampler are shown in Table 4.7. The results indicate:

- Average summer SO_2 values are in the 1.9 to 2.6 $\mu g/m^3$ range (as sulphate) or in the 1.3 to 1.7 $\mu g/m^3$ (0.5 to 0.6 ppb) range as SO_2.
- Average winter SO_2 values are in the 6.4 to 7.3 $\mu g/m^3$ range (as sulphate) or in the 4.2 to 4.8 $\mu g/m^3$ (1.6 to 3.2 ppb) range as SO_2.
- Average summer SO_4^{-2} values are in the 0.5 to 0.9 $\mu g/m^3$ range.
- Average winter SO_4^{-2} values are in the 0.6 to 1.1 $\mu g/m^3$ range.

The occurrence of higher concentrations in the winter is similar to what was observed at Cree Lake.

In summary, based on both Cree Lake and the six day sampling at Royal Park, the average SO_2 and SO_4^{-2} concentrations are:

Season	SO_2		SO_4^{-2}
	($\mu g/m^3$)	(ppb)	($\mu g/m^3$)
Summer	1.0	0.4	0.8
Winter	3.8	1.4	1.2
Annual	2.4	0.9	1.0

These values were deemed to be representative of the background values that could occur in the Athabasca oil sands area in the absence of local oil sands activity. The larger values observed during the winter are related to the more stable air masses and to the reduced removal rate that occurs during the winter.

4.4 Annual Trends

While the annual average concentrations computed from the continuous analyzers are of limited use from an absolute perspective, they can be used in a relative sense to help identify year-to-year trends. Figures 4.14 to 4.16 show the annual average SO_2 concentrations observed at each of the 12 monitoring stations. The 1995 values shown in the figures are based on six months of data.

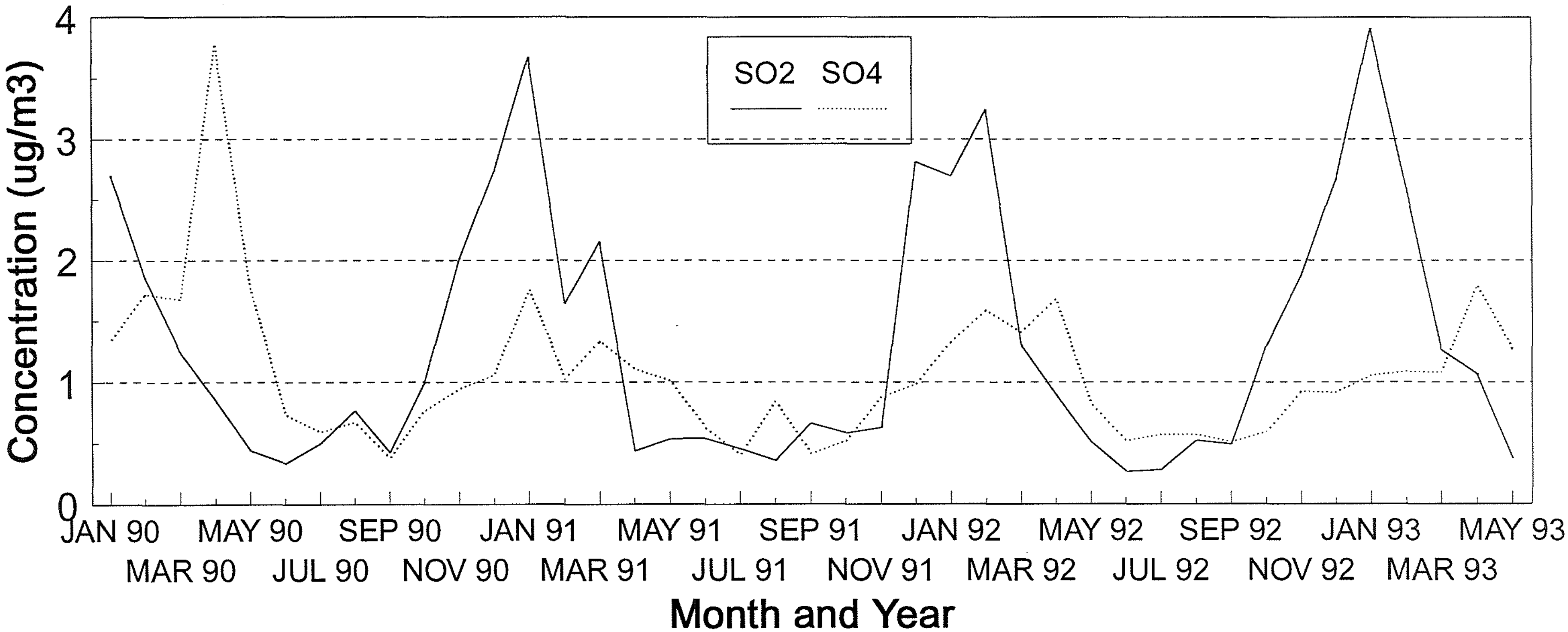


Figure 4.13 SO_2 and SO_4^{-2} concentrations measured at the Environment Canada monitoring station located at Cree Lake, Saskatchewan (January 1990 to May 1993).

Table 4.5 SO_2 concentrations ($\mu g/m^3$) measured in Cree Lake (Shaw 1995, personal communication).

Month	1990	1991	1992	1993	Average
January	2.71	3.68	2.69	3.91	3.25
February	1.86	1.64	3.24	2.39	2.33
March	1.24	2.15	1.30	1.25	1.49
April	0.85	0.42	0.90	1.06	0.81
May	0.43	0.53	0.50	0.37	0.46
June	0.33	0.53	0.26	-	0.38
July	0.49	0.45	0.27	-	0.41
August	0.76	0.35	0.52	-	0.54
September	0.42	0.66	0.48	-	0.52
October	0.99	0.58	1.29	-	0.95
November	2.01	0.63	0.88	-	1.50
December	2.73	2.81	2.66	-	2.73
Average	1.23	1.20	1.33	1.84	1.28

Table 4.6 SO_4^{-2} concentrations ($\mu g/m^3$) measured in Cree Lake (Shaw 1995, personal communication).

Month	1990	1991	1992	1993	Average
January	1.34	1.75	1.32	1.05	1.37
February	1.72	1.02	1.59	1.08	1.35
March	1.68	1.33	1.40	1.08	1.37
April	3.78	1.11	1.68	1.79	1.14
May	1.76	1.01	0.82	1.26	1.21
June	0.73	0.63	0.52	-	0.63
July	0.99	0.40	0.57	-	0.65
August	0.67	0.84	0.57	-	0.69
September	0.37	0.41	0.50	-	0.43
October	0.77	0.51	0.59	-	0.62
November	0.94	0.88	0.93	-	0.92
December	1.05	0.98	0.91	-	0.98
Average	1.32	0.91	0.95	1.25	0.95

Table 4.7 SO_2 and SO_4^{-2} concentrations (µg/m^3) measured in Vegreville (Royal Park) in 1992.

	SO_2 [(a)]		SO_4^{-2}	
	1 day[(b)]	6 days[(b)]	1 day[(b)]	6 days[(b)]
Summer (Apr. 1 to Oct. 31)				
Number	23	23	23	23
Average	1.92	2.58	0.52	0.93
Maximum	7.04	7.52	1.56	1.90
Minimum	-0.01	0.88	-0.07	0.29
Standard Deviation	1.67	1.37	0.49	0.38
Winter (Jan. 1 to Mar. 30, Nov. 1 to Dec. 31)				
Number	23	23	23	23
Average	6.37	7.26	0.60	1.11
Maximum	15.86	14.00	2.14	3.53
Minimum	1.19	0.86	-0.02	0.08
Standard Deviation	4.25	3.80	0.66	0.86
Annual				
Number	52	61	52	61
Average	4.32	5.19	0.55	1.00
Maximum	15.99	14.00	2.14	3.51
Minimum	-0.02	0.86	-0.08	0.06
Standard Deviation	4.09	3.69	0.60	0.69

(a) Expressed as sulphate equivalent.
(b) Integrated samples were collected for 1 day and 6 day periods.

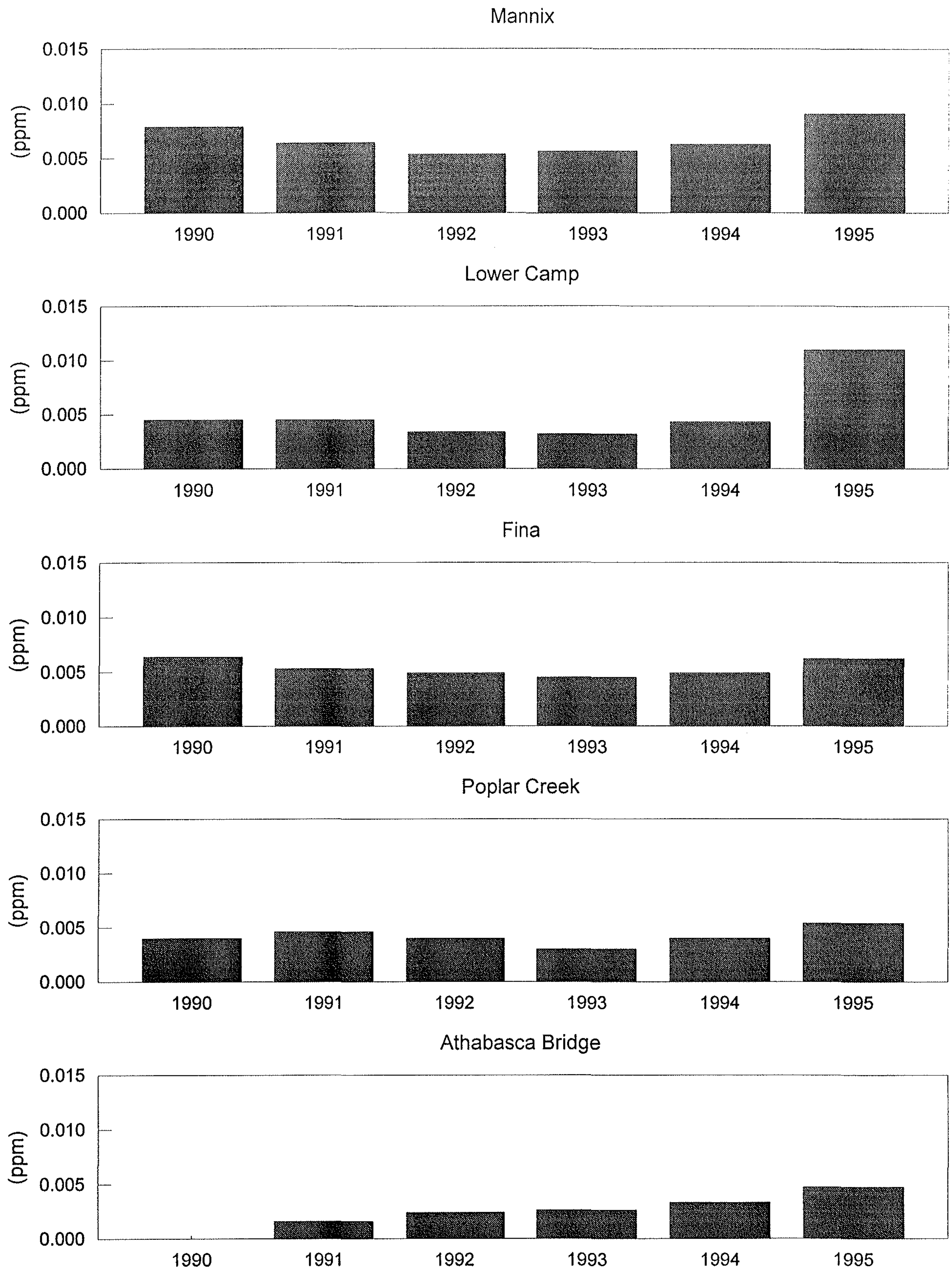


Figure 4.14 Annual average SO_2 concentrations observed at each of the Suncor ambient air quality monitoring stations.

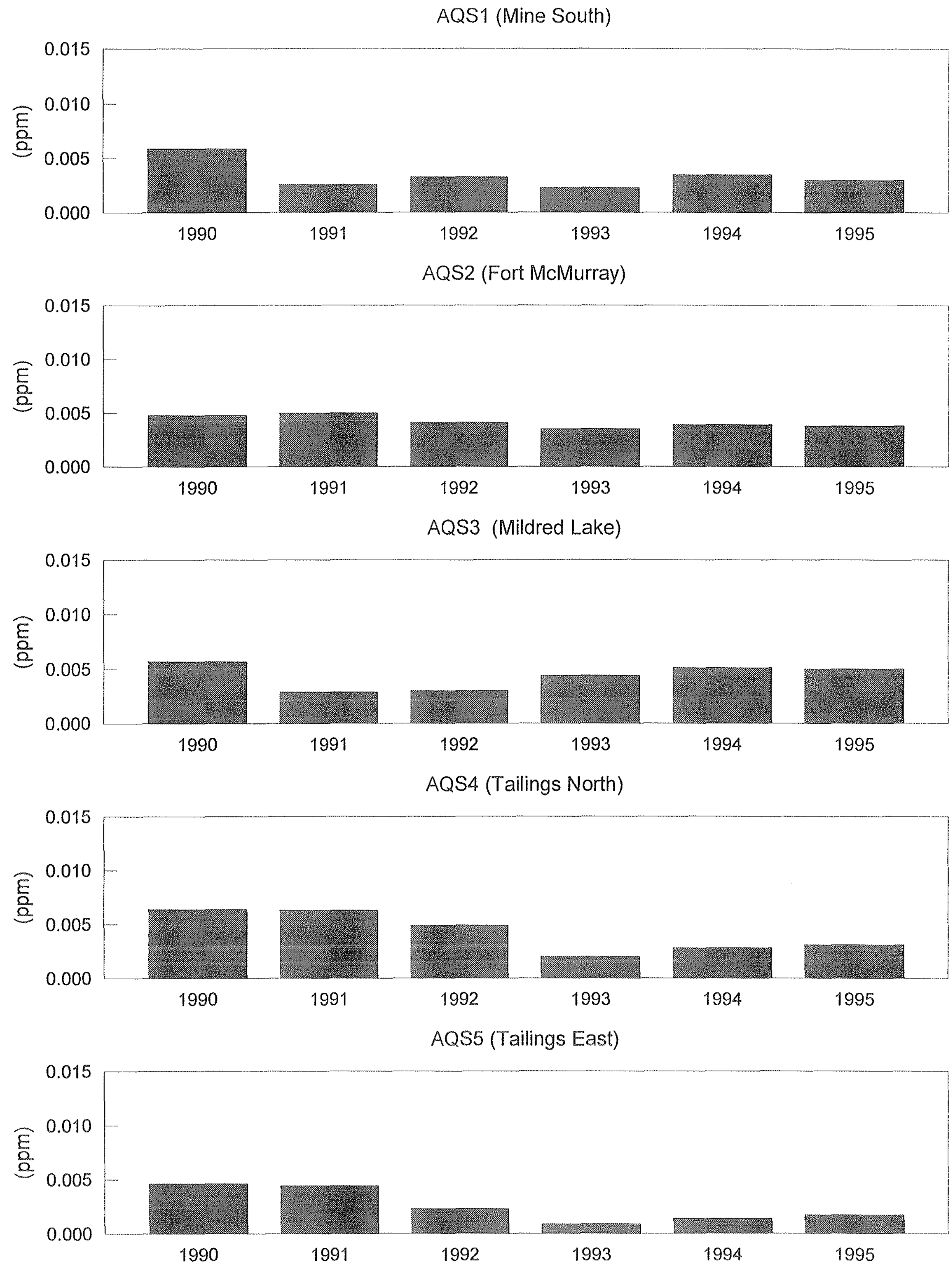


Figure 4.15 Annual average SO_2 concentrations observed at each of the Syncrude ambient air monitoring stations.

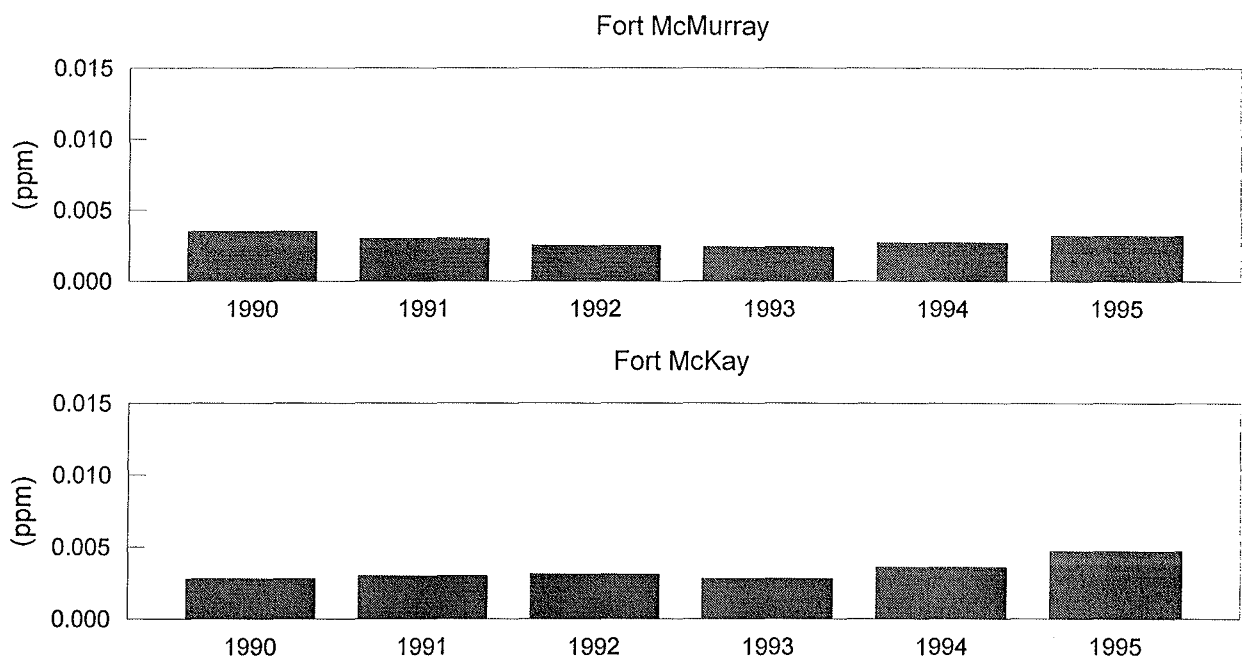


Figure 4.16 Annual average SO_2 concentrations observed at each of the Alberta Environmental Protection air monitoring stations.

A review of the Suncor monitoring stations indicates an increase in the annual average for 1995 (Figure 4.14), especially at Mannix and Lower Camp. This trend was not observed at Syncrude stations where the largest values were observed in 1990 and 1991 (Figure 4.15). The Alberta Environmental Protection Fort McKay station showed the trend for larger values in 1995. At all stations, except Lower Camp in 1995, the average concentration is less than the 0.010 ppm guideline.

5.0 HYDROGEN SULPHIDE (H_2S)

The air quality data from the continuous H_2S analyzers were reviewed to determine the magnitudes and frequencies of relatively large H_2S concentrations. In particular, all hours when the hourly average H_2S concentration exceeded 0.01 ppm (10 ppb or 14 $\mu g/m^3$) were identified. The observed H_2S concentrations were compared to regulatory guidelines. Trends with respect to meteorology and time of occurrence were also determined.

The tables and figures in this section are based on computer databases provided by Syncrude, Suncor and AEP. Some discrepancies between values provided in the supplied computer database files and those contained in the respective annual and monthly reports were found. Follow-up discussions with Syncrude and Suncor were required to resolve these differences.

5.1 Comparison to Air Quality Guideline

Table 5.1 provides a summary of the number of hours per year when the 0.01 ppm guideline as a one-hour average was exceeded for each monitoring station. Over the 5-½ year period, the average number of hourly exceedences is 86 per year with a minimum value of 7 (1992) and a maximum value of 242 (1990). Most of the exceedences occurred at the Mannix (total = 161; average annual = 29), Lower Camp (total = 115; average annual = 21) and AQS3 (total = 89; average annual = 16) and Mildred Lake (total = 89; average annual = 16) stations. The fewest exceedences were observed at Fort McKay (total = 3; average annual = 0.5) and AQS5 or Tailings East (total = 3; average annual = 0.5).

5.2 Trends with Time and Meteorology

H_2S exceedence hours were classified according to month, time of day, wind speed and wind direction to identify trends. The analysis results in a histogram format are presented on a station-by-station basis in the following figures:

- Figure 5.1 Suncor Mannix (#2)
- Figure 5.2 Suncor Lower Camp (#4)
- Figure 5.3 Suncor Fina (#5)
- Figure 5.4 Suncor Poplar Creek (#9)
- Figure 5.5 Suncor Athabasca Bridge (#10)
- Figure 5.6 Syncrude AQS1 (Mine South)
- Figure 5.7 Syncrude AQS2 (Fort McMurray)
- Figure 5.8 Syncrude AQS3 (Mildred Lake)
- Figure 5.9 Syncrude AQS4 (Tailing North)
- Figure 5.10 Syncrude AQS5 (Tailing East)
- Figure 5.11 Fort McMurray (FMMU)
- Figure 5.12 Fort McKay (FRMU)

Table 5.1 Number of hourly H_2S concentrations greater than 0.01 ppm (10 ppb or 14 g/m^3).

Station	1990	1991	1992	1993	1994	1995[(a)]	Total	Average
Mannix (#2)	44	37	5	24	42	9	161	29
Lower Camp (#4)	100	7	0	2	2	4	115	21
Fina (#5)	-	-	-	-	2	0	2	1.8
Poplar Creek (#9)	0	15	1	0	0	4	20	3.6
Athabasca Bridge (#10)	1	0	0	1	2	2	6	1.1
AQS1 (Mine South)	10	2	0	4	10	0	26	4.7
AQS2 (Fort McMurray)	3	0	0	3	13	0	19	3.5
AQS3 (Mildred Lake)	80	4	1	3	1	0	89	16
AQS4 (Tailing North)	2	1	0	5	6	2	16	2.9
AQS5 (Tailing East)	0	1	0	0	0	2	3	0.5
Fort McMurray (FMMU)	1	5	0	0	5	0	11	2.0
Fort McKay (FRMU)	1	0	0	0	0	2	3	0.5
Total	242	72	7	42	83	25	471	86

(a) Up to June 30, 1995.

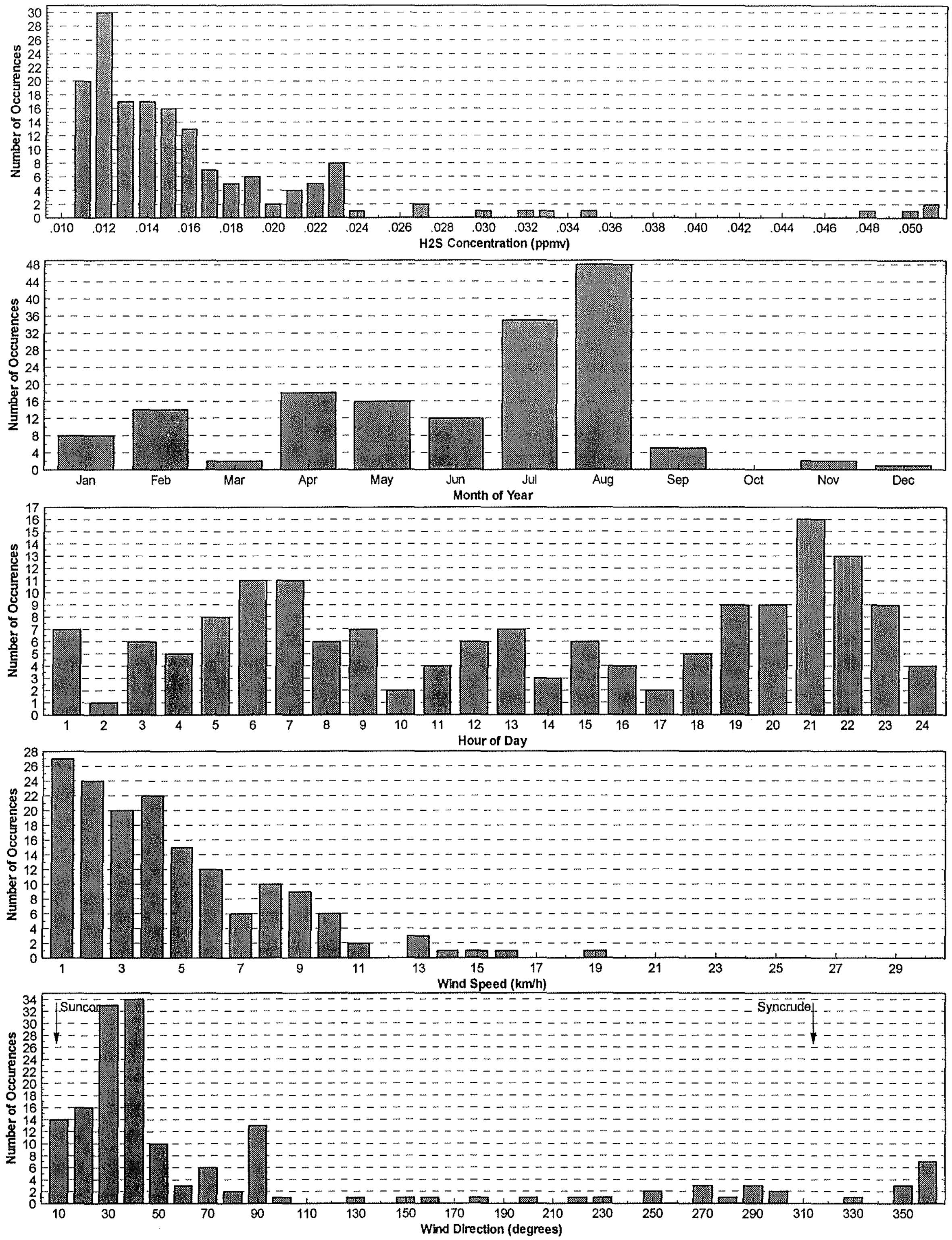


Figure 5.1 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Suncor (Station #2) Mannix (January 1990 to June 1995).

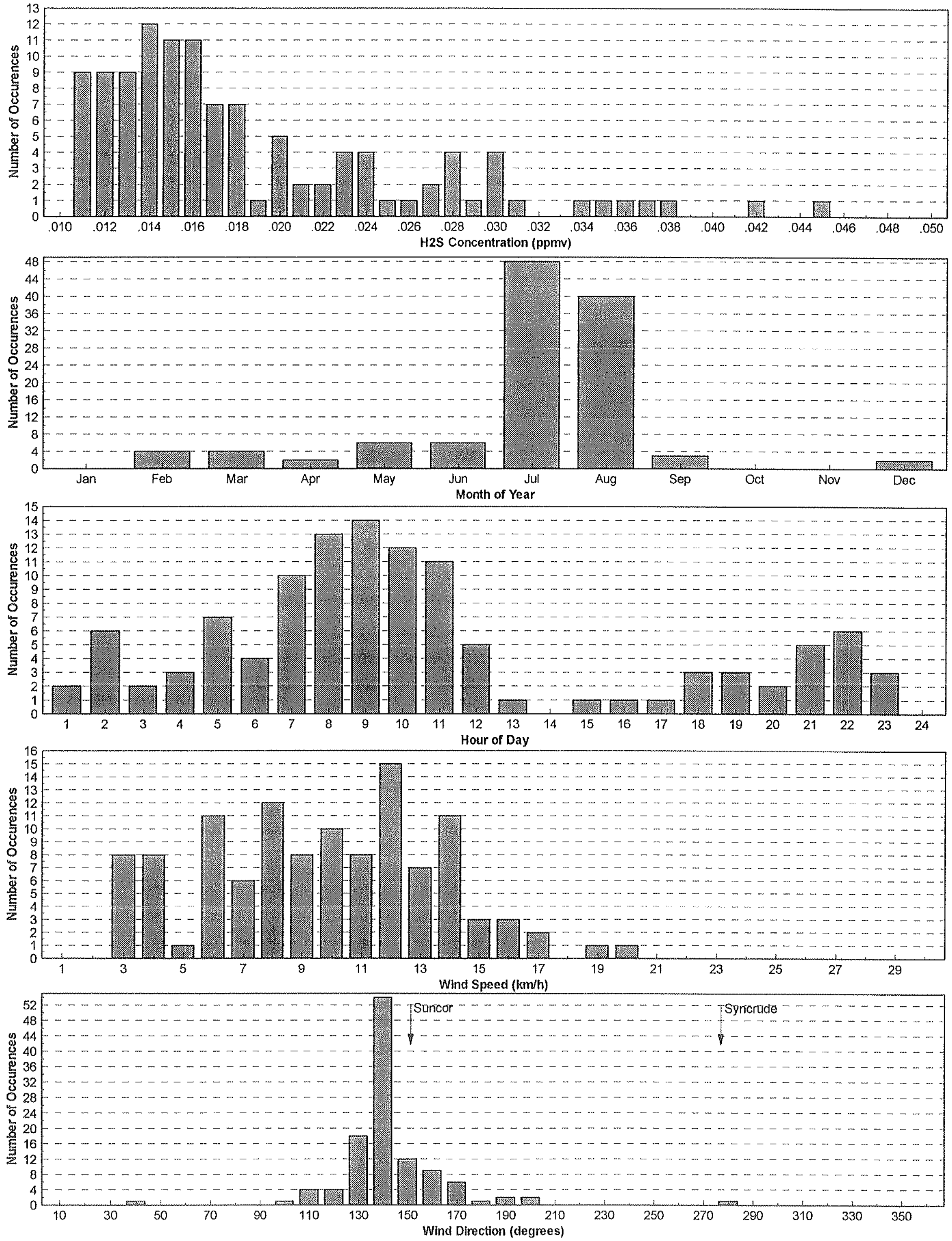


Figure 5.2 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Suncor (Station #4) Lower Camp (January 1990 to June 1995).

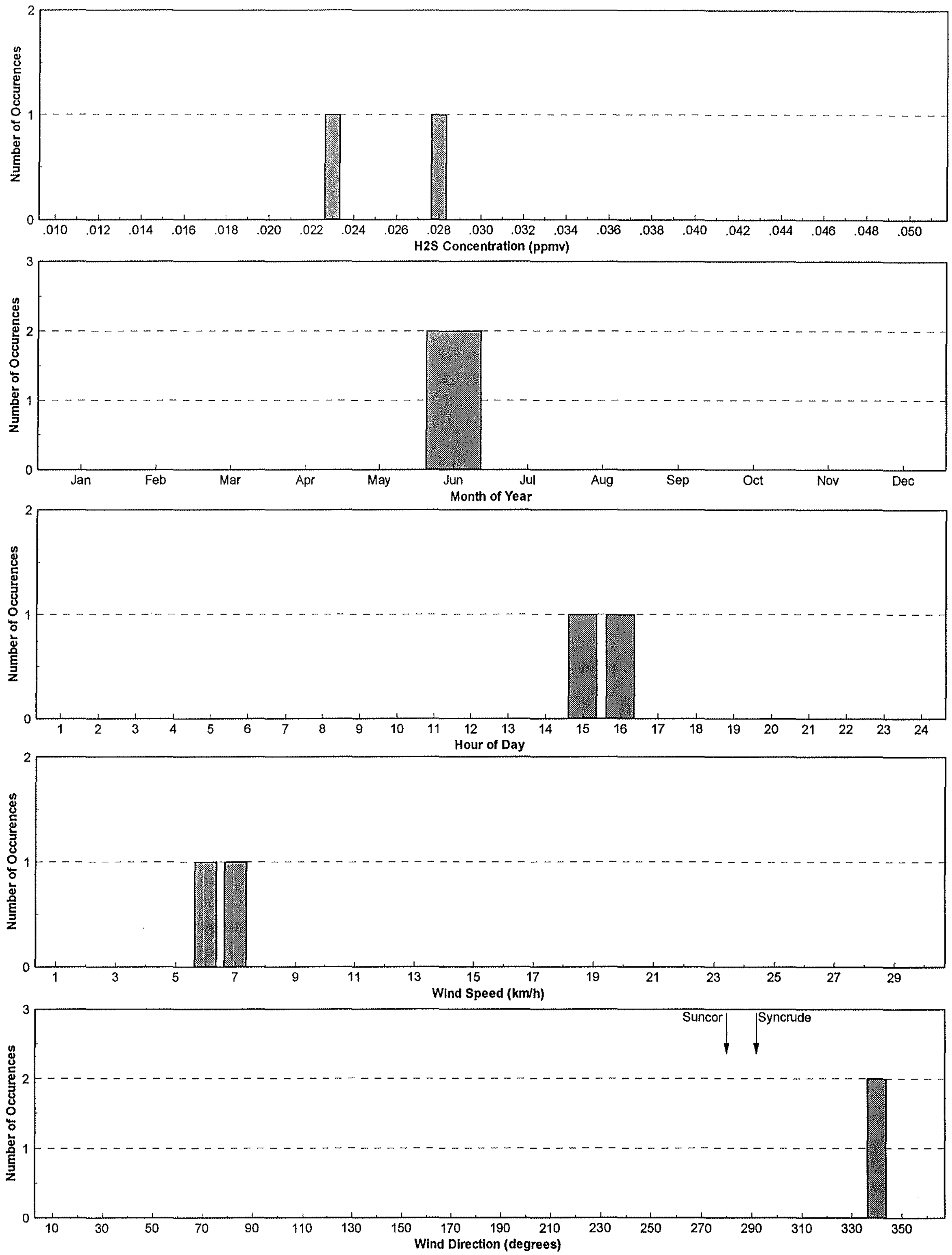


Figure 5.3 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Suncor (Station #5) Fina (January 1990 to June 1995).

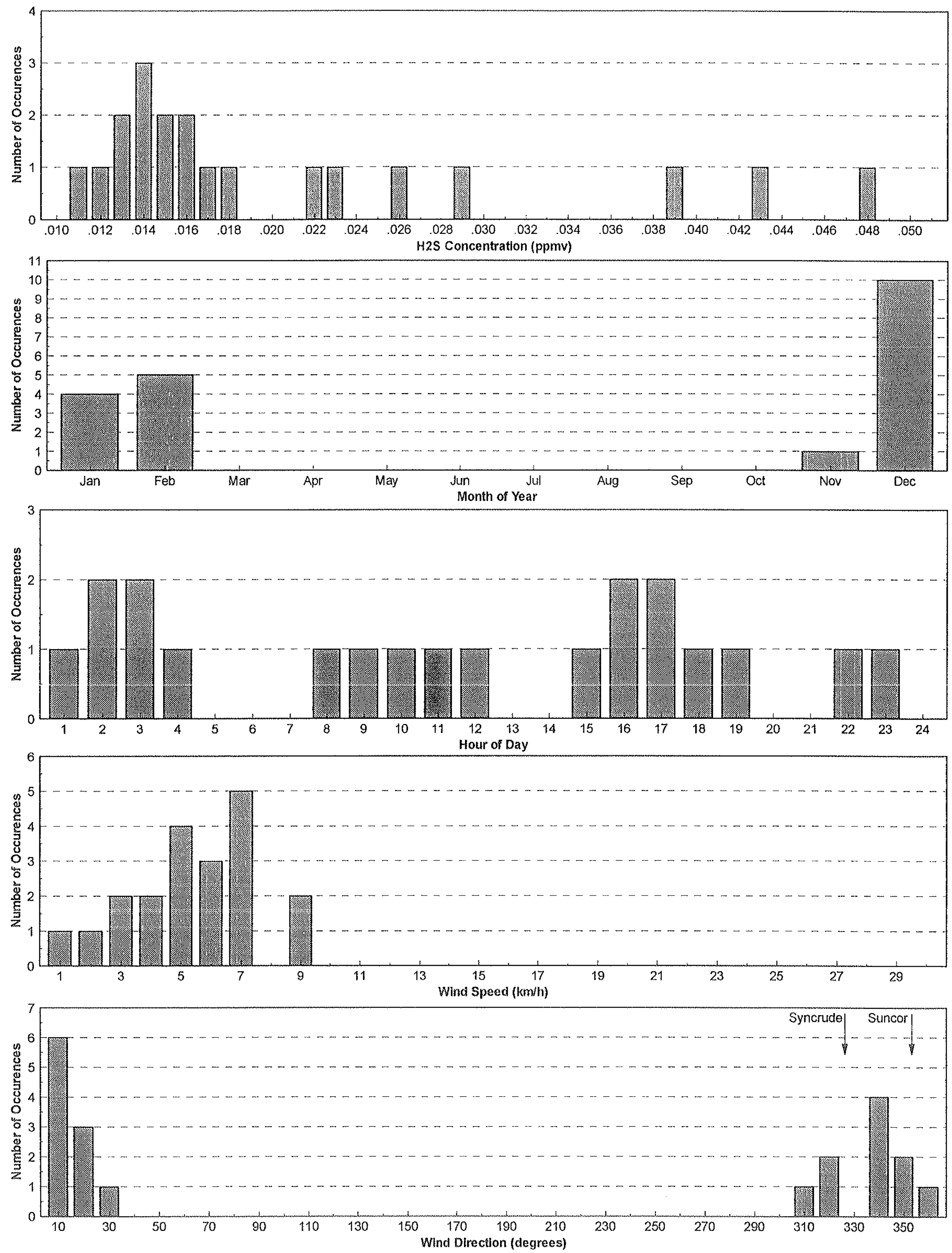


Figure 5.4 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Suncor (Station #9) Poplar Creek (January 1990 to June 1995).

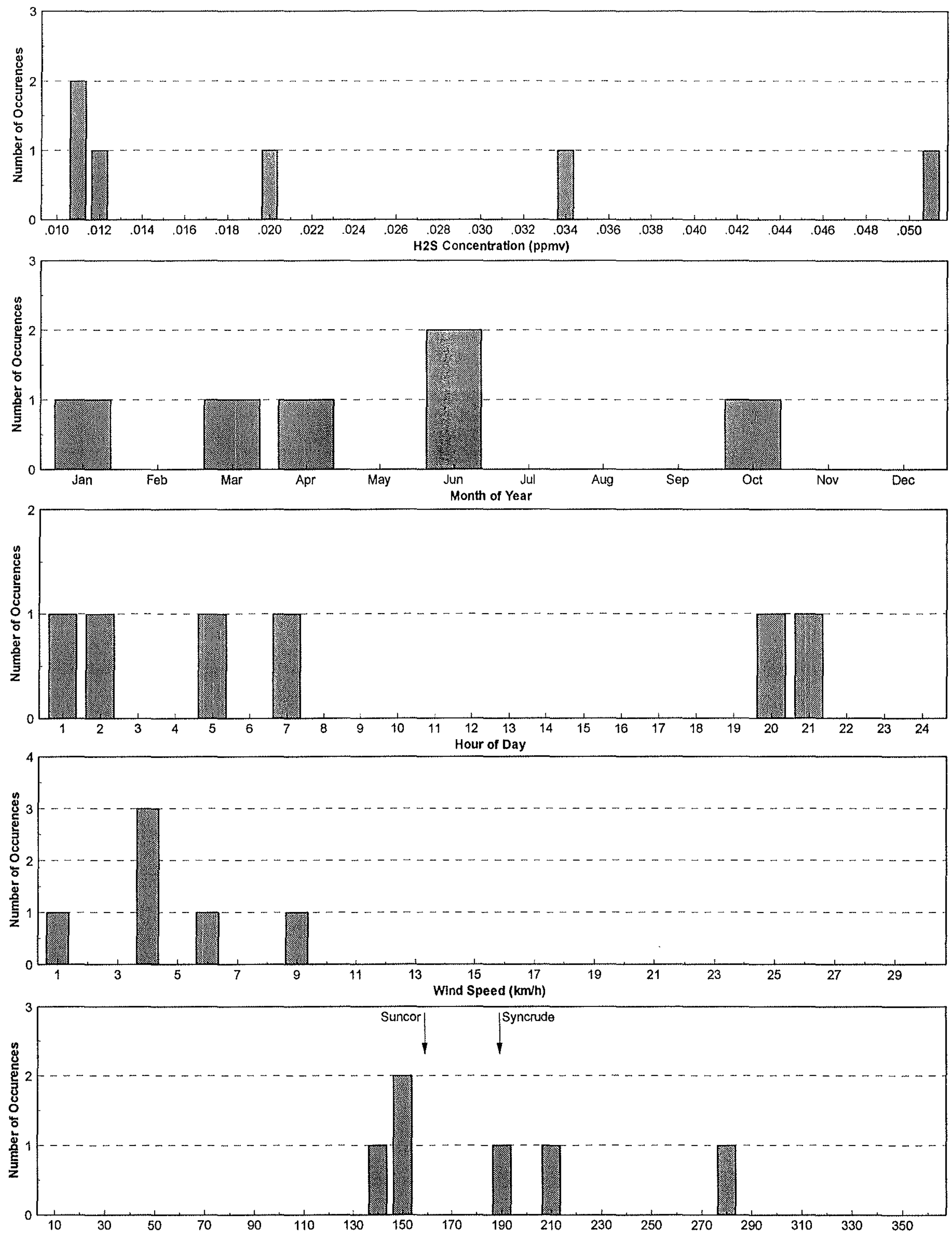


Figure 5.5 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Suncor (Station #10) Athabasca Bridge (January 1990 to June 1995).

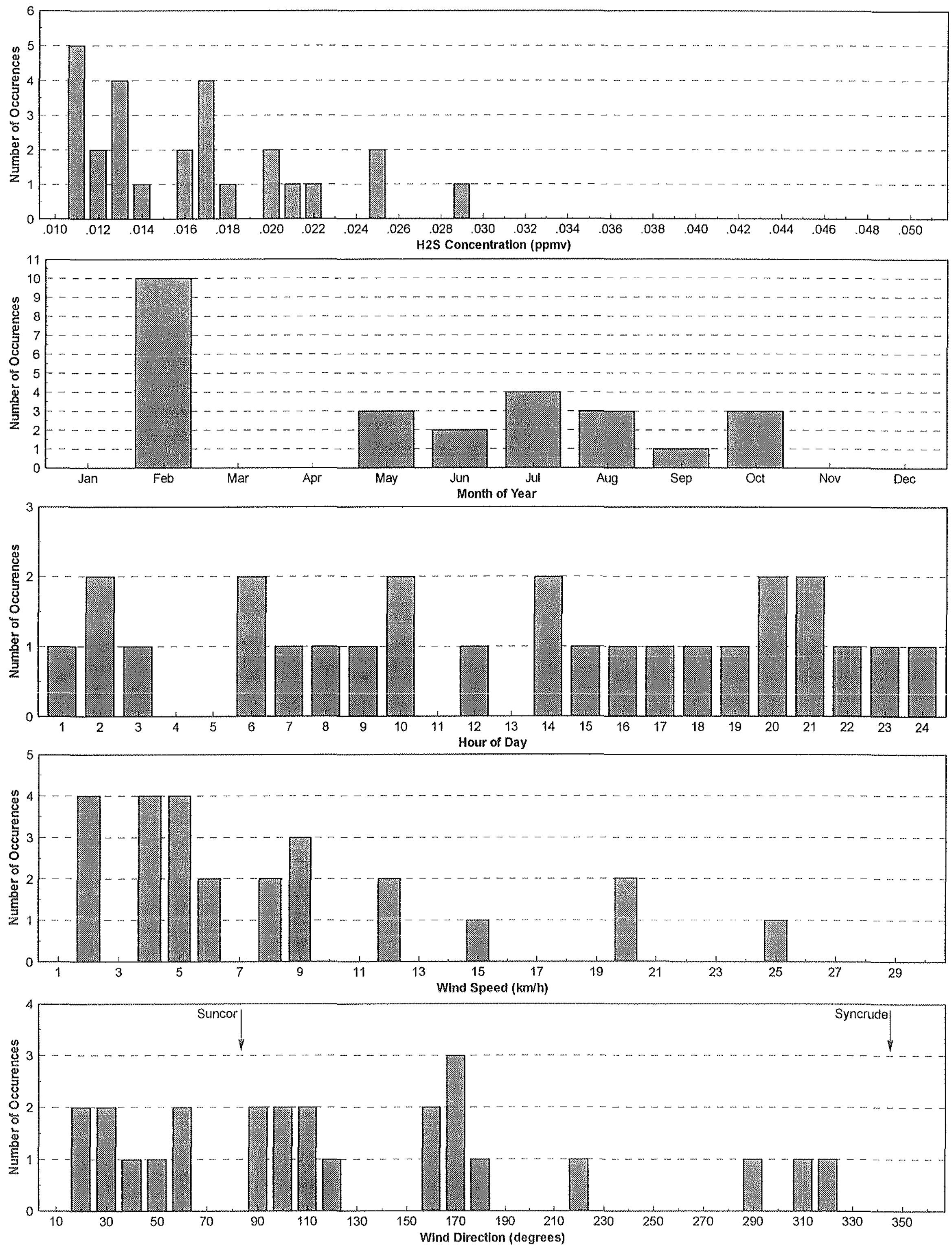


Figure 5.6 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Syncrude AQS1 (Mine South) (January 1990 to June 1995).

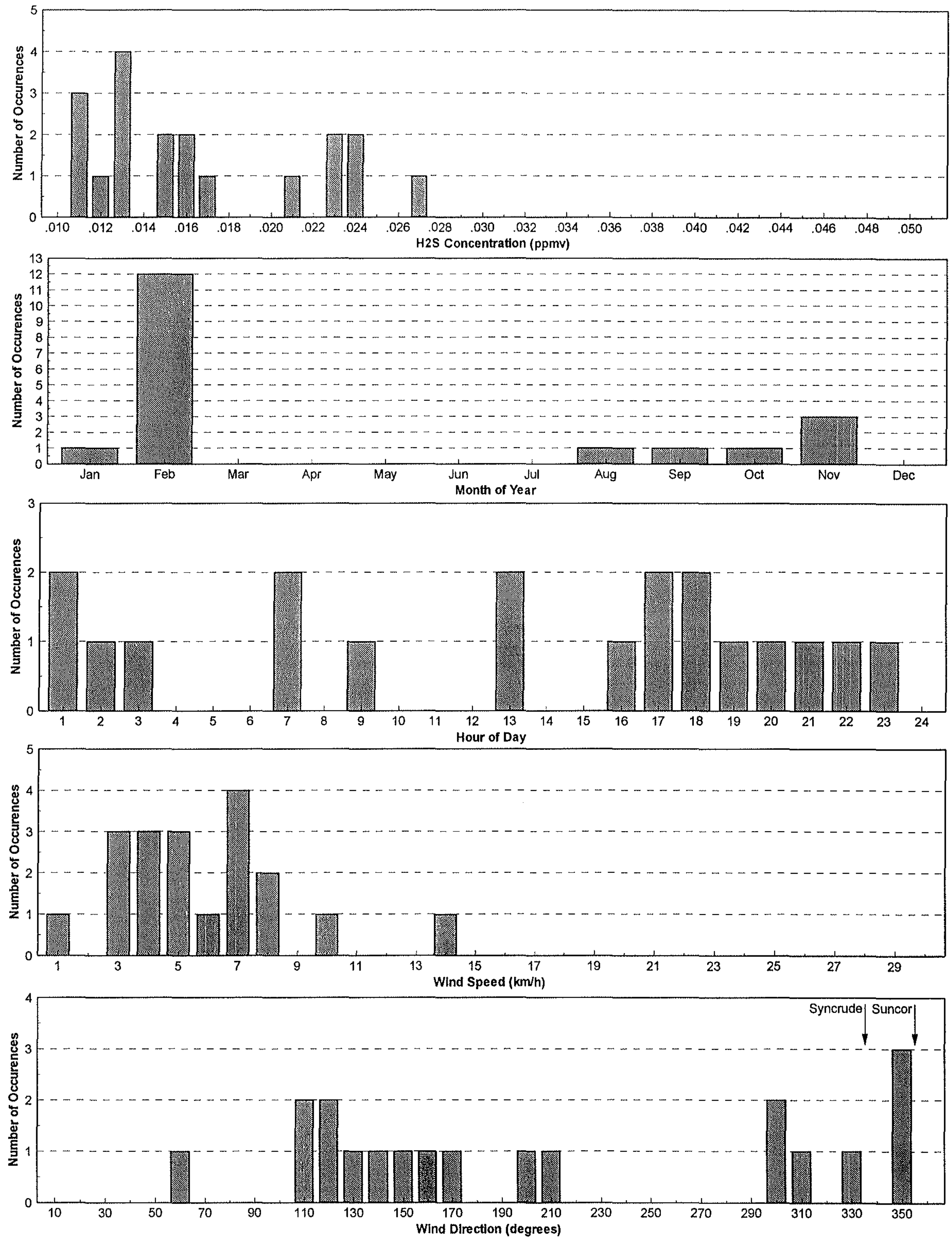


Figure 5.7 Hourly average H_2S concentrations greater than 0.17 ppm and associated conditions at Syncrude AQS2 (Fort McMurray) (January 1990 to June 1995).

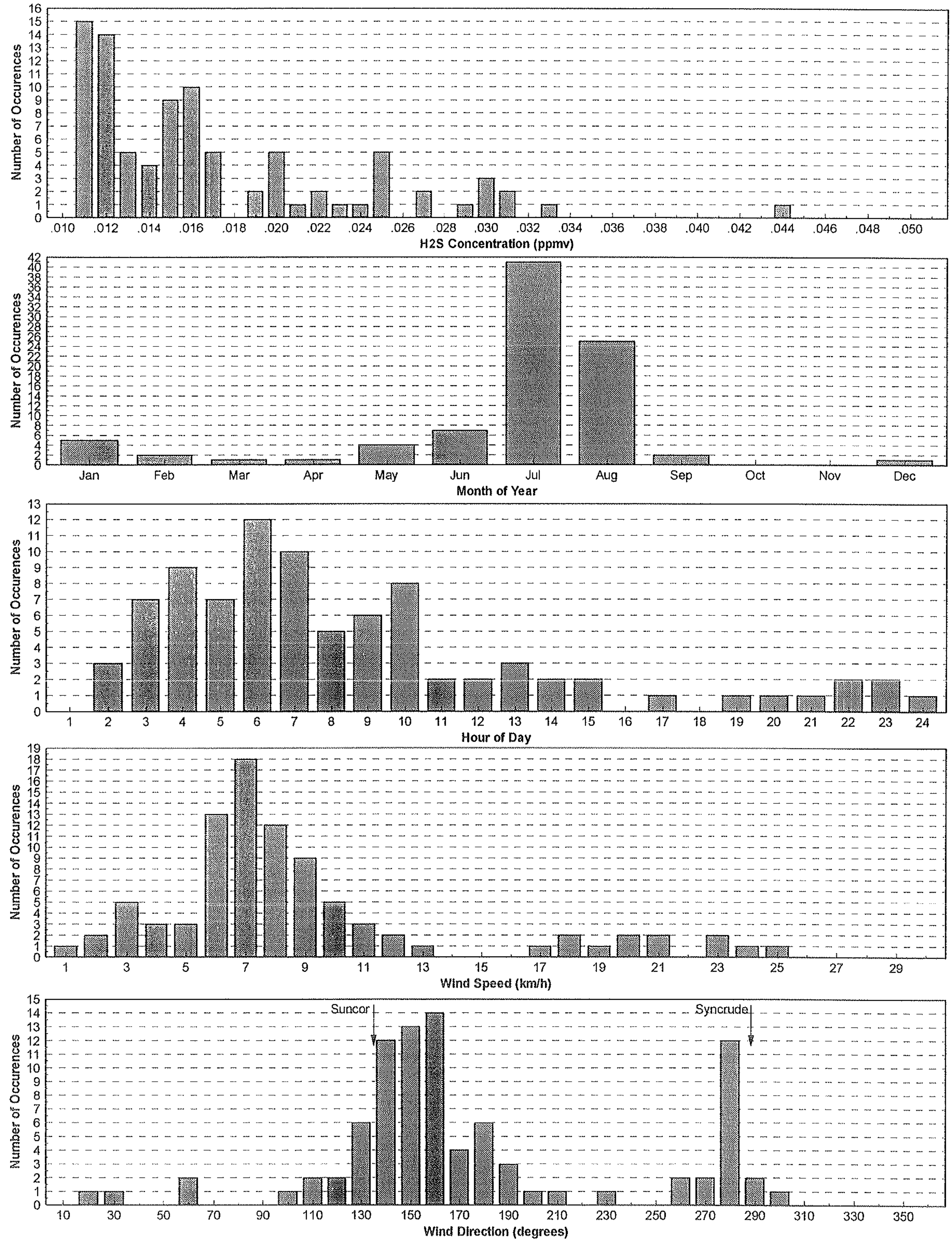


Figure 5.8 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Syncrude AQS3 (Mildred Lake) (January 1990 to June 1995).

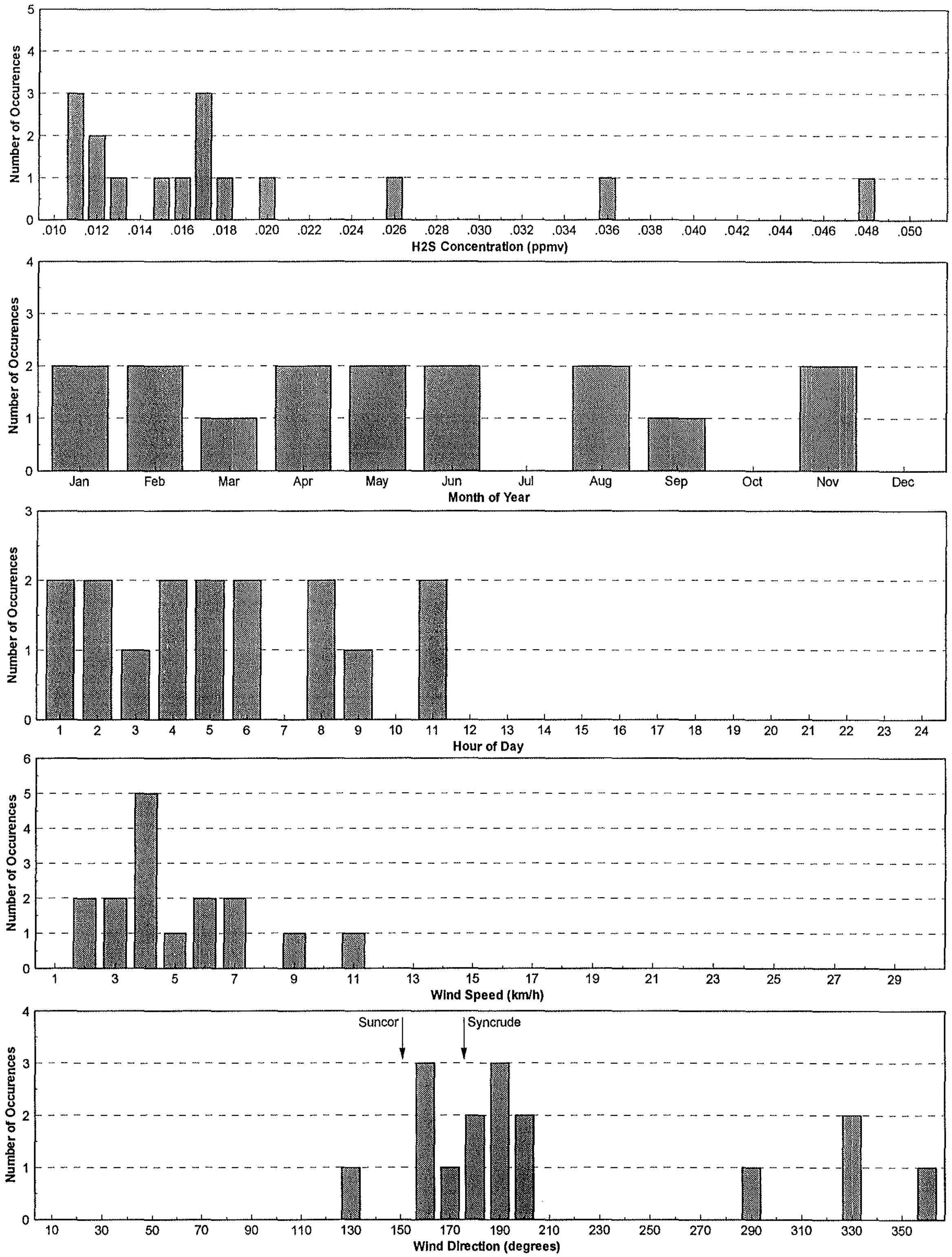


Figure 5.9 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Syncrude AQS4 (Tailings North) (January 1990 to June 1995).

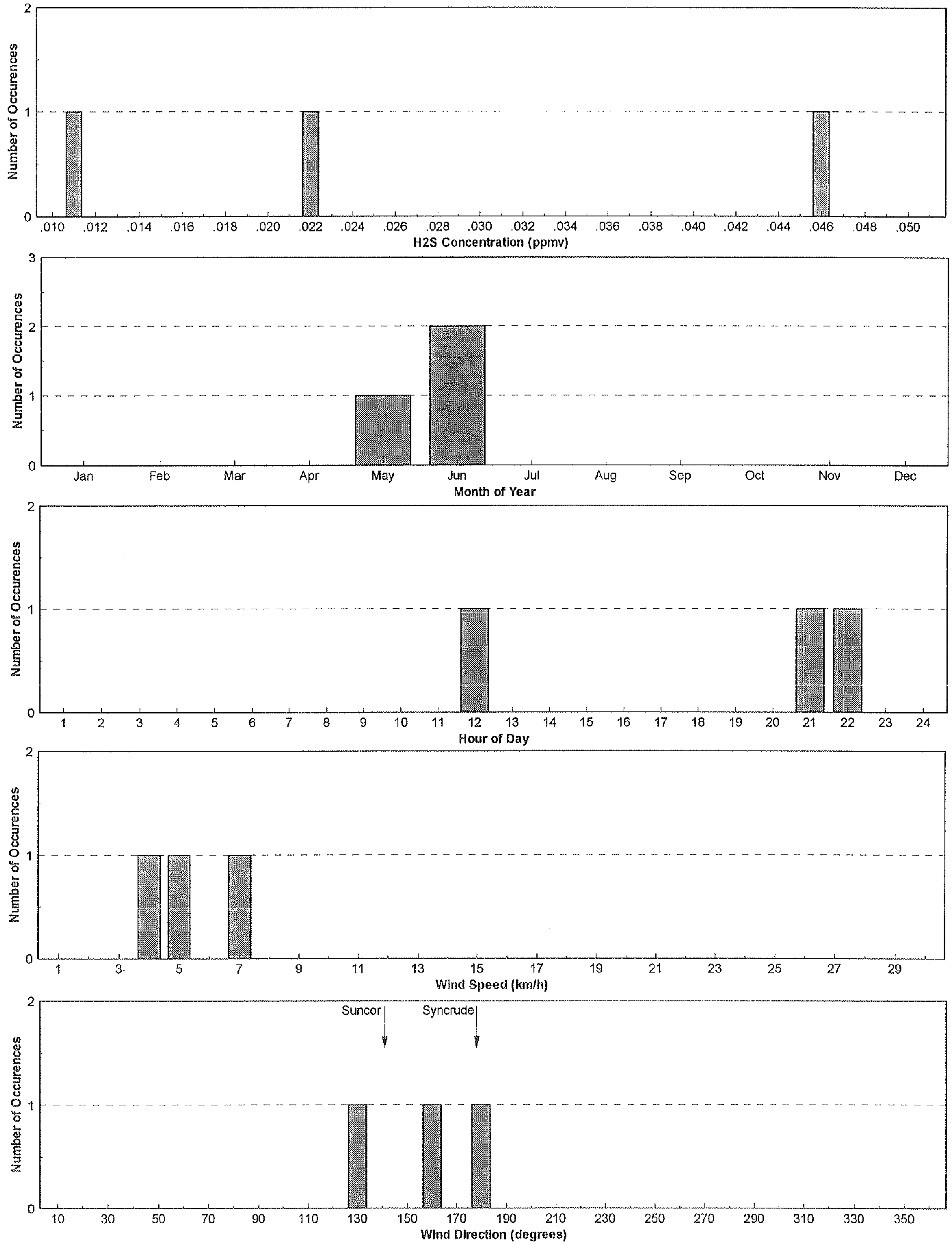


Figure 5.10 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Syncrude AQS5 (Tailings East) (January 1990 to June 1995).

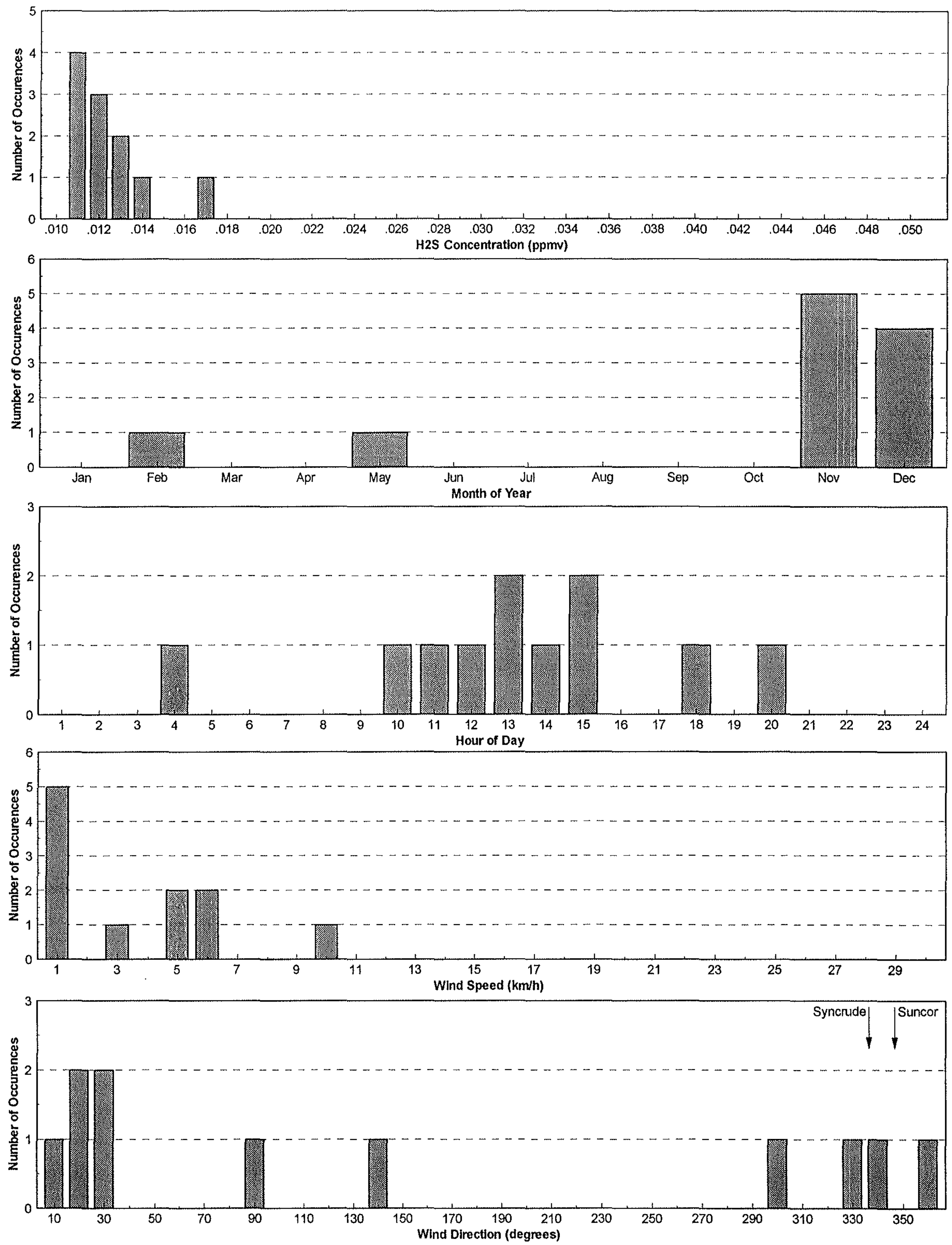


Figure 5.11 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Fort McMurray (FMMU) (January 1990 to June 1995).

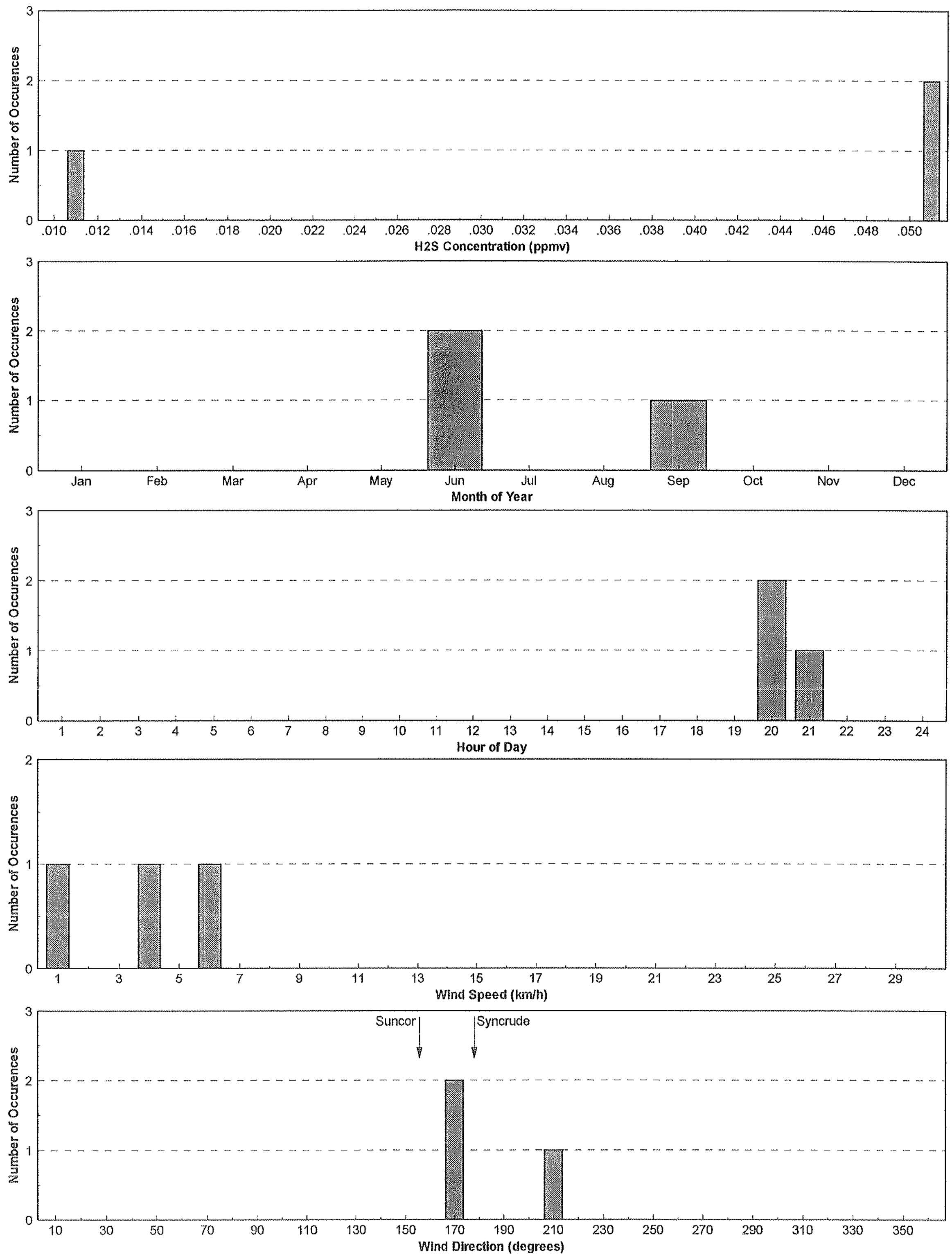


Figure 5.12 Hourly average H_2S concentrations greater than 0.010 ppm and associated conditions at Fort McKay (FRMU) (January 1990 to June 1995).

The trends identified from these figures are summarized in Table 5.2 and are repeated below:

- The largest hourly average H_2S concentrations (greater than 50 ppb) were observed at Athabasca Bridge (100 ppb), Lower Camp (75 ppb), Mannix (68 ppb) and Fort McKay (71 ppb).
- The values of the median exceedences are in the 12 to 25 ppb range. The two 1995 occurrences of H_2S at Fort McKay are in excess of 50 ppb and result in a median value for the site of 71 ppb.
- Exceedences are most frequently observed during the summer (June, July, August) period.
- Exceedences were observed during the night-time more frequently than during the day-time.
- Exceedences were generally associated with wind speeds less than 8 km/h (2.2 m/s).
- In some cases, the exceedences were clearly related to the location of the plant, while in other cases, the wind relationships were not as good.

In summary, the high H_2S concentrations that are observed in the region are, for the most part, well correlated with one of the two oil sand plants being clearly located upwind, with night-time hours and with wind speeds less than 8 hr/h. High concentrations tend to be observed more frequently during the summer months.

The trends associated with high H_2S concentrations are different from those associated with high SO_2 concentrations. The day-time occurrence of high SO_2 values result in elevated emissions under convective and/or trapping conditions. The night-time occurrence of high H_2S values indicates low-level sources of H_2S that is transported downwind from the plants under stable atmospheric conditions.

5.3 Annual Trends

While the annual average concentrations computed from the continuous analyzers are of limited use from an absolute perspective, they can be used in a relative sense to help identify year-to-year trends. Figures 5.13 to 5.15 show the annual average H_2S concentrations observed at each of the 12 monitoring stations. The 1995 values shown in the figures are based on six months of data.

Table 5.2 Summary of time and conditions associated with hourly average H_2S concentrations in excess of 0.010 ppm (10 ppb or 14 $\mu g/m^3$) for the 5-½ year period January 1, 1990 to June 30, 1995.

Station	Number of Exceedences (h)	Number of Exceedences (h/a)	Maximum Concentration (ppb)	Median Exceedence (ppb)	Month	Hour	Wind Speed (km/h)	Direction (degrees)
Suncor								
Mannix (#2)	161	29	68	14	July, Aug.	5 to 7, 19 to 23	1 to 6	10 to 40
Lower Camp (#4)	115	21	75	16	July, Aug.	5 to 11	3 to 14	140
Fina (#5)[a]	2	1.8	28	25	June	15, 16	6, 7	340
Poplar Creek (#9)	20	3.6	48	16	Dec.	2 to 3, 16, 17	5 to 7	340 to 10
Athabasca Bridge (#10)	6	1.1	100	16	June	20 to 7	1 to 9	150
Syncrude								
AQS1 (Mine South)	26	4.7	29	16	Feb.	all	2 to 9	170
AQS2 (Fort McMurray)	19	3.5	27	15	Feb.	varied	3 to 7	350
AQS3 (Mildred Lake)	89	16	44	15	July, Aug.	3 to 10	6 to 9	130 to 160, 280
AQS4 (Tailing North)	16	2.9	48	17	All	1 to 11	1 to 7	160 to 200
AQS5 (Tailing East)	3	0.5	46	22	May, June	21, 22	4 to 7	130 to 180
AEP								
Fort McMurray	11	2.0	17	12	Nov., Dec.	13, 14	1 to 6	360 to 30
Fort McKay	3	0.5	71	63	June	20, 21	1 to 6	170 to 210

[a] This station only measured H_2S values for the period May 1994 to June 1995.

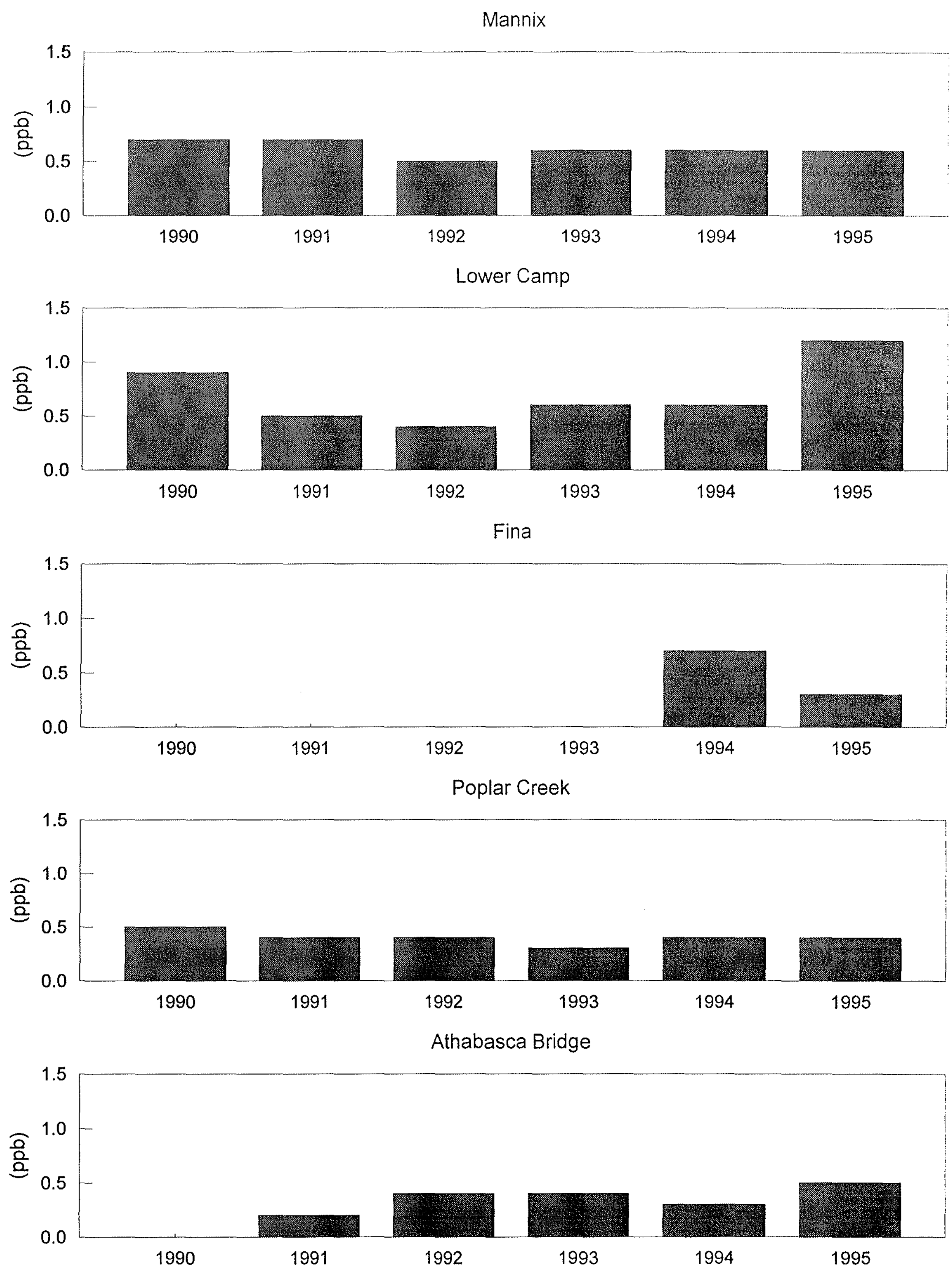


Figure 5.13 Annual average H_2S concentrations observed at each of the Suncor ambient air quality monitoring stations.

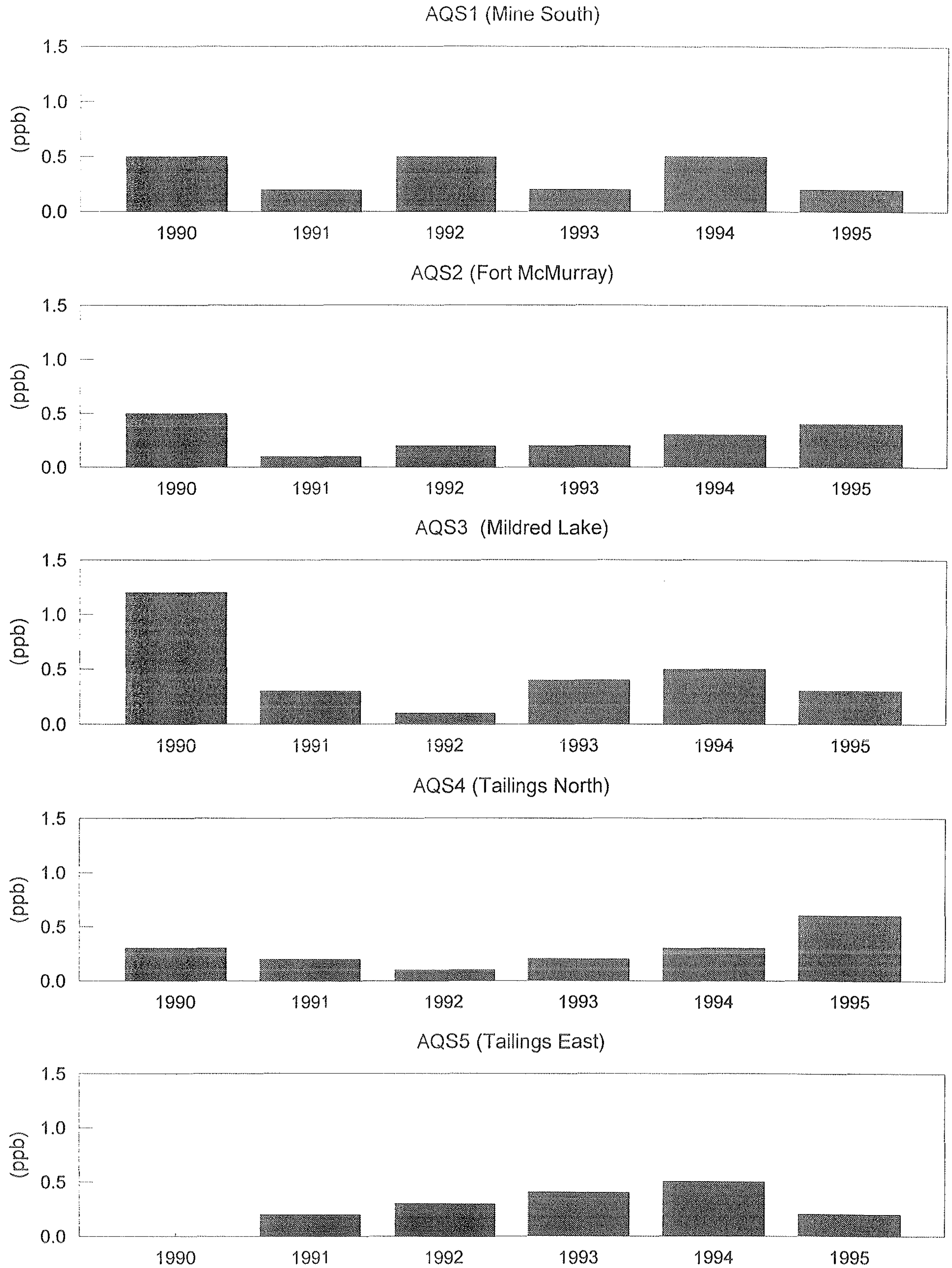


Figure 5.14 Annual average H_2S concentrations observed at each of the Syncrude ambient air monitoring stations.

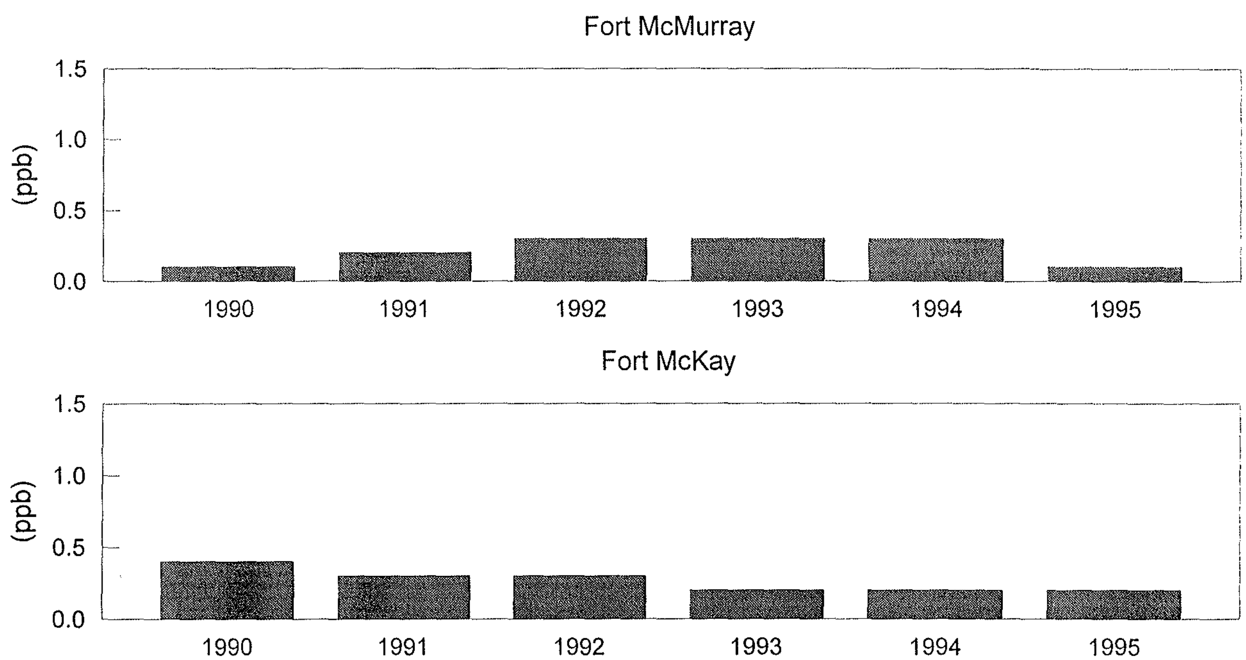


Figure 5.15 Annual average H_2S concentrations observed at each of the Alberta Environmental Protection air monitoring stations.

A review of the Suncor stations (Figure 5.13) showed an increase in the annual average in 1995 (Figure 5.14) for Lower Camp and Athabasca Bridge. A decrease was noted at Fina. A review of the Syncrude stations (Figure 5.14) showed an increase at AQS4 in 1995. The largest values were observed in 1990 at Mildred Lake. The Alberta Environmental Protection 1995 values are relatively low when compared to other years (Figure 5.15).

6.0 OXIDES OF NITROGEN (NO_x)

Only the Syncrude AQS4 (Tailings North) and the AEP Fort McMurray stations monitor for oxides of nitrogen (NO_x). The Syncrude station reports total NO_x while the AEP Fort McMurray station reports NO_x, NO and NO_2.

6.1 Comparison to Air Quality Guidelines

For this comparison the Syncrude data were conservatively assumed to be equivalent to NO_2 and only the AEP NO_2 data were compared to the NO_2 air quality objective of 0.21 ppm (400 $\mu g/m^3$). On this basis, two Syncrude NO_x values exceeded 0.21 ppm with the maximum being 0.24 ppm. These values were attributed to exhausts from vehicles parked and left running adjacent to the air monitoring station in December 1993. The maximum NO_2 concentration observed in Fort McMurray was 0.22 ppm, which was also the only value in excess of 0.21 ppm occurring the 5-½ year period.

6.2 Trends with Time and Meteorology

To identify trends according to month, time of day, wind speed and wind direction, hourly data when the NO_x concentration exceeded 0.21 ppm were reviewed. Only data from the Fort McMurray site were considered for the analysis presented in Figure 6.1. The results indicate:

- High NO_x concentrations were observed most frequently during the winter (November to February).
- High NO_x concentrations occurred most frequently during morning to late evening hours 0800 to 2400.
- High NO_x concentrations were associated with light wind speeds of 1 km/hr (0.28 m/s).
- High NO_x concentrations were associated with winds from the east to south (90 to 180°).

In summary, maximum NO_x concentrations are associated with light wind speeds in the evening hours of winter months and easterly to southerly wind directions. The likely sources of the high NO_x values observed in Fort McMurray are residential wood combustion and/or local traffic.

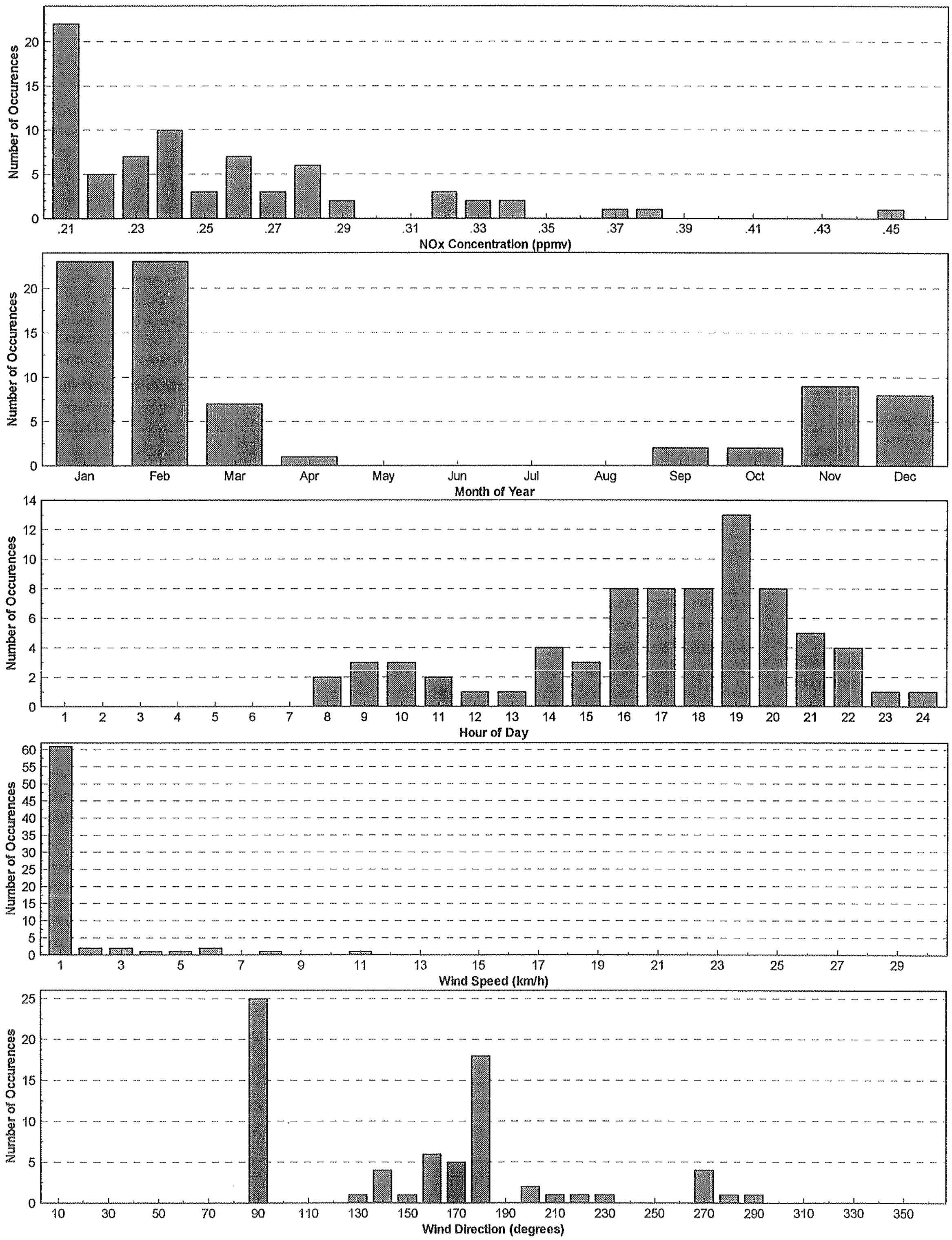


Figure 6.1 Hourly average NO_x concentrations greater than 0.21 ppm and associated conditions at AEP Fort McMurray station (January 1990 to June 1995).

6.3 NO_x and NO_2 Relationships

Most of the NO_x emitted from combustion sources is in the form of nitric oxide (NO) and reactions in the atmosphere result in the formation of nitrogen dioxide (NO_2) through the following chemical reaction:

$$NO + O_3 \rightarrow NO_2 + O_2$$

Figure 6.2 shows the relationship between the NO_2/NO_x ratio and the NO_x concentration. The median NO_2/NO_x ratio decreases with increasing NO_x concentrations. For low NO_x concentrations, about 80% of the NO_x is in the form of NO_2. For larger NO_x concentrations, about 20% of the NO_x is in the form of NO_2. The general relationship depicted in Figure 6.2 is based on observations in Fort McMurray that likely result from local traffic emissions.

6.4 Synergistic Effects

The World Health Organization (WHO) guidelines for vegetation imply that ambient air quality objectives may have to be more stringent in areas where two or more contaminants may be present. For example, WHO recommends that simultaneous occurrences of NO_2 and SO_2 should not individually exceed 0.05 ppm in order to protect vegetation from potentially adverse effects. The Clean Air Strategy (CASA) Report for Alberta Report to the Ministers (1991) states that injury to sensitive vegetation can occur with simultaneous occurrences of NO_2 and SO_2 of 0.05 ppm and 0.10 ppm, respectively.

The following table indicates the number of one hour periods over the 5-½ year period when these simultaneous events occurred where both SO_2 and NO_x were measured:

Station	AQS4 (Tailings North)	Fort McMurray (AEP)
NO_2 greater than 0.05 ppm	76	84
SO_2 greater than 0.05 ppm	372	174
SO_2 greater than 0.10 ppm	61	20
Both NO_2 and SO_2 greater than 0.05 ppm	4	0
NO_2 greater than 0.05 ppm and SO_2 greater than 0.10 ppm	4	0

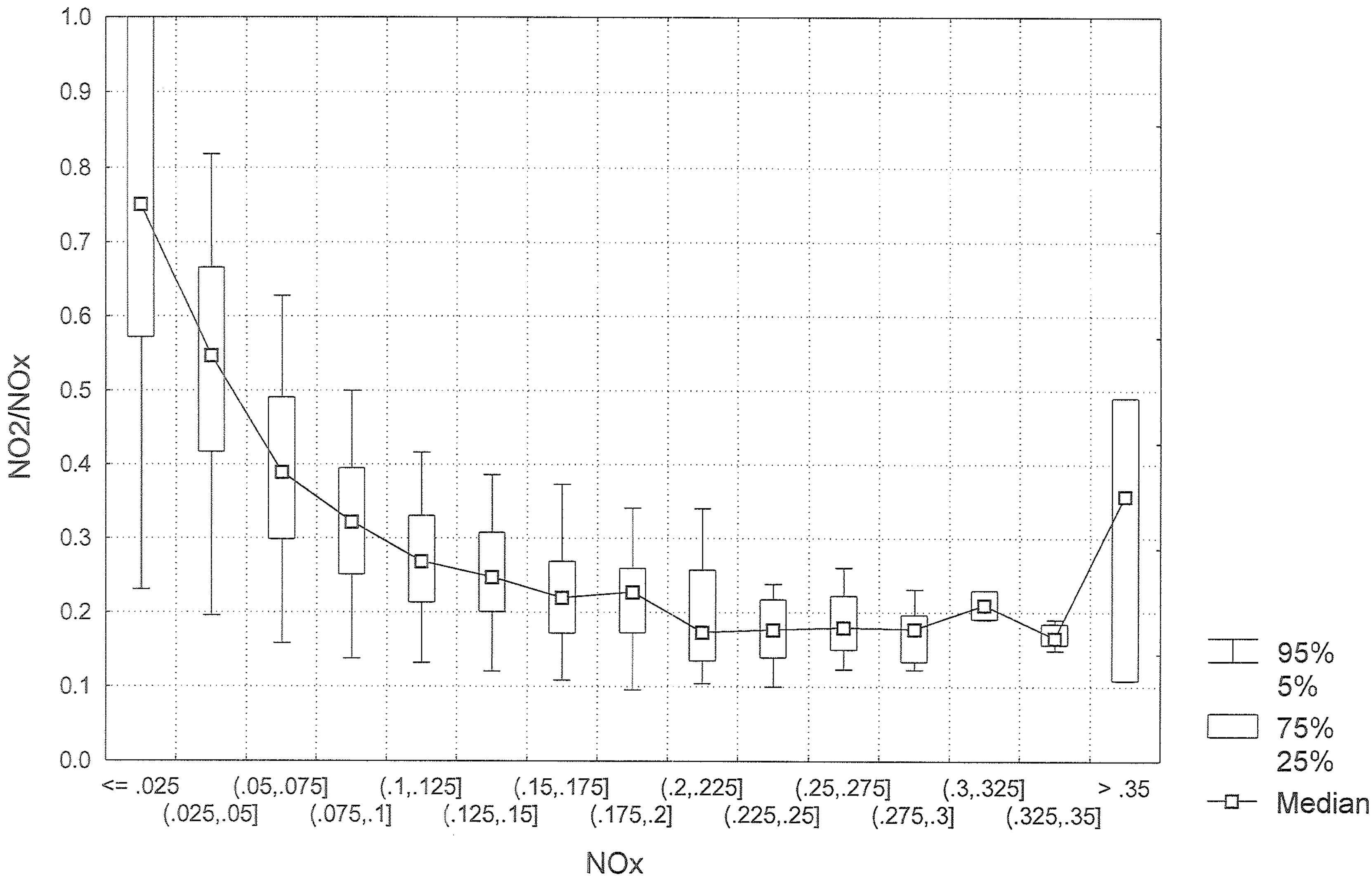


Figure 6.2 Median NO_2/NO_x ratio as a function of NO_x concentrations based on observations at Fort McMurray.

For the AQS4 site, NO_x was conservatively used as a surrogate for NO_2. The results are based on 5-½ years of data which indicate that the WHO and CASA criteria are met at the Fort McMurray station.

In summary, higher NO_x concentrations are observed in Fort McMurray than near Fort McKay (Syncrude AQS4; Tailings North). The high concentrations observed in Fort McMurray are likely associated with local traffic. At the monitoring locations, it is unlikely that adverse synergistic effects to vegetation could result from simultaneous exposures to both SO_2 and NO_2.

6.5 Annual Trends

While the annual average concentrations computed from the continuous analyzers are of limited use from an absolute perspective, they can be used in a relative sense to help identify year-to-year trends. Figure 6.3 shows the annual average NO_x and NO_2 concentrations observed. The 1995 values shown in the figures are based on six months of data.

The results presented in Figure 6.3 indicate a slightly decreasing trends at Fort McMurray. The annual average values at Fort McMurray are much larger than those observed at the Syncrude AQS4 (Tailings North) site. All annual average values are well below the annual air quality guideline of 0.03 ppm.

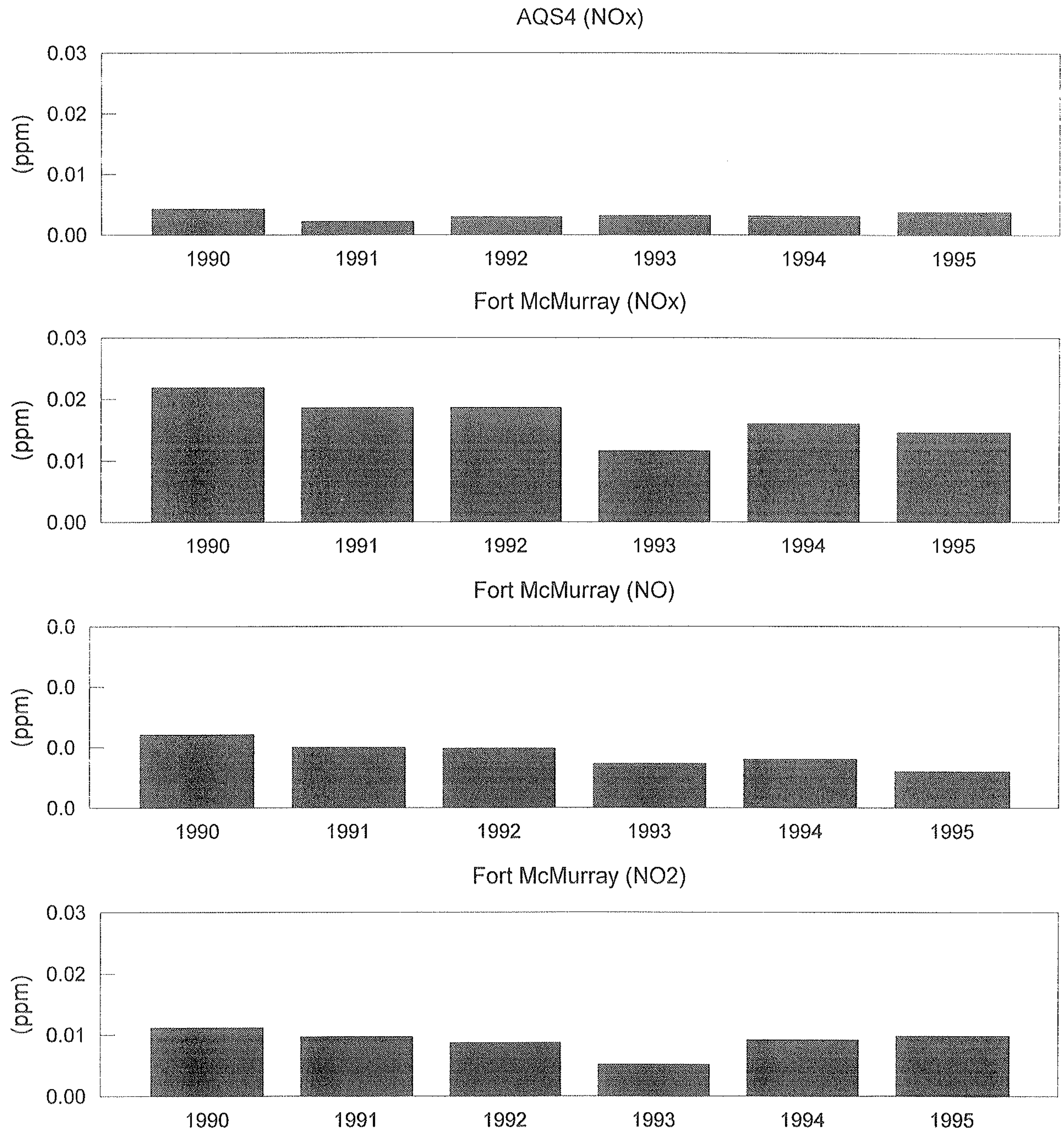


Figure 6.3 Annual average NO_x, NO and NO_2 concentrations observed at AQS4 and Fort McMurray.

7.0 OZONE (O_3)

Ozone concentrations are only measured at the AEP Fort McMurray station. The tables and figures in this section are based on computer databases provided by Alberta Environmental Protection (AEP). Some discrepancies between values provided in the supplied computer database files and those contained in the annual reports were found.

7.1 Comparison to Air Quality Guidelines

All hours when the hourly average O_3 concentration exceeded 0.08 ppm (160 $\mu g/m^3$ or 80 ppb) and all days when the daily average O_3 concentration exceeded 0.025 ppm (50 $\mu g/m^3$ or 25 ppb) were identified. Table 7.1 shows the observed number of exceedences in Fort McMurray. The results indicate the mean and median O_3 values are 23 and 22 ppb, respectively. Maximum hourly values range from 59 to 91 ppb over the period January 1990 to June 1995. There have been 20 exceedences (annual average = 3.6) of the AEP 1-hour guideline of 80 ppb since 1990. Maximum daily values ranged from 43 to 68 ppb. The average number of days when the daily average O_3 concentration exceeded 25 ppb is 135 days per year. The annual average O_3 concentration of 23 ppb has remained relatively constant over the period depicted in Table 7.1.

7.2 Trends with Time and Meteorology

The exceedence hours were classified according to month, time of day, wind speed and wind direction. The analysis which is presented in Figure 7.1 indicates:

- High ozone concentrations are associated with the late spring and summer months (April to July).
- High ozone concentrations are associated with afternoon hours (13 to 18).
- High ozone concentrations are associated with light wind speeds in the 1 to 5 km/h range (0.3 to 1.4 m/s).
- There does not appear to be a significant wind direction trend for high ozone concentrations.

High ozone concentrations have been observed in rural areas of Alberta (Angle and Sandhu 1986, Peake and Fong 1990). Exceedences of the guideline occur more frequently in rural than in urban areas such as Calgary and Edmonton. Exceedences of the daily guidelines have been observed 50 to 90% of the time in rural Alberta areas compared with only 10 to 40% of the time in urban areas (Angle and Sandhu 1989).

Table 7.1 Summary of hourly and daily O_3 concentrations observed at Fort McMurray.

Station	1990	1991	1992	1993	1994	1995[a]	Combined
Hourly Statistics							
Mean (ppb)	25	22	21	22	24	25	23
Median (ppb)	22	21	20	21	22	23	22
Maximum (ppb)	89	65	59	91	77	71	91
N ≥ 80 ppb (h/a)	16	0	0	4	0	0	3.6
Daily Statistics							
Mean (ppb)	25	22	21	22	24	25	23
Median (ppb)	23	22	21	21	23	25	22
Maximum (ppb)	68	43	43	54	58	50	68
N ≥ 25 (ppb) (d/a)	156	131	91	127	153	86	135

[a] Up to June 30, 1995.

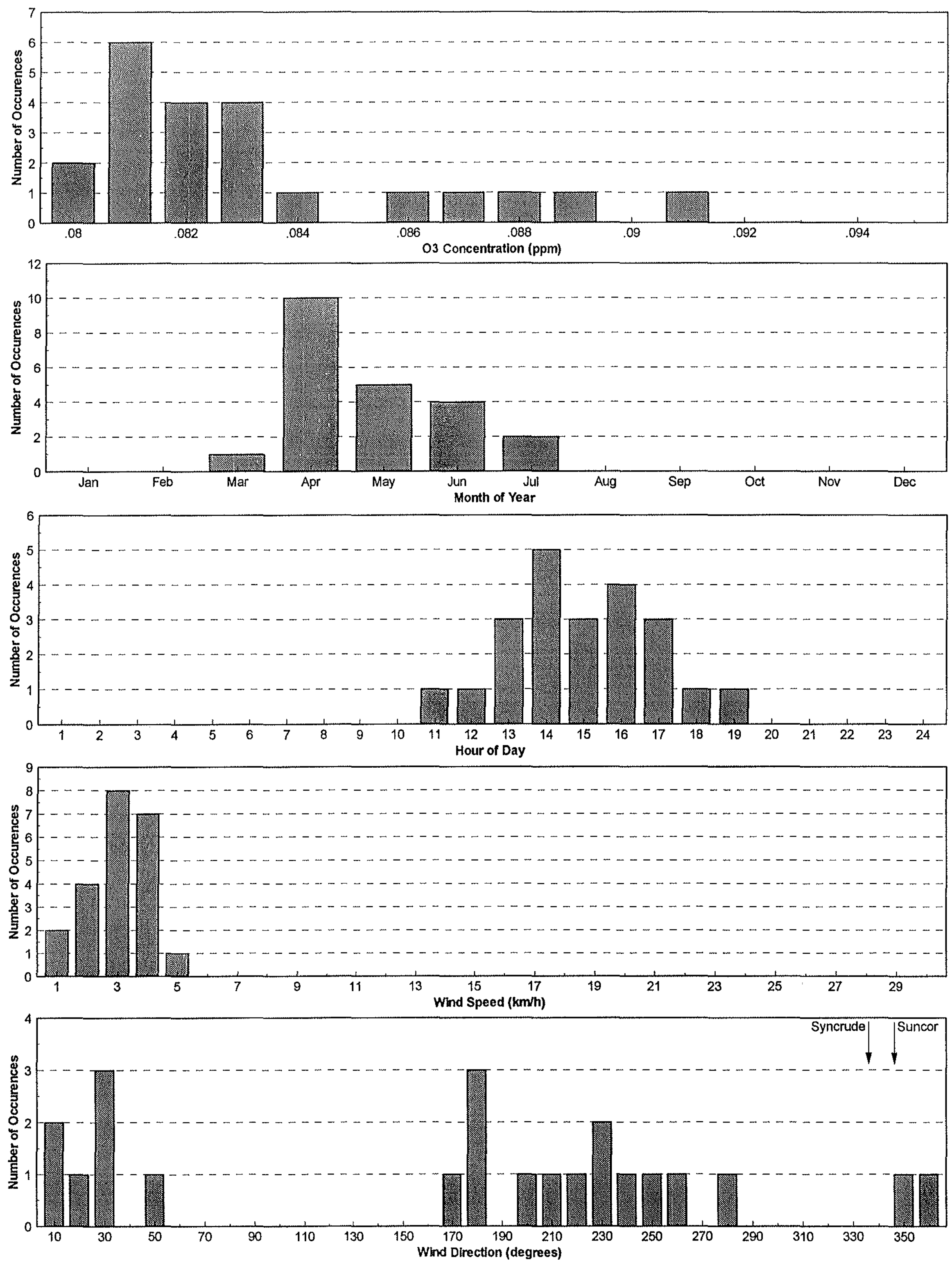


Figure 7.1 Hourly average O_3 concentrations greater than 80 ppm and associated conditions observed at Fort McMurray (January 1990 to June 1995).

7.3 Protection of Sensitive Vegetation

Lefohn (1992) presented maximum ozone concentration criteria (ppb) for the protection of vegetation based on the duration of the exposure and the resistance level of the vegetation:

Exposure Period (h)	Vegetation Resistance		
	Sensitive	Intermediate	Less Sensitive
1	75	180	250
2	60	130	200
4	50	100	180

The ozone observations from Fort McMurray were reviewed to determine the frequencies that these events were exceeded:

Exposure Period (h)	O_3 Concentration (ppb)	Frequencies (event/a)	Vegetation Resistance
1	75	10	Sensitive
2	60	66	Sensitive
4	50	80	Sensitive
1	180	0	Intermediate
2	130	0	Intermediate
4	100	0	Intermediate
1	250	0	Less Sensitive
2	200	0	Less Sensitive
4	180	0	Less Sensitive

This information is based on 5-½ years of data and indicates that the O_3 concentration criteria may be exceeded for sensitive vegetation. Lefohn indicates that hourly ozone concentrations in excess of 50 ppb (the four hour criteria) routinely occur at many clean site locations and that these concentrations are not necessarily associated with anthropogenic emissions.

8.0 CARBON MONOXIDE (CO)

Carbon monoxide concentrations are measured only at Fort McMurray. The figure in this section is based on computer databases provided by Alberta Environmental Protection (AEP).

8.1 Comparison to Air Quality Guidelines

The maximum hourly average value observed at Fort McMurray for the period January 1, 1990 to June 30, 1995 is 7.5 ppm (8.7 mg/m^3). This is much less than the one-hour average guideline value of 13 ppm (15 mg/m^3) for CO.

8.2 Trends with Time and Meteorology

Hours when the CO concentration exceeded 4 ppm were classified according to magnitude, month, time of day, wind speed and wind direction to help identify trends. The analysis which is presented in Figure 8.1 indicates:

- High CO concentrations are associated with the months October to March.
- High CO concentrations are associated with hours 9 to 23.
- High CO concentrations are associated with light wind speeds of 1 to 6 km/h (0.3 to 1.7 m/s).
- High CO concentrations are associated with easterly and southernly wind directions.

Some of the trends associated with CO are similar to those associated with NO_x; there is a tendency for high levels to be observed during the winter period, under low wind speeds and in association with winds from the easterly and southerly directions. Both high NO_x and CO concentrations tend to occur during the evening hours rather than the morning hours. This may suggest that residential wood combustion (during winter evenings) is the potential source for these high values.

The annual average CO concentrations in Fort McMurray has varied between 0.35 to 0.59 ppm with the lowest and highest values occurring in 1993 and 1990, respectively.

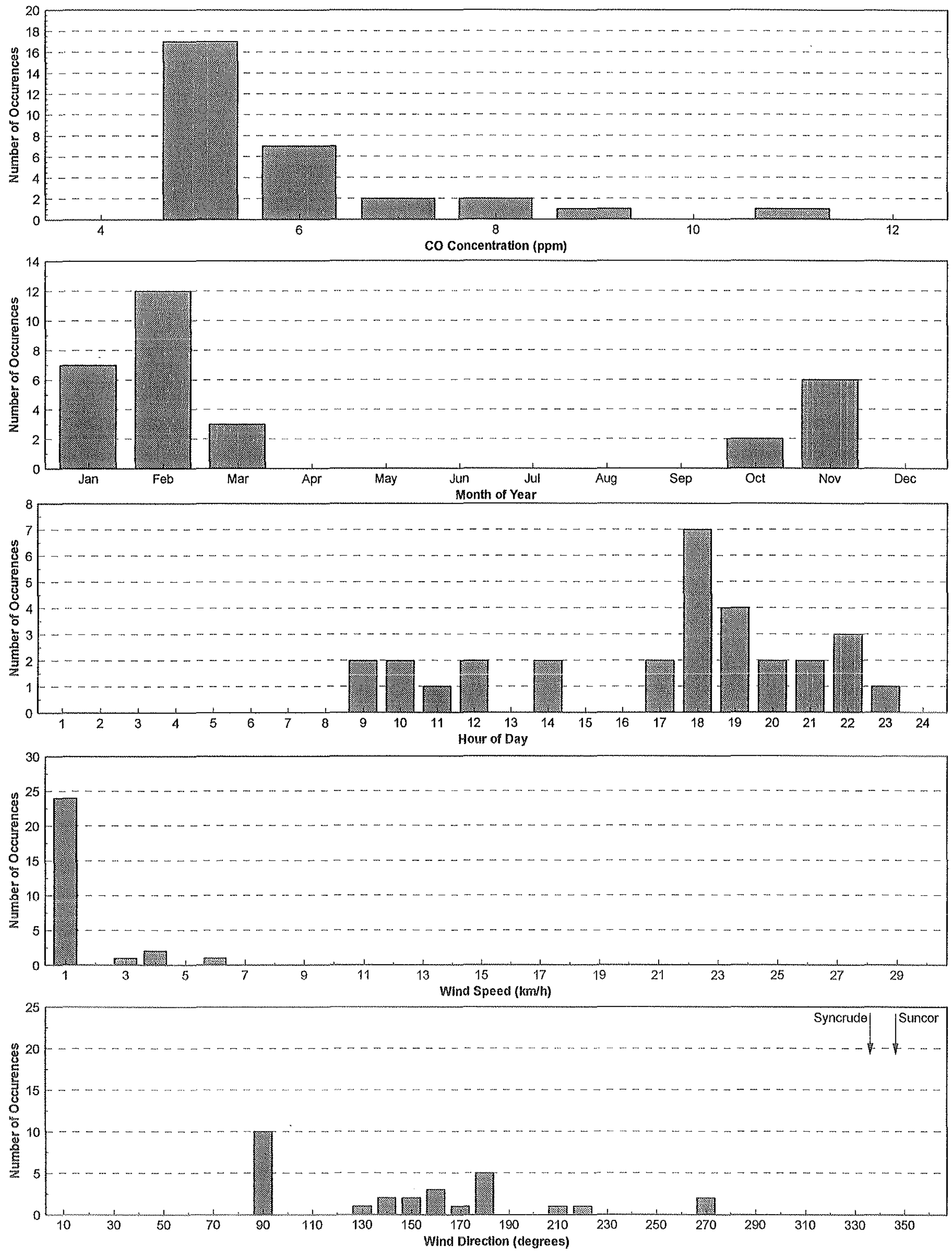


Figure 8.1 Hourly average CO concentrations greater than 4 ppm and associated conditions observed at Fort McMurray (January 1990 to June 1995).

9.0 HYDROCARBON (HC)

Total hydrocarbon data are available from two Syncrude stations, four Suncor stations and the two AEP stations. Total hydrocarbon (THC) includes methane (CH_4) as well as non-methane (NMHC) components. For two of the Suncor stations, Mannix and Lower Camp, data are available for only an 18 month period (May 1994 to June 1995). Because of the short record, a limited analysis of trends associated with these two sites are provided.

9.1 Maximum HC Values

There are no air quality guidelines for either the CH_4 or NMHC components.

Table 9.1 shows the median and maximum THC concentrations observed in the region. The median values range from 1.4 to 2.1 ppm. The median observed values are similar at each of the six stations. In general, maximum observed THC concentrations are in the 3 to 15 ppm range, however, three of the reported maxima are in excess of 30 ppm. Maximum THC values in excess of 15 ppm were reported at the Poplar Creek and the Athabasca Bridge monitoring stations.

9.2 Trends with Time and Meteorology

Hours when THC values exceeded 3.0 ppm were classified according to month, time of day, wind speed and wind direction to identify trends. The analysis is presented on a station-by-station basis in the following figures:

- Figure 9.1 Suncor Poplar Creek (#9)
- Figure 9.2 Suncor Athabasca Bridge (#10)
- Figure 9.3 Syncrude AQS2 (Fort McMurray)
- Figure 9.4 Syncrude AQS4 (Tailings North)
- Figure 9.5 AEP Fort McMurray (FMMU)
- Figure 9.6 AEP Fort McKay (FRMU)

The trends depicted in the figures are summarized below:

- Most of the THC values in excess of 3 ppm are less than 4 ppm. The largest reported THC concentrations 34 and 50 ppm were observed at the Suncor Poplar Creek and Athabasca Bridge monitoring stations.

- THC concentrations in excess of 3 ppm are associated with all months of the year, and generally occur most frequently in the October to March period (i.e. non-summer months).

Table 9.1 Median and maximum THC concentrations (ppm).

		Mannix (#2)	Lower Camp (#4)	Poplar Creek (#9)	Athabasca Bridge (#10)	AQS2 (Fort McMurray)	AQS4 (Tailings North)	Fort McMurray (FMMU)	Fort McKay (FRMU)
Median	1990	n/a	n/a	2.0	2.1	n/a[a]	1.8	1.6	1.8
	1991	n/a	n/a	1.9	1.7	1.7	1.8	1.6	1.6
	1992	n/a	n/a	1.8	2.0	1.8	2.0	1.8	1.7
	1993	n/a	n/a	1.7	1.9	1.6	1.8	2.0	1.8
	1994	1.7	1.7	1.5	1.6	1.4	1.5	2.2	1.7
	1995	1.9	1.6	1.6	n/a	1.6	1.7	2.0	1.7
Maximum	1990	n/a	n/a	9.0	30.9	n/a	5.9	3.5	4.1
	1991	n/a	n/a	7.4	13.5	4.0	6.1	8.6	3.5
	1992	n/a	n/a	9.1	12.7	3.1	7.0	3.8	3.9
	1993	n/a	n/a	51.4	35.0	3.3	5.7	3.2	3.6
	1994	12.9	14.0	11.1	13.7	4.6	4.3	3.7	3.3
	1995	13.0	7.6	18.6	n/a[a]	2.7	14.6	2.7	3.5

[a] No data collected.

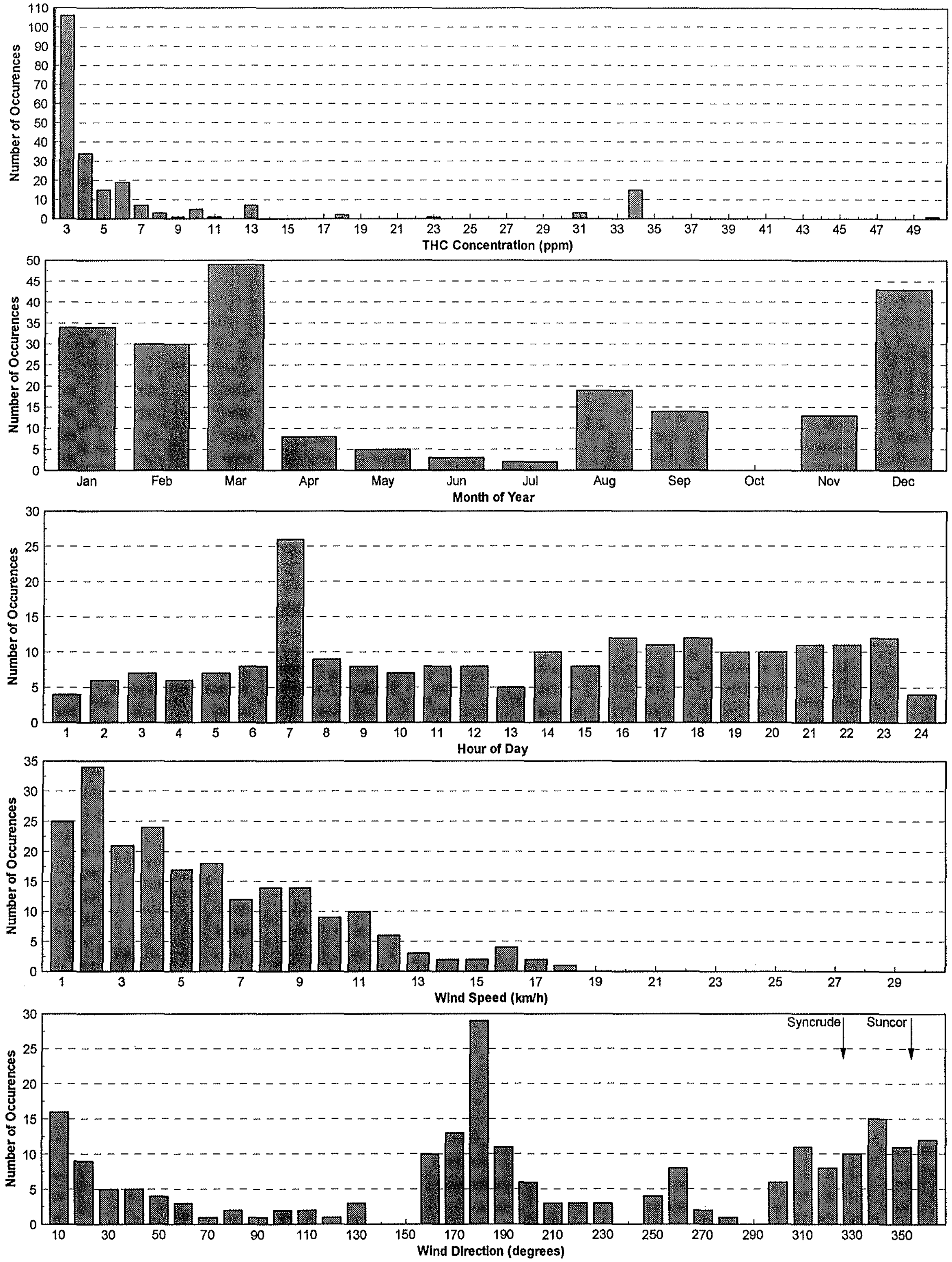


Figure 9.1 Hourly average THC concentrations greater than 3 ppm and associated conditions at the Suncor Poplar Creek (#9) station (January 1, 1990 to June 30, 1995).

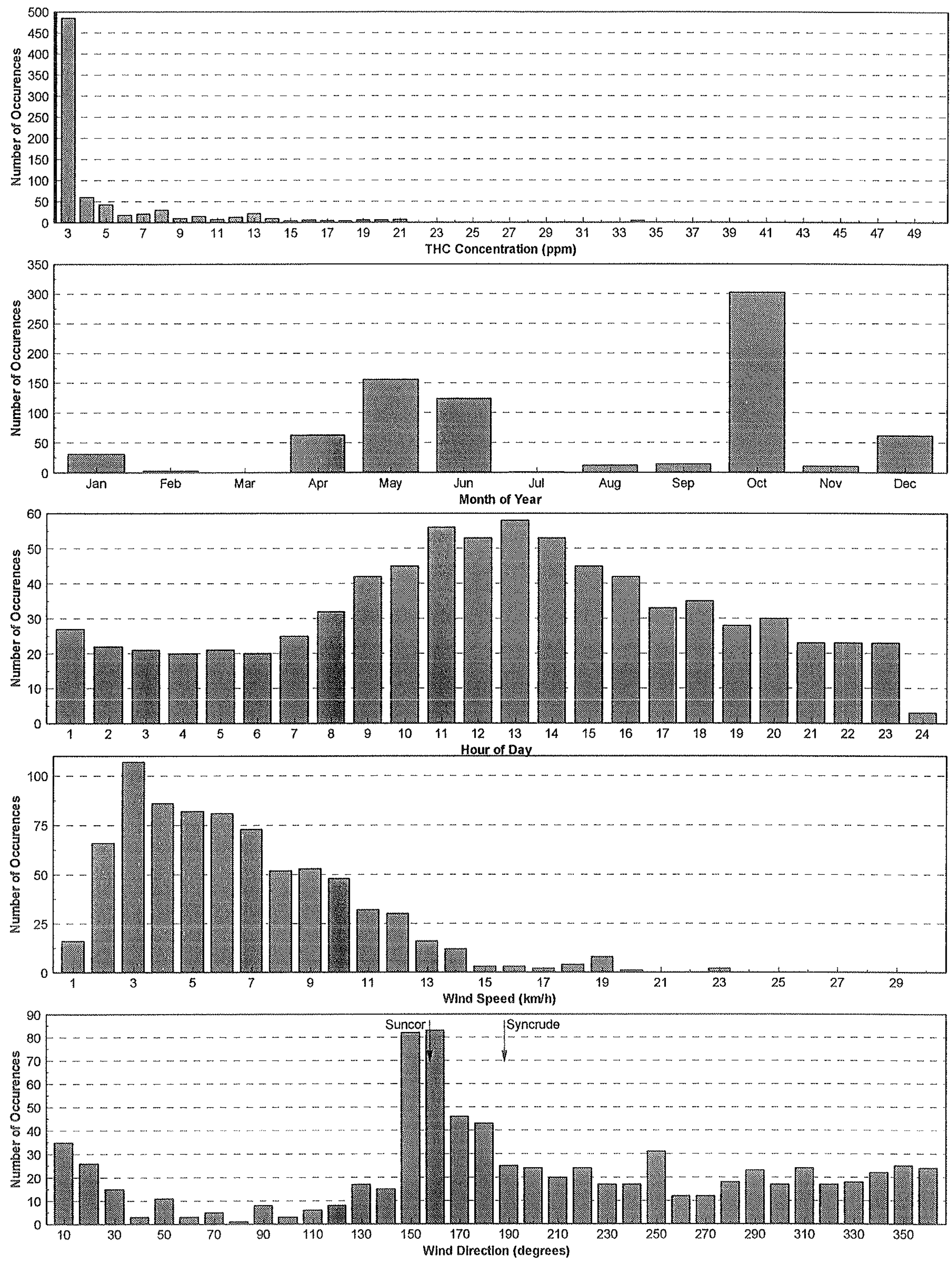


Figure 9.2 Hourly average THC concentrations greater than 3 ppm and associated conditions at the Suncor Athabasca Bridge (#10) station (January 1, 1990 to June 30, 1995).

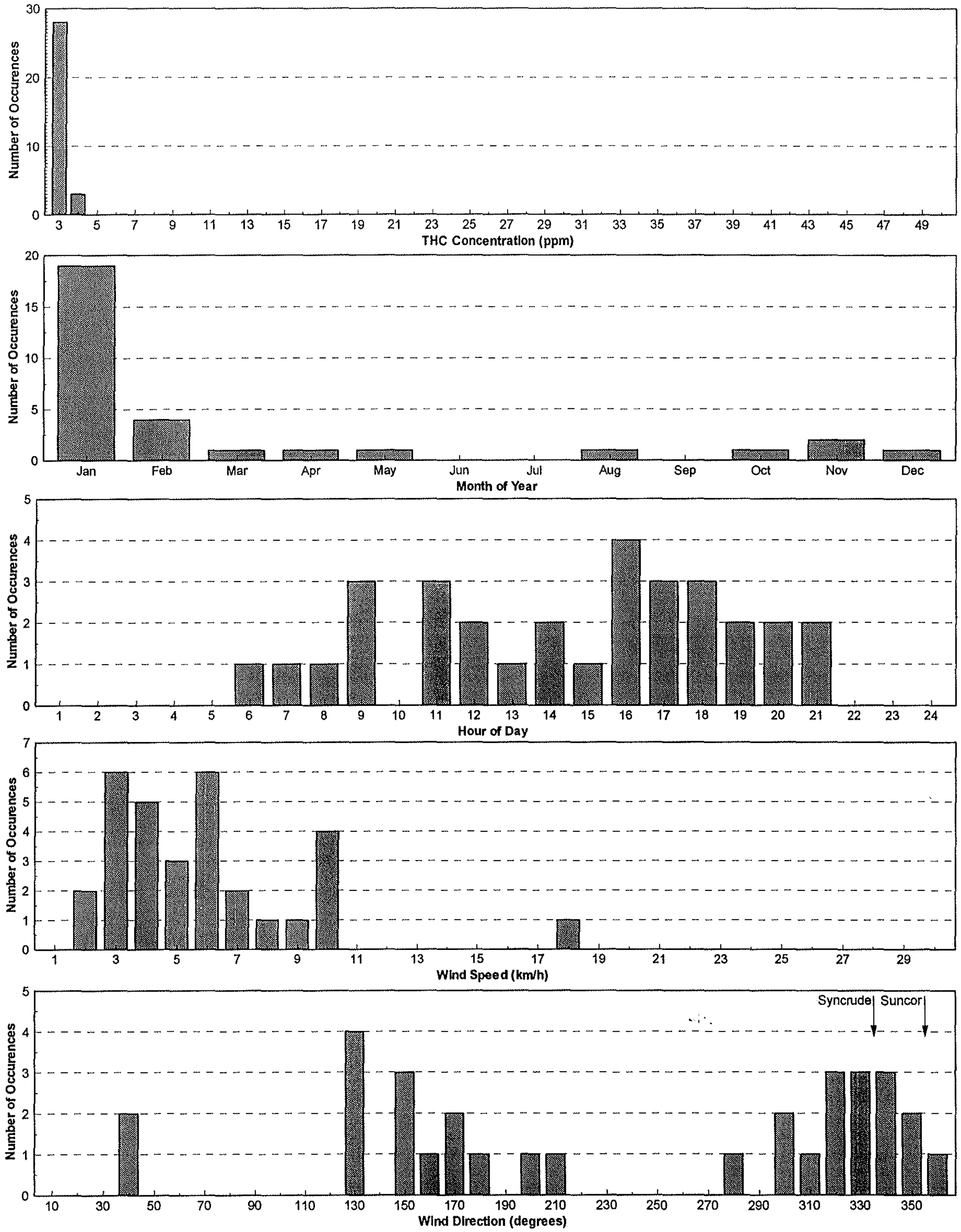


Figure 9.3 Hourly average THC concentrations greater than 3 ppm and associated conditions at the Syncrude AQS2 (Fort McMurray) station (January 1, 1990 to June 30, 1995).

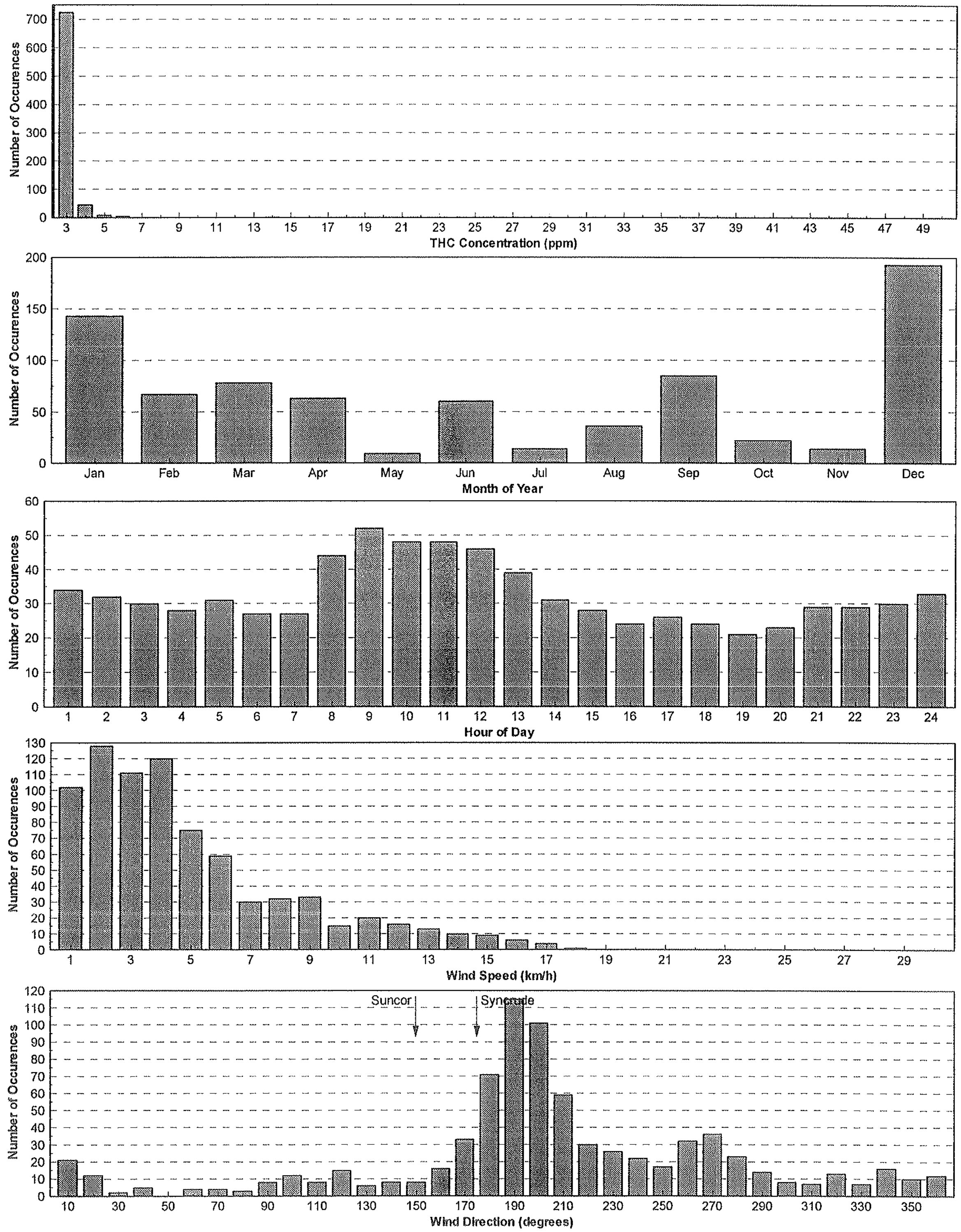


Figure 9.4 Hourly average THC concentrations greater than 3 ppm and associated conditions at the Syncrude AQS4 (Tailings North) station (January 1, 1990 to June 30, 1995).

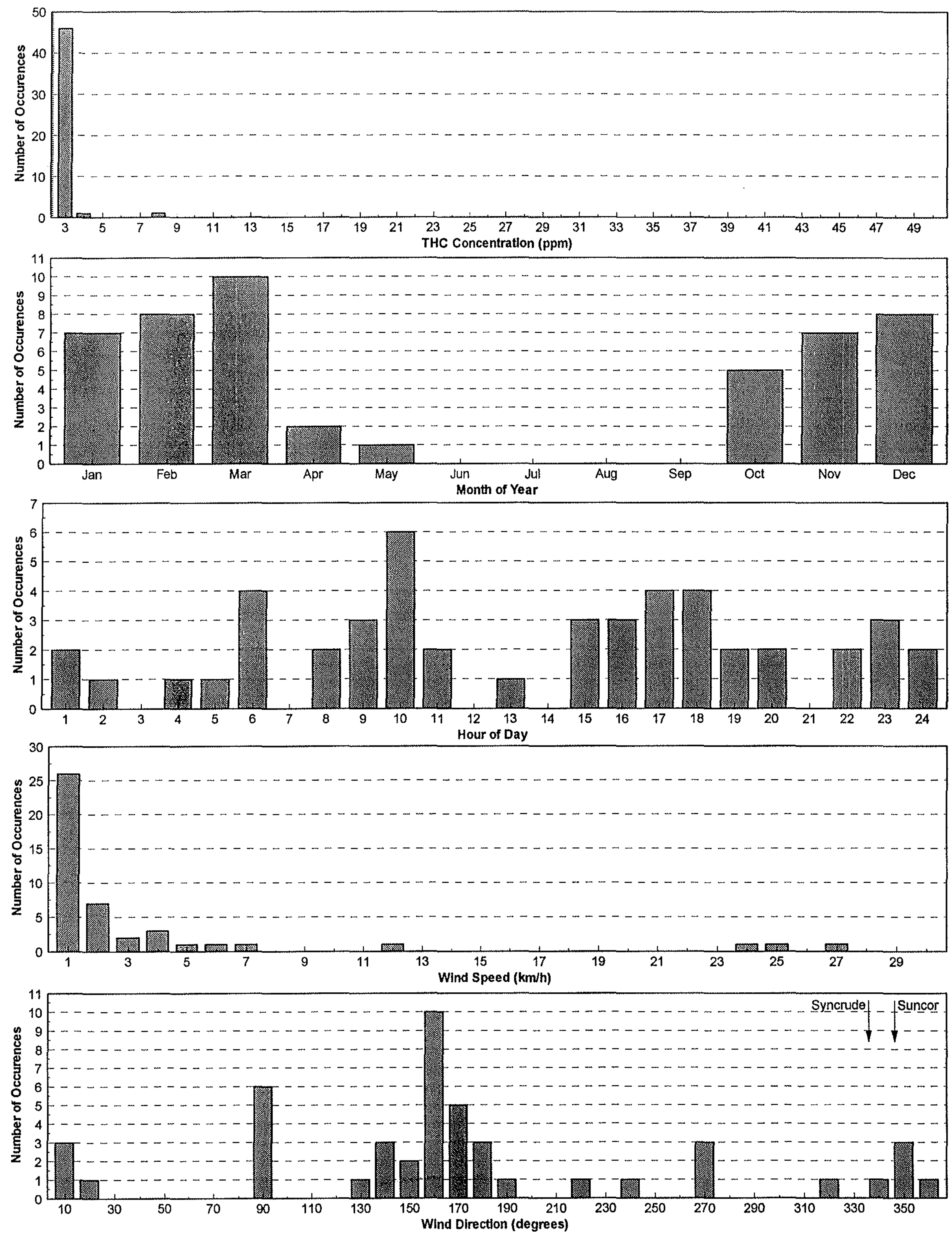


Figure 9.5 Hourly average THC concentrations greater than 3 ppm and associated conditions at the AEP Fort McMurray (FMMU) station (January 1, 1990 to June 30, 1995).

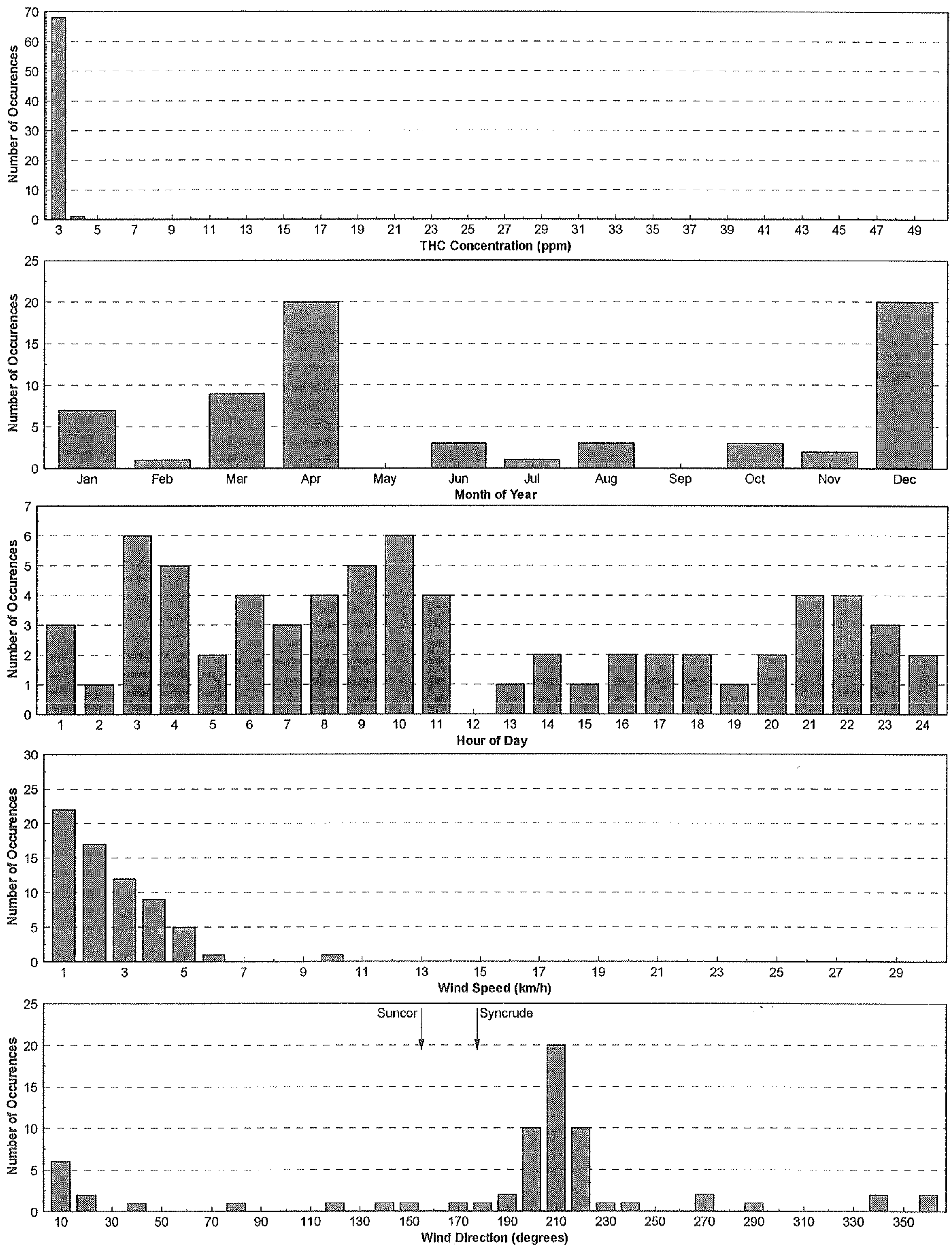


Figure 9.6 Hourly average THC concentrations greater than 3 ppm and associated conditions at the AEP Fort McKay (FRMU) station (January 1, 1990 to June 30, 1995).

- THC concentrations greater than 3 ppm occur during all hours of the day and generally occur more frequently in daytime hours.

- THC concentrations greater than 3 ppm are associated with a range of wind speeds from 1 km/h up to 27 km/h, but most frequently in the 1 km/h to 5 km/h range.

- The wind direction distributions for THC concentrations greater than 3 ppm indicate the presence of the oil sands plant sources and the town sites of Fort McMurray and Fort McKay.

In summary, while THC concentrations are typically in the 1.4 to 2.1 ppm range, peak hourly values have exceeded 30 ppm at Poplar Creek and Athabasca Bridge. The occurrence of peak values at these locations suggests that emissions from low level fugitive hydrocarbon sources at Suncor can be channelled by the river valley. Further down valley, the maximum values at Fort McMurray (8.6 ppm) and Fort McKay (4.1 ppm) are much less than those associated with these other two sites.

9.3 Annual Trends

Figures 9.7 and 9.8 show the annual average THC concentrations observed. The 1995 values shown in the figures are based on six months of data. The average THC values are relatively constant, being between 1.1 and 2.2 ppm. The values at all site are also somewhat similar, with no clear temporal trends.

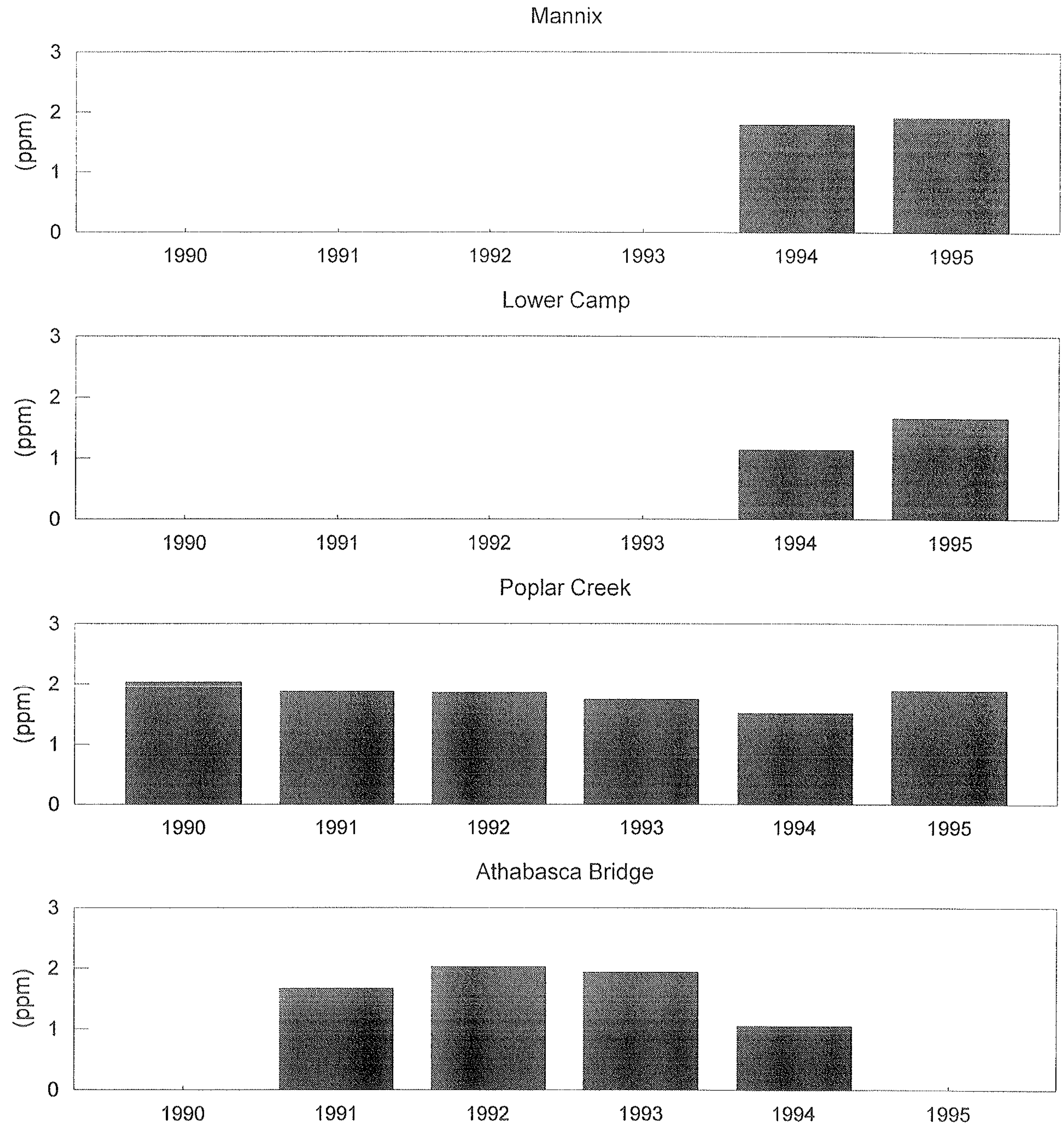


Figure 9.7 Annual average THC concentrations observed at the Suncor stations.

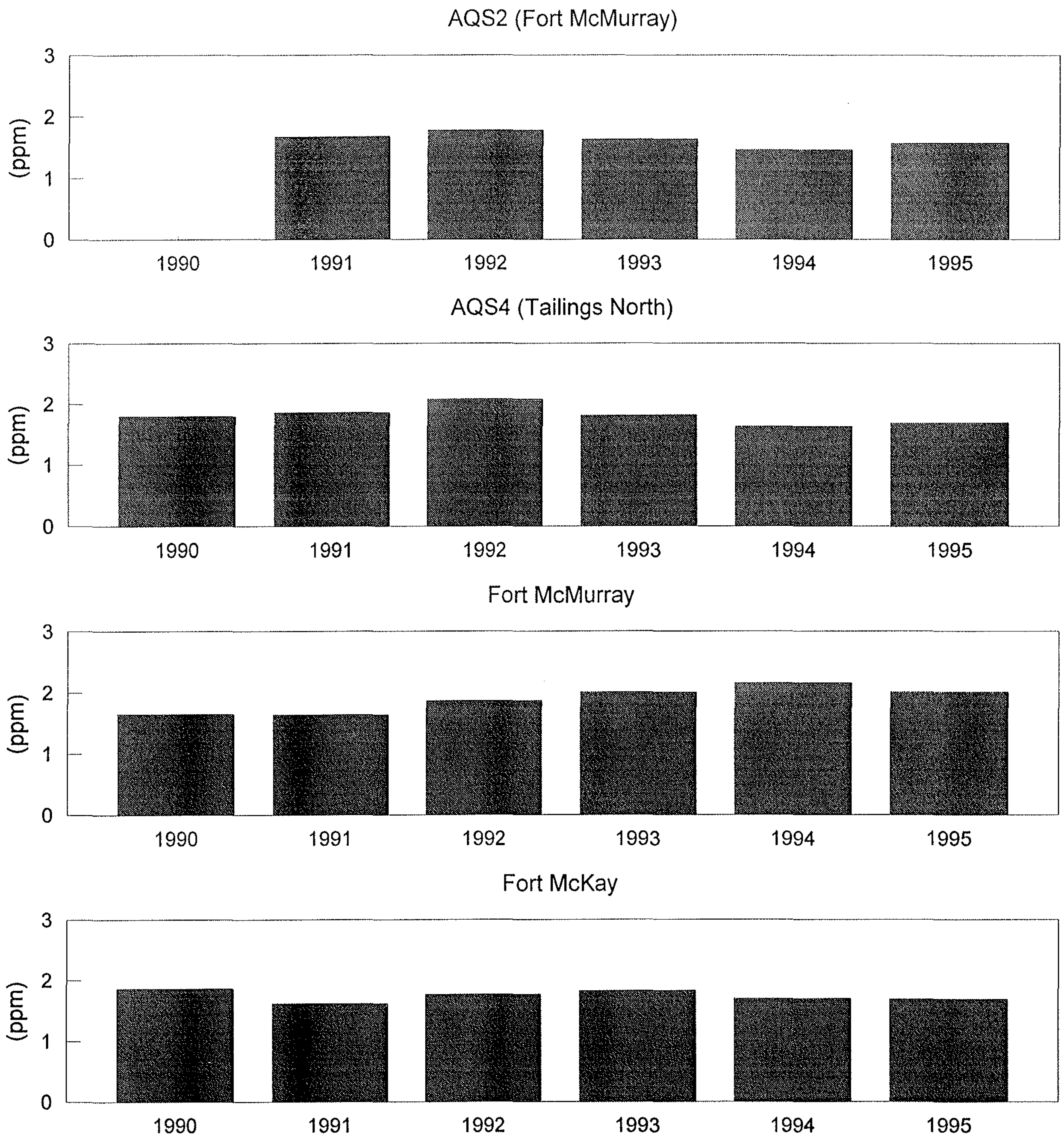


Figure 9.8 Annual average THC concentrations observed at the Syncrude and AEP monitoring stations.

10.0 PARTICULATE

Syncrude has two high volume samplers, one located at AQS2 (Fort McMurray) and the other at AQS4 (Tailings North). Neither Suncor nor AEP operate any high volume samplers in the area. TSP typically measures particulates that are less than 30 μm in diameter. These data are collected for a 24 sampling period once every 6 days (~ 61 samples per year).

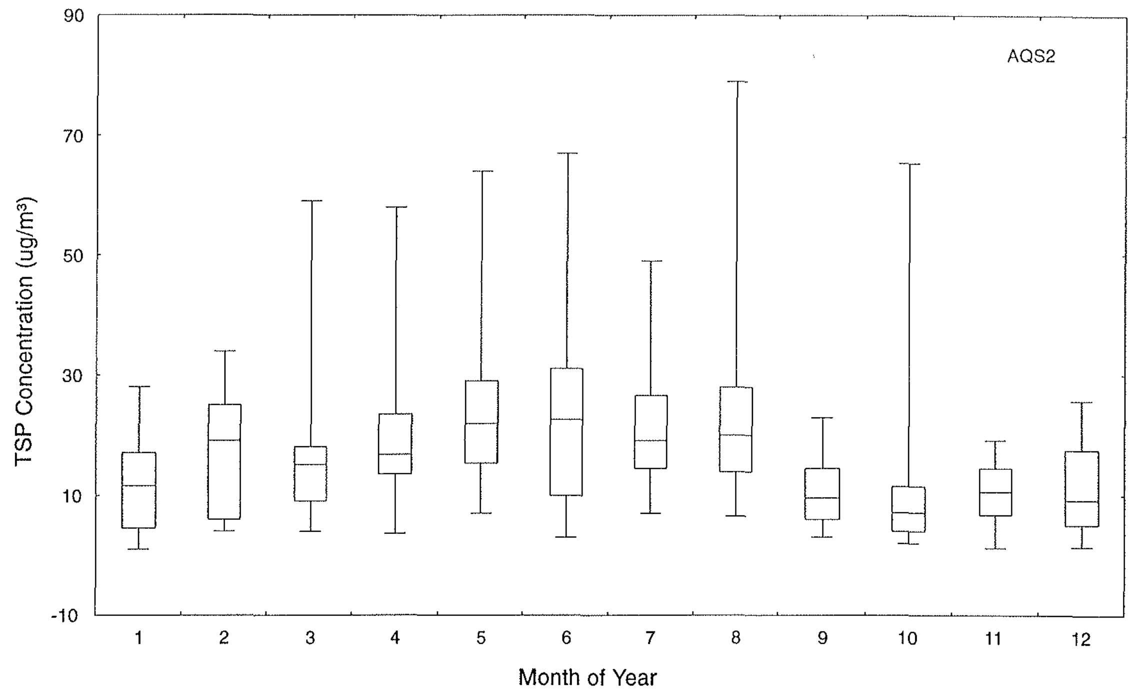
Table 10.1 provides a summary of the high volume measurements of total suspended particulate (TSP) that have been conducted at these two sites. While there have been three exceedences of the 24-hour 100 $\mu g/m^3$ guideline, most of the observed values are within guideline levels. The highest value of 273 $\mu g/m^3$ that occurred in 1993 was attributed to a truck that was left running outside the monitoring station during a calibration visit. The annual geometric means are well below the 60 $\mu g/m^3$ guideline.

Figure 10.1 shows box plots of TSP data by month for each station. The 5, 25, 50, 75 and 95th percentile values for each month are shown. The ASQ2 (Fort McMurray) site has the largest median and 95th percentile values from March to October while the ASQ4 (Tailings North) site has large values in March to August and November to December.

Figures 10.2 and 10.3 show box plots of TSP data by year for each station. The 5, 25, 50, 75 and 95th percentile values for each year of monitoring are shown, along with a regression line. At ASQ2 (Fort McMurray) the largest TSP values were observed in 1992, while the ASQ4 (Tailings North) site had the highest observations in 1991. Both sites show a reduction in the magnitudes of the observed TSP values in time as indicated by the regression lines.

Table 10.1 Measured statistics of TSP at the Syncrude AQS2 and AQS4 monitoring site.

	AQS2 (Fort McMurray)	AQS4 (Tailings North)
1990		
Maximum	not operational	165
Number greater than 100 µg/m^3	not operational	1
Annual Geometric Mean	not operational	16.0 (Aug. to Dec.)
1991		
Maximum	64	96
Number greater than 100 µg/m^3	0	0
Annual Geometric Mean	14.9	19.0
1992		
Maximum	65	121
Number greater than 100 µg/m^3	0	1
Annual Geometric Mean	13.7	15.8
1993		
Maximum	79	273
Number greater than 100 µg/m^3	0	1
Annual Geometric Mean	12.9	16.6
1994		
Maximum	34	88
Number greater than 100 µg/m^3	0	0
Annual Geometric Mean	9.4	10.5



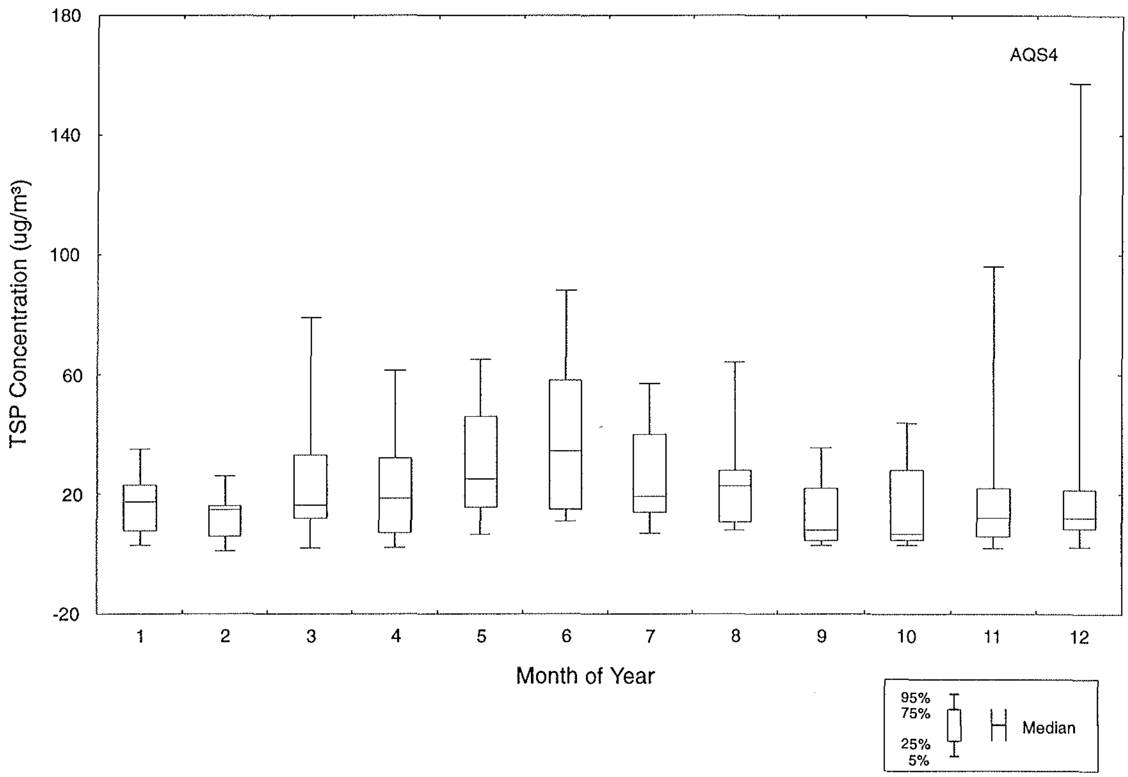


Figure 10.1 Box plots of 5, 25, 50 (median), 75, and 95th percentile values of Total Suspended Particulates (TSP) collected at AQS2 (Fort McMurray) and AQS4 (Tailings North) by month.

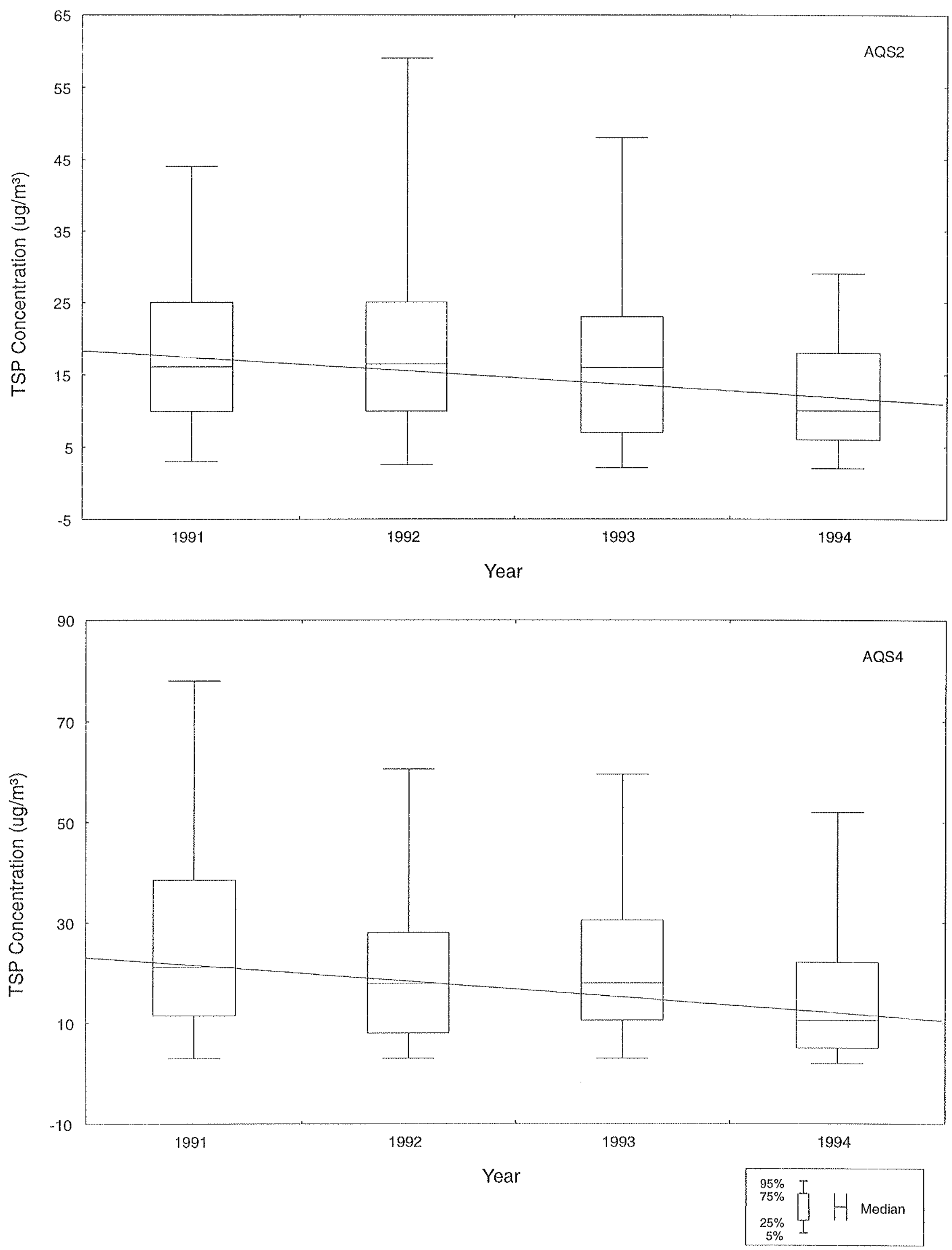


Figure 10.2 Box plots of 5, 25, 50 (median), 75, and 95th percentile values of Total Suspended Particulates (TSP) collected at AQS2 (Fort McMurray) and AQS4 (Tailings North) by month.

11.0 PASSIVE MONITORING

Syncrude, Suncor and AEP each maintain independent networks of passive monitoring sites in the Athabasca oil sands area. The sites are referred to as "passive" in that a pump is not used to draw an air sample through a detector or over a reactive surface as with other types of monitoring. For passive monitoring, a reactive surface is exposed to the ambient air for either nominal 30 day or three month periods. After the exposure period, the reactive surface is shipped to a laboratory for analysis.

11.1 Monitoring Approach

Each passive station in the oil sands area is comprised of two separate monitors, one for total sulphation and the other for hydrogen sulphide (H_2S). Total sulphation is typically measured with a lead dioxide exposure cylinder that reacts with sulphur compounds in the air to produce lead sulphate (Appendix A-3 of Alberta Environmental Protection's Air Monitoring Directive). Hydrogen sulphide is measured with zinc acetate strips that react to form zinc sulphide (Appendix A-4 of Alberta Environmental Protection's Monitoring Directive 1989).

In 1991, AEP changed its methodology for measuring total sulphation. This method described in Bertram *et al.* (1988) is based on K_2CO_3 impregnated filters mounted in a diffusion screen. The chemical compounds used in the latter AEP method are identified as being less hazardous to handle and easier to analyze. The use of a diffusion screen allows monthly (or quarterly) average SO_2 equivalent concentrations to be calculated. In contrast, the lead dioxide method does not allow corresponding concentration calculations because of the response variability with environmental conditions. For this reason, the results are expressed in units of mg SO_3^- equivalent/100 cm^2/day. For continuity, AEP also expresses the results based on the new method in the same units.

The comparison and combination of the total sulphation and H_2S monitoring results has to account for differences between the field and analytical methods adopted for each network. Two sets of nearly co-located sites were selected from the Syncrude, Suncor and AEP passive monitoring stations.

- Set A. Suncor site #14, Syncrude site #2 and AEP site #3 are nearly co-located, so a comparison of the results for the three networks can be made. These sites are located on the Supertest hill adjacent to Highway 63 and the largest distance between these three sites based on UTM coordinates is 531 m.

- Set B. The Suncor site #6, Syncrude site #10 and AEP site #6 are also nearly co-located. A similar comparison of the static monitoring results for the three networks can be provided. These sites are located near the Syncrude AQS5 (Tailings East) monitoring site and the largest distance between these three sites based on UTM coordinates is 995 m.

Table 11.1 provides a comparison of the four annual averages for these sites. The 1994 yearly values were not included as the AEP H_2S data are currently under review by AEP staff (Myrick, pers. comm.). The combined average for both sites and selected ratios are shown in the table. In general:

- The sulphation measurements based on the Syncrude data are the largest and those based on the Suncor data are the smallest (Syncrude over Suncor ratio = 1.7).

- The H_2S measurements based on the Suncor data are the largest and those based on AEP measurements are the smallest (Suncor over AEP ratio = 1.4).

Given the variability in Table 11.1, it was arbitrarily decided to select AEP data as a reference and modify all the Suncor and Syncrude data prior to combining the three data sets. The conversion factors are indicated in Table 11.1.

Syncrude site #19 is located on their plant site and has consistently higher readings than any other site. The maximum raw and converted total sulphation values at the site are 0.868 and 0.574 mg SO_3^- equivalent/100 cm^2/day. These annual average values are in excess of the 0.5 mg SO_3^- equivalent/100 cm^2/day guideline. The maximum raw and converted annual hydrogen sulphide values at this site are 0.192 and 0.159 mg SO_3^- equivalent/100 cm^2/day, respectively. Both values are in excess of the AEP guideline for H_2S of 0.1 mg SO_3^- equivalent/ 100 cm^2/day.

11.2 Total Sulphation

Figure 11.1 shows contours of the maximum annual total sulphation values for the years 1990 to 1994. The contours are based on the combined Syncrude, Suncor and AEP static monitoring station data assuming the conversion factors in Table 11.1. The contours indicate that the maximum annual values occur in the vicinity of each plant and a point southeast of Syncrude and north-northwest of Suncor (near Lower Camp). The peak non-plant site value is 0.423 mg SO_3^- equivalent/100 cm^2/day (or 0.279 mg SO_3^- equivalent/100 cm^2/day after conversion) which is less than the Alberta Environmental Protection guideline of 0.5 mg SO_3^- equivalent/ 100 cm^2/day.

11.3 Hydrogen Sulphide

Figure 11.3 shows contours of the maximum annual hydrogen sulphide (H_2S) values for the years 1990 to 1994 (assuming the conversion factors in Table 11.1). The patterns are similar to those for the total sulphation depiction with maxima at each plant site and a point southeast of Syncrude and north-northwest of Suncor. The maximum non-site value is 0.096 mg SO_3^- equivalent/100 cm^2/day (or 0.071 mg SO_3^- equivalent/100 cm^2/day after conversion) which is less than the AEP guideline of 0.1 mg SO_3^- equivalent/100 cm^2/day.

Table 11.1 Average Total Sulphation and H_2S (mg SO_3^- equivalent/100 cm^2/day) values at nearly co-located Suncor, Syncrude and AEP passive monitoring sites.

		Total Sulphation			H_2S		
		Suncor	Syncrude	AEP	Suncor	Syncrude	AEP
Set A[(a)]	1990	0.080	0.137	0.092	0.026	0.024	0.026
	1991	0.052	0.124	0.110	0.026	0.030	0.019
	1992	0.091	0.149	0.080	0.025	0.022	0.021
	1993	0.095	0.170	0.103	0.031	0.033	0.021
	Average	0.080	0.145	0.096	0.027	0.027	0.023
Set B[(b)]	1990	0.057	0.067	0.045	0.020	0.170	0.010
	1991	0.035	0.086	0.067	0.029	0.020	0.010
	1992	0.065	0.111	0.074	0.023	0.018	0.021
	1993	0.075	0.102	0.048	0.023	0.020	0.017
	Average	0.058	0.092	0.059	0.024	0.019	0.015
Both	Averaging	0.069	0.118	0.078	0.0126	0.023	0.019

(a) Set A: Suncor #14; Syncrude #2; AEP #3.
(b) Set B: Suncor #6, Syncrude #10; AEP #6.
(c) Sulphation conversion factors: Multiply Suncor data by 0.078/0.069 = 1.13
Multiply Syncrude data by 0.078/0.118 = 0.66
Multiply AEP data by 0.078/0.078 = 1.00
(d) H_2S conversion factors: Multiply Suncor data by 0.019/0.026 = 0.73
Multiply Syncrude data by 0.019/0.023 = 0.83
Multiply AEP data by 0.019/0.019 = 1.00

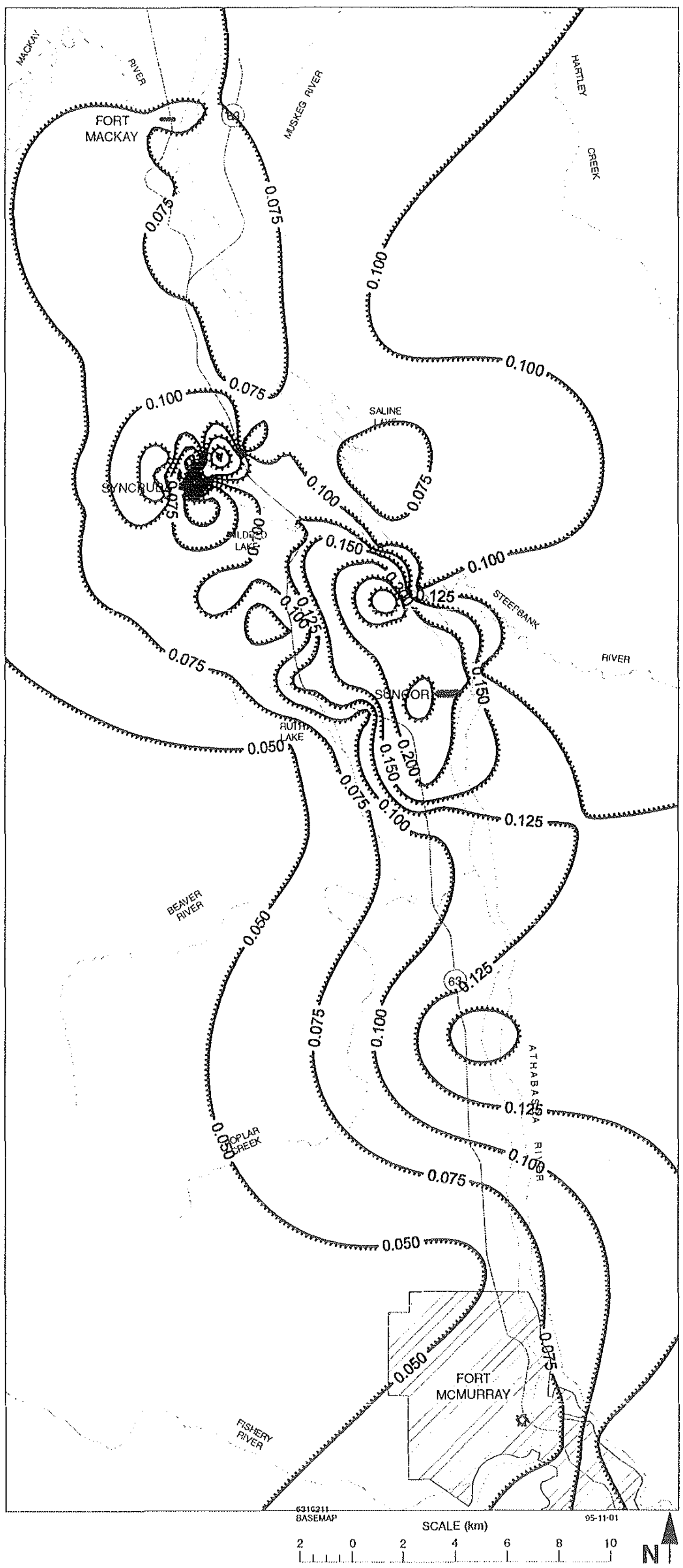


Figure 11.1 Maximum annual static exposure station total sulphation values for the period 1990 to 1994 (contour values = 0.05, 0.075, 0.1, 0.125, 0.15, 0.2, 0.25, 0.3, 0.35, 0.4, 0.5, 0.6, and 0.7 mg SO_3^- equivalent/100 cm^2/day).

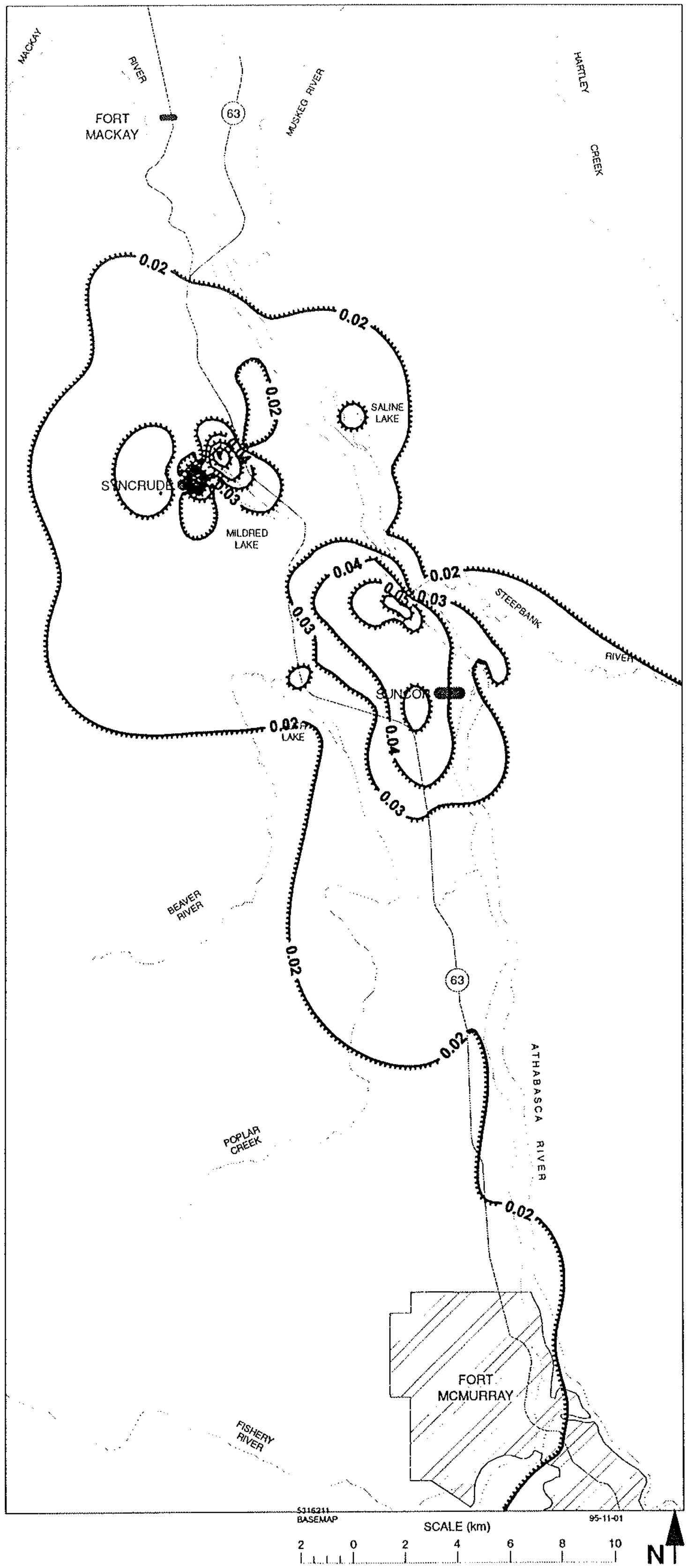


Figure 11.2 Maximum annual static exposure station hydrogen sulphide values for the period 1990 to 1994 (contour values = 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.1, and 0.15 mg SO_3^- equivalent/100 cm^2/day).

11.4 Annual Trends

Figure 11.3 shows the annual average total sulphation and H_2S exposures observed for each monitoring network. The highest total sulphation values were observed in 1993 (Suncor and Syncrude). The highest H_2S values were observed in 1995 (Suncor and AEP).

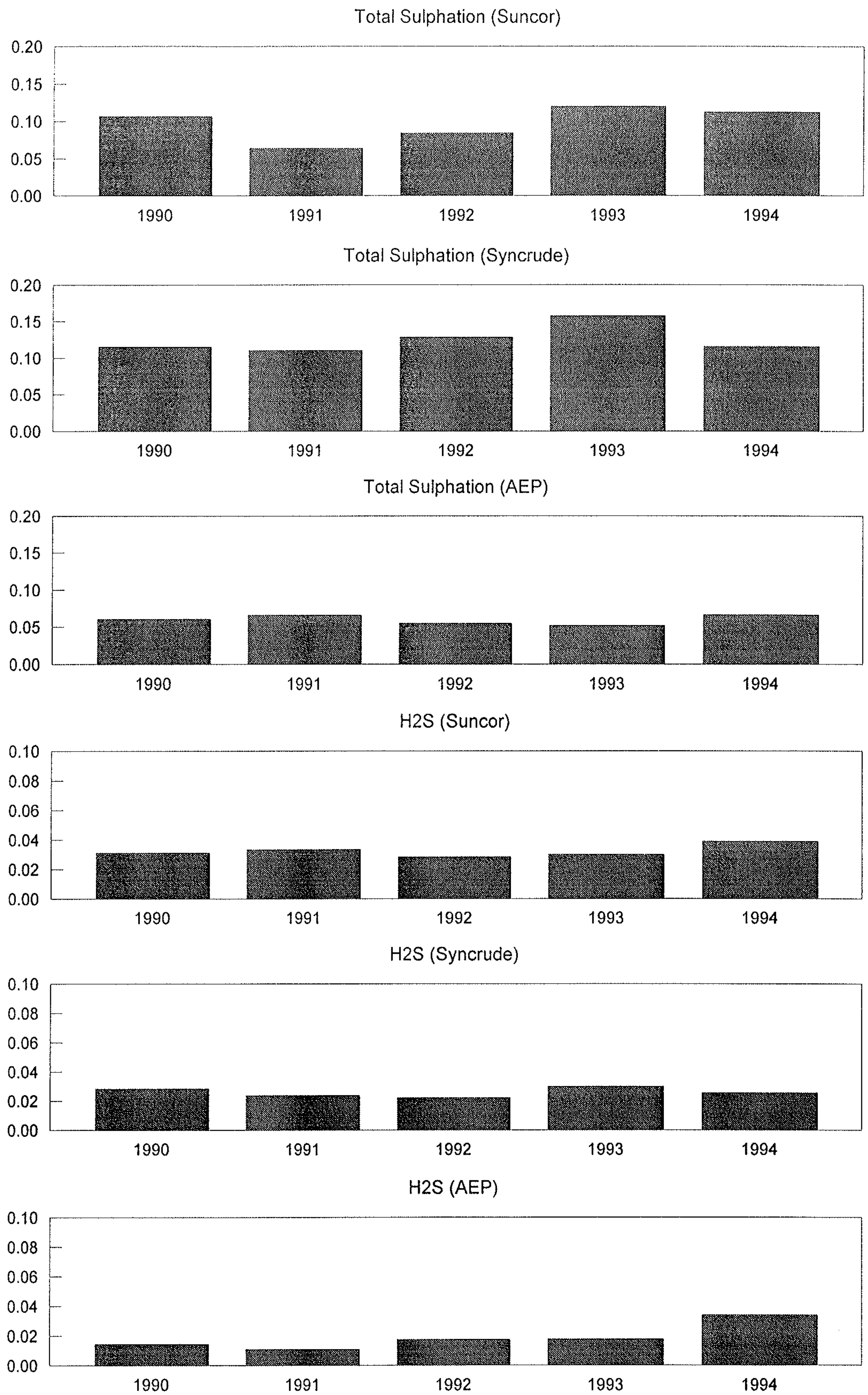


Figure 11.3 Total sulphation and H_2S exposures (mg SO_3^- equivalent/100 cm^2/d) for each monitoring station network.

12.0 PRECIPITATION CHEMISTRY

Acid forming substances released into the atmosphere will eventually be deposited to the earth's surface in the form of precipitation (wet deposition) or directly as particles or gases (dry deposition). The effects of the deposition will depend on the amount being deposited and the buffering capacity of the receptor. Alberta Environmental Protection conducts precipitation chemistry measurements with the following objectives:

- To monitor the quality of precipitation,
- To detect any significant trends in precipitation quality,
- To determine long-range transport of pollutants into the province.

This provincial monitoring program been supplemented by a parallel program conducted by Environment Canada. The Environment Canada focus, while being placed more in eastern Canada, does include two sites in the Alberta and Saskatchewan region.

Table 12.1 identifies precipitation quality stations in northern Alberta and Saskatchewan. Fort McMurray and Fort Chipewyan are the closest stations to the oil sands area. The Fort Vermilion, High Prairie and Beaverlodge stations are located in northwestern Alberta and they can provide a measure of the precipitation quality of air entering the oil sands area. The Cold Lake and Vegreville stations are located to the south of the oil sands area and Cree Lake station to the east. These latter stations may provide an indication of downwind effects.

Precipitation is collected by a sampler that opens automatically whenever it is raining (or snowing). Samples are retrieved monthly, weekly or daily and sent to a laboratory for analysis. The analysis provides precipitation chemistry data for acidity (pH), cation concentrations (positively charged ions) and anion concentrations (negatively charged ions). By also collecting total precipitation values, the deposition can be calculated from the concentration measurements. Tables in this section are based on computer databases provided by Alberta Environmental Protection (AEP). Some discrepancies between values provided in the supplied computer database files and those contained in the annual reports were found. Follow-up discussions were required to resolve these differences.

12.1 pH

The term pH is used as a direct indication of acidity and is defined on a logarithmic scale from the following relationship:

$$pH = -\log_{10} [H^+]$$

where $[H^+]$ = hydrogen ion concentrations expressed in moles per litre. pH values less than 7 are associated with acidic solutions, while those greater than 7 are associated with alkaline (or basic) solutions. A pH of 7 is regarded as neutral; a pure water solution would have a pH of 7. Clean

Table 12.1 Identification of precipitation quality monitoring stations, their respective distances from the Athabasca oil sands region and averaging period associated with sample collection.

Station	Distance[c]	Direction[c]	Monthly (M), Weekly (W) or Daily (D) Samples				
			1990	1991	1992	1993	1994
Fort McMurray	36	SSE	M	M	M,W[a]	W	W
Fort Chipewyan	190	N	M	M	M,W[a]	W	W
Fort Vermilion	310	WNW	M	M	M,W[a]	W	W
High Prairie	360	SW	M	M	M,W[a]	W,D	W,D
Beaverlodge	530	SW	M	M	M,W[a]	W	W
Cold Lake	300	SSE	M	M	M,W[a]	W	W
Vegreville	395	S	n/o	n/o	M	W,D	W,D
Cree Lake	285	ENE	M	M	M	M[b]	n/o

n/o Station not operational.

(a) Weekly samples started September 1, 1992.
(b) January to May, then station closed.
(c) From the Suncor site.

water in equilibrium with "unpolluted" air would be slightly acidic with a pH of 5.6 which is a result of the water being in equilibrium with CO_2 in the atmosphere.

Table 12.2 provides the annual average pH values at the stations identified in Table 12.1 for the period 1990 to 1994. On the average, it appears that the pH of the precipitation in locations closest to the oil sands area (i.e. Fort McMurray) is more acidic (pH ~ 4.8) than other regions in northern Alberta. Other more distant regions in northern Alberta tend to have pH values between 5.1 and 5.3. This compares with the average value in northern Saskatchewan (i.e. Cree Lake) of about 5.0.

12.2 Selected Anions and Cations

Anions such as sulphate (SO_4^{-2}) and nitrate (NO_3^-) result from sources venting products of combustion such as SO_2 and NO_2 into the atmosphere. Industrial sources venting these compounds include oil sands plants, gas processing plants, oil refineries and coal-fired power plants. Cations such as calcium (Ca^{+2}), magnesium (Mg^{+2}) and ammonium (NH_4^+) result from different sources. Ca^{+2} and Mg^{+2} can result from natural sources such as wind-blown soil and dust. NH_4^+ can result from agricultural sources.

Tables 12.3 to 12.7 show the annual variation of SO_4^{-2}, NO_3^-, Ca^{+2}, Mg^{+2} and NH_4^+ deposition at the identified precipitation sites. When two sampling periods are available, the value associated with the shorter sampling period is used to calculate the overall station average. The results indicate:

- Sulphate (SO_4^{-2}) deposition ranges from a low of 1.7 kg/ha/a in Cree Lake to a maximum of 5.6 kg/ha/a in Vegreville. Depositions at other northern Alberta sites range from 1.9 to 4.9 kg/ha/a. The SO_4^{-2} deposition observed at the Fort McMurray site is 4.9 kg/ha/a (Table 12.3).

- Nitrate (NO_3^-) deposition ranges from 0.9 kg/ha/a at Fort Chipewyan to 4.2 kg/ha/a at Vegreville. The value observed in Fort McMurray is 2.3 kg/ha/a (Table 12.4).

- Calcium deposition (Ca^{+2}) ranges from 0.2 kg/ha/a at Cree Lake to 1.9 kg/ha/a at High Prairie. The value observed in Fort McMurray is 1.1 kg/ha/a (Table 12.5).

- Magnesium (Mg^{+2}) deposition ranges from 0.05 kg/ha/a at Cree Lake to 0.27 kg/ha/a at High Prairie. The value observed in Fort McMurray is 0.25 kg/ha/a (Table 12.6).

- Ammonium (NH_4^+) deposition ranges from 0.3 kg/ha/a at Cree Lake to 2.2 kg/ha/a at Vegreville. The value observed in Fort McMurray is 0.4 kg/ha/a (Table 12.7).

Table 12.2 Precipitation acidity (pH) observed at northern Alberta and Saskatchewan precipitation stations.

	Year										
	1990[a]	1991	1992			1993			1994		Average[d]
	M	M	M	W	M +W	M	W	D	W	D	
Fort McMurray	4.9	4.9	4.7	4.7	4.7	-	4.7	-	4.8	-	4.8
Fort Chipewyan	5.1	5.0	5.4	5.2	5.3	-	5.0	-	5.4	-	5.1
Fort Vermilion	5.3	5.3	5.2	5.3	5.2	-	5.2	-	5.0	-	5.2
High Prairie	5.6	5.3	5.1	5.2	5.1	5.3	5.1	-	5.2	5.2	5.3
Beaverlodge	5.1	5.2	5.0	5.1	5.1	-	5.0	-	5.0	-	5.1
Cold Lake	5.6	5.1	5.2	5.1	5.2	-	5.3	-	5.2	-	5.3
Vegreville	n/a	n/a	5.3	-	5.3	5.1	5.3	4.4	5.1	5.0	5.3
Cree Lake	5.0	5.0	-	5.0	-	-	4.9[b]	-	n/o[c]	n/o[c]	5.0

(a) Values in AEP report were calculated improperly.
(b) Only first quarter values, then station closed.
(c) Not operational.
(d) Averages include monthly values 1990, 1991 then weekly values 1992, 1993, 1994 and are precipitation weighted.

Table 12.3 Annual average sulphate (SO_4^{-2}) deposition (kg $SO4^{-2}$/ha/a) observed at northern Alberta and Saskatchewan precipitation stations.

	Year								
	1990	1991	1992*	1993			1994		Average
	M	M	M + W	M	W	D	W	D	
Fort McMurray	5.2[a]	6.0	4.5	-	5.3	-	3.0	-	4.9
Fort Chipewyan	1.5[a]	1.6[c]	4.8[d]	-	4.3	-	3.1	-	3.1
Fort Vermilion	2.5[b]	2.9[a]	1.6[e]	-	1.2	-	1.5	-	1.9
High Prairie	4.2	4.4	2.0	-	2.0	4.3	1.5	5.7[a]	3.4
Beaverlodge	2.4	2.2[b]	1.9	-	2.3	-	3.3	-	2.4
Cold Lake	3.4	2.8	2.0	-	3.4	-	2.9	-	2.9
Vegreville	-	n/o	3.1	2.8	6.8	6.8	8.2	5.7	5.6
Cree Lake	1.4	1.6	2.3	0.4[f]	-	-	n/o	-	1.7

* 1992 data were monthly till August, then weekly.
(a) 10 months.
(b) 11 months.
(c) 8 months.
(d) 6 of 8 monthly values.
(e) 7 of 8 monthly values.
(f) 5 months (January to May) not included in average.

Table 12.4 Annual average nitrate (NO_3^-) deposition (kg NO_3^-/ha/a) observed at northern Alberta and Saskatchewan precipitation stations.

	Year								
	1990	1991	1992*	1993			1994		Average
	M	M	M + W	M	W	D	W	D	
Fort McMurray	2.8[a]	3.7	1.7	-	1.7	-	1.5	-	2.3
Fort Chipewyan	1.0[a]	0.8[c]	0.8[d]	-	0.7	-	1.1	-	0.9
Fort Vermilion	2.0[b]	2.6[a]	0.9[e]	-	0.7	-	0.9	-	1.4
High Prairie	2.6	2.5	1.2	-	1.1	3.0	1.0	5.0	2.4
Beaverlodge	1.7	1.8[b]	1.1	-	1.1	-	1.9	-	1.5
Cold Lake	2.7	2.9	1.9	-	2.4	-	2.6	-	2.5
Vegreville	-	-	2.3	1.9	4.6	4.9	6.4	4.8	4.2
Cree Lake	1.1	1.4	1.5	0.4[f]	-	-	n/o	-	1.3

* 1992 data were monthly till August, then weekly.
(a) 10 months.
(b) 11 months.
(c) 8 months.
(d) 6 of 8 monthly values.
(e) 7 of 8 monthly values.
(f) 5 months (January to May) not included in average.

Table 12.5 Annual average calcium (Ca^{+2}) deposition (kg Ca^{+2}/ha/a) observed at northern Alberta and Saskatchewan precipitation stations.

	Year								
	1990	**1991**	**1992***	**1993**			**1994**		**Average**
	M	**M**	**M + W**	**M**	**W**	**D**	**W**	**D**	
Fort McMurray	1.5[a]	1.0	0.4	-	1.2	-	0.7	-	1.1
Fort Chipewyan	0.3[a]	0.4[c]	1.7[d]	-	1.6	-	2.0	-	1.2
Fort Vermilion	0.6[b]	2.2[a]	0.7[e]	-	0.4	-	0.7	-	0.9
High Prairie	2.2	2.2	0.7	-	0.9	3.1	0.9	3.4	1.9
Beaverlodge	0.3	0.5[b]	0.3	-	0.5	-	0.7	-	0.4
Cold Lake	0.7	0.6	0.4	-	1.1	-	1.2	-	0.8
Vegreville	-	-	0.5	0.7	0.7	0.7	2.2	1.7	1.1
Cree Lake	0.2	0.2	0.2	0.1[f]	-	-	n/o	-	0.2

* 1992 data were monthly till August, then weekly.
[a] 10 months.
[b] 11 months.
[c] 8 months.
[d] 6 of 8 monthly values.
[e] 7 of 8 monthly values.
[f] 5 months (January to May) not included in average.

Table 12.6 Annual average magnesium (Mg^{+2}) deposition (kg Mg^{+2}/ha/a) observed at northern Alberta and Saskatchewan precipitation stations.

	Year								
	1990	1991	1992*	1993			1994		Average
	M	M	M + W	M	W	D	W	D	
Fort McMurray	0.55[a]	0.18	0.11	-	0.29	-	0.14	-	0.25
Fort Chipewyan	0.05[a]	0.07[c]	0.24[d]	-	0.21	-	0.33	-	0.18
Fort Vermilion	0.09[b]	0.25[a]	0.12[e]	-	0.05	-	0.07	-	0.12
High Prairie	0.84	0.34	0.09	-	0.10	0.18	0.11	0.25	0.27
Beaverlodge	0.07	0.07[b]	0.06	-	0.06	-	0.09	-	0.07
Cold Lake	0.24	0.12	0.09	-	0.24	-	0.24	-	0.19
Vegreville	-	-	0.10	0.09	0.26	0.22	0.34	0.24	0.16
Cree Lake	0.04	0.05	0.06	0.01[f]	-	-	n/o	-	0.05

* 1992 data were monthly till August, then weekly.
(a) 10 months.
(b) 11 months.
(c) 8 months.
(d) 6 of 8 monthly values.
(e) 7 of 8 monthly values.
(f) 5 months (January to May) not included in average.

Table 12.7 Annual average ammonium (NH_4^+) deposition (kg NH_4^+/ha/a) observed at northern Alberta and Saskatchewan precipitation stations.

	Year								
	1990	1991	1992*	1993			1994		Average
	M	M	M + W	M	W	D	W	D	
Fort McMurray	0.4[a]	0.1	0. 5	-	0.5	-	0.4	-	0.4
Fort Chipewyan	0.2[a]	0.0[c]	0.9[d]	-	0.2	-	0.7	-	0.4
Fort Vermilion	0.4[b]	0.6[a]	0.1[e]	-	0.2	-	0.6	-	0.4
High Prairie	1.2	1.0	0.3	-	0.3	0.9	0.8	1.1	0.8
Beaverlodge	0.2	0.5[b]	0.3	-	0.3	-	0.7	-	0.4
Cold Lake	1.6	1.1	0.6	-	1.9	-	1.0	-	1.2
Vegreville	-	-	1.3	1.4	2.6	2.7	2.7	2.5	2.2
Cree Lake	0.2	0.3	0.3	0.1[f]	-	-	n/o	-	0.3

* 1992 data were monthly till August, then weekly.
(a) 10 months.
(b) 11 months.
(c) 8 months.
(d) 6 of 8 monthly values.
(e) 7 of 8 monthly values.
(f) 5 months (January to May) not included in average.

In summary, the largest average deposition of sulphate was observed in Fort McMurray. The largest average deposition of nitrates were located at Fort Chipewyan. The Cree Lake station observed the lowest average depositions of all species but nitrates. High Prairie had the largest average deposition of calcium and magnesium. Vegreville observed the largest average deposition of ammonium.

12.3 Acidifying Potential and Effective Acidity (Wet Deposition Only)

The acidifying potential (AP) as defined by the Interim Acid Deposition Critical Loadings Group (1990) is:

$$AP = [SO_4^{-2}] - [Ca^{+2}] - [Mg^{+2}]$$

The AP values for northern Alberta and Saskatchewan stations were calculated and are presented in Table 12.8. The AP is expressed in units of kmol H^+ equivalent/ha/a and ranges from -0.02 kmol H^+ equivalent/ha/a at High Prairie to 0.03 kmol H^+ equivalent/ha/a at Fort McMurray. Fort Chipewyan and Fort Vermilion both had negative average values of -0.01 kmol H^+ equivalent/ha/a. The values in Table 12.8 are all less than the interim critical range of 0.12 to 0.31 kmol H^+ equivalent/ha/a.

The effective acidity (EA) as defined by Coote *et al.* (1982) is:

$$EA = [H^+] + 1.15\ [NH_4^+] - 0.7\ [NO_3^-]$$

EA values were calculated and are presented in Table 12.9 for the northern Alberta and Saskatchewan sites. The EA is also expressed in units of kmol H^+ equivalent/ha/a and ranges from 0.03 kmol H^+ equivalent/ha/a at Fort Vermilion to 0.13 kmol H^+ equivalent/ha/a at Vegreville. Fort McMurray's average effective acidity was 0.06 kmol H^+ equivalent/ha/a. For high sensitivity soils and aquatic sites, the preliminary deposition limits are in the 0.1 to 0.3 kmol H^+ equivalent/ha/a range. The average EA values in Table 12.8 are less than the preliminary deposition limits for sensitive soil systems except for Vegreville.

12.4 Dry Deposition Contribution

The estimation of accompanying dry deposition will depend on the corresponding ambient concentrations and on the removal efficiency. The recommended method to calculate the dry contribution to the effective acidity (EA) is (Table 3.2):

$$EA_{dry} = [SO_4^{-2}] + [SO_2] + 1.15\ [NH_4^+] - 0.7\ [NO_3^-]$$

Table 12.8 Annual average Acidifying Potential (AP) (kmole H^+ equivalent/ha/a) observed at northern Alberta and Saskatchewan precipitation stations.

	Year								
	1990[a]	1991	1992	1993			1994		Average
	M	M	M + W	M	W	D	W	D	
Fort McMurray	-0.01	0.06	0.06		0.03		0.03		0.03
Fort Chipewyan	0.01	0.01	-0.00		-0.01		-0.06		-0.01
Fort Vermilion	0.02	-0.07	-0.01		0.00		-0.01		-0.01
High Prairie	-0.09	-0.04	-0.00		-0.01	+0.03	-0.02	-0.07	-0.02
Beaverlodge	0.03	0.02	0.02		0.02		0.03		0.02
Cold Lake	0.02	0.02	0.02		-0.00		-0.02		0.01
Vegreville	-	-	0.03	0.02	-0.09	0.09	0.03	0.01	0.02
Cree Lake	0.02	0.02	0.03	0.01	-		-		0.02

Table 12.9 Annual average Effective Acidity (EA) (kmole H^+ equivalent/ha/a) observed at northern Alberta and Saskatchewan precipitation stations.

	Year					
	1990[a]	1991	1992	1993	1994	Average
	M	M	M + W	W	W	
Fort McMurray	0.05	0.05	0.07	0.07	0.05	0.06
Fort Chipewyan	0.02	0.04	0.07	0.06	0.04	0.05
Fort Vermilion	0.03	0.03	0.02	0.02	0.05	0.03
High Prairie	0.06	0.06	0.04	0.03	0.05	0.05
Beaverlodge	0.04	0.04	0.03	0.04	0.07	0.04
Cold Lake	0.08	0.06	0.04	0.12	0.05	0.07
Vegreville	-	-	0.07	0.16	0.17	0.13
Cree Lake	0.05	0.05	0.06	-	-	0.05

where all the depositions are presented in units of H^+ equivalent/ha/a. Background measurements of ambient concentrations are available from Cree Lake and Vegreville (Royal Park). These values are summarized in Table 12.10.

For the purposes of calculating dry deposition, a single annual deposition velocity is often used for each compound. This is not strictly correct as the deposition velocities change with time of day and season to reflect the variability of meteorological and receptor uptake processes. For the purpose of this assessment, however, the annual deposition velocities identified in Table 3.3 are used to estimate dry deposition. The values specific to the estimation of dry depositions of the compounds provided in Table 12.10 are:

Component	Deposition Velocity (cm/s)
SO_4^{-2}	0.1
SO_2	0.7
NH_4^+	0.1
NO_3^-	0.1
HNO_3	3.0

Sulphation (SO_4^{-2}), ammonium (NH_4^+) and nitrates (NO_3^-) are deposited as fine particles, and SO_2 and HNO_3 are deposited as gases. At Cree Lake, most of the dry deposition is in the form of gaseous compounds such as SO_2 and HNO_3 (2.9 and 1.8 kg/ha/a, respectively). The corresponding dry component of EA is 0.08 kmol H^+ equivalent/ha/a. At Vegreville the largest compounds are again SO_2 and HNO_3; the values, however, are much larger (11.5 and 7.8 kg/ha/a, respectively) than those observed at Cree Lake. The corresponding Vegreville dry component of EA is 0.29 kmol H^+ equivalent/ha/a. These values correspond to the calculated value of 0.28 kmol H^+ equivalent/ha/a observed at Fortress Mountain (Table 3.3). Dry values in the vicinity of an SO_2 emitting point source are around 0.50 to 0.79 kmol H^+ equivalent/ha/a (Crossfield West and East, respectively).

Table 12.10 Background ambient concentrations of SO_4^{-2}, SO_2, NH_4^+, NO_3^- and HNO_3 and corresponding dry deposition components of effective acidity at Cree Lake and Vegreville (Royal Park).

	Cree Lake	**Vegreville (Royal Park)**
SO_4^{-2} (particulate)		
Concentration (μg/m³)	1.07	1.00
Deposition (kg/ha/a)	0.34	0.32
Deposition (kmol H^+/ha/a)	0.01	0.01
SO_2 (gas)		
Concentration (μg/m³)	1.33	5.19
Deposition (kg/ha/a)	2.93	11.46
Deposition (kmol H^+/ha/a)	0.09	0.36
NH_4^+ (particulate)		
Concentration (μg/m³)	0.22	0.83
Deposition (kg/ha/a)	0.07	0.26
Deposition (kmol H^+/ha/a)	0.00	0.01
NO_3^- (particulate)		
Concentration (μg/m³)	0.08	1.01
Deposition (kg/ha/a)	0.02	0.32
Deposition (kmol H^+/ha/a)	0.00	0.01
HNO_3 (gas)		
Concentration (μg/m³)	0.19	0.82
Deposition (kg/ha/a)	1.83	7.76
Deposition (kmol H^+/ha/a)	0.03	0.12
EA (kmol H^+/ha/a)	0.08	0.29

13.0 SPECIAL STUDIES

Specialized studies that have been conducted in the area fall into the three following areas:

- Limited ambient air quality monitoring program conducted at a second site in Fort McMurray.
- Ambient hydrocarbon (HC) and reduced sulphur (RS) species measurements conducted in the vicinity of the plant and tailings pond areas. While the objective of these studies is to estimate emissions from these areas, they do provide ambient measurements to which on-site personnel may be exposed.
- Odour calculations to qualitatively identify sources and responses by an odour panel. Qualitative odour assessments have the advantage of evaluating odour potentials from mixtures of compounds whereas a detailed speciation tends to evaluate odours on a single compound basis.
- Ongoing odour "patrols" to identify and track odours to identify sources or activities that produce the odours. This ongoing assessment also provides a follow-up to identify the odours that have been undertaken to reduce the release of odour compounds.
- Regional throughfall and stemflow estimates of total deposition in the region by the University of Alberta in the late 1970s.

The following sections summarize these specialized studies.

13.1 Ambient Monitoring in Fort McMurray

Alberta Environmental Protection installed a second ambient air quality monitoring trailer in downtown Fort McMurray. Air quality data were collected at this station for the period October 1, 1991 to June 30, 1992 and were compared to the permanent station located on the east bank of the Athabasca River adjacent to the Snye (Myrick 1992). The results are summarized as:

- Average SO_2 concentrations were 15% higher at the permanent station site than at the downtown station.
- Average H_2S concentrations were consistently high at the permanent station. During the period, the permanent station had five exceedences of the one-hour H_2S guideline compared to only one exceedence at the downtown station.

- Concentrations of urban pollutants such as CO and THC were higher at the downtown station than at the permanent station by 31 and 26%, respectively.

- Concentrations of NO_2 and NO_x were higher at the downtown station than at the permanent station by 5 and 13%, respectively.

- Concentrations of the secondary pollutant O_3 were higher at the permanent station by 10%.

- During periods when odours were noted, the average SO_2 and H_2S concentrations were much higher (15 and 75% higher, respectively) than during the remainder of the monitoring period. THC concentrations were only 4% during odour periods than during the remainder of the year.

The study concluded that the permanent station location was more suitable to monitor air pollutants transported into Fort McMurray from the Suncor/Syncrude region. The permanent site was also deemed to be suitable for monitoring urban pollutants.

13.2 Ambient THC and TRS Monitoring

A number of field studies have been conducted in the region to identify and quantify THC and TRS emissions and ambient concentrations. Ambient THC and TRS emissions are dependent on plant facilities and operating practices. The results presented in this section span more than a decade and as a consequence, some of the earlier measurements may not be representative of the current facilities and operating conditions. None-the-less, the earlier studies are presented here for the purposes of completeness. For the purposes of presentation, the studies have been grouped according to their sponsors.

13.2.1 *Alberta Environmental Protection*

A mobile air monitoring survey of the Fort McKay - Fort McMurray corridor was conducted in the summer of 1990 during the scheduled Suncor turnaround (Environmental Protection Service 1991). Observations were made prior to shut-down (May 18 to 20: 3 days), during shut-down (May 21 to 24: 4 days), after shut-down (May 28, 29: 2 days), during plant start-up (June 28 to July 10: 8 days) and following plant start-up (July 27 and September 26 to 28: 4 days).

The survey made use of two mobile monitoring units. The AQML unit was instrumented to measure CO, H_2S, THC, SO_2, NO_x and O_3. The BT-5 unit was instrumented to measure H_2S, SO_2 and THC. Specific monitoring sites were identified and observations for a minimum of 10 minutes were taken at each site. When elevated concentrations were noted or when odours were observed, whole air samples were collected in Tedlar bags for further speciation.

The report provided a very limited analysis and one of the conclusions was that the Suncor turnaround "did not appear to be a major impact on regional air quality". While the AEP report was minimal in deriving conclusions, the following are noted:

- Relatively high SO_2 values (greater than 0.2 ppm) occurred when Suncor and Syncrude were flaring.

- Relatively high THC values (greater than 20 ppm) were observed within both the Suncor (upgrading, tank farm, pond 1 and API pond road) and Syncrude (effluent pond, extraction and API) facilities.

- THC values more distant from the two oil sands facilities were typically in the 1.5 to 3 ppm range although values of up to 9 ppm were observed. These latter high values were associated with highway traffic.

- On one occasion, high THC (greater than 20 ppm) appeared to be associated with a flaring event. This occurrence was also accompanied by high CO values which would suggest incomplete hydrocarbon combustion.

- The highest H_2S values were observed during the shut-down period.

- During the mobile monitoring period, odour complaints were received and reviewed. Both Syncrude and Suncor were identified as sources of odourous emissions.

Tedlar bag samples were collected in the vicinity of the Suncor tailings pond (7 samples), the Suncor API (2 samples) and the Suncor north tank farm (2 samples). Additional samples were collected to characterize the Suncor Naphtha Recovery Unit and the Syncrude diverter stack emissions. Table 13.1 summarizes the average ambient concentrations observed in the vicinity of the Suncor tailings pond, API and north tank farm (NTF). The ambient concentration information presented in the table occur in locations in the plant area where high values were observed. During post start-up operations, significantly higher concentrations were observed in the vicinity of the Suncor Pond 1 than during other periods. It is likely these values were obtained adjacent to an outfall and are more representative of source conditions rather than general conditions along the pond perimeter.

13.2.2 *Syncrude Canada*

The following studies have been conducted in the vicinity of the Syncrude facility:

- Background H_2S observations were collected near the Thickwood Hills forest tower located about 30 km southwest of the oil sands facilities and 30 km northwest of the town of Fort McMurray (Concord Scientific Corporation 1982). Two sites near the Thickwood Hills forest tower were selected, a forest site and a bog site. H_2S levels ranged from 0.03 to 0.50 ppb (0.04 to 0.71 $\mu g/m^3$) at the bog site and from 0.13 to

Table 13.1 Compounds identified and associated ambient air concentrations observed by Alberta Environment in 1990.

Compound ($\mu g/m^3$)	Suncor Pond	Suncor Pond	Suncor	
	Shut-down and Post Shut-down	Post Start-Up	API	NTF
Cyclopentane	9.5	363	13.2	5.6
2-Methyl Pentane	36.1	1730	54.6	23.3
Hexane	81.0	3890	107.4	29.9
2,4-Dimethyl Pentane	4.8	-	-	1.94
Benzene	11.8	1841	14.8	15.2
Thiophene	15.9	170	8.0	4.7
Cyclohexane	31.5	852	47.6	7.8
3-Methyl Hexane	31.7	535	48.7	8.7
2,2,4-Trimethyl Pentane	27.8	-	-	8.1
Heptane	72.4	2075	108.9	18.2
Methyl Cyclohexane	43.1	690	60.5	10.2
2,5-Dimethyl Hexane	18.5	-	22.4	-
2,3,4-Trimethyl Pentane	17.5	-	-	1.6
Toluene	37.9	558	53.8	37.2
2-Methyl Thiophene	9.8	166	12.3	2.2
2,2,5-Trimethyl Hexane	7.7	-	7.5	-
Octane	35.7	217	51.2	8.2
Ethyl Benzene	11.0	116	26.2	7.0
M-Xylene	23.9	47.7	32.1	18.0
P-Xylene	10.3	44.6	12.1	7.4
Styrene	5.5	39.3	6.4	3.6
O-Xylene	11.5	52.2	13.0	8.8
Nonane	19.3	33.5	27.6	4.6
Trimethyl Benzene	14.3	18.2	16.4	11.9
Decane	15.0	-	20.7	6.4
Diethyl Benzene	2.8	-	2.3	1.1
Di-Isopropyl Benzene	1.9	-	-	3.8
THC-Benzene Equivalent (mg/m^3)	2.2	40.9	3.0	1.0

0.56 ppb (0.18 to 0.78 $\mu g/m^3$) at the forest site. The larger observed values were associated with smoke and haze from forest fires burning in the region. The maximum observed values upwind and downwind of identified plant sources are:

Source	H_2S (ppb)
Recycle Pond	6.2
Effluent Pond Inlet	30
Mine Sump Basin	16
Tailings Pond	0.56
Coke Cells	0.26
Coke Settling Basin Inlet	47
Sulphur Loading Areas	200
API Separator	1.2
Entire Facility	6.0

Within and along the perimeter of each source area, relatively large H_2S concentrations can occur.

- Ambient HC and TRS measurements in the vicinity of the mine, process area and tailings pond (September 1987) (Concord Scientific Corporation 1988). Ambient concentration measurements were taken in the following areas through whole air sample collection (Tedlar bags) and subsequent analysis:

  - The perimeter of the extraction and upgrading complex (Julian Day 254 and 263).
  - Around the perimeter of the tailings pond dike (Julian Day 254 and 263).
  - Around the Coke Settling pond (Julian Day 263).
  - Around the Syncrude site as a whole (Julian Day 265).

The compounds identified at each of these locations and the associated maximum concentrations observed at the previously mentioned sites are provided in Table 13.2. The largest ambient hydrocarbon concentrations were measured near the API separator. These values exceed those observed at other locations by factors of 10 to 100.

Table 13.2 Compounds identified and associated maximum ambient air concentrations ($\mu g/m^3$) observed in the vicinity of the Syncrude facilities (1987).

Compound Julian Day	Extraction / Upgrading 254 / 263	Tailings Pond 254	API Separator 263	Coke Settling Pond 263	Whole Site 265
C_1 - C_3	9.14	22.50	8.62	7.07	7.65
iC_4H_{10}	0.91	0.26	0.10	0.08	0.17
nC_4H_{10}	0.7	0.06	0.72	0.48	0.27
Unknown	-	-	-	-	0.03
iC_5H_{12}	0.33	0.16	1.92	0.21	0.05
nC_5H_{12}	0.57	0.01	5.13	0.32	0.03
Cyclopentane	0.25	-	3.30	0.19	-
2-ME-Pentane	0.47	-	11.22	0.48	0.05
3-ME-Pentane	0.22	-	6.03	0.26	0.01
N-Hexane	0.36	0.20	33.39	1.48	0.09
Unknown	-	-	0.36	-	-
ME-Cyclopentane	0.84	0.33	26.36	1.39	0.09
Benzene	0.43	0.10	3.28	0.40	0.05
Cyclohexane	0.24	0.06	10.73	0.53	-
2,3-Dimethylpentane	0.28	0.07	13.94	0.65	0.04
3-Methylhexane	0.76	0.22	38.50	1.91	0.12
N-Heptane	0.64	0.23	65.36	1.78	0.13
ME-Cyclohexane	0.51	0.16	19.57	1.48	0.10
Branched Octane	0.17	0.06	6.03	0.50	0.05
Toluene	1.21	0.27	13.16	1.31	0.40
3-Methylheptane	0.68	0.19	21.68	1.71	0.22
2.3,4-Trimethylhexane	0.27	0.04	5.84	0.50	0.09
N-Octane	0.78	0.13	12.96	1.06	0.24
Branched Nonane	0.49	0.63	5.73	0.50	0.12
ET-Benzene	0.42	-	2.05	0.18	0.10
M,P-Xylenes	1.47	0.12	3.83	0.63	0.38
O-Xylene	4.33	0.04	4.09	0.62	0.26
Unknown	-	-	-	-	0.02
nC_9H_{20}	0.48	-	1.93	0.28	0.12
Cumene	0.01	-	0.24	-	-
Unknown	-	-	0.47	-	0.05
UPG367	0.51	-	0.46	0.15	0.14
UPG377	1.11	0.20	1.17	0.12	0.13
UPG378	0.27	-	-	-	-
UPG387	0.29	0.07	0.36	0.16	0.08
N-Decane	0.31	-	0.45	0.23	0.09
C_1-C_{10}	17.43	23.90	326.08	26.07	9.54
C_5-C_{10}	10.24	3.06	318.37	18.88	2.77

- Ambient HC measurements in the vicinity of the tailings pond (May and June 1992) (Concord Environmental Corporation 1992). Ambient air monitoring was conducted using passive sampling devices deployed around the perimeter of the tailings pond dike to obtain measurements of VOCs. The nominal exposure period for these sampling devices was one week. The compounds identified and the associated maximum concentrations observed are provided in Table 13.3. Larger concentrations were observed near the Plant #6 outfall and in the vicinity of the bitumen recovery area along the general dike area.

- Ambient HC measurements in the vicinity of Syncrude were conducted in March and April 1994 during plant shut-down (BOVAR-CONCORD Environmental 1994). The results are summarized in Table 13.4. More compounds and larger associated concentrations are generally observed at the upgrading, extraction and tailings pond sites than at either the mine or background sites.

13.2.3 *Suncor Monitoring*

Suncor conducts two fugitive emission surveys per calendar year (one in the spring and the other in the summer) for compounds such as H_2S, TRS, TS and THC. The surveys are conducted using a mobile monitor to collect data in the vicinity of the plant and tailings ponds, and are typically conducted for a 3 to 5 day period. The maximum readings depend upon the operating conditions of the plant, the skill of the operator to find a location downwind of a fugitive source and on the prevailing meteorological conditions during the survey.

Table 13.5 summarizes the maximum one-minute averages observed during each survey. The variability of the maximum values provided in the table does not indicate any clear trends. Perhaps more importantly, the interpretive reports that accompany these surveys indicate in general that the maximum values occur downwind of the inlet to tailings pond 1, the tank farms and the plant area.

13.3 Odour Assessment Studies

Suncor initiated a series of odour assessment studies over the period 1989 to 1994 with the objective of identifying and quantifying sources of odours from their facilities. The findings associated with the studies are provided as follows:

Table 13.3 Maximum observed hydrocarbon concentrations ($\mu g/m^3$) measured along the perimeter of the Syncrude Tailings pond (May and June 1992).

Compound	Near Plant #6 Outfall	Bitumen Recovery Area	Perimeter
n-Pentane	16.8	3.5	7.8
Cyclopentane	35.9	0.8	1.1
n-Hexane	664.1	925.8	50.3
2,4-Dimethylpentane	138.2	145.7	131.7
Benzene	20.7	1.2	0.8
Cyclohexane	47.5	2.3	1.8
2,3-Dimethylpentane	88.2	0.6	0.7
3-Methylhexane	318.3	1.7	2.1
Unknown-1	135.4	0.0	1.3
2,2,4-Trimethylpentane	127.2	39.6	35.1
n-Heptane	1137.3	4.3	5.5
Unknown-2	725.4	4.0	4.0
Unknown-3	334.3	1.5	1.7
Unknown-4	172.1	0.4	0.8
Toluene	513.6	8.3	4.3
Unknown-5	1783.9	5.6	8.2
3-Methylheptane	556.2	1.9	2.7
2,2,5-Trimethylhexane	490.6	3.1	3.8
n-Octane	1716.2	6.3	12.3
Unknown-6	150.6	4.0	5.3
Unknown-7	174.9	2.0	2.7
Unknown-8	63.3	0.9	0.5
Ethylbenzene	299.8	2.2	1.9
p-Xylene+, m-Xylene	684.4	9.0	5.8
o-Xylene	265.0	6.8	5.2
n-Nonane	654.6	4.5	4.1
n-Propylbenzene	54.5	13.6	13.3
Unknown-9	202.6	51.9	36.3
1,3,5-Trimethylbenzene	26.8	11.2	10.8
n-Decane+1,2,4-TMB	134.2	34.3	33.0
p-Cymene+1,2,3-TM	31.4	2.7	2.3
Total C_5-C_{10} species	11150	1275	289

Table 13.4 Concentrations of volatile organic compounds ($\mu g/m^3$) measured in the vicinity of the Syncrude facility in 1994.

	Tailings Pond Site	Upgrading and Extraction Sites	Mine Sites	Background Sites
n-pentane	0.4	15.6	0	0.2
cyclopentane	0	3.4	0	0
hexane	5.3	19.0	0	9.4
2,4-dimethylpentane	0	0.7	3.3	1.6
cyclohexane/2,3-dimethylpentane	1.9	5.6	0	0
3-methylhexane	4.7	15.2	0	0
benzene	0.6	587.1	0	0
j-octane	1.5	5.4	0	0
n-heptane	15.5	60.6	0	0
2,2,5-trimethylhexane	0.4	28.5	1.9	0.3
toluene	15.5	4.5	0	0
n-octane	23.8	52.4	0	0.9
ethyl benzene	10.3	8.7	0	2.4
m\p-xylene/n-nonane	22.5	24.7	0	0
o-xylene	9.1	7.8	0	0
cumene	4.2	1.4	0	0
n-propylbenzene	4.0	0.2	0.7	0
n-decane	0	0	0	0
1,3,5-trimethylbenzene	3.3	6.9	0	0
p-cymene	0	0	0	0
1,2,3-trimethylbenzene	7.8	8.9	7.5	7.0
1,2,4-trimethylbenzene	3.4	8.0	8.2	6.1
naphthalene	0	0	0	0

Table 13.5 Maximum ambient concentrations observed during the fugitive emissions monitoring at the Suncor plant.

Year	Month	H_2S (ppb)	TRS (ppb)	TS (ppb)	THC (ppm)	Averaging Period (minutes)
1989	September/October	262	208	N/A	174	15
1990	July	133	N/A	497	24	15
	September	115	877	1081	54	15
1991	February	N/A	N/A	N/A	N/A	N/A
	August	27	N/A	41	19	1
1992	N/A	N/A	N/A	N/A	N/A	N/A
	N/A	N/A	N/A	N/A	N/A	N/A
1993	April	24	40	N/A	12	1
	October	124	180	N/A	64	1
1994	April	93	> 133[a]	N/A	85	1
	October	45	> 114[a]	N/A	15	1
1995	N/A	N/A	N/A	N/A	N/A	N/A

[a] The inequality indicates that the reading exceeded the maximum range of the analyzer.

- An odour sensory studies was undertaken to assess off-site odours associated with emissions from the Tailings Pond 1, the Powerhouse Stack and the Extraction Plant 4 vents (Clayton Environmental Consultants Ltd. 1989*a*). An off-site panel comprised of 8 to 10 members was exposed to samples collected from these sources who provided a description of the associated odours and a determination of odour units. The study concluded that the emissions from the Tailings Pond 1 would create greater downwind odour problems than those from the Powerhouse Stack (the two major odour sources).

- A follow-up dispersion modelling study was undertaken to provide estimates of odours from emissions due to the Powerhouse stack and Tailings Pond 1 in downwind communities of Fort McMurray and Fort McKay (Clayton Environmental Consultants 1989*b*). The study concluded that the Powerhouse stack will not create adverse odours under most conditions and that Pond No. 1 emissions can create significant odours under low wind speed, night-time conditions.

- Additional odour sensory studies were conducted to rank odour emission sources from Plants 3 and 4 and the south tank farm, to evaluate any improvements around Tailings Pond 1 due to the operation of the Naphtha Recovery Unit NRU and to determine the effects of the incinerator stack emissions (Clayton Environmental Consultants 1989*c*). The report concludes that the emissions from the Tailings Pond 1 is still the major source, there appears to be some improvement in air quality due to the NRU and that the incinerator stack should not cause any odour problems in downwind communities.

- Viswanathan (1989) provided a summary of the odour assessment program conducted by Suncor during the 1988-1989 period. The conclusions of the assessment are:

    - Tailings Pond 1 is the major source of odours. Modelling indicated these emissions could cause odour complaints for distances up to 15 km. Operational problems (i.e. a leaking heat exchanger) increased the hydrocarbon emissions from the pond. Tailings Pond 1 was identified as a **high** potential odour causing source.

    - The Powerhouse stack emissions can cause odour complaints up to 6 km. The powerhouse stack is defined as a **low-medium** potential to generate odour complaints.

    - The incinerator emissions are important within 4 km and the Plant 3, Plant 4 and South Tank Farm vents effects are within 2 km. These sources were defined as having a **low** contribution level.

The ambient air analyzed in the vicinity of Tailings Pond 1 indicated the primary components were C_1 to C_5 hydrocarbons and H_2S.

- A review of odour incidents indicated that odours are associated with two types of meteorological conditions (ORTECH International 1992):

  - Persistent northwest wind with a significant upvalley component towards Fort McMurray. Low level emissions will be subject to building downwash effects and will be carried within the valley floor. Tall stack emissions are more likely to be carried out of the valley. The net result is a stable flow that is trapped in the valley with winds flowing towards Fort McMurray;.

  - Along valley flow reversal from upvalley to downvalley occurs under a period of very light and variable winds. These conditions allow emissions to accumulate within the valley.

  Accompanying dispersion modelling indicated highest predicted odour concentrations at Fort McMurray under low wind speed (3.6 km/h) stable and neutral atmospheric conditions. The most significant sources were predicted to result from Building #4 source 4EIA and 4EIB vents (50 to 70%) and from source 3C20 (10 to 17%). The modelling did not include Tailings Pond 1.

- An assessment was conducted to determine odour thresholds for pure compounds (Ortech Corporation 1994). The results are as follows:

Compound	Odour Threshold (ppb)	Literature (ppb)
H_2S	2.9	1.0 to 4.70
Ethyl mercaptan	0.2	0.32 to 1.00
n-butyl mercaptan	0.3	0.62
Thiophene	13.5	0.9 to 8.13
2-Methyl Thiophene	443	N/A
2,5-Dimethyl Thiophene	15.8	N/A

  A review of the literature odour threshold values indicated ranges of several orders of magnitude. The literature values provided above represent what was identified as a "reliable" range.

13.4 Ongoing Odour Tracking

In response to the occurrence of odours and associated complaints, an "Odour Response Protocol" (ORP) was developed to address methods of procedures for odour incident investigations and follow-ups (Glen Lynn Engineering Ltd. 1990).

The number of odour related complaints, the number of odour incidents, the location of the odour complaints and the associated source of the odours over the period 1991 to 1994 are summarized in Table 13.6. The number of complaints is related to the occurrence of an odour incident, and the presence of residences downwind. The results in the table indicate:

- The number of incidents in 1994 (70) is greatly reduced from those in 1991 and 1992 (122 and 134, respectively).
- Each incident receives up to four complaints on average.
- The decrease of the complaint to incident ratio indicates that the magnitude of the odour incidents has decreased.
- Most of the complaints and incidents (~ 85%) are associated with the larger community of Fort McMurray.
- Most incidents are not related to an identifiable source (~ 50%).
- Incidents traceable to the oil sands plants are: Suncor ~ 26%; Syncrude ~ 6%; and both Suncor and Syncrude ~ 18%.
- For the unknown sources, the complaint to incident ratio is typically between 1 and 2.
- For the oil sands plants, the complaint to incident ratio of up to 10 for a single quarter suggest fairly significant odour incident events have occurred.

The odour identification and tracking appears to have resulted in reducing both the frequency and magnitude of odour incidents over the 1991 to 1994 period. This reduction may be a result of improved operational procedures and/or a reduction in community response.

13.5 Throughfall and Stemflow Studies

Deposition represents the removal of atmospheric contaminants by the earth's surface. The removal will depend on the contaminant, meteorological conditions and nature of the surface. For forested areas, the throughfall and stemflow method has been used to provide a measure of wet and dry deposition. The throughfall and stemflow method is based on the assumption that during dry periods, contaminants such as sulphate particulates will deposit and collect on tree canopy foliage. When rainfall occurs, the dry deposits are washed off and the sulphates in the

Table 13.6 Summary of odour complaints and incidents over the period 1991 to 1994.

		Complaint Locations												Odour Sources											
		Total			Fort McMurray			Fort McKay			Other			Suncor			Syncrude			Both			Other / Unknown		
Year	Quarter	C	I	C/I	C	I	C/I	C	I	C/I	C	I	C/I	C	I	C/I	C	I	C/I	C	I	C/I	C	I	C/I
1991	1	45	31	1.5	41	27	1.5	4	4	1	0	0	0	12	8	1.5	4	3	1.3	5	2	2.5	24	18	1.3
	2	50	26	1.9	48	24	2	2	2	1	0	0	0	25	11	2.3	3	2	1.5	1	1	1	21	13	1.6
	3	128	37	3.5	123	32	3.8	3	3	1	2	2	1	76	15	5.1	2	2	1	20	4	5	30	16	1.9
	4	118	28	4.2	113	23	4.9	5	5	1	0	0	0	94	9	10	3	1	3	1	1	1	20	16	1.3
	Annual	341	122	2.8	325	106	3.1	14	14	1	2	2	1	207	43	4.8	12	8	1.5	2.7	8	3.4	95	63	1.5
1992	1	43	28	1.5	39	24	1.6	4	4	1	0	0	0	13	6	2.2	1	1	1	15	9	1.9	14	13	1.1
	2	117	47	2.5	104	38	2.7	11	7	1.6	2	2	1	57	14	4.1	4	4	1	36	9	4	20	20	1
	3	100	39	2.6	96	35	2.7	4	4	1	0	0	0	14	7	2	2	2	1	69	17	4.1	15	13	1.2
	4	54	20	2.7	54	20	2.7	0	0	0	0	0	0	35	3	12	0	0	0	1	1	1	18	16	1.1
	Annual	314	134	2.3	293	117	2.5	19	15	1.3	2	2	1	119	30	4	7	7	1	121	35	3.5	67	62	1.1
1993	1	14	0	0	0	0	0	0	0	0	0	0	0	14	0	0	4	0	0	6	0	0	1	0	0
	2	28	0	0	0	0	0	0	0	0	0	0	0	11	0	0	2	0	0	7	0	0	8	0	0
	3	69	20	3.5	65	18	3.6	0	0	0	4	2	2	46	8	5.8	10	2	5	2	2	1	11	8	1.4
	4	30	22	1.4	26	18	1.4	4	4	1	0	0	0	1	1	1	0	0	0	11	4	2.8	18	17	1.1
	Annual	141	42	3.4	91	36	2.5	4	4	1	4	2	2	72	9	8	15	2	7.5	26	6	4.3	38	25	1.5
1994	1	14	13	1.1	12	11	1.1	2	2	1	0	0	0	5	4	1.3	0	0	0	1	1	1	8	8	1
	2	46	26	1.8	40	20	2	4	4	1	2	2	1	12	4	3	2	2	1	17	8	2.1	15	12	1.3
	3	29	16	1.8	3	3	1	3	1	3	10	4	2.5	10	4	2.5	0	0	0	10	4	2.5	15	12	1.3
	4	24	15	1.6	21	12	1.8	2	2	1	1	1	1	5	3	1.7	2	2	1	10	4	2.5	7	6	12
	Annual	113	70	1.6	76	46	1.7	11	9	1.2	13	7	1.9	32	15	2.1	4	4	1	38	17	2.2	45	38	1.2
	Total	909	368		785	305		48	42		21	13		430	97		38	21		212	66		245	188	

C = # of Complaints
I = # of Incidents
C/I = Complaint/Incident Ratio

rainfall collected below the forest canopy will be enhanced. This enhanced is a measure of the dry deposition. This approach assumes uptake and leaching within the canopy either offset each other or are negligible.

In the summer of 1976, field studies were conducted in the oil sands region which measured sulphate deposition in precipitation and in the throughfall and stemflow from trees (Nyborg *et al.* 1985). Dry deposition estimates are available from two field components of the Nyborg *et al.* report:

- The nutrient cycling study that was conducted during the summer of 1976.
- Field studies of precipitation, throughfall and stemflow at 14 sites in the region.

The nutrient cycling study involved two sites; a **control site** near Algar forestry air strip, 101 km south-southwest of the emission source and an **exposed site**, 32 km southeast of the emission sources (Steepbank Airport). The average sulphate content of precipitation, throughfall, stemflow and computed dry deposition for Trembling Aspen and Jack Pine are:

kg/ha/3 months	Control (Algar)	Exposed (Steepbank Airport)
Trembling Aspen		
Rain	1.11	>2.20
Troughfall	2.36	2.58
Stemflow	0.29	> 1.12
Dryfall	1.64	1.50
Jack Pine		
Rain	0.76	> 2.20
Throughfall	4.97	6.42
Stemflow	> 0.14	> 0.22
Dryfall	4.35	4.45

The results of the nutrient cycling study indicate:

- Sulphate deposition in throughfall and stemflow is greater than that in rainfall.
- Sulphate deposition in throughfall and stemflow is greater beneath a Jack Pine canopy than beneath a Trembling Aspen canopy. All things being equal, Jack Pine appears to be more efficient in removing sulphate from the atmosphere than Trembling Aspen.

- Most of the dry deposition is associated with throughfall instead of stemflow.

- There does not appear to be a big difference between the controlled and exposed sites. At both sites, dry deposition is about 1.6 kg SO_3^{-2}/ha/3 months for Trembling Aspen and 4.4 kg/SO_4^{-2}/ha/3 months for Jack Pine.

These deposition values can be extrapolated to annual values by assuming that one-half the amount rainfall occurs during the summer. On this basis, dry deposition to Trembling Aspen and Jack Pine are about 3.2 kg SO_4^{-2}/ha/a and 8.8 kg SO_4^{-2}/ha/a, respectively. The wet deposition at both sites averaged about 3.1 kg SO_4^{-2}/ha/a.

The "field study" component involved the collection of precipitation, throughfall and stemflow samples at 14 sites collected in the summer of 1976. These sites, listed in Table 13.7, range in distance between 4 and 173 km from Suncor's operations. Table 13.7 also shows the rainfall, throughfall, stemflow and calculated dry values expressed as kg S/ha/month and as kg SO_4^{-2}/ha/a. The conversion is based on the collection period of 2.5 months and the assumption that one-half the rainfall occurs during this period. Comments with respect to information presented in Table 13.5 are:

- Wet deposition values expressed on an annual basis range from 2.4 to 9.0 kg SO_4^{-2}/ha/a. For the most part, the highest values occur relatively close (about 30 km or less) to the plant. At the more distant locations, the wet deposition values range from about 2.5 to 4 kg SO_4^{-2}/ha/a. This is consistent with the observations associated with the nutrient cycling study. For the purpose of comparison, the average wet sulphate deposition at Fort McMurray is about 4.9 kg SO_4^{-2}/ha/a (Table 12.3). This Fort McMurray value is based on two operating oil sands facilities, whereas the values from the Nyborg *et al.* report were collected when only one oil sands plant was operating.

- The calculated dry deposition values exhibit a much greater range, with low and high values of 3.8 and 67 kg SO_4^{-2}/ha/a, respectively.

The calculated dry deposition at Algar of 21 kg SO_4^{-2}/ha/a is more than double the annual value of 8.8 kg SO_4^{-2}/ha/a calculated for the same site from the nutrient cycling portion of the study. Similarly, the calculated dry deposition at Steepbank Airport of 38 kg SO_4^{-2}/ha/a, is more than four times the value calculated for the site from the nutrient cycling portion of the study.

These differences and the extrapolation from individual measurements to a regional forest canopy indicate elements of uncertainty with respect to the following:

- Edge effects: Higher depositions are expected for trees located at the edge of a canopy than for trees located within the canopy.

Table 13.7 Rainfall, throughfall and stemflow measurements in the Athabasca oil sands area collected over the period July to September 1976.

Site		Rainfall		Throughfall		Stemflow		Dry
	(km)	(kg S/ha/mo)	(kg SO_4^{-2}/ha/a)	(kg S/ha/mo)	(kg SO_4^{-2}/ha/a)	(kg S/ha/mo)	(kg SO_4^{-2}/ha/a)	(kg SO_4^{-2}/ha/a)
Steepbank 2	4	0.60	9.0	0.8	12.0	0.19	2.9	5.9
Mildred Lake	11	0.47	7.1	1.3	19.5	0.14	2.1	14.6
Steepbank 1	17	0.19	2.9	1.5	22.5	ND	ND	19.7
MacKay River	21	0.21	3.2	4.5	67.5	0.16	2.4	66.8
Thickwood Hills	31	0.56	8.4	1.9	28.5	0.13	2.0	22.1
Steepbank A	32	0.17	2.6	2.7	40.5	ND	ND	38.0
Muskeg Mountain	38	0.29	4.4	1.0	15.0	0.19	2.9	13.5
Bitumount	39	0.16	2.4	1.0	15.0	0.10	1.5	14.1
Hanginstone River	67	0.25	3.8	2.2	33.0	0.13	2.0	31.2
Gordon Lake	75	0.25	3.8	1.2	18.0	0.01	0.2	14.4
Birch Mountain	79	0.25	3.8	1.3	19.5	0.01	0.2	15.9
Algar	101	0.25	3.8	1.6	24.0	0.06	0.9	21.2
Richardson	102	0.18	2.7	0.4	6.0	0.03	0.5	3.8
May	173	0.25	3.8	0.6	9.0	0.04	0.6	5.9

Dry = throughfall + stemflow - rainfall

All measurements associated with coniferous trees (white spruce, black spruce, and Jack Pine).

- Canopy closure: Typically a forest canopy will not have a uniform 100% closure as there are open spaces between individual trees.

- Regional canopy: The oil sands area is represented by a mosaic of various vegetation canopy types.

In summary, the limited throughfall and stemflow information collected in the region does indicate that dry deposition of sulphur compounds is as, or even more important than the wet deposition component. However, caution is advised in extrapolating individual plot measurements to the regional airshed.

14.0 SUMMARY AND COMMENTS

The ambient air quality monitoring program in the Athabasca oil sands region is comprised of continuous monitoring, passive monitoring, precipitation monitoring and specialized studies. Suncor, Syncrude and Alberta Environmental Protection (AEP) collectively maintain 12 continuous ambient air quality stations and 76 passive monitoring stations. AEP and Environment Canada collectively maintain 8 precipitation monitoring stations in northern Alberta and Saskatchewan. These monitoring programs are further supplemented by short-term specialized studies that have focussed on characterizing ambient hydrocarbon and reduced sulphur specie concentrations; odours; and deposition.

14.1 Continuous Monitoring Summary

Five and one-half years of continuous ambient air quality data (January 1990 to June 1995) from the 12 Suncor, Syncrude and Alberta Environmental Protection monitoring stations were reviewed, summarized and compared to air quality guidelines.

14.1.1 *SO_2 Concentrations*

Relatively high SO_2 concentrations (in excess of the 0.34 ppm or 900 $\mu g/m^3$ guideline) have been observed on the edge of the Athabasca River valley escarpment adjacent to the Suncor powerhouse stack (that is, at the Fina and Mannix sites). While exceedences of the 0.17 or 450 $\mu g/m^3$ guidelines have been observed at least once at all of the monitoring sites, these exceedences are most frequently observed at the Fina and Mannix stations and least frequently at the AQS5 (Syncrude Tailings East) and FMMU (Fort McMurray) stations. The maximum one-hour average concentrations observed in Fort McMurray and Fort McKay are 0.18 and 0.26 ppm, respectively.

The relatively high SO_2 concentrations are well correlated with one of the two oil sands plants being located upwind. The high values tend to be associated with daytime hours and with wind speeds less than 10 km/h. Convective and/or limited trapping meteorological conditions are associated with these SO_2 events.

Background annual values of SO_2 are expected to be in the 0.01 ppm (1 ppb) range. These values are based on extrapolating measurements from Cree Lake and Vegreville to the region. The compliance monitoring program conducted by Suncor, Syncrude and AEP do not allow meaningful annual or background values to be calculated.

14.1.2 *H_2S Concentrations*

Relatively high H_2S concentrations (in excess of 10 ppb or 14 $\mu g/m^3$) have been observed at all locations. The most frequent exceedences have been observed at the Mannix, Lower Camp and

AQS3 (Mildred Lake) Stations. Most of these exceedences were observed in 1990 with the following years showing a decrease.

The relatively high H_2S concentrations were observed during the summer and during the night-time periods. The H_2S events are, for the most part, well correlated with one of two oil sands plants being located upwind. It is likely that the H_2S events result from low-level H_2S sources that are transported downwind under stable atmospheric conditions.

14.1.3 *NO_x Concentrations*

NO_x was only observed at the AQS4 (Tailings North) and FMMU (Fort McMurray) stations. Only one exceedence of the 0.21 ppm NO_2 guidelines was observed in Fort McMurray. High NO_x concentrations in Fort McMurray tend to occur during the winter months and during the evening hours. The likely source of high ambient NO_x concentrations in Fort McMurray are residential wood combustion and/or local traffic.

A review of the NO_2/NO_x ratio indicated a dependence on the NO_x concentrations. For small NO_x concentrations (that is, less than 0.05 ppm), the NO_2 concentration is typically 55 to 75% of the NO_x value. For larger NO_x concentrations (that is, greater than 0.2 ppm), the NO_2 concentration is typically 20% of the NO_x value.

14.1.4 *O_3 Concentrations*

Relatively high ozone levels are observed in Fort McMurray during the late spring and summer months. Ozone events tend to occur during the afternoon hours. While exceedences of the hourly guideline (80 ppb or 0.08 ppm), are relatively infrequent, exceedences of the daily guideline (25 ppb or 0.025 ppm) occur on average about 135 days per year. This is typical of rural Alberta areas where the daily guidelines have been exceeded about 50 to 90% of the time.

14.1.5 *CO Concentrations*

CO values observed in Fort McMurray have all been within the 13 ppm guideline (as a one hour average). The higher CO values are associated with the winter period and tend to occur during the evening hours. Local sources (i.e., residential wood combustion) are likely the most significant contributor to the CO values observed in Fort McMurray.

14.1.6 *THC Concentrations*

While THC concentrations are typically in the 1.4 to 2.1 ppm range, maximum values in excess of 30 ppm have been reported in Athabasca River valley locations (that is, Poplar Creek and Athabasca Bridge). These values suggest channelling of emissions from low level fugitive hydrocarbon sources by the valley. Further along the valley, the maximum observed values are less at Fort McMurray (8.6 ppm) and Fort McKay (4.1 ppm).

14.1.7 *Particulates*

Total suspended particulates are measured at AQS2 (Fort McMurray) and AQS4 (Tailings North). While the annual mean concentrations at both sites have been less than the 60 $\mu g/m^3$ guideline, three exceedences of the daily guideline of 100 $\mu g/m^3$ have been observed at AQS4. There appears to be a tendency for decreasing TSP values over the period 1990 to 1994.

14.2 Passive Monitoring Summary

A review of nearby co-located Suncor, Syncrude and AEP passive samplers indicated biases that may be due to either the sampling approach and/or the analytical approach. Adjustment factors were applied to normalize the data prior to analysis.

The locations of the passive samplers are biased on a north/south axis parallel to the Athabasca River valley. Maximum total sulphation and hydrogen sulphide values occur in the vicinity of each plant and in the river valley near Lower Camp.

14.3 Precipitation Chemistry Summary

14.3.1 *Precipitation Chemistry*

The average acidity of the precipitation observed in Fort McMurray (pH 4.8) is more acidic than other locations measured in northern Alberta or Saskatchewan (pH = 5.0 to 5.3). The following table compares the wet deposition of specific anions and cations observed in Fort McMurray with other northern locations:

Anion / Cation	Wet Deposition (kg/ha/a)	
	Fort McMurray	Other
SO_4^{-2}	4.9	1.7 to 5.6
NO_3^-	2.3	0.9 to 4.2
Ca^{+2}	1.1	0.2 to 1.2
Mg^{+2}	0.25	0.05 to 0.19
NH_4^+	0.4	0.3 to 2.2

Generally, the lowest deposition values are observed at Cree Lake (SO_4^{-2}, Ca^{+2}, Mg^{+2}, NH_4^+). For some compounds (SO_4^{-2}, NO_3^- and NH_4^+), the highest values were observed at Vegreville.

The annual average acidifying potential (AP) observed in Fort McMurray is 0.03 kmol H^+ equivalent/ha/a. This compares to the range of -0.02 to +0.02 kmol H^+ equivalent/ha/a observed at the other locations.

The annual average effective acidity (EA) observed in Fort McMurray is 0.06 kmol H^+ equivalent/ha/a. This compares to the range of 0.03 to 0.13 kmol H^+ equivalent/ha/a observed at the other locations.

14.3.2 *Dry Deposition*

Background concentration measurements at Cree Lake and Vegreville were used to estimate dry deposition of selected compounds. The results can be summarized as:

- The dry deposition of sulphur compounds expressed as sulphate equivalent ranges from 4.7 kg SO_4^{-2} equivalent/ha/a at Cree Lake to 17.5 kg SO_4^{-2} equivalent/ha/a at Vegreville. About 70% of the deposition is in the dry form.

- The dry deposition of NH_4^+ ranges from 0.07 kg NH_4^+/ha/a at Cree Lake to 0.26 kg NH_4^+/ha/a at Vegreville. About 15% of the deposition is in the dry form.

- The dry deposition of the other nitrogen containing compounds expressed as nitrate equivalent ranges from 1.8 kg NO_3^- equivalent/ha/a at Cree Lake to 8.0 kg NO_3^- equivalent/ha/a at Vegreville. About 60% of the deposition is in the dry form.

The calculated dry contribution to the Effective Acidity (EA) are 0.08 and 0.29 kmol H^+/ha/a at Cree Lake and Vegreville, respectively. This compares to the corresponding wet contributions of 0.05 and 0.13 kmol H^+/ha/a at the two respective sites. The dry component of the EA is about 65% of the total EA.

14.4 Special Studies Summary

A number of short-term and/or specialized monitoring programs have been conducted by the oil sands operations and others in the region. These studies are summarized in the following subsections.

14.4.1 *Fort McMurray*

A second monitoring station was installed in downtown Fort McMurray. Air quality data collected at this station were compared to the corresponding data collected at the permanent Fort McMurray station. The study concluded that the permanent station location was more suitable to monitor pollutants transported into Fort McMurray from the oil sands region.

14.4.2 *THC and TRS Monitoring*

Alberta Environmental Protection conducted a mobile ambient air monitoring survey in 1990. The results of the study indicated:

- Relatively high SO_2 and THC levels were associated with plant flaring events.

- Relatively high THC concentrations were observed within the Suncor and Syncrude facilities.

Limited speciation of whole air samples collected around the Suncor facilities was conducted.

A number of studies have been conducted by Syncrude since the early 1980's. Selected conclusions indicate:

- Remote background H_2S concentrations ranged from 0.03 to 0.5 ppb at a bog site and from 0.13 to 0.56 ppb at a forested site. The larger values were associated with smoke and haze from forest fires.

- Relatively large H_2S and hydrocarbon concentrations were observed within and adjacent to specific facility operations such as the Effluent Pond inlet, API separator, near the inlet to the tailings pond and in the bitumen recovery area of the tailings pond.

Speciation of whole air samples and passive samplers collected around the Syncrude facility has been conducted.

Suncor conducts a nominal two mobile ambient monitoring surveys per year for reduced sulphur species and total hydrocarbons. Relatively high values have been observed in the vicinity of the inlet to Tailings Pond 1, the tank farms and the plant area.

14.5 Odour Assessment Studies

A number of assessment studies to identify and quantify odours resulting from the Suncor plant have been conducted. The studies identified Tailings Pond 1 as a high potential for causing off-site odours whereas the powerhouse stack emissions was defined as a low-medium potential for causing off-site odours.

A review of regional odour complaint information indicated a reduction of both the frequency and magnitude of odour incidents over the 1991 to 1994 period.

14.6 Throughfall and Stemflow Studies

Field studies were conducted in 1976 to measure sulphate deposition in precipitation and in the throughfall and stemflow below a tree canopy. The studies indicated:

- Sulphate deposition in throughfall and stemflow is greater than that in the rainfall indicating a dry deposition contribution. Most of the dry deposition is associated with throughfall rather than stemflow.

- Wet sulphate deposition ranged from 2.4 to 9 kg SO_4^{-2}/ha/a. At the more distant locales, the wet deposition values were in the 2.5 to 4.0 kg SO_4^{-2}/ha/a range. This compares to the more recent values of 1.9 kg SO_4^{-2}/ha/a and 4.9 SO_4^{-2}/ha/a observed at Cree Lake and Fort McMurray, respectively.

- Dry deposition estimates ranged from 3.8 to 67 kg SO_4^{-2}/ha/a with some uncertainty with the estimates provided by two separate field components of the program. Estimated dry deposition of sulphur components at Cree Lake is about 4.7 kg SO_4^{-2}/ha/a.

The results of the throughfall and stemflow studies, in spite of some limitations, do indicate that dry deposition can be as important or even more important than wet deposition.

14.7 Database Problems

Most of the analyses and review provided in this report are based on electronic database files supplied by Suncor, Syncrude and Alberta Environmental Protection. During the review of these databases, comparisons were made with the summaries presented in the respective annual reports and inconsistencies were noted. Considerable time was spent to resolve these inconsistencies. Examples of the problems found include:

- The AEP Fort McMurray station reports a wind direction of 90° (east winds) when the wind speed is calm.

- The frequency of O_3 exceedences obtained from the electronic database did not match those provided in the annual reports.

- The number of SO_2 and H_2S exceedences obtained from the electronic database provided by Suncor and Syncrude did not match the values reported in the annual reports.

- The threshold value for reporting an hourly SO_2 exceedence varies from year to year. Threshold values of 0.165, 0.170 and 0.175 ppm have been used.

- The annual geometric mean for total suspended particulate concentrations were incorrectly calculated.

- Difficulties were found with the precipitation database supplied by AEP.

Many of the difficulties with the database appear to result from the use of manual procedures to quality control the raw data that exist in electronic form. As the process is manual, the changes do not get incorporated into the database. It is therefore recommended that ambient air quality databases reflects all quality control changes, these changes be documented and the database files be appropriately updated and archived.

Other difficulties resulted from errors in the annual reports. In these cases, the results presented in the annual reports did not match either the electronic database or the monthly report. While errors can occur, there needs to be a follow-up mechanism that identifies the error and provides the correct results. It is therefore recommended that all annual reports contain an "errata" section that is retroactive to previous reports.

14.8 Conclusions

The operation of the Suncor and Syncrude oil sands facilities has resulted in changes to the quality of the air downwind of the facilities. The major changes appear to be associated with the controlled emissions of SO_2 from the main stacks and from fugitive reduced sulphur species and hydrocarbon emissions from lower level sources.

The SO_2 emissions have resulted in ambient SO_2 concentrations that are in excess of ambient guidelines. These exceedences occur most frequently in the vicinity of the Suncor site. The wet sulphate deposition observed in Fort McMurray is higher than in other regions of northern Alberta or Saskatchewan. Dry deposition can be as important or more important than wet deposition.

Fugitive hydrocarbon and reduced sulphur compound emissions from the plant area and associated ponds have resulted in off-site odours. The frequency and magnitude of reported odour incidents have decreased in the 1991 to 1994 period.

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APPENDICES

APPENDIX A FILE DOCUMENTATION

An important part of any project where a large amount of data are handled is file management. The computer files associated with the project include the following:

- Continuous monitoring data files
- Passive monitoring data files
- Precipitation monitoring 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 graphs files were all prepared using standard off-the-shelf commercial MS-DOS WINDOWS (Microsoft Corporation) based software.

A1. Continuous Monitoring Data Files

The statistical analysis and data management program STATISTICA for WINDOWS (Release 4.5) (Statsoft, Tulsa, Oklahoma) was used as the primary data base manager and analytical tool for the continuous air quality monitoring data. The following twelve time series data files with one record per hour were used.

Continuous Monitoring Data Files

Site	Statistica Data Base File Name	File Size (bytes)
Suncor Mannix (#2)	SUNSTN2.STA	4239808
Suncor Lower Camp (#4)	SUNSTN4.STA	4239808
Suncor Fina (#5)	SUNSTN5.STA	4239984
Suncor Poplar Creek (#9)	SUNSTN9.STA	3817920
Suncor Athabasca Bridge (#10)	SUNSTN10.STA	2886016
Syncrude AQS1 (Mine South)	SYNSTN1.STA	3460696
Syncrude AQS2 (Fort McMurray)	SYNSTN2.STA	3845104
Syncrude AQS3 (Mildred Lake)	SYNSTN3.STA	3845104
Syncrude AQS4 (Tailings North)	SYNSTN4.STA	4229512
Syncrude AQS5 (Tailings East)	SYNSTN5.STA	3460696
AEP Fort McMurray (FMMU)	FMCMRY.STA	6937728
AEP Fort McKay (FRMU)	FMAKAY.STA	3854464

Data fields contained within these files are identified in Tables A1 through A12.

Table A1. List of variables contained in the Suncor Mannix (#2) continuous monitoring data base file (SUNSTN2.STA) from January 1, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	SO_2	1-hr average SO_2 concentration	(ppm)
6	H_2S	1-hr average H_2S concentration	(ppb)
7	THC	1-hr average THC concentration	(ppm)
8	WS	1-hr average Wind Speed	(km/h)
9	WD	1-hr average Wind Direction	(degrees)
10	Sigth	1-hr average Standard Deviation of Wind Direction	(degrees)
11	Temp	1-hr average Temperature	(degrees C)

Table A2. List of variables contained in the Suncor Lower Camp (#4) continuous monitoring data base file (SUNSTN4.STA) from January 1, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	SO_2	1-hr average SO_2 concentration	(ppm)
6	H_2S	1-hr average H_2S concentration	(ppb)
7	THC	1-hr average THC concentration	(ppm)
8	WS	1-hr average Wind Speed	(km/h)
9	WD	1-hr average Wind Direction	(degrees)
10	Sigth	1-hr average Standard Deviation of Wind Direction	(degrees)
11	Temp	1-hr average Temperature	(degrees C)

Table A3. List of variables contained in the Suncor Fina (#5) continuous monitoring data base file (SUNSTN5.STA) from January 1, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	SO_2	1-hr average SO_2 concentration	(ppm)
6	H_2S	1-hr average H_2S concentration	(ppb)
7	THC	1-hr average THC concentration	(ppm)
8	WS	1-hr average Wind Speed	(km/h)
9	WD	1-hr average Wind Direction	(degrees)
10	Sigth	1-hr average Standard Deviation of Wind Direction	(degrees)
11	Temp	1-hr average Temperature	(degrees C)

Table A4. List of variables contained in the Suncor Poplar Creek (#9) continuous monitoring data base file (SUNSTN9.STA) from July 20, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	SO_2	1-hr average SO_2 concentration	(ppm)
6	H_2S	1-hr average H_2S concentration	(ppb)
7	THC	1-hr average THC concentration	(ppm)
8	WS	1-hr average Wind Speed	(km/h)
9	WD	1-hr average Wind Direction	(degrees)
10	Sigth	1-hr average Standard Deviation of Wind Direction	(degrees)
11	Temp	1-hr average Temperature	(degrees C)

Table A5. List of variables contained in the Suncor Athabasca Bridge (#10) continuous monitoring data base file (SUNSTN10.STA) from October 4, 1991 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	SO_2	1-hr average SO_2 concentration	(ppm)
6	H_2S	1-hr average H_2S concentration	(ppb)
7	THC	1-hr average THC concentration	(ppm)
8	WS	1-hr average Wind Speed	(km/h)
9	WD	1-hr average Wind Direction	(degrees)
10	Sigth	1-hr average Standard Deviation of Wind Direction	(degrees)
11	Temp	1-hr average Temperature	(degrees C)

Table A6. List of variables contained in the Syncrude AQS1 (Mine South) continuous monitoring data base file (SYNSTN1.STA) from January 1, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	H_2S	1-hr average H_2S concentration	(ppm)
6	SO_2	1-hr average SO_2 concentration	(ppm)
7	WD	1-hr average Wind Direction	(degrees)
8	WS	1-hr average Wind Speed	(km/h)

Table A7. List of variables contained in the Syncrude AQS2 (Fort McMurray) continuous monitoring data base file (SYNSTN2.STA) from January 1, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	H_2S	1-hr average H_2S concentration	(ppm)
6	SO_2	1-hr average SO_2 concentration	(ppm)
7	WD	1-hr average Wind Direction	(degrees)
8	WS	1-hr average Wind Speed	(km/h)
9	THC	1-hr average Total Hydrocarbon Concentration	(ppm)

Table A8. List of variables contained in the Syncrude AQS3 (Mildred Lake) continuous monitoring data base file (SYNSTN3.STA) from January 1, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	H_2S	1-hr average H_2S concentration	(ppm)
6	SO_2	1-hr average SO_2 concentration	(ppm)
7	WD	1-hr average Wind Direction	(degrees)
8	WS	1-hr average Wind Speed	(km/h)
9	Temp	1-hr average Temperature	(degrees C)

Table A9. List of variables contained in the Syncrude AQS4 (Tailings North) continuous monitoring data base file (SYNSTN4.STA) from January 1, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	H_2S	1-hr average H_2S concentration	(ppm)
6	SO_2	1-hr average SO_2 concentration	(ppm)
7	WD	1-hr average Wind Direction	(degrees)
8	WS	1-hr average Wind Speed	(km/h)
9	THC	1-hr average Total Hydrocarbon Concentration	(ppm)
10	NO_x	1-hr average Total Oxides of Nitrogen	(ppm)

Table A10. List of variables contained in the Syncrude AQS5 (Tailings East) continuous monitoring data base file (SYNSTN5.STA) from January 1, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	H_2S	1-hr average H_2S concentration	(ppm)
6	SO_2	1-hr average SO_2 concentration	(ppm)
7	WD	1-hr average Wind Direction	(degrees)
8	WS	1-hr average Wind Speed	(km/h)

Table A11. List of variables contained in the AEP Fort McMurray continuous monitoring data base file (FMCMRY.STA) from January 1, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	CO	1-hr average Carbon Monoxide Concentration	(ppm)
6	H_2S	1-hr average Hydrogen Sulphide Concentration	(ppm)
7	NO_2	1-hr average Nitrogen Dioxide Concentration	(ppm)
8	O_3	1-hr average Ozone Concentration	(ppm)
9	Sigth	1-hr average Standard Deviation of Wind Direction	(degrees)
10	SO_2	1-hr average Sulphur Dioxide Concentration	(ppm)
11	THC	1-hr average Total Hydrocarbons Concentration	(ppm)
12	WD	1-hr average Wind Direction	(degrees)
13	WS	1-hr average Wind Speed	(m/s)
14	NO	1-hr average Nitric Oxide Concentration	(ppm)
15	NO_x	1-hr average Total Oxides of Nitrogen	(ppm)

Table A12. List of variables contained in the AEP Fort McKay continuous monitoring data base file (FMAKAY.STA) from January 1, 1990 to June 30, 1995.

Variable Number	Code Name	Variable Description	Variable Units
1	Year	Year	
2	Month	Month	
3	Day	Day	
4	Hour	Hour	
5	H_2S	1-hr average Hydrogen Sulphide Concentration	(ppm)
6	Sigth	1-hr average Standard Deviation of Wind Direction	(degrees)
7	SO_2	1-hr average Sulphur Dioxide Concentration	(ppm)
8	THC	1-hr average Total Hydrocarbons Concentration	(ppm)
9	WD	1-hr average Wind Direction	(degrees)
10	WS	1-hr average Wind Speed	(m/s)

A2. Passive Monitoring Data Files

The spreadsheet program Excel for Windows (Version 5.0) was used as the primary data base manager for the Passive Monitoring Data. The following three time series files with one record per sampling period were used:

File Name	File Contents	File Size
FMSTATIC.XLS	Alberta Environmental Protection Static Data for Fort McMurray Region	34304
SCSTATIC.XLS	Suncor Static Data	26112
SYSTATIC.XLS	Syncrude Static Data	89088

The Syncrude and AEP Fort McMurray data are monthly values, while the Suncor data is in yearly averages. AEP operates six stations while Syncrude and Suncor maintained up to 40 stations during the 1990 to 1995 period. Files contain both H_2S and Total Sulphation loading values.

A3. Precipitation Monitoring Data Files

The spreadsheet software Excel (Version 5.0) was used as the primary data base manager for the Precipitation Chemistry Monitoring data files. The following two files were provided by AEP staff:

File Name	File Size (bytes)
PRECIP.XLS	966656
MOREPREC.XLS	377344

A4. Report Files

The word processing program, WORD (Version 6.0), (Microsoft Corporation) was used to prepare this report. The figures were prepared using a number of different graphics packages: FREELANCE Graphics for Windows (Release 2.01) (Lotus Development Corporation) and SURFER (Version 6) (Golden Software). Table A.13 identifies the WORD text files and Table A.14 identifies the graphics files that comprise this report.

Table A.13 Report 2 Text Files.

Section	File	File Size (bytes)
1	sec-1.doc	44032
2	sec-2.doc	53248
3	sec-3.doc	59904
4	sec-4.doc	73216
5	sec-5.doc	244736
6	sec-6.doc	47616
7	sec-7.doc	52224
8	sec-8.doc	40448
9	sec-9.doc	40448
10	sec-10.doc	96256
11	sec-11.doc	53760
12	sec-12.doc	25088
13	sec-13.doc	109056
14	sec-14.doc	43520
15	sec-15.doc	27648

Table A14. Report 2 Graphics Files.

Figure	Software Package	File	File Size (bytes)
2.1	Photocopy Reproduction	-	-
2.2	FREELANCE 2.0	FIG22.PRE	94982
2.3	FREELANCE 2.0	FIG23.PRE	37218
4.1	FREELANCE 2.0	STN2SO2.PRE	56868
4.2	FREELANCE 2.0	STN4SO2.PRE	56833
4.3	FREELANCE 2.0	STN5SO2.PRE	56995
4.4	FREELANCE 2.0	STN9SO2.PRE	56809
4.5	FREELANCE 2.0	STN10SO2.PRE	56737
4.6	FREELANCE 2.0	SYN1SO2.PRE	56809
4.7	FREELANCE 2.0	SYN2SO2.PRE	56809
4.8	FREELANCE 2.0	SYN3SO2.PRE	56809
4.9	FREELANCE 2.0	SYN4SO2.PRE	56809
4.10	FREELANCE 2.0	SYN5SO2.PRE	56809
4.11	FREELANCE 2.0	FMSO2.PRE	56809
4.12	FREELANCE 2.0	FKSO2.PRE	56809
4.13	FREELANCE 2.0	FIG413.PRE	21720
4.14	LOTUS 1-2-3	ANNSO2.WK4	14544
4.15	LOTUS 1-2-3	ANNSO2.WK4	14544
4.16	LOTUS 1-2-3	ANNSO2.WK4	14544
5.1	FREELANCE 2.0	STN2H2S.PRE	56784
5.2	FREELANCE 2.0	STN4H2S.PRE	57205
5.3	FREELANCE 2.0	STN5H2S.PRE	57199
5.4	FREELANCE 2.0	STN9H2S.PRE	56795
5.5	FREELANCE 2.0	STN10H2S.PRE	56795
5.6	FREELANCE 2.0	SYN1H2S.PRE	57145
5.7	FREELANCE 2.0	SYN2H2S.PRE	57145

Table A14. Concluded.

Figure	Software Package	File	File Size (bytes)
5.8	FREELANCE 2.0	SYN3H2S.PRE	57145
5.9	FREELANCE 2.0	SYN4H2S.PRE	57057
5.10	FREELANCE 2.0	SYN5H2S.PRE	57145
5.11	FREELANCE 2.0	FMH2S.PRE	56784
5.12	FREELANCE 2.0	FKH2S.PRE	56784
5.13	LOTUS 1-2-3	ANNH2S.WK4	17192
5.14	LOTUS 1-2-3	ANNH2S.WK4	17192
5.15	LOTUS 1-2-3	ANNH2S.WK4	17192
6.1	FREELANCE 2.0	FMNOX.PRE	56510
6.2	FREELANCE 2.0	FIG62.PRE	107466
6.3	LOTUS 1-2-3	ANNNOX.WK4	14748
7.1	FREELANCE 2.0	FMO3.PRE	56479
8.1	FREELANCE 2.0	FMCO.PRE	56375
9.1	FREELANCE 2.0	STN9THC.PRE	56808
9.2	FREELANCE 2.0	STN10THC.PRE	56778
9.3	FREELANCE 2.0	SYN2THC.PRE	56794
9.4	FREELANCE 2.0	SYN4THC.PRE	56863
9.5	FREELANCE 2.0	FMTHC.PRE	56800
9.6	FREELANCE 2.0	FKTHC.PRE	56808
9.7	LOTUS 1-2-3	ANNTHC.WK4	11104
9.8	LOTUS 1-2-3	ANNTHC.WK4	11104
10.1	FREELANCE 2.0	FIG101&2.PRE	31438
10.2	FREELANCE 2.0	FIG103&4.PRE	25753
11.1	FREELANCE 2.0	TSMAX2.PRE	11336
11.2	FREELANCE 2.0	H2SMAX2.PRE	85487
11.3	LOTUS 1-2-3	ANNTS.WK4	14544