A PRELIMINARY INVESTIGATION INTO THE MAGNITUDE OF FOG OCCURRENCE AND ASSOCIATED PROBLEMS IN THE OIL SANDS AREA

by

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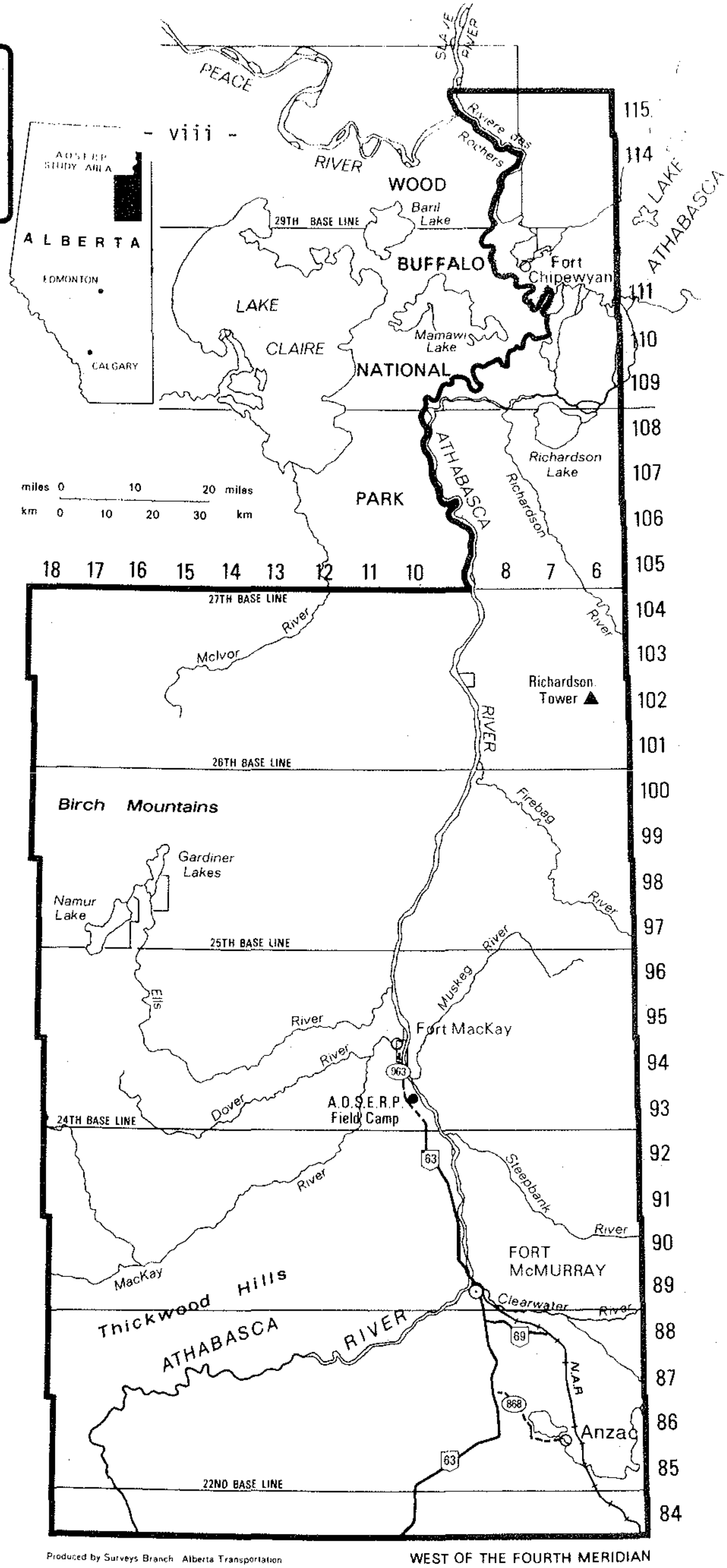

FIGURE A. Location of the AOSERP study area.

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ABSTRACT

Water and ice fogs were investigated for the existing situation (GCOS) and a potential situation (GCOS, Syncrude, plus three more plants).

Based on meteorological and historical fog data, Fort McMurray Airport experiences 4 to 5 days with ice fog and 18 total days with fog per year. There is potential for ice fog to occur in the Oil Sands Area 10 - 18 days per year covering 320 to 1580 km^2 (2 plants) or up to 4000 km^2 (5 plants) under severe persistent conditions.

Pollutant concentrations caused by normal low level emissions could increase by 2 - 3 times during ice fogs. The potential for pollutant interaction with water fogs is low because plume mixing to the ground during fog occurrence is remote.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOGRAPHS

1. INTRODUCTION

The Alberta Oil Sands Environmental Research Program (AOSERP) has been set up to provide scientific and technical knowledge for use by governments and industry for environmental planning and protection within the Athabasca Oil Sands region. This ten year research program, which has an estimated cost of 40 million dollars, will consist of an integrated multi-agency series of research projects. The Meteorology and Air Quality Technical Research Committee will provide information on atmospheric pollution processes, baseline climatological and air quality data. Air pollution transport and disposition within the downwind of the Oil Sands area will also be studied.

A portion of the area under study by the Alberta Oil Sands Environmental Research Program is currently undergoing large scale development by Syncrude Canada Ltd. which is constructing a bitumen extraction and upgrading plant. This plant is scheduled to go into production in 1978 joining the Great Canadian Oil Sands plant which has been in operation since 1967. Three other applications have been put forward to construct and operate oil sands processing plants of similar capacity to that of the Syncrude operation. These current and proposed operations illustrate the magnitude of this type of development in northeastern Alberta.

The oil sands plants release large amounts of water vapour to the atmosphere from combustion processes, process vents and losses, tailings, holding and cooling ponds, and cooling towers. The addition of significant quantities of man-made water vapour to the atmosphere could increase both the frequency and extent of water fogs and ice fogs in the region. These fogs have potential to interfere with transportation in the area and with industrial operations.

In addition to water vapour, a processing plant also emits sulphur dioxide in large quantities (ie. 10 to 15 tons per hour). Other pollutants such as particulates, oxides of nitrogen, hydrocarbons, and heavy metals are also released to the atmosphere. In combination with fog, these pollutants may react with the dispersed water droplets or ice particles to form chemical products which may possibly be hazardous to health and damaging to the environment and property.

This study was carried out as part of the AOSERP Meteorology and Air Quality Technical Research Committee (TRC). The objective of this preliminary study was to determine the magnitude and occurrence of fog and the potential impact of fog in the Athabasca oil sands area. If warranted, a comprehensive study outline would be prepared for future use by the Meteorology and Air Quality TRC.

The approach taken in the study was to search literature dealing with fog formation, characteristics, and interaction with pollutants. In addition, literature dealing with impact of fogs and fog-pollutant mixtures on the environment was also taken into account. Information and data were also collected on the meteorology, topography and water vapour emissions of the Oil Sands area. Fog data for the Fort McMurray and processing plant areas were compared with data from Embarras, an abandoned weather station located 200 kilometers north of Fort McMurray, as well as ice fogs occurring at Fairbanks, Alaska. Fairbanks was included because it has problems of ice fog which have been studied extensively by the Geophysical Institute of the University of Alaska.

2. CONDITIONS FOR FOG FORMATION

Fog is defined by McIntosh (1972) as follows: "It is an obscurity in the surface layers of the atmosphere, which is caused by a suspension of water droplets, with our without smoke particles, and which is defined, by international agreement, as being associated with a horizontal visibility less than 1 km. Ice fog is an obscurity produced by a suspension of numerous minute ice crystals."

The occurrence of fog in industrial areas is due in large measure to the plentiful supply of hygroscopic particles which act as condensation nuclei. These fogs can form when relative humidities are less than 100%. The term "smog" is sometimes used for this type of fog, however, smog can also be used to describe the Los Angeles haze which is a photochemically formed mixture of gases and aerosols.

Fogs which are composed entirely or mainly of water droplets are generally classified according to the physical process which results in saturation or near saturation of the air; examples are radiation fog, advection fog, upslope fog, and evaporation fog, the latter including frontal fog and steam fog. Natural fogs are frequently the result of combined action of two or more physical processes.

2.1 ICE FOGS

The phenomenon of ice fog is a reduction in visibility due to the presence of ice crystals in the atmosphere. Huffman and Ohtake (1971) indicate that the most prominent feature of ice fog is that it severely restricts visibility through the lowest part of the atmosphere. Ice fog appears at temperatures of -30°C and colder in the lower layer of the atmosphere with a well defined upper boundary and a thickness ranging from 15 - 100 m (Ohtake and Huffman, 1969; Oliver and Oliver, 1949).

Benson (1970) has indicated that ice fog is a type of "low temperature air pollution" which occurs in concentrated centers of population when extremely strong inversions are formed in calm air by outgoing radiation. Low temperature refers to values below -35°C. Other researchers have identified factors which cause the formation of ice fog as follows:

- Ice fog may occur when temperatures are below -20°C in conjunction with a continuous source of water vapour and suspended particulate matter in the air (Behlke and McDougall, 1973).

- Ice fog results from water vapour and nuclei emitted to the atmosphere from localized sources of moisture near the ground during atmospheric conditions which create stable stratification of the air, very cold temperatures and virtually cloudless skies (Bell, 1955).

- In 1949, Oliver and Oliver considered that persistent ice fog formed when the temperature fell to about -40°C and smoke nuclei were present; however, the authors pointed out that sources of smoke were also sources of moisture and thus the fog might be due entirely to the additional moisture.

Cloud physicists generally agree (Mason, 1971, Chapter 4) that the spontaneous freezing of liquid droplets begins at temperatures lower than -32°C and increases rapidly as temperature drops. At -40°C complete glaciation occurs.

At temperatures warmer than -32°C very few ice particles will form in a cloud and, due to the fact that air saturated with respect to water is supersaturated with respect to ice, these few ice particles will grow to crystals. Large crystals can also occur by a process called "riming". Rime is formed when ice crystals collide with supercooled cloud droplets which freeze onto the crystal upon impact.

The physical characteristics of ice fog have been studied in detail by Ohtake (1970). He found that most nuclei of ice fog crystals were combustion by-products. Conversely, many individual crystals collected near open water did not have a nucleus, especially at temperatures below -40°C. Dust particles were found to stimulate freezing at higher temperatures than the spontaneous freezing temperatures (-40°C). Ohtake emphasized that nuclei were not essential for the formation of ice fog and described the formation of ice fog as follows:

1. Water vapour from open water and combustion exhausts is released into an atmosphere almost saturated with water vapour with respect to ice and condenses into water droplets.

2. The droplets freeze shortly after their formation and before entirely evaporating.

3. These ice crystals do not evaporate or grow and remain in the atmosphere with insignificant fallout, and,

4. These processes are more efficient in colder weather (which makes ice fog more serious at lower temperatures).

The results of sampling investigations (Ohtake, 1970) have shown that crystals can range in size from 1 to 30 microns but mainly in the 4 - 15 micron range. Kumai (1964) found that most ice fog particles are between 2 and 15 microns with a sharp peak in the size distribution near 7 microns. Crystal size depends upon temperature, humidity and the localized supply rate of water vapour. The mean diameter of the crystals decreases with decreasing temperatures (Ohtake, 1970); he found diameters were 3 to 4 microns in downtown Fairbanks, 5 microns close to air traffic areas and 10 microns at points adjacent to open water. Ohtake (1970) also found the solid water content to vary from 0.01 to 0.18 g/m^3.

Benson and Weller (1975) found that the existence of ice fog in Fairbanks had two distinct and opposing ramifications:

1. It is a problem of which the population is generally well aware. This problem has introduced the concept of air pollution to people in the Fairbanks area, but generally only in association with the ice fog.

2. The overemphasis on ice fog has minimized public awareness of the more serious aspects of air pollution which exists independently of ice fog.

2.2 WATER FOG

Fog is formed when the relative humidity of air increases either because of cooling or addition of water, and results in water vapour condensing into droplets. The relative humidity at which the onset of fog is observed depends on the concentration, size and type of condensation nuclei; the most active nuclei have been found to be particles of sea salt or products of combustion containing sulphuric and nitric acids (Petterssen, 1969).

When relative humidity increases in dirty city air to 70 percent, condensation begins on the largest and most active nuclei. If the relative humidity increases further, the visibility decreases steadily as the haze thickens and changes gradually into a grayish mist. This mist will thicken into a fog (visibility 1 km or less) at a relative humidity of approximately 90 percent. In contrast, on the high seas or in polar regions, where air is relatively pure, the decrease in visibility before the onset of fog is very small and fog is formed rather abruptly.

The quantity of liquid water present in fogs varies within wide limits. In a dense sea fog there may be as much as 3 g/m^3. In contrast, in light city fog having a visibility of 1 km, the water content may be less than 0.02 g/m^3.

Fogs may be produced by air being cooled or as a result of evaporation of water into air. There are a number of types of fogs; these are now briefly discussed:

Radiation Fog

During calm and clear nights the ground loses much heat because of outgoing longwave radiation and air in contact with the ground cools. If the air is sufficiently humid, this cooling process will produce a radiation fog.

Advection Fog

If air moves from a warmer to a colder region, it will lose heat to the underlying surface and may result in an advection fog. Both advection and radiation fogs occur over land; however, most land fogs are brought about by advection of warm moist air followed by nocturnal cooling.

Upslope Fog

When air moves up the slope of a hill or mountain it cools by adiabatic expansion, though heat need not be removed and upslope or mountain fog may occur. This type of fog is closely related to clouds formed by similar processes.

Evaporation Fog

This type of fog is formed when air is in contact with water having a higher temperature. It is caused by evaporation from the warmer water which causes the colder air above to become supersaturated and the end result is a formation of fog. This process continues as long as the temperature difference prevails and supersaturation exists. The latter criterion would not be met if winds constantly ventilated the water surface preventing attainment of saturation conditions.

Evaporation fogs are also formed when rain from warm air aloft falls through a layer of cool air at the ground. These fogs are called rain fogs or frontal fogs, the term frontal indicating that the favourable temperature distribution normally occurs in association with a front. In general, the frontal fogs are of mixed origin; often evaporation is secondary rather than a primary cause, and advection of warmer air over a colder surface is often present.

Frontal fogs are the most frequent source of persistent, widespread fogs in Northern Alberta and they most frequently occur with low wind speeds and stationary fronts.

3. THE OIL SANDS AREA

3.1 TOPOGRAPHY

The Oil Sands area is located in northeastern Alberta adjacent to the Canadian Shield. The main drainage of the area is provided by the Athabasca-Clearwater system, the valleys of which are incised into a broad, muskeg-covered interior plain to depths of 200 to 300 feet. The tributary streams originate in three highland areas: the Birch Mountains to the west of the Athabasca River rising to approximately 2,700 feet, Stony Mountain south of Fort McMurray which reaches an elevation of 2,500 feet and Muskeg Mountain to the east of the Athabasca River which rises gradually to 1,900 feet. To the southwest of the area, between Birch Mountain and Stony Mountain and north of the eastward flowing Athabasca River is a highland area with gentle slopes called the Thickwood Hills. These hills give rise to northward flowing tributaries of the MacKay River, and a few short streams flowing southward to the Athabasca.

Many shallow lakes are located in the area, the largest and most numerous of which are located on the top of the Birch Mountains and form an interconnected chain of lakes which flow into the Ells River. These are the Eaglenest, Gardiner and Namur Lakes. The only significant lakes of any size south of Fort McMurray are Algar and Gregoire Lakes. McClelland Lake, located in the lowlands northeast of Bitumont, is an area of internal drainage.

Cross-sections indicated in Figure 1 are shown in Figure 2. These cross-sections show the topography at various points north of Fort McMurray. Stack elevations for GCOS and Syncrude area also shown in Figure 2. Inspection of Figure 2 shows the broadening of the Athabasca River valley in the northerly direction from Fort McMurray. In addition, the relative heights of the stacks with respect to the surrounding hills are also shown.

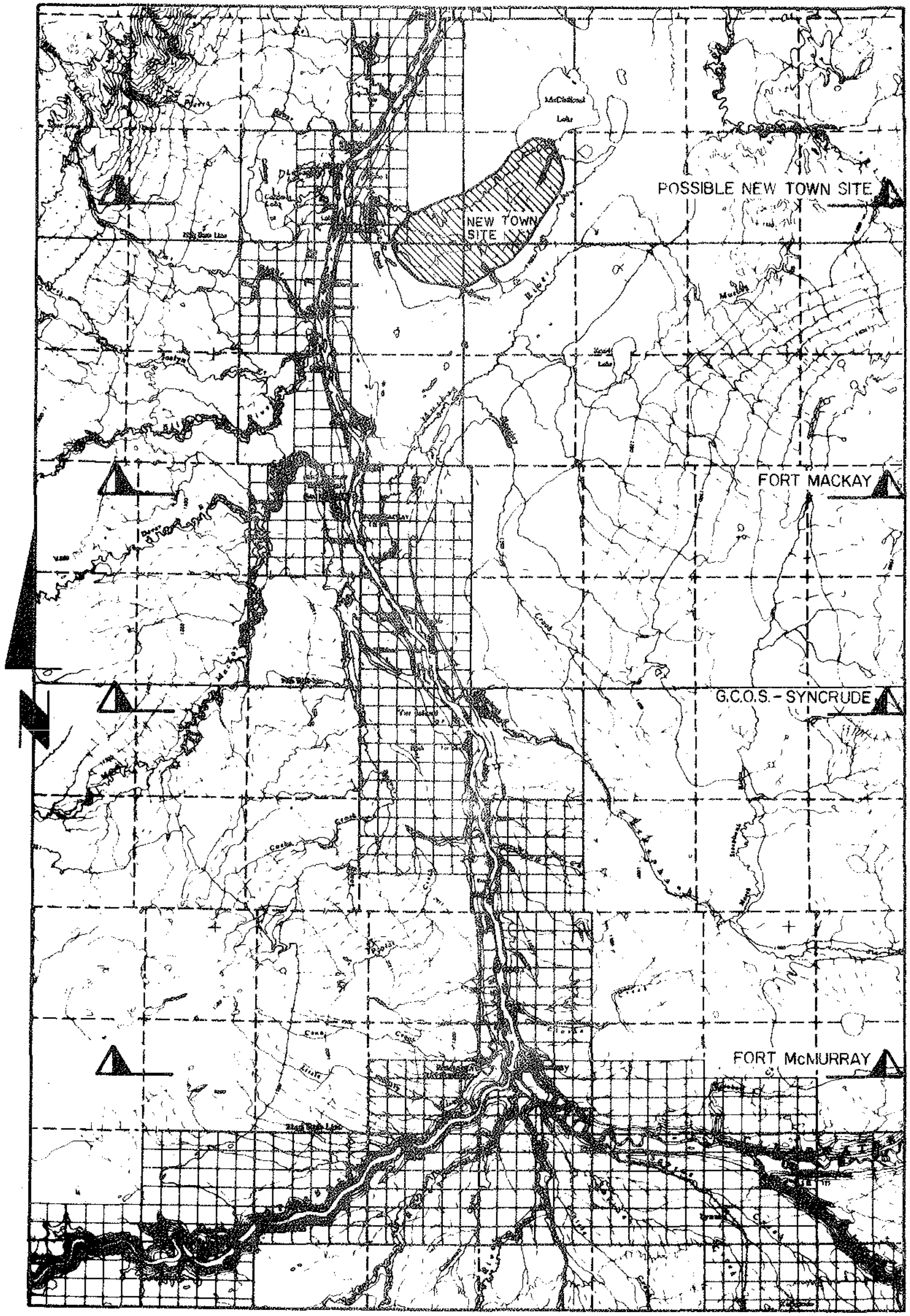

FIGURE I — TOPOGRAPHICAL CROSS SECTIONS

SCALE

5 0 5 10 15 Miles

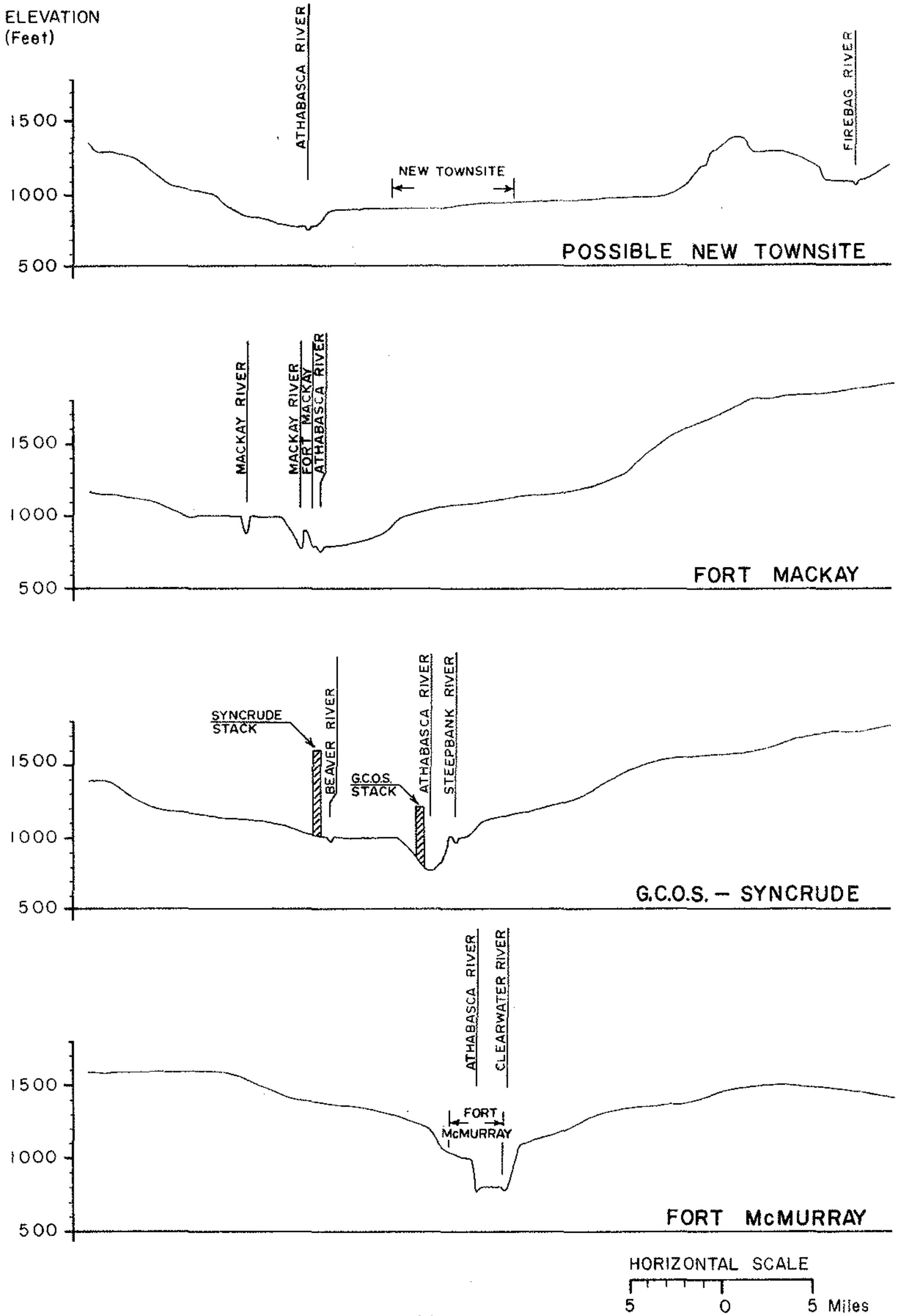

FIGURE 2 – TOPOGRAPHICAL CROSS SECTIONS

3.2 METEOROLOGY

Wind

Annual wind roses for a number of locations in the study area are shown in Figure 3; wind roses for January are shown in Figure 4.

The prevailing winds in Fort McMurray are from the east, and the southwest to northwest quadrant. Average speeds range from 6 to 15 km/hr, being highest during the spring and fall and lowest during the winter. Low average wind speeds during the winter are associated with the frequent occurrence of calm conditions which occur 20% of the time during December, January and February (Table 1). These frequent calm conditions during winter are representative of the Oil Sands area. In contrast, data from Edmonton, as shown, indicate percent calm conditions ranging from 3 - 9% for the same period.

A limited amount of wind data was available from a station location at the Syncrude site and from a GCOS station located at the Mildred Lake Airstrip. Inspection of these data presented in Table 1 shows greater periods of calm at the airstrip compared to Fort McMurray (70% compared to 20%). In contrast, data for Syncrude (approximately 1 km from the GCOS monitoring station) indicate only 1 - 2% calm conditions.

The large difference can be explained partially by (1) differences in anemometer starting speeds, (2) differences in data recording techniques, (3) differences in exposure and (4) possible differences in maintenance.

The Syncrude station has a sensitive instrument (starting speed of 1.6 km/hr) which has an open, elevated exposure. The GCOS instrument has a starting speed of 3.2 km/hr and also has an open exposure. Both record data continuously on a strip chart which is used to determine integrated hourly average wind speeds. The previous data for the airports are measured by equipment having a starting speed of 3.2 to 4.0 km/hr and recorded by observing

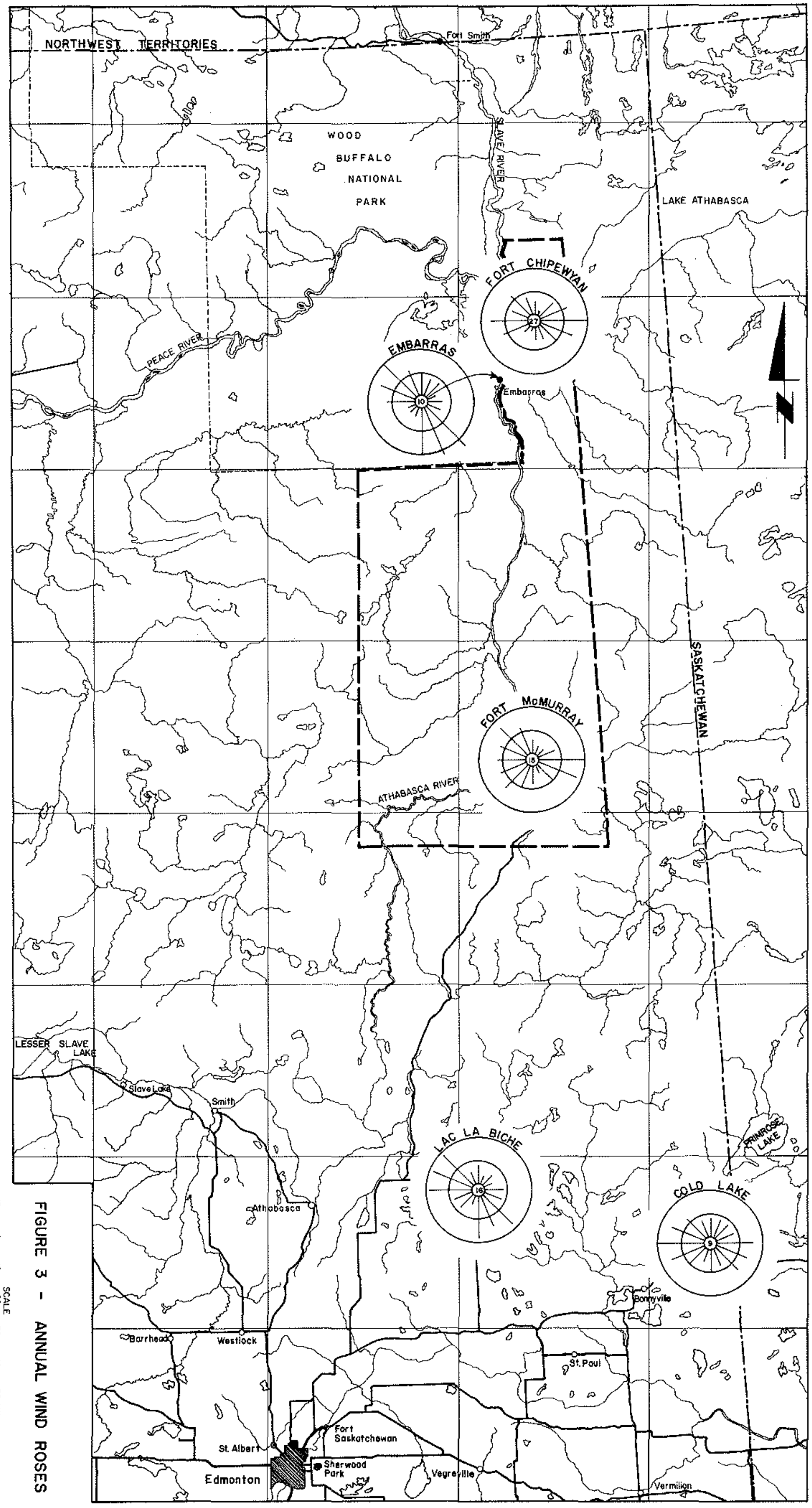

FIGURE 3 - ANNUAL WIND ROSES

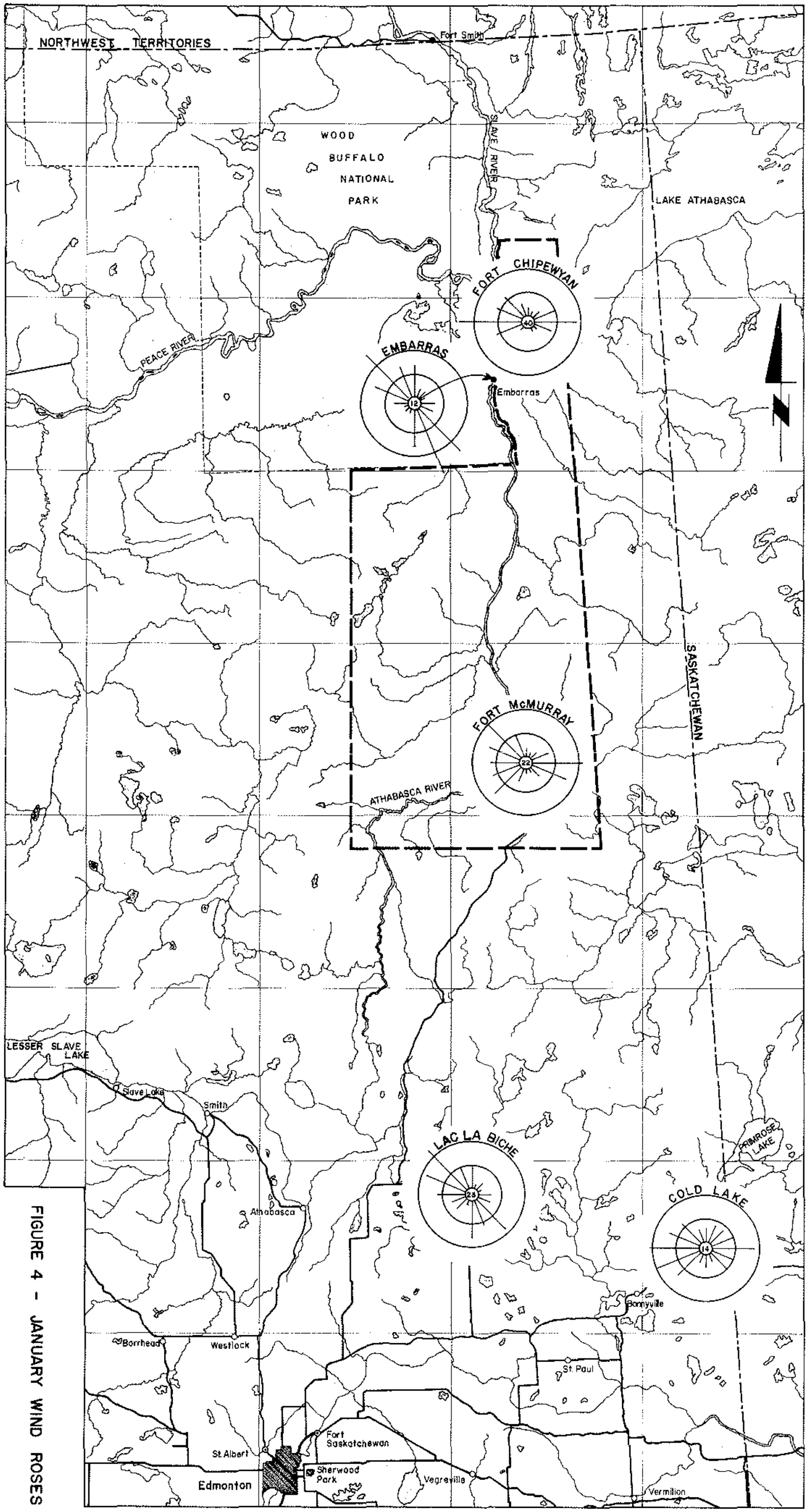

FIGURE 4 - JANUARY WIND ROSES

TABLE 1 - Frequency of Calm Conditions

Station	Percent Calm				Period
	Dec.	Jan.	Feb.	Average	
Fort Chipewyan (A)	34	40	34	36	1967 - 1972
Embarras (A)	16	12	13	14	1955 - 1962
Fort McMurray (A)	20	22	19	21	1955 - 1972
Lac La Biche (A)	18	23	18	20	1958 - 1972
Cold Lake (A)	12	14	12	13	1955 - 1972
Edmonton (Industrial A)	3	4	3	3	1955 - 1972
Edmonton (Int'l A)	9	9	8	9	1960 - 1972
Edmonton (Namao A)	7	8	6	7	1955 - 1972
Mildred Lake Airstrip	73	66	72	70	1974 - 1975 Winter
Syncrude	1	1	0.3	1	1974 - 1975 Winter
Syncrude	2	1	2	2	1975 - 1976 Winter

(A) -- Airport

the output dial for two minutes every hour. Exposures depend on the various airport locations which are indicated by the Canadian Wind Normals to vary from rolling wooded land to flat farmland. None have any serious obstructions. It must be emphasized that the above information does not fully explain the vast difference in calms reported by the two stations.

Also important for this study is the frequency of low wind speeds (less than 5 km/hr). This range of wind speeds is important because fogs occur less frequently at higher wind speeds. Hourly Data Summaries obtained for Embarras, Fort McMurray and Edmonton International Airport were used to determine the low wind speed frequencies given in Table 2.

TABLE 2 - Frequency of Low Wind Speeds*

Station	Percent				Period
	Dec.	Jan.	Feb.	Annual	
Embarras (A)	33	34	32	27	1953 - 1962
Fort McMurray (A)	34	30	30	26	1957 - 1966
Edmonton (Int'l A)	18	18	16	17	1961 - 1967

(A) -- Airport
* Less than 5 km/hr including calm conditions.

These frequencies become important when considering the potential for fog formation.

Shaw, et al (1972) studied the persistence of light surface winds (less than 11 km/hr) in Canada. This study concluded that, in general, persistent light winds occur most frequently in British Columbia, the Yukon and northern Alberta. Over a 10 year period (1957 - 66) the Oil Sands area experienced approximately 50 occurrences of light winds lasting 24 - 48 hours during spring, 100 during summer, 100 during fall and 100 during winter. Light winds persisting longer than 48 hours occurred approximately 25 times over the same period in winter and fall. No such occurrences were indicated for spring or summer. These data confirm the previous data on frequencies of low wind speeds discussed above.

The most important topographical features of the area can influence microscale and mesoscale winds. When the general wind flow is light and skies are clear, the difference in rates of heating and cooling of various portions of valley floors and sides cause slight density and pressure differences resulting in small scale circulations. During the evening hours, radiation of heat from the earth's surface and consequent cooling of the ground and air adjacent to the ground cause density changes. The air adjacent to the ground becomes cooler and heavier and flows downhill under the influence of gravity. The steeper the slopes of the valleys and side walls of the drainage area, the stronger the down slope winds become. Vegetation tends to reduce the flow due to frictional effects. Drainage winds are generally strongest during the winter months and lighter during the remaining part of the year. Beaton et.al. (1972) and Defant (1951) provide reviews of drainage winds.

In well-defined valleys, complex flow patterns are usually encountered. At night, a thin layer of drainage wind usually flows down the valley sides toward the centre where a well developed flow towards the lower end of the valley often forms. During daytime hours the air flows up the centre of the valley but is poorly defined. When a wind flows over a valley, the valley tends to channel the general flow along the valley axis resulting in a bi-directional wind frequency distribution.

The Athabasca River valley and the hills to the east and west can effect wind flows as discussed above. Drainage winds would flow towards the valley centre and then north towards Lake Athabasca. The valley would also channel winds in the north-south direction. This latter characteristic was confirmed during the March, 1976 AOSERP Field Study when the valley flow was found to extend 100 - 200 m above the valley wall.

Humidity

There are several ways in which the atmospheric moisture content may be specified; mixing ratio, vapour pressure, dew point temperature, wet bulb temperature and relative humidity. Relative humidity is defined as the water vapour pressure expressed as a percentage of the saturation vapour pressure at the given temperature, where saturation is with respect to water even at temperatures below 0°C. Thus saturated air has a relative humidity of 100%. Since the saturation vapour pressure changes with temperature, relative humidity varies with the temperature, even though the amount of water vapour present remains unchanged.

Relative humidity is determined from wet and dry bulb temperatures. Since the wet bulb thermometer becomes inoperative below -37°C, an estimate of average moisture content at these low temperatures is obtained by assuming 80 percent of the amount required for saturation with respect to an ice surface at the mean dry bulb temperature.

The quantity of water vapour which air can contain increases with temperature as shown in Table 3 below.

TABLE 3 - Water Vapour Content of Saturated Air*
at 101.4 kPa

Temperature (°C)	Water Vapour (g/m^3)
-50.0	0.03
-40.0	0.120
-30.0	0.341
-20.0	0.883
-10.0	2.231
0.0	4.849
10.0	9.401
20.0	17.30
30.0	30.39
40.0	51.21

* Lange's Handbook of Chemistry, Ed. J.A. Dean, Eleventh Edition, 1973.

TABLE 4 - Mean Relative Humidities at Fort McMurray*

Month	0500 MST	1100 MST	1700 MST	2300 MST
January	78	77	75	77
February	77	77	70	77
March	82	68	63	76
April	81	55	47	68
May	78	46	41	64
June	85	52	45	71
July	88	57	51	78
August	90	66	55	84
September	89	69	57	83
October	81	66	57	83
November	82	78	77	81
December	82	78	82	82

* Climate Normals, Volume IV, "Humidity"

Data shown in Table 4 indicates that peaks in relative humidity are evident throughout July, August, and September during the early morning. It will be seen that this correlates with the frequency of radiation fogs during this period of the year.

Using the data presented in Tables 3 and 4, and mean temperature data given in Table 5 and discussed later, it is possible to determine the mean water vapour content in the air and the amount of water vapour required to bring the air to slightly super-saturation conditions required for the formulation of fog. This technique was used to determine the potential for fog formation and potential impact.

Temperatures

Temperatures at Fort McMurray Airport vary from a mean daily maximum of 23°C in July to a mean daily minimum of -27°C in January. The mean annual temperature is +0.5°C. The occurrence of ice fog is dependent on the frequency of temperatures colder than approximately -35°C. The potential for occurrence of these low temperatures is illustrated in Figure 5 which shows extreme minimum temperatures over the year for Fort McMurray and for Fairbanks, Alaska for comparison purposes. Inspection of this figure shows that Fairbanks has a significantly greater potential for temperatures lower than -35°C, based on the integrated area below the -35°C line.

Temperature data from the Fort McMurray townsite and Fairbanks Airport for the period 1915 - 1945 were studied to determine the number of days when the temperature dropped to -40°C or colder. Fort McMurray had 295 such days in the 30 year period while Fairbanks had 318. The average was approximately 10 days per year for both locations. It should be pointed out that Fort McMurray data from 1948 to the winter of 1974-75 showed a decrease in this average to 6 days per year. This decrease in the number of -40°C days per year may have started in 1943 when the Fort McMurray observation location was moved from the townsite in the valley to the airport on the plateau.

Evaluation of these data also showed that the frequency of low temperature days varied considerably from year to year. Both locations experienced winters where -40°C was not recorded but during other extreme winters there were 35 such days in Fairbanks and 25 in Fort McMurray.

Temperatures at Embarras were compared with those at Fort McMurray Airport for the 18 years that the Embarras station was in operation. This analysis showed that Embarras averaged three more -40°C days per year

TABLE 5 - Mean Daily Temperatures at Fort McMurray Airport (°C)

	Minimum	Mean	Maximum
January	-30.3	-24.2	-18.0
February	-25.9	-18.7	-11.5
March	-18.5	-10.6	- 2.6
April	- 6.1	1.4	8.8
May	1.9	10.1	18.3
June	6.9	15.2	23.4
July	10.2	18.3	26.4
August	8.6	16.5	24.4
September	3.2	10.1	17.1
October	- 2.8	3.4	9.6
November	-14.8	- 9.5	- 4.3
December	-24.4	-19.1	-13.7

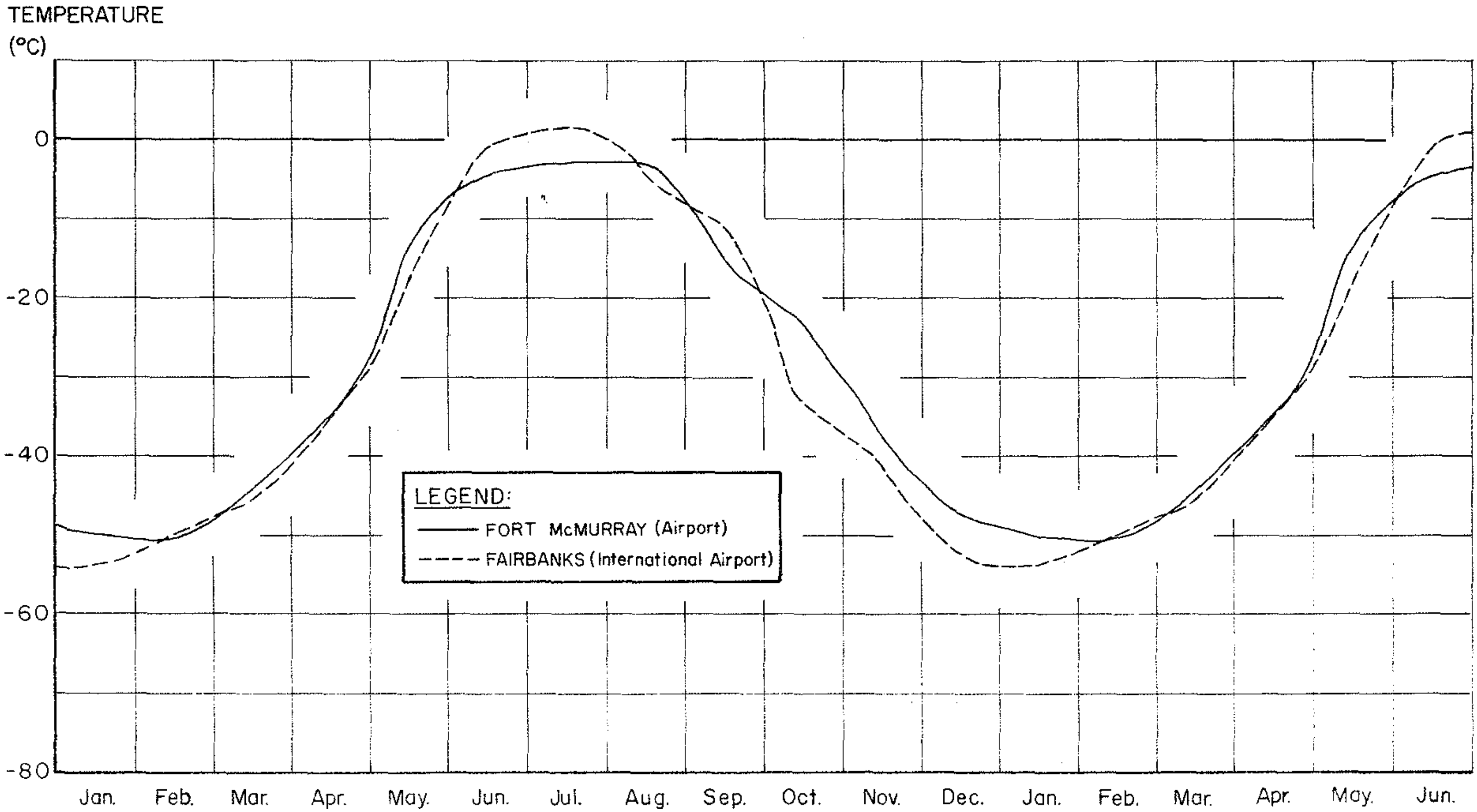

FIGURE 5 - EXTREME MINIMUM TEMPERATURE

than Fort McMurray. Thus, based on the difference in temperature between the Airport and townsite at Fort McMurray, it can be concluded that the temperature at Embarras is very similar to that of the townsite.

Information on the persistence of low temperatures during cold periods was an important aspect of this study. Ice fog could potentially be widespread if temperatures did not rise above -30°C for 48 hours or longer. This criterion was used in assessing Fort McMurray temperature data for 19 winters, 1955 - 1975. It was possible to identify 12 such periods, of which January 1965 and January 1970 experienced continuous periods of seven and six days, respectively. Based on data for Fairbanks for 11 winters, there were 32 such periods. During 1971 there was one period lasting 18 days when temperatures at the Fairbanks Airport remained at -30°C or below. This analysis shows the more frequent persistence of very cold spells in Fairbanks compared to Fort McMurray.

Inversions and Mixing Heights

Northeast Alberta has a typically continental climate with inversions on most nights and lapse conditions during the day. Munn et al. (1970) provided preliminary information on the frequency of ground based inversions utilizing data from 1966 - 68. The frequency of inversions at Fort McMurray as determined by that study are provided in Table 6.

TABLE 6 - Frequency (%) of Ground Based Inversions at Fort McMurray

Time	Dec-Feb	Mar-May	June-Aug	Sept- Nov.
11 GMT (0400 MST)	55	65	75	60
23 GMT (1600 MST)	40	0	0	10

Inspection of Table 6 shows that ground based inversions tend to persist during the winter months in contrast to the remainder of the year.

Billello (1966) analyzed inversions in arctic and subarctic regions. At Churchill, Manitoba, the frequency of ground based inversions was 44 percent from November to April and 28 percent from May to October with the inversion thickness averaging 560 m and 320 m respectively.

A recent meteorolcgical study of the Oil Sands area (Murray and Kurtz, 1976) found that nocturnal inversions occurred on most mornings and extended to higher levels and persisted longer in fall and winter than in spring and summer. Winter inversions were very deep with the mean height of the inversion top being 800 m. During summer this mean height was 400 m and increased to 500 m during spring and fall.

Mean maximum mixing depths have been calculated (Portelli, 1976) for Stony Plain (Edmonton) and Fort Smith as shown in Table 7. Values for Fort McMurray should lie between those for these two stations although this may not be completely true because of topographical differences between the three locations. Murray and Kurtz (1976) found that mixing heights in the Oil Sands area had median values of 200 m and 1000 m during the winter and summer respectively. It is apparent that restrictive mixing conditions occur from October to March when mixing takes place only in the lower 200 to 500 m of the atmosphere. The potential for limited mixing and poor dispersion during this winter period becomes even higher when wind speeds are taken into consideration to determine ventilation coefficients.

TABLE 7 - Mean Maximum Mixing Heights (meters)

Month	Stony Plain March 1966 - June 1969	Fort Smith July 1965 - June 1969
January	277	208
February	295	323
March	696	547
April	1579	1025
May	2396	1499
June	2185	1779
July	1954	1610
August	1563	1537
September	1322	1010
October	998	558
November	420	283
December	219	231

3.3 EXISTING AND POTENTIAL DEVELOPMENTS

The following major developments are currently located in the Oil Sands Study Area:

- Town of Fort McMurray
- Great Canadian Oil Sands Ltd.
- Syncrude Canada Ltd. (Under construction)

The following potential developments should be taken into consideration:

- Shell Canada Limited and Shell Explorer Limited Oil Sands Plant
- Home Oil Company Limited and Alminex Limited Oil Sands Plant
- Petrofina Canada Ltd., Pacific Petroleums Ltd., Hudson's Bay Oil and Gas Company Limited Murphy Oil Company Ltd., and Candel Oil Ltd. Oil Sands Plant
- Other mining/upgrading oil sands plants
- Second major town
- Chlor-alkali plant
- Pulp and paper mill (early 1980's)
- In-situ oil sands plant(s)

The three proposed open pit mining oil sands plants would be on the same scale as Syncrude.

There are also a number of smaller settlements in the Study Area.

- Fort Chipewyan
- Fort MacKay
- Anzac
- Indian Reserves: 174, 174A, 174B, 175, 176, 176A, 176B, 201 201C, 201D, 201E, 201F, 201G

Table 8 provides current and projected (Stanley Associates Engineering, 1976) populations for the study area.

TABLE 8 - Current and Projected Population

	Current (1974)	Projected*
Fort McMurray	16,000	61,000**
Fort Chipewyan	1,500	2,500
Fort MacKay	250	450
Anzac	150	275

* Three more oil sands plants
** Major urban centre(s)

3.4 WATER EMISSIONS

The formation of water fog and especially ice fog can be dependent upon the addition of water vapour to the atmosphere. In the Oil Sands area there are three general sources from which water vapour is released:

- Industrial sources
- Urban sources
- Natural evaporation

Each of these was addressed in order to determine the overall water vapour losses. It should be pointed out at the onset that a detailed analysis was not carried out because of the nature of the study. The figures developed should therefore be considered preliminary and subject to refinement.

Industrial Sources

Water vapour losses from the existing and potential oil sands plants were obtained from public information sources, directly from the company or estimated. Table 9 provides the significant water emissions rates from the plants. Photographs illustrating fog at GCOS are provided at the end of this section.

TABLE 9 - Average Water Vapour Emission Rates from Oil Sands Plants (10^6 kg/day)

Source	GCOS(1)	Syncrude(2)	Shell	Home(7)	Petrofina
Tailings Pond	3.7(6)	36.5	28.5(3)	16.0	6.8(3)
Cooling Spray Pond	2.0	-	-	-	21.8(3)
Steam Vents	1.0	2.0	1.0(4)	7.0	1.0(6)
Main Stack	1.0	8.8	2.4(4)	3.9	3.4(6)
Cooling Tower	-	20.4	10.4(4)(5)	9.8	-
Process Furnaces	2.0	3.9	3.5(6)	3.5(6)	3.5(6)
TOTAL	9.7	71.6	45.4	40.2	36.5

(1) Estimated and confirmed (Cary, 1976)
(2) Syncrude, 1976
(3) Application to ERCB
(4) Shell Oil, 1976
(5) Not operational in winter
(6) Estimated but unconfirmed
(7) Home Oil, 1976

The above information shows some significant variances between plants. For instance, Petrofina estimates that tailings pond evaporation rate will be 25% of Shell's rate but the Petrofina pond is approximately 60% the area of the Shell pond. In addition, vent losses vary from 1.0×10^6 to 7.0×10^6 kg/day. These examples illustrate the need for refinement of available data in order to more accurately determine the water vapour outputs.

The total water emission rate of 203×10^6 kg/day is an average value over the year. During the summer, evaporation and cooling tower or pond losses would be higher while power plant, process heater and steam vent emissions would be lower. This situation would be reversed in the winter. Variation of tailings pond natural evaporation rates has been estimated (Syncrude, 1976) as follows: winter 2%, spring 16%, summer 69% and fall 13% of annual loss. An independent analysis by R. Charlton indicated that Syncrude would emit 22×10^6 kg of water/day during a cold winter day. This can be compared to the yearly average rate of approximately 72×10^6 kg/day.

Figure 6 shows the increase in water vapour emissions over future years. Some assumptions on construction and start-up of new plants are inherent in this figure; for example, the time scale is only an estimate. Furthermore, the Shell, Home and Petrofina plants may not be constructed for some time or may not be constructed at all.

Urban Sources

The three major sources of water vapour in Fort McMurray are combustion of fuels for residential and commercial heating, power generation and vehicular movement.

The ERCB (1975) has projected annual gas consumption rates for residential and commercial users on a per household basis which is applicable to Fort McMurray since it is supplied with natural gas by the Albersun gas line. The current population of Fort McMurray is 16,000 corresponding to 4,000 households, assuming four people per household. An annual consumption of 319 thousand cubic feet per household results in a total consumption per year

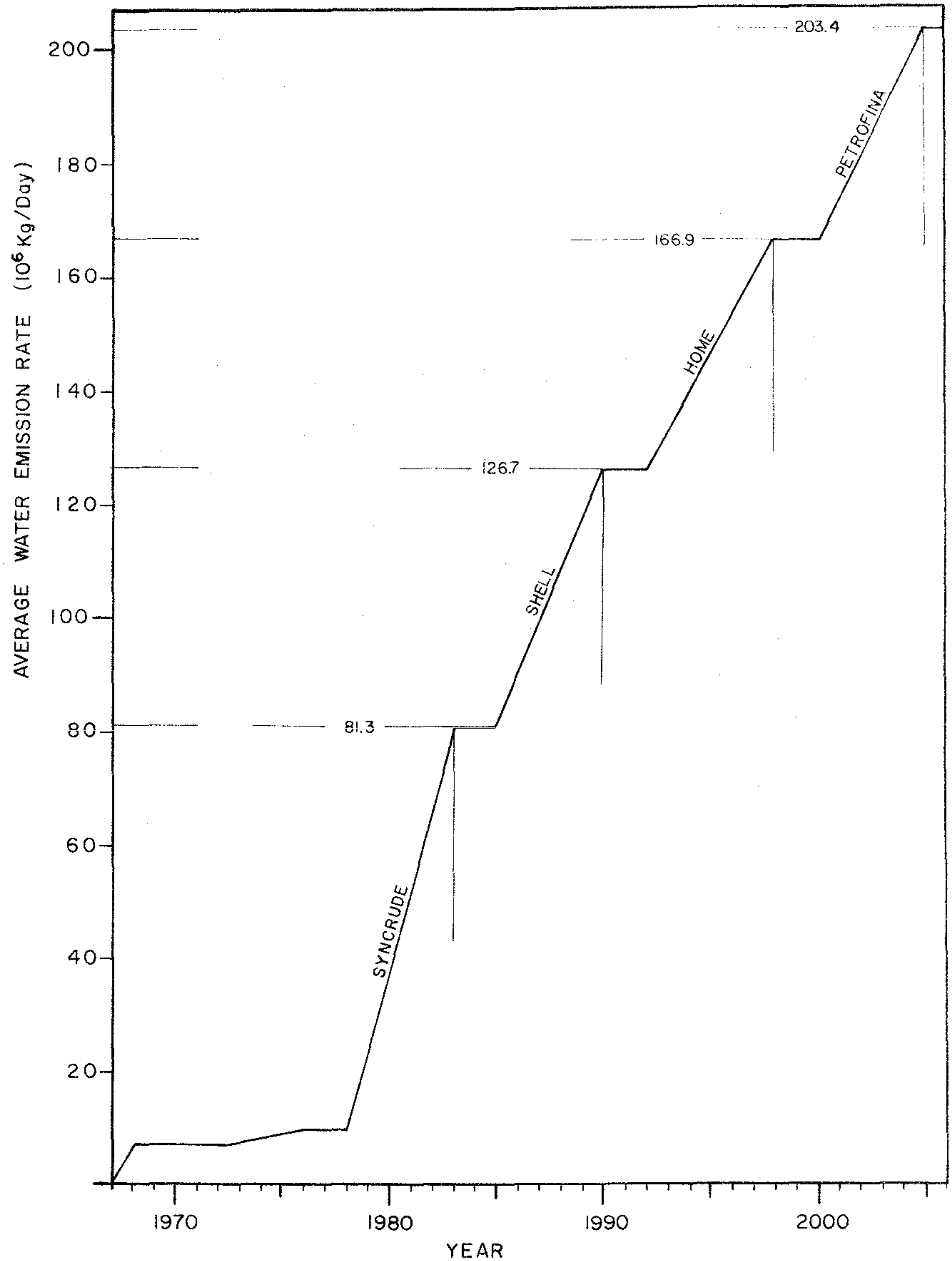

FIGURE 6 - EXISTING AND POTENTIAL INDUSTRIAL WATER VAPOUR LOSSES TO ATMOSPHERE

of 1.2 billion cubic feet. Peak day consumption would be ten million cubic feet, if a load factor of 33% is used. The quantity of water vapour produced, based on stoichiometric combustion relationships would be as follows:

Annual	53.2×10^6 kg/year
Peak day (winter)	0.44×10^6 kg/day

Alberta Power operates a 25 MW (installed capacity) power generating station at Fort McMurray. This station will be phased out of continuous operation in mid 1976 when a 72 KV power transmission line from the Mildred Lake site will be connected to the Town's network. This station when operating at a peak daily demand of 18,000 KW (Gunn, 1976) would emit approximately 0.5×10^6 kg/day water vapour. This station will be used only for peaking and standby purposes in the future. Thus, future water emissions from this source are assumed to be negligible for the purpose of this study.

Fuel purchased in Fort McMurray for consumption by mobile sources (cars, trucks, heavy equipment, etc.) amounts to approximately 15 million gallons per year on a 1975 basis (Peterson, 1976). Assuming that 50% of this quantity is combusted in or near Fort McMurray, it can be shown that water vapour emitted by mobile sources would amount to approximately 0.13×10^6 kg/day.

Water vapour emissions from Fort McMurray are summarized in Table 10.

With an additional three oil sands plants, the population could quadruple and thus urban water vapour emissions would also quadruple to an order of magnitude value of 2.3×10^6 kg/day. These emissions could be located in either one or two urban centres.

Natural Sources

Water bodies will release water vapour to the atmosphere through natural evaporation. The study area includes many small creeks, streams, ponds, lakes and some marsh areas in addition to the Athabasca River and a portion of Lake Athabasca. Vegetation also releases large quantities of water vapour to the atmosphere through transpiration. Evapotranspiration and evaporation varies over the year with a maximum during late summer and a minimum during winter. The average evaporation rate for this area of Alberta is approximately 43 - 51 cm per year (Gray, 1970). The potential evapotranspiration rate is 46 - 51 cm per year but the actual evapotranspiration is 36 - 41 cm per year (Atlas of Alberta, 1969).

For the purposes of this study, evaporation from open water surface is assumed to be 46 cm and actual evapotranspiration 38 cm. Water vapour losses due to evapotranspiration will average 1050 $kg/day/km^2$ and 1250 $kg/day/km^2$ over open water. Open water was estimated to cover approximately 10% of the study area. The relatively small northern portion is approximately 50% open water and the remaining portion is 5% open water. The 28,000 km^2 study area therefore releases approximately 30×10^6 kg water vapour on an average day. This figure would increase to approximately 84×10^6 kg/day during July (Coligado et al., 1968). Water vapour losses due to snow evaporation during the winter months are negligible according to Williams (1961) but increase rapidly during the spring.

It should be remembered that these water vapour losses are spread over a 28,000 km^2 area and are therefore of low intensity, except over open water.

errata

page 34: second paragraph:

change: 1050 $kg/day/km^2$ to 1050×10^3 $kg/day/km^2$

1250 $kg/day/km^2$ to 1250×10^3 $kg/day/km^2$

30×10^6 kg to 30×10^9 kg

84×10^6 kg/day to 84×10^9 kg/day

Summary

A summary of water vapour emissions from industrial, urban and natural sources is given in Table 10.

TABLE 10 - Summary of Average Water Emissions (10^6 kg/day)

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page 35: replace Table 10 with the following:

Table 10 - Summary of Average Water Emissions (10^6 kg/day)

Source			Existing	Future
Industrial:	GCOS		9.7	9.7
	Syncrude		-	71.6
	Shell		-	45.4
	Home		-	40.2
	Petrofina		-	36.5
		Total	9.7	203.4
Urban:	Fort McMurray:			
	heating (peak day)		0.44	1.77
	power (peak day)		0.50	-
	mobile		0.13	0.52
		Total	1.07	2.29
Total Industrial and Urban			10.77	205.69
Natural:	Average for study area		30,000	
	Peak day		84,000	

3.5 POLLUTANT EMISSIONS

The principal sources of pollutant emissions are from the oil sands plant(s) with small quantities originating from the Town of Fort McMurray. Each type of emission source is now discussed.

Oil Sands Plants

GCOS is the only plant operating to date and therefore emission rates of particulates and sulphur dioxide have been measured. The current Licence to Operate under the Clean Air Act permits the emission of 300 LT (long tons) SO_2 per day from the power plant and 48 LT per day from the Claus plant incinerator. Particulate emissions from the power plant must not exceed 0.85 lbs. per 1000 lbs. of flue gas. However, the plant does not currently meet this standard and had undertaken a schedule which is aimed at reducing emissions to a level of 0.2 lbs/1000 lbs. flue gas. This improvement must be operational by July 31, 1979 according to the amended Licence to Operate.

According to recent stack tests, the emission rate of particulates is 1.63 lbs. per 1000 lbs. flue gas (Alberta Environment, 1976). This is equivalent to an average emission rate of approximately 40,000 kg/day.

The ash from coke combusted in the boilers has been subjected to electrostatic precipitation pilot tests and the collected ash was then analyzed for a number of heavy metals. Analytical results are presented in Table 11.

The Syncrude power plant will burn natural gas and fluid coker off gases rather than coke. Therefore, the uncontrolled particulate emission concentration will be less than for coke combustion. Through use of electrostatic precipitation, emissions will comply with the requirement of 0.2 lbs/1000 lbs flue gas specified in the Permit to Construct. This value is equivalent to a particulate emission rate of approximately 12,500 kg/day.

TABLE 11 - Analysis of GCOS Particulate Emissions*

Component	Weight (%)	Emission Rate (kg/day)
SiO_2	34.30	13,700
Al_2O_3	22.40	9,000
Fe_2O_3	6.27	2,500
V_2O_5	4.70	1,900
TiO_2	3.33	1,330
CaO	2.12	850
S	2.09	840
K_2O	1.69	675
NiO	1.36	545
MgO	1.23	490
Na_2O	0.50	200
MoO_3	0.18	72
MnO	0.16	64
P_2O_5	0.14	56

* Alberta Environment, 1976.

The applications of the other three plants to the Energy Resources Conservation Board have indicated that sulphur dioxide emissions will be 116, 168 and 107 LT/day for Shell, Petrofina and Home respectively. Particulate emission rates were not given but it is anticipated that these would be similar to the rate for Syncrude given above. Table 12 presents a summary of particulate and sulphur dioxide rates.

TABLE 12 - Pollutant Emission Rates from Oil Sands Plants (Metric tons/day)

Plant	SO_2	Particulates
GCOS	354*	40.6
Syncrude	292**	12.7
Shell	118	12
Petrofina	171	12
Home	109	12
TOTAL	1044	89.3

* License to operate 73-AL-114A (75), Maximum Allowable

** Permit to construct 73-AP-054 (75), Maximum Allowable

Other compounds such as hydrocarbons, oxides of nitrogen, carbon monoxide and hydrogen sulphide will also be emitted. These emissions discussed above will be released to the atmosphere through stacks; the main stack at GCOS is 106.7 m high, the one at Syncrude is 183 m. The height of the main stacks at the other plants will probably range from 120 to 200 m. It should be pointed out that some emissions come from low levels within the plant but the majority are released through the main stacks.

Fort McMurray

Combustion of natural gas, gasoline and diesel fuel account for the major portion of pollutant emissions in Fort McMurray. Natural gas for residential and commercial heating is combusted at a peak daily rate of 10 million cubic feet per day. Emission rates from natural gas combustion were estimated by applying known emission factors (EPA, 1973). The rates are given in Table 13 and presented below.

Particulates	86 kg/day
Sulphur Oxides (as SO_2)	0.3
Carbon Monoxide	9.1
Hydrocarbons(as CH_4)	3.6
Nitrogen Oxides (as NO_2)	41.0

These figures would be quadrupled , due to urban growth, if three more open pit plants became operational.

Approximately 4 x 10^6 gallons of gasoline were sold in Fort McMurray in 1975 (Peterson, 1976). It is assumed that 2 x 10^6 gallons were combusted in or near Fort McMurray by vehicles averaging 15 miles per gallon. Thus, there were 30 x 10^6 vehicle miles in the immediate area of Fort McMurray last year, that is, approximately 80,000 vehicle miles on an average day. Applying emission factors (EPA, 1973) emission rates of pollutants due to gasoline consumption can be calculated. These are given in Table 13 and presented below.

Carbon Monoxide	4000 kg/day
Hydrocarbons (as CH_4)	300
Nitrogen Oxides (as NO_2)	400

Approximately 10 x 10^6 gallons of diesel fuel were sold in Fort McMurray during 1975 (Peterson, 1976) for heavy truck and heavy equipment use. It is assumed that approximately 30% or 3 x 10^6 gallons were consumed in and near Fort McMurray. Therefore, there were 8,200 gallons combusted per day. Application of typical emission factors (EPA, 1973) results in the emission rates given in Table 13 and presented below.

Carbon Monoxide	360 kg/day
Hydrocarbons (as CH_4)	120
Nitrogen Oxides (as NO_2)	1520
Sulphur Oxides (as SO_2)	120
Particulates	110

Emission rates for Fort McMurray are summarized in Table 13.

TABLE 13 - Fort McMurray Pollutant Emissions (kg/day)

Source	Particulates	SO_2	CO	NO_x	HC's
Natural gas combustion	86	0.3	9.1	41	3.6
Gasoline combustion			4000	400	300
Diesel fuel combustion	110	120	360	1520	120
TOTAL	196	120	4370	1960	424

It must be emphasized that the figures given in Table 13 should be considered preliminary and subject to refinement and upgrading by the addition of other sources. It is anticipated that the daily average values given in Table 13 would fluctuate greatly from day to day and from hour to hour during the day.

PHOTOGRAPH 1. Great Canadian Oil Sands
March 15, 1976 - 0900 hours - Looking West
Temperature: -21 degrees Celsius

Note power plant plume above inversion layer

Photo by: F. Fanaki, AES, Downsview, Ontario.

PHOTOGRAPH 2. Great Canadian Oil Sands
March 15, 1976 - 0900 hours - Looking North West
Temperature: -21 degrees Celsius

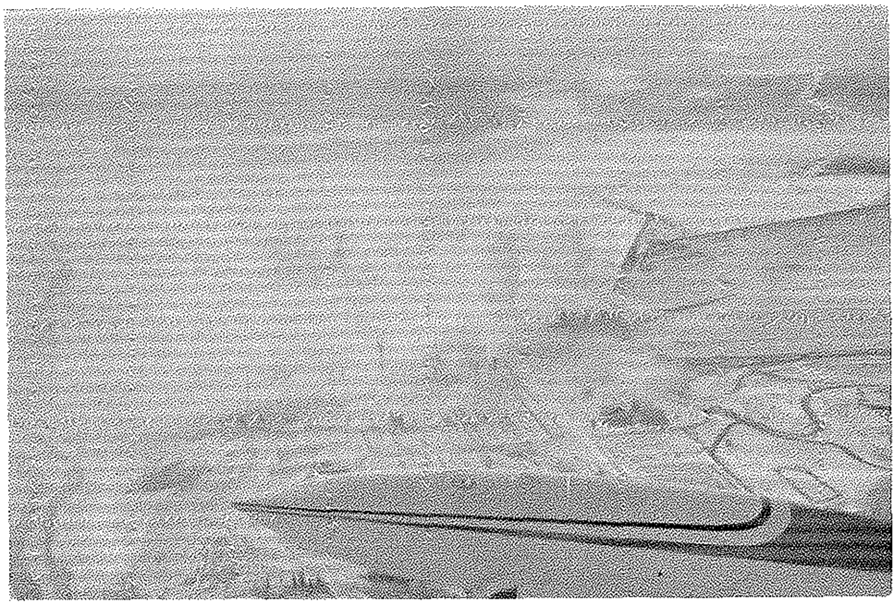
Note fog from water ponds drifting over plant area

Photo by: F. Fanaki, AES, Downsview, Ontario.

PHOTOGRAPH 3. Great Canadian Oil Sands
March 15, 1976 - 0900 hours - Looking North North West
Temperature: -21 degrees Celsius

Note plant obscured by fog.

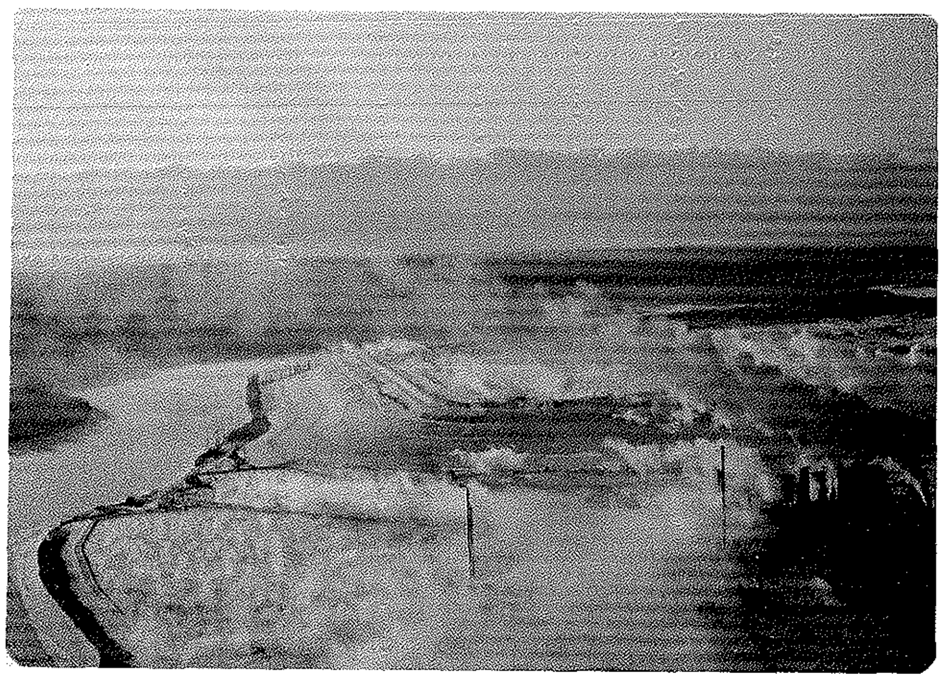
Photo by: F. Fanaki, AES, Downsview, Ontario.



PHOTOGRAPH 4. Great Canadian Oil Sands
March 15,1976 - 0750 hours - Looking South
Temperature: -24 degrees Celsius

Note fog from plant and water ponds.

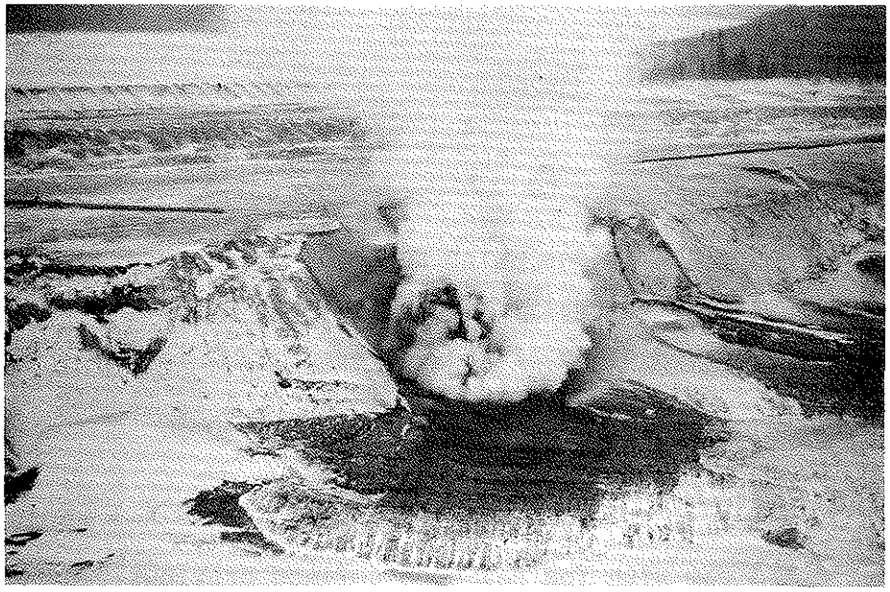
Photo by: Intera Environmental Consultants Ltd.,Calgary



PHOTOGRAPH 5. Great Canadian Oil Sands
March 11,1976 - 0800 hours - Looking South
Temperature: -18 degrees Celsius

Note fog from water ponds drifting north (drainage wind
while fog at higher levels drifts east

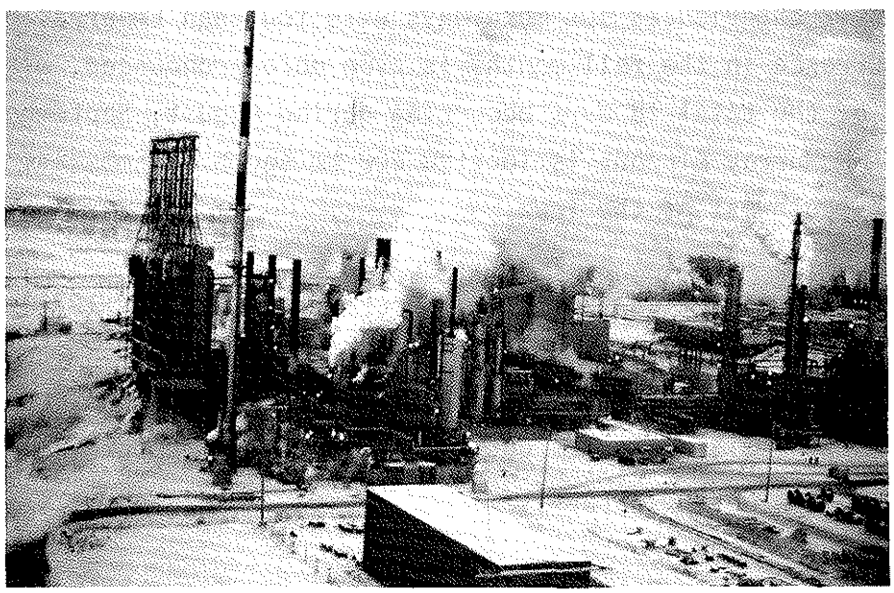
Photo by: Intera Environmental Consultants Ltd., Calgary



PHOTOGRAPH 6. Great Canadian Oil Sands
December 3,1975 - 1000 hours
Temperature: -23 degrees Celsius

Note water vapour from tailings discharge point

Photo by: R. Dunbar, ERCB, Calgary



PHOTOGRAPH 7. Great Canadian Oil Sands
December 3,1975 - 1000 hours
Temperature: -23 degrees Celsius

Note water vapour from Great Canadian Oil Sands plant

Photo by: R. Dunbar, ERCB, Calgary

4. FOG OCCURRENCE

The conditions which cause or could result in the formation of fog were discussed previously. The actual and potential frequency of fogs in the study area is now discussed.

4.1 EXISTING FOG

Fort McMurray

A day with fog has been defined previously as one on which the fog reduces visibility to less than 1 km at any time during the 24 hour period. Hemmerick (1971) summarized fog data from synoptic stations across Canada for 1941 - 1970 and the pertinent results are presented in Table 14.

Inspection of these data show that 12 days of fog per year are experienced at Embarras, located on the Athabasca River. Approximately 40% of these days occur during the fall (August - September). The Fort McMurray Airport experiences 50% more days with fog than Embarras; the frequency of occurrence in the fall months is even more pronounced, with approximately 50% of the total 18 days occurring during August, September and October. The Fort McMurray Airport is located 200 km south of Embarass on a forested plateau just southwest of the Town.

Radiation fogs have been observed (Prusak, 1976) to form in the Clearwater valley north of the airport during late summer and fall nights. In the morning these fogs are lifted due to heat from the sun. As the fog rises it begins to drift out of the valley and depending upon wind direction causes fog at the airport.

Hourly Data Summary (HDS) provide fog data by hour and month, however, visibility criteria for fog in this publication is 9.6 km or less. Based on recorded visual observations at Fort McMurray, HDS shows that hourly fog occurs most frequently during the early morning, 48% of the fog observations being recorded between 0300 and 0800 hours. Figure 7 shows the diurnal

TABLE 14 - Mean Monthly and Annual Days With Fog

Station	Number of Years	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Edmonton Industrial (A)	30	2.5	2.4	2.1	1.0	0.7	0.7	1.1	1.9	0.9	1.3	2.9	1.7	19.5
Edmonton Int'l (A)	9	1.3	3.3	3.1	0.7	0.8	1.0	1.1	1.2	0.6	1.7	4.6	2.1	21.5
Edmonton Namao (A)	15	3.8	3.8	3.2	1.3	0.7	0.9	0.9	1.6	0.9	1.5	3.5	3.0	25.1
Embarras (A)	20	0.9	0.4	0.6	0.2	0.6	1.0	1.3	1.7	2.0	1.4	0.6	1.1	11.8
Fort Chipewyan (A)	8	1.0	0.8	0.5	1.0	0.4	0.1	0.5	0.9	1.5	2.6	0.9	1.6	11.8
Fort McMurray (A)	30	0.8	0.5	0.4	0.9	1.3	1.5	2.3	3.5	2.8	1.4	1.0	1.2	17.6
Lac La Biche (A)	26	2.0	0.9	0.8	0.5	1.1	0.6	0.9	1.7	1.2	0.9	1.7	1.2	13.5

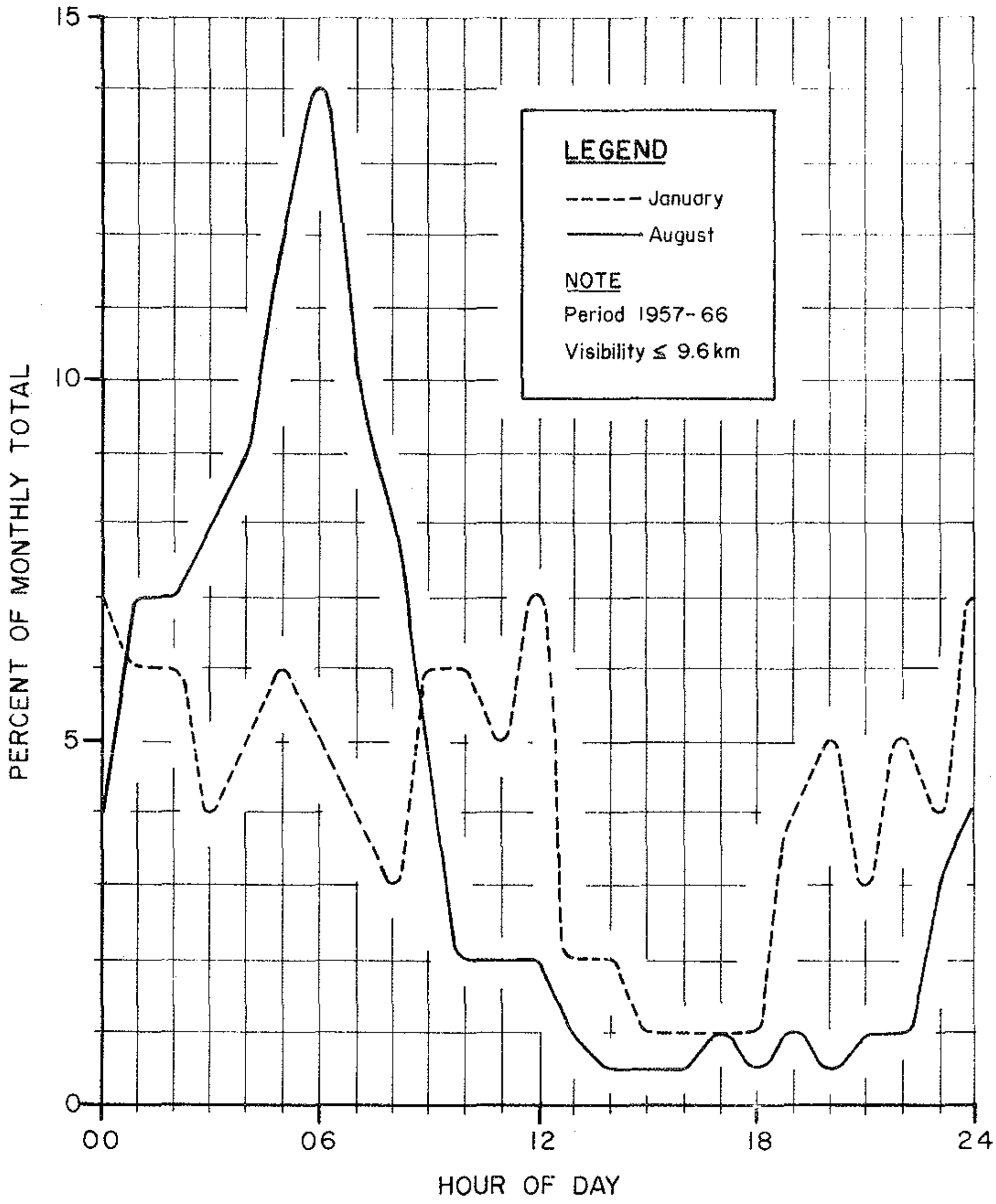


FIGURE 7 - DIURNAL VARIATION OF FOG OCCURRENCE AT FORT McMURRAY

variation of fog occurrence for January and August. The significance of this figure is that August fogs are formed mainly during early morning while January fogs occur at any time of day with a drop in frequency only during the afternoon.

Fog occurrence at the Edmonton Industrial Airport according to HDS-59, shows a quite different monthly variation. This airport is located within the City of Edmonton; fogs occur most frequently during the winter months (December to February), these months accounting for 53% of the fogs which were observed during the period 1957 - 1966. Inspection of hourly data shows that during the winter months the maximum fog frequency occurs at 0900 hours. Fogs occurring at this time of day are probably caused by water vapour emissions from morning rush hour traffic combined with ground based inversions and low wind speeds. These causes were confirmed, in part, by Western Research and Development Ltd. (1976) who concluded that the intensity of fog at the Edmonton Industrial Airport was inversely proportional to wind speed and insensitive to wind direction when temperatures were less than -35°C. At temperatures higher than -35°C the fog intensity was independent of wind speed and highly dependent on wind direction. Their data, in fact, showed that when temperatures were less than -35°C approximately 70% of the fog occurrences were associated with wind blowing from a major freeway (Kingsway Ave) towards the terminal building. The Fort McMurray Airport is not sufficiently close to the town for a comparable situation to occur. However, as the town expands, this could occur resulting in more winter fogs at the airport.

Fog occurrence statistics at the Fort McMurray townsite prior to 1944 were not obtainable in a useful format. However, during 1944, hourly observations were taken for seven spring, summer and fall months at both the airport and the townsite. A compilation of those data (Climatology Division, 1945) showed that there was no correlation between the two sites with respect to fog, haze and moderate to low visibilities. The micro climates are probably sufficiently different to result in no observable relationship between the occurrence of fog at the two locations.

Since fogs occurring at the Airport during the late summer and fall are generally radiation fogs, it can be concluded that the town would also experience fog during these seasons although occurrence at the two locations may not be simultaneous. Similarly, it is probable that Fort McMurray would experience fog concurrently with the airport during the winter because of water vapour emissions from the vehicles and household heating. Indeed, the town would probably experience low temperature fogs more frequently than the airport because of its topographic location and the high number of water vapour sources compared to the airport.

Oil Sands Development Area

Few data were available for this study on the frequency of fog occurrence in the oil sands development area. Climatic observations of temperature and precipitation have been made at the Syncrude Mildred Lake site and the GCOS plant site since October, 1973, but very few comments or observations on fog have been recorded at the Syncrude station and none at the GCOS site.

During the ten winter months, from October, 1973 to February, 1976, there were observations of ice fog at 0800 hours on 10 days at the Syncrude site. During the same months there were 20 days with temperatures of -35°C or lower at the time of observation and 17 days having daily minimums of -40°C and less. The highest temperature associated with the observation of ice fog was -32°C. If it can be assumed that all occurences of fog were recorded, it can be concluded from these very limited data that ice fog at the Syncrude construction site occurs on approximately 50% of the very cold mornings (-35°C or less). This assumption may not be valid, however, since some observers at no time made written comments on fog or other phenomenon while other observers usually did.

Hourly observations taken at Fort McMurray were compared with those from Syncrude Mildred Lake site for the winter of 1975-1976. Ice fog was reported at Mildred Lake on December 11, 12, 1975 and January 5, 6 and 7, 1976. December 12 and January 6 and 7 reported no ice fog at Fort McMurray Airport although the temperatures were -30°C, -40°C and -39°C respectively. On December 11, however, ice fog was reported for nine hours at Fort McMurray Airport and the temperature ranged from -39°C to -41°C. On January 5 four hours of ice fog were observed at the Fort McMurray Airport with temperatures of -39°C and -40°C. This limited data suggests that ice fog occurs more frequently at the Syncrude construction site than at the Fort McMurray Airport. During the AOSERP Intensive Field Study of March, 1976 there were three mornings when fog was observed over the river during the morning hours of 0700 - 0800. This fog must have originated from the GCOS plant since the river was frozen over.

Radiation fogs also occur in this area over the Athabasca River similar to those which form in Fort McMurray. Radiation fogs would also form over the tailings pond; however, no observations or evaporation data or records are maintained by GCOS which might substantiate this conclusion. These fogs may have less frequency and duration than those over the riverdue to the more open and exposed location, but this would be offset somewhat because of greater evaporation rates near the tailings discharge point.

4.2 POTENTIAL FOG FORMATION

Fort McMurray

The town presently has a population of 16,000. It is estimated that with the potential introduction of three more oil sands plants in the area, this population will reach 60,000. This increase in population is not expected to influence the formation of water fogs at the town or airport since they are formed mainly as a result of radiative cooling in the lowest part of the valley. The existing power plant is assumed to be on standby service and therefore there will not be any major man-made sources of water vapour located in the town. The Athabasca and Clearwater Rivers will continue to be the most significant sources of water vapour for the formation of radiation and evaporation fogs.

Growth of the downtown area could cause a heat island to form resulting in an inhibiting effect on the formation of radiation fogs over the downtown area. Residential development of Fort McMurray will take place in designated areas which are at higher elevations than the downtown area, with a number being located on the plateau above the valley. It is anticipated that these areas will experience water fogs at a frequency similar to that at the airport.

In contrast, the frequency, duration and magnitude of ice fog formation will probably increase as the town grows. Recent work by Bowling (1971) indicates that Fairbanks experienced a significant increase in the frequency and magnitude of ice fog, around the start of the North Slope oil boom in 1968. In 1967, when the population of Fairbanks and Fort Wainwright totalled 30,000, the maximum southwestward (downwind) extension of ice fog reached Chena Ridge (a 200 m hill five km from Fairbanks). However, in the winters of 1968-69 and in 1970-71, ice fog extended southwest beyond the limits of vision from Chena Ridge. Previous investigations had shown that the ratio of days per winter on which visibilities dropped below 0.4 km due to ice fog to days with minimum temperatures of -40°C or less has fluctuated widely between 0 and 0.75 for the period 1951 to 1967. However, during 1968-69 and 1970-71, this ratio approached unity. In 1969-70, the visibility dropped to 0.4 km on two occasions, even though the minimum temperature was above -40°C. Bowling (1971) attributes this to development of the urban centre and the resulting increase of water vapour emissions.

If the Fort McMurray population reached 60,000, water vapour emissions would increase from the current 570,000 kg/day to approximately 2.3×10^6 kg/day assuming no significant increase in industrial emissions. In contrast, the emissions from Fairbanks amounted to approximately 4×10^6 kg/day in 1965 (Benson, 1970) and will have reached an estimated upper limit of 10×10^6 kg/day in 1976 (Benson, 1976). The large difference between the emissions from these two population centres can be attributed to power plants and associated cooling ponds located at Fairbanks.

Some preliminary quantitative estimates have been made to determine the potential for ice fog formation. It is reasonable to assume that some ice fog will occur in the Town of Fort McMurray 100% of the time when temperatures fall to -40°C or below since this is the spontaneous freezing temperature of water droplets.

An assessment of temperature data collected at the Fort McMurray townsite (1915 - 1943) showed that temperatures of -40°C and lower occurred on the average 10 days per year. It was pointed out earlier in this report that this average dropped to six days per year after the observing station was moved from the town to the airport. Bowling (1976) indicated that the onset of ice fog in Fairbanks is occurring at higher temperatures as the city increases in size. For example, during the 1975-76 winter the airport was closed due to dense ice fog (visibility less than 0.4 km) at a temperature of -38°C.

On the basis of the above observations, data on the incidence of temperatures of -37°C are presented in Table 15 to assist in the evaluation of future ice fog potential. This table was developed from a study of Canadian sub-zero temperatures by Hagglund and Thompson (1964) and used in conjunction with the frequency of occurrence of days with -40°C temperatures at Embarras airport compared to Fort McMurray airport.

TABLE 15 - Frequency of -37°C (-35°F) Temperatures at Fort McMurray Airport

Month	Embarras Airport		Fort McMurray Airport		
	No. of Cases Per 10 years	%	No. of Cases Per 10 years	%	Days Per Year
November	5	1.7	4	1.3	0.4
December	21	6.8	16	5.2	1.6
January	67	21.6	52	16.8	5.2
February	32	11.3	25	8.9	2.5
March	10	3.2	8	2.6	0.8
TOTAL					10.5

The number of days per winter with temperature of -37°C or less at the townsite has been estimated in the following manner:

1. 10.5 days per winter at the Fort McMurray Airport when temperature is -37°C or less.

2. The town experiences 10 days per year when the temperature is -40°C or less while the airport experiences only 6 days.

3. Using the above information and the 10:6 ratio, it is calculated that during an average winter there would be 17.5 days when temperatures drop to -37°C or less.

Ice fog will probably occur in Fort McMurray on those days when the temperature drops to -40°C. As the Town develops there will be potential for ice fogs to form during the additional 7 days per year which experience temperatures between -37°C and -40°C.

According to past records there is also potential for ice fogs to persist for 2 days and longer at a frequency once every two years. This persistence reached an extreme of 7 continuous days when temperatures did not rise above -30°C. Thus, it can be concluded that as the Town expands in the future, there is potential for ice fog to occur on 17 days per year with episodes of continuous fog lasting 2 consecutive days occurring once every two years. An extreme episode lasting 7 days could occur every ten years.

Investigations by Benson (1970) showed that ice fog, whenever it formed in Fairbanks, covered approximately 62 km^2 and had an average depth of 15 m. After 2 to 3 days the area covered had increased to 100 km^2 and after 10 days the maximum area covered was 166 km^2. The water vapour input under these conditions was 4×10^6 kg/day or approximately 65×10^3 $kg/day/km^2$ of fog. Comparing these figures to the potential water vapour emission rate at Fort McMurray of 2.3×10^6 kg/day, (Table 10) it is estimated that an area of 36 km^2 could be covered by a typical fog. If meteorological conditions persisted for several days this area could increase to 58 km^2 as indicated by Benson (1970) and under extremely persistent cold periods could reach a maximum of 96 km^2.

Benson (1970) developed a simple mass balance equation for determining the growth and ultimate area of an ice fog. The equation and estimates for Fairbanks and Fort McMurray parameters are given in Table 16. This equation takes account of such factors as the core and outlying areas, precipitation rates, density of ice fog crystals and the rate of fog thickening.

This mass balance equation was applied to the Fort McMurray area, assuming steady state conditions. A major assumption is that the core area is 25% of the total area (core + outlying areas). This assumption was used by Benson (1970) in the analysis of the ice fog situation for Fairbanks.

Using this equation for Fort McMurray, it was found that the core area, after steady state conditions had been reached, would cover 29 km^2 and the outlying area would be 87 km^2 giving a total area of 116 km^2. It should be emphasized that steady state, or extremely persistent conditions, were assumed. This is therefore the worst situation. This fog would be located in the Athabasca and Clearwater River Valleys with some drainage wind carrying it northward. The Athabasca valley is approximately 0.5 - 1.0 km in width while the Clearwater Valley, which meanders over its flood plain is approximately 1.5 - 2.0 km wide. In contrast, Fairbanks is located in the Tanana River valley which is 40 km wide at that point and flat bottomed. This topography allows the ice fog to spread out quite easily. Since the mass balance equation was based on the Fairbanks situation, it is considered that the areas calculated above may be greater than actual conditions during a persistent ice fog.

This is potentially the worst situation since water vapour emitted by urban areas located on the plateaus above the valley, which were included in the calculation, may not contribute water to the ice fog. In addition,

TABLE 16 - Equation for the Growth of an Ice Fog

Equation: $I = P_1A_1 + P_2A_2 + E_1A_1 + E_2A_2 + e_1A_1 \frac{dz_1}{dt} + e_2A_2 \frac{dz_2}{dt}$

Parameters		Fairbanks*	Fort McMurray
I	= rate of input, kg/day	4.1×10^6	2.3×10^6
A_1	= core area of ice fog, km^2	50	-
A_2	= outlying area, km^2	150	-
P_1	= precipitation rate, $gm/cm^2/day$ in core area	4.3×10^{-3}	4.3×10^{-3}
P_2	= precipitation rate, $gm/cm^2/day$ in outlying area	4.3×10^{-5}	4.3×10^{-5}
e_1	= density of ice fog crystals gm/m^3 in core area	0.21	0.10**
e_2	= density of ice fog crystals, gm/m^3 in core area	0.07	0.07
$\frac{dz_1}{dt}$	= rate of thickening over core area m/day	3 - 3.5	3 - 3.5
$\frac{dz_2}{dt}$	= rate of thickening over outlying area, m/day	1 - 3	1 - 3
E	= average evaporation rate from entire area, $g/cm^2/day$	9.2×10^{-4}	9.2×10^{-4}
E_1	= evaporation rate in core area	$E_1 > 2E_2$	15×10^{-4}
E_2	= evaporation rate in outlying area		7×10^{-4}

* Benson, 1970

** Ohtake, 1970

the period of time required for steady state to be reached is not given and thus prolonged cold periods at Fort McMurray may be too short for this to occur. Another approach to the determination of the extent of ice fog would be to consider the extreme topography of the valley and to assume that the fog would thicken much more than it does in Fairbanks. This thickening effect would inhibit the horizontal movement of the fog across and down the valley. If the thickening rates were tripled, in comparison to Fairbanks, there would be a significant reduction in the calculated areas. The above discussion highlights the uncertainties in predicting areal extent of ice fogs which might occur in the Fort McMurray area in the future.

In summary, it can be said that ice fog, at Fort McMurray, could cover approximately 36 km^2 under typical conditions expanding to slightly more than 100 km^2 under extremely persistent conditions. In spite of the uncertainties in the data and the many assumptions which have to be made, it is evident that there is the potential for significant ice fog coverage in the Athabasca and Clearwater Valleys at Fort McMurray. The frequency of cold temperatures which cause ice fog occurrences has been shown to be approximately 10 days per year rising to possibly 17 days as the town develops in the future.

Oil Sands Development Area

Water Fog

The formation of water fogs will be enhanced by the addition of water vapour to the atmosphere at both low and medium elevations. Inspection of Figure 6 shows the potential increase of industrial water vapour emissions from the existing level of 10×10^6 kg/day to approximately 200×10^6 kg/day. However, it should be pointed out that only water vapour from tailings, spray and other ponds, steam vents and cooling towers will contribute to the formation of water fog. These amount to 6.7×10^6 kg/day from GCOS, 58.9×10^6 kg/day from Syncrude and 101.9 kg/day from the other three plants.

In terms of forming evaporation fog over tailings ponds, Vogel and Huff (1975) assumed that a temperature excess of 17°C or more would exist between the water surface and the air, in their determination of a conservative estimate (safe low numbers) of the maximum possible hours of heavy fog initiation over cooling ponds. This assumption was combined with the requirement that the saturation deficit for fog formation would be equal to or less than 1.0 g water vapour/kg dry air during winter and equal to or less than 2 g/kg during other times of the year. In order for dense fog to form, which could drift downwind, Vogel and Huff suggested a value of 0.7 g/kg for the maximum required saturation deficit. Surface temperatures of the tailings ponds were assumed to range from 1°C in winter and 22°C in summer.

Saturation deficit frequencies were not available but Table 17 was compiled to show the number of possible hours per month when steam would form over open ponds provided the relative humidity was greater than the indicated average value. Factors not considered in preparing this table are:

- wind speed, which would cause ventilation of the saturated air,
- freezing of the pond surface during winter

TABLE 17 - Potential Fog Formation Over Open Ponds

Month	Pond Surface* Temp. (°C)	Critical Relative** Humidity for Steam Formation (%)	Hours of Steam per Month
January	1	7	525
February	2	29	370
March	6	43	310
April	10	63	58
May	15	75	36
June	21	79	29
July	22	82	17
August	21	79	12
September	15	75	21
October	10	63	30
November	6	43	240
December	2	29	380

* Estimated for cold ponds according to Vogel and Huff (1975).

** Pond surface temperature greater than air temperature by 17°C or more.

- oil and bitumen on the pond surface, and
- nocturnal radiative cooling during summer nights which would cause radiation fogs over the pond surface.

The indicated relative humidity is defined as that required to give a saturation deficit of 0.7 g/kg in a specified temperature range. This table was calculated from hourly temperature frequencies given in the Climatic Data Summary - 39 for Fort McMurray. From this table it can be seen that dense steam fog could form over tailings pond water surfaces 50% or more of the time during December, January and February.

The dispersal of pond fogs was addressed by Vogel and Huff (1975), however, they concluded that there were great limitations in available methodology for calculating downwind diffusion of fog from a cooling lake. Thus, no attempts were made in this preliminary study to determine the drift of tailings pond water fogs.

The frequency of fog occurrence may be increased by cooling tower water vapour emissions which could potentially reach 40×10^6 kg/day and will be 20×10^6 kg/day when Syncrude achieves a production rate of 125,000 barrels per day. These water vapour plumes have some velocity and buoyancy rise and thus normally disperse in a manner similar to other plumes. Hosler (1973) studied cooling tower vapour dispersal and concluded that if all pertinent data on cooling tower emissions, including drop size distribution plus all atmospheric parameters for a flat terrain case were available, it was possible to predict cooling tower vapour dispersal to within a factor of five. Work carried out in England on natural draft cooling towers show minimal influence on the environment (Central Electricity Research Laboratories, Symposium, 1973); however, the various authors were careful to point out that their experience did not cover forced draft cooling towers, long periods of freezing temperatures or the influence on fog by cooling towers located in deep valleys (Spurr, 1974).

An important phenomenon worth noting is as wind speed increases, the potential for extensive fog formation decreases; however, at some critical wind speed, the cooling tower plume will become trapped in the aerodynamic cavity of the tower creating a fog plume at ground level. This phenomenon could cause significant reduction in visibility near the cooling tower. The extent of this visibility effect cannot be estimated without detailed tower information. Icing which could be a major problem would occur at temperatures less than 0°C.

Ice Fog

Ice fog formation will be enhanced by the significant quantities of water vapour being emitted from low level sources during the winter. Syncrude (1976) has estimated that 2% of the annual natural evaporation from the tailings pond will occur during the three winter months. Therefore 2.5×10^6 kg/day water vapour is emitted due to natural evaporation from the tailings pond in the winter. Thermal evaporation has been found (Behlke and McDougall, 1973) to drop to 50% of the summer thermal evaporation rate. The average thermal evaporation rate from the Syncrude pond is 5.9×10^6 kg/day, thus the winter rate is 2.9×10^6 kg/day. From the above data it can be seen that total evaporation from the Syncrude tailings pond during the winter is 5.4×10^6 kg/day in comparison to the annual average of 36.5×10^6 kg/day (see Table 9). Similarly, it can be found that evaporation from tailings at the other plants are: GCOS, 0.55×10^6 kg/day; Shell, 4.2×10^6 kg/day; Home, 2.4×10^6 kg/day; Petrofina, 1×10^6 kg/day. Thus, tailings pond water vapour losses in the winter could reach 13.6×10^6 kg/day.

Water vapour from other low level sources (cooling spray ponds, cooling towers, and steam vents) must be added to those from the tailings pond to give a total water loss rate during the winter. Table 9 provides this data and Table 18, below, shows the resulting water vapour emission rates from each plant during the winter months. The mass budget equation developed by Benson (1970) can be applied to each plant as it was for Fort McMurray, to determine the potential extent of ice fog produced by each plant under steady state conditions. The results of these calculations are given in Table 18.

TABLE 18 - Potential Ice Fog from Oil Sands Plants

Plant	Winter Water Vapour Emission Rates (10^6 kg/day)	Worst Case Fog Area (km^2)		
		Core	Outlying	Total
GCOS	3.6	45	135	180
Syncrude	27.8	350	1050	1400
Shell*	5.2	65	195	260
Home	19.2	240	720	960
Petrofina	23.8	300	900	1200
TOTAL	79.6			4000

* Shell's cooling tower will not operate during the winter.

Data presented in Table 18 illustrate potentially the worst case situation since water vapour emitted by cooling towers may exhaust above the fog layer creating low level stratus clouds. Cooling tower and cooling spray pond water vapour may also form rime resulting in a lowering of water vapour emission estimates used for these calculations.

A more realistic assumption might be that when ice fog occurs it lasts for approximately eight hours. The following areas of coverage have been calculated using Benson's (1970) findings in Fairbanks and the above assumption. Water emission rates used included tailings ponds, cooling tower, cooling spray pond and vent losses as previously determined. Table 19 presents the area covered by ice fog from each plant under these more realistic conditions.

TABLE 19 - Eight Hour Ice Fog from Oil Sands Plants

Plant	Winter Water Vapour Emission Rates (10^6 kg/day)	Eight Hour Case Fog Area (km^2)
GCOS	3.6	55
Syncrude	27.8	430
Shell	5.2	80
Home	19.2	300
Petrofina	23.8	370
TOTAL	79.6	1235

Reduced area of coverage may be brought about by greater fog thickening due to the topography. Benson (1970) used thickening rates of 3 - 3.5 m/day and 1 - 2 m/day for the core and outlying areas, respectively. Because of the Athabasca Valley and surrounding hills, actual thickening rates may be greater than these values. If thickening is assumed to be 50% more than in Fairbanks, the area covered by ice fog would be 2/3 the areas presented in Table 19.

Taking the above information into consideration, it is possible to estimate the range of areas expected to be covered under various conditions as follows:

	Eight Hour Fog with Enhanced Thickening	Worst Case
GCOS	37 km^2	180 km^2
Syncrude	285	1400
Shell	53	260
Home	200	960
Petrofina	245	1200
TOTAL	820 km^2	4000 km^2

The large range in values illustrates the range of uncertainty associated with estimates of the potential area covered by an ice fog. These values could not be confirmed for the existing plant, GCOS, in the absence of pertinent field data. Figure 8 shows the projected area covered by ice fog with five oil sands plants in operation. The drainage winds are presumed to flow downhill and along the Athabasca River valley.

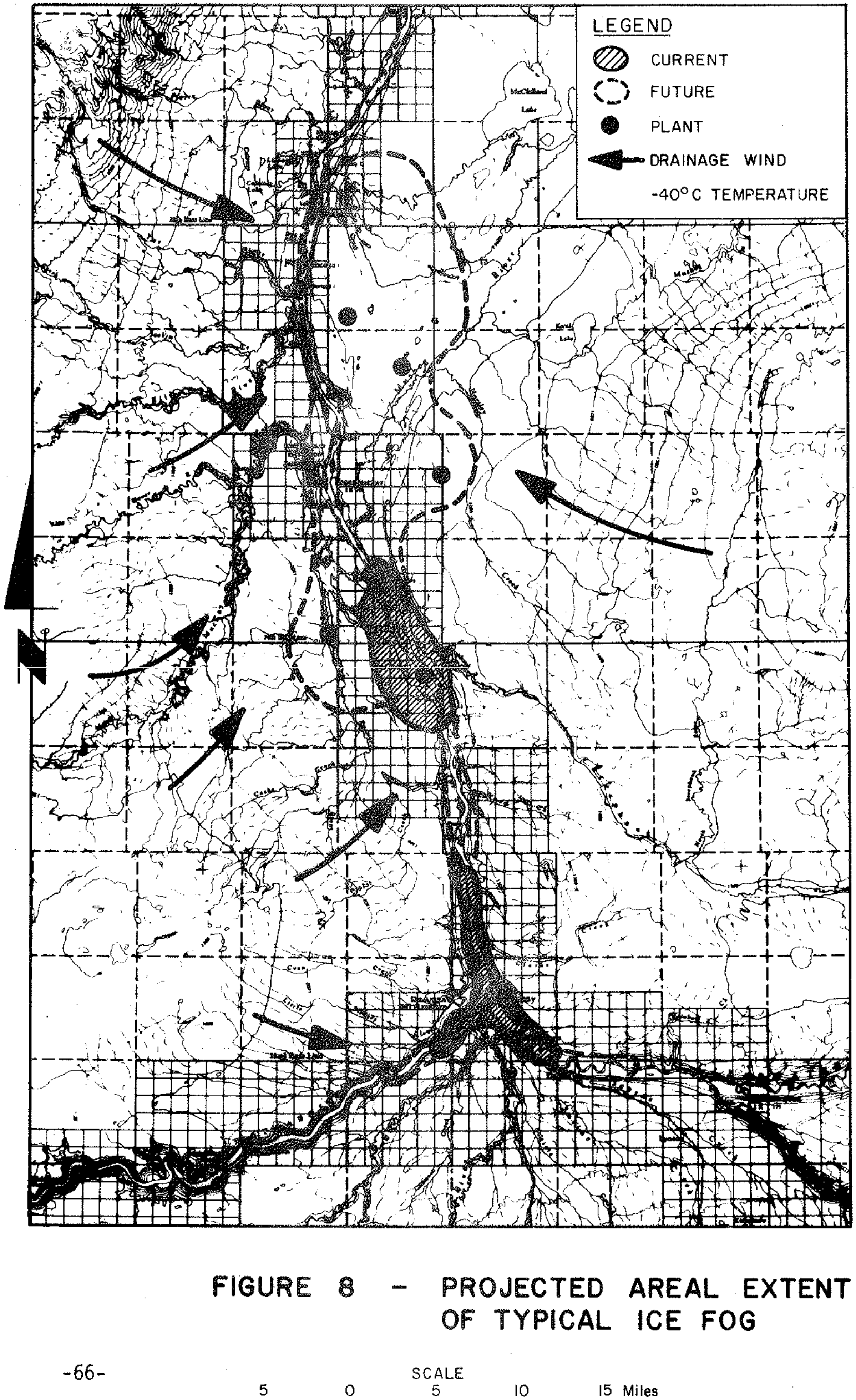


FIGURE 8 - PROJECTED AREAL EXTENT OF TYPICAL ICE FOG

5. FOG-POLLUTANT INTERACTION

5.1 LITERATURE REVIEW

The major pollutants being emitted by the oil sands plants are sulphur dioxide and particulate matter, including heavy metals. In Fort McMurray, the major pollutants are carbon monoxide, particulates, oxides of nitrogen and hydrocarbons with sulphur dioxide ranking last according to emission rate information developed previously.

Literature on the interaction of pollutants and fog or water droplets deals mainly with sulphur dioxide. Urone and Schroeder (1969), Bufalini (1971) and Barrie (1975) reviewed sulphur dioxide reaction studies. Mason (1971) discussed the effect of various pollutants on the microphysics of fogs, clouds and precipitation.

Katz (1950) was one of the first researchers to note that oxidation of sulphur dioxide might take place at nights as well as in daylight, and that fine particles of dust and metallic oxides catalyze the oxidation reaction. Brimblecomb and Spedding (1974) indicated that early work showed uncatalyzed sulphur dioxide oxidation was extremely slow and very sensitive to traces of dust or metal ion impurities. Shira, et al. (1962) compared photoxidation rates of sulphur dioxide in the vicinity of a smelter to rates in an industrial area located close to Tokyo. The rate of sulphur dioxide disappearance at the smelter was found to be high and dependent on the quantity of moisture in the air. Pronounced catalytic or complementary effects from other pollutants was also suggested. Gartrell, et al. (1963) studied sulphur dioxide in power plant plumes and found that oxidation rates depended to a great extent on concentration and relative humidity. The highest oxidation rate was observed in a light mist.

Haagan-Smit (1963) in a review of photochemistry and smog stated that the reaction of sulphur dioxide with oxygen is slow and that heavy metals catalyzed the reaction. Nitrogen oxides, olefins and sunlight were found to increase substantially the reaction rate. Cox and Penkett (1972) estimated the average photochemical oxidation rate of sulphur dioxide to be 0.10%/hr in clean air and 3%/hr in polluted air. Matteson (1967) found the rate of sulphur dioxide consumption was 0.56%/min in a humid air stream containing 70 ppm sulphur dioxide and 30 mg/m^3 manganous sulphate.

Urone et al. (1968) found that sulphur dioxide in the presence of powdered oxides of aluminum, calcium, chromium, iron, lead and vanadium reacted within minutes even without ultraviolet radiation.

Johnston and Moll (1960) combined artificial fogs with 250 ppm sulphur dioxide and found that manganous sulphate catalyzed the oxidation of sulphur dioxide at a rate four times that when ferrous sulphate was used. It is interesting to note that Meetham (1954) calculated that the half life of sulphur dioxide in the heavy London fog of 1952 was six hours. It should be noted that many laboratory studies reported in the literature are carried out using pollutant and aerosol concentrations several orders of magnitude higher than those which exist in polluted ambient air.

Cheng et al. (1971), however, conducted a study at conditions much closer to ambient (3 - 5 ppm sulphur dioxide and metallic salts micron in size). Their results were extrapolated to atmospheric conditions and the following assumptions were made with respect to conditions existing in a natural fog in an industrial atmosphere.

1. Concentration of sulphur dioxide in the air is 0.1 ppm.

2. Average diameter of fog droplets is 15 microns.

3. Half of the fog droplets contain 500 ppm manganous sulphate. This droplet could be nucleated by a single particle of manganous sulphate having a diameter of 0.55 microns or other types of catalyst with strength equivalent to 500 ppm manganous sulphate.

4. The fog concentration is 0.2 g water/m^3 air.

Based on these assumptions, the rate of sulphur dioxide conversion to sulphuric acid was calculated to be 2%/hr. This study also concluded that relative humidity appeared to exert the strongest influence on the rate of sulphur dioxide oxidation in air.

Very little work has been carried out to date on the interaction of pollutants and ice fog. Holty (1973) carried out a study at Fairbanks during which air quality was measured under ice fog conditions and in the absence of ice fog. Analytical results are given in Table 20 which shows that pollutant concentrations are increased on the average by a factor of two to three during ice fog. These high concentrations were caused by stable meteorological conditions and low ventilation coefficients which also contribute to ice fog formation.

Holty also found that during an ice fog lead tended to preferentially remain in the aerosol relative to its concentration in suspended particulates longer than other contaminants. Sulphate and nitrate appeared to precipitate at five times the rate of lead aerosols during ice fog. This difference in settling velocities was possibly due to the difference in emission elevation of these pollutants with crystals of sulphates and nitrates forming larger crystals which would therefore settle faster. It was also implied that anions of sulphur and nitrogen could have seeding potential for ice fog.

Another interaction mechanism to consider is the effect of pollutants on the formation or onset of fog. Bowling (1971) had reported that dense ice fogs in Fairbanks were occurring at higher temperatures (-37°C) than had previously been noted (-40°C). This phenomenon was first noticed during 1968-69 when the North Slope boom started and can be explained by the increase in concentrations of condensation nuclei and increasing water vapour emissions occurring as a result of increased urban activity. Water fogs also occur at lower relative humidities if active condensation nuclei are suspended

TABLE 20 - Pollution Levels at Fairbanks During Ice Fog

Parameter	Non-Ice Fog Conditions $\mu g/m^3$	Ice Fog Conditions $\mu g/m^3$	% Increase During Ice Fog
NO_2	37	85.2	130
$NO + NO_2$	66	198.2	200
SO_2	0.6	33.8	5530
HCHO	7.3	10.3	40
Total Particulates	492	-	-
$NO^-{}_3 + NO_2{}^-$ (N)	0.16	0.3	90
$SO_4{}^=$	3.6	5.8	60
Cl^-	2.1	4.3	100
Pb	0.6	1.8	300
NH_4	Trace	1.6	

in the atmosphere. The most active nuclei are particles of sea salt or products of combustion containing sulphuric or nitric acids.

From the information presented above it is concluded that the oxidation rate of sulphur dioxide to sulphate and sulphuric acid is significantly increased during the presence of fog and heavy metals. Particulate matter acting as condensation nuclei also causes fog and ice fog to occur at lower humidities and higher temperatures, respectively. Thus, we see two types of fog-pollutant interactions:

1. Fogs can occur more frequently because of additional condensation nuclei,

2. Fogs can react chemically with pollutants causing reaction products which, environmentally, may be of more significance.

From the literature it appears that water droplet fogs are affected more by the latter interaction while ice fogs more by the first.

5.2 OIL SANDS AREA

The Oil Sands area, for discussion purposes, can be broken down into its urban and industrial areas. The urban area has negligible pollutant emissions compared to the development area (See Section 3.5). However, it is considered that increases in ambient pollutant levels similar to those increases found in Fairbanks would occur in Fort McMurray during an ice fog occurrence. This increase in pollutant concentrations would be due to the meteorological conditions causing the ice fog not the fog itself. Ambient concentrations could not be projected for the Town of Fort McMurray since appropriate air quality data were not available for the Town.

The analysis of fog-pollutant interaction in the industrial development area is more difficult because fogs form near the ground while the majority of plant emissions are released from tall stacks. The problem is to determine what potential there is for pollutants to mix with fogs. It is realized that there are normal low level pollutant emissions which could mix with fogs; however, it was beyond the scope of this preliminary study to determine the quality and quantity of these discharges.

Particulate and sulphur dioxide emissions can mix and react with fogs only if the plume disperses to the ground at a location where fog is present. It has been shown that radiative fogs are frequently present along the river valley during early morning hours. However, the plume under these same conditions would exhibit a fanning appearance until the radiation inversion was eroded from below and fumigation occurred. This could result in mixing; however, it is quite possible that mixing would last only briefly as the fog would evaporate when dispersed through the ever increasing mixing depth.

Fogs and plumes could also mix if light winds carried the fog upslope where plume fumigation of the slope was occurring. This appears to be possible with the GCOS plume and the surrounding topography. Plume measurements (Whaley, Lee and Galbraith, 1974) during February 1973 showed that significant sulphur dioxide concentrations (530 $\mu g/m^3$) can be experienced on the hill across the Athabasca River (See Figure 2) with a west wind and morning inversion conditions. Fog was not observed at the time, however, if a fog were drifting out of the valley at the same time there would have been interaction. Similarly, there may be potential for emissions from one plant to mix with fog formed by a plant downwind.

During plant emergency upset conditions, it also is possible for higher ground level pollutant concentrations to occur. These emergency conditions are immediately reported to Alberta Environment and normally do not last for more than a few hours. If high ground level pollutant concentrations are detected, Alberta Environment can order plant operating conditions to be adjusted so that emissions are reduced. Fog-pollutant interaction under emergency upset conditions could occur briefly but would be controlled if high pollutant concentrations were monitored or anticipated.

It is concluded from this analysis of meteorological, fog and plant emission data, that significant fog-pollutant interaction (i.e. an acid fog episode) will not occur in the oil sands area.

Serious air pollution episodes involving fogs have occurred in the past (Williamson, 1973) at Donora, Pennsylvania (1949) and London, England (1952). Analysis of both episodes revealed the following common factors:

- stagnant anticyclone persisted for four or five days,
- persistent dense fog was trapped below an elevated inversion for the duration of the episode.
- sulphur dioxide and particulate concentrations were very high due to high emission rates of these pollutants from low level stacks,
- a population centre was blanketted by the polluted fog for the duration of the episode and increased morbidity resulted.

It is concluded that a similar situation will not occur in the oil sands area because:

- Fogs do not normally last for longer than one or two days under persistent conditions.
- Main stack plumes will not normally reach the ground under the same atmospheric conditions that produce fog.
- Fort McMurray is not in close proximity to the existing or projected plants. However, no consideration is given here to a potential new town.

It is evident also from the amount of pollutants and water vapour emitted that plant enhanced clouds may touch the higher terrain causing polluted fogs. The degree of interaction between the cloud and plume before contact with the ground has not been determined but it would involve cloud physics processes to a great extent. These processes include condensation and ice nuclei, precipitation development, droplet and ice particle chemistry, precipitation scavenging or wash-out and a number of other dynamic effects peculiar to clouds formed over rolling terrain. Useful information could be gained by field studies since the mathematical modelling of such processes can be best understood only when some real data are available.

6. COMPREHENSIVE STUDY

The results of this preliminary study indicate that there will be potential fog problems in Fort McMurray and the oil sands development area for two major reasons.

1. Based on existing information, it appears that ice fog could be widespread when it occurs in the development area and in the urban area.

2. At the present time, there is potential for fog-pollutant interaction during water fogs where the dispersing plume(s) become mixed with the fog resulting in acid fog conditions.

It is considered that the potential for extensive fog formation in the oil sands development area is sufficient to warrant further study.

The purpose of this Section is therefore to outline general and specific areas for further detailed investigation. The execution of this comprehensive study will provide a basis for precisely determining the existing and potential magnitude of these problems and will outline techniques for decreasing or controlling the occurrence of fog.

6.1 GENERAL AREAS REQUIRING FURTHER STUDY

An outline of further work required to better determine the magnitude and occurrence of fog in the Oil Sands area is now given. It must be emphasized that many of the estimates provided in this report have been based on many assumptions and only limited data have been used. Results of the work described below will provide a firm basis for a more exact delineation of the fog problem.

1. Investigation of seasonal evaporation rates from the tailings ponds, including surface temperatures, atmospheric saturation deficits, and the effects of surface oil and surface freezing.

2. Investigation of cooling tower operation with respect to plume rise, drift and downwash, including water vapour losses available for fog formation.

3. Water vapour emission rates from natural, urban and industrial sources would be refined according to season and the results utilized in conjunction with field study data to provide better estimates of fog occurrence and magnitude.

4. Routine observations of fogs would be made at the Fort McMurray townsite, GCOS and Syncrude in conjunction with wind and temperature observations.

5. Techniques for reducing water vapour emissions would be investigated. The major areas of emphasis would be cooling towers, cooling spray ponds and tailings ponds.

It is considered that the most important items in the work outlined above are the more precise estimation of water vapour emission rates according to season and the initiation of routine fog observations.

6.2 FIELD STUDIES

The fog mass balance equation was used to determine the areal extent of ice fog coverage. Water content, evaporation and precipitation rates determined in Fairbanks were used for the Fort McMurray and industrial development areas. Two techniques should be used to confirm or modify the preliminary estimates of fog areal extent presented earlier:

1. Solid water content and precipitation rates should be determined during an ice fog occurrence at both the urban and development areas.

2. Photographs taken at intervals ranging from 1 - 4 hours from aircraft during an ice fog occurrence should be used to determine changing extent and thickness of the fog.

By combining these two techniques, it should be possible to determine more accurately the evaporation rate and the use of parameters applicable to the Oil Sands area in the mass balance equation. The photographic results would be used for comparison with results of the water balance equation. These photographs would indicate behavior of ice fog along the Athabasca Valley and would permit adjustment of the results of the water balance approach to take account of the topography of the area. If accurate water vapour emission rates were available for the study period, it would then be possible to project areal extent of ice fog under future conditions.

Ice crystal precipitation rates should be determined by setting up several one meter by one meter plastic covered collection surfaces, protected from winds or extraneous sources of precipitation. By cleaning the surface at regular intervals it would be possible to determine precipitation rate. These crystal samples should be weighed and analyzed for pH, sulphate, nitrate and heavy metals content. These analytical results would permit the estimation of environmental impact which could occur in the spring and growing period after precipitated crystals melt and enter the ecosystem.

The solid water content should be measured by the high volume sampler technique or estimated from the precipitation rates and knowledge of the crystal size distribution.

Results of this field study when combined with estimates of future emission rates would permit accurate estimates to be made of ice fog coverage for future years.

Water droplet fogs should receive study mainly in relation to chemical composition, with particular emphasis placed on the formation of acid fog. The main impact of water fogs will occur when these fogs have mixed or are mixed with pollutants such as sulphur dioxide, nitrogen dioxide, particulates, hydrogen sulphide or heavy metals. The resulting heterogenous mixture might effect materials, vegetation or health.

It is anticipated that such a study would be difficult to undertake since sampling would be carried out downwind of the plant(s) within a fog. It may be difficult to gain access to the desired location and power would have to be generated on site. Equipment and personnel would have to be maintained in readiness for sampling.

The following measurements should be made:

1. Ambient sulphur dioxide concentration.

2. Ambient particulate and heavy metal concentration.

3. Droplet pH, sulphate and heavy metal content.

4. Liquid water content of fog.

5. Duration of mixing conditions.

These measurements should be repeated for two separate incidents. With these data it should be possible to estimate the degree of environmental impact caused by the fog-pollutant interaction.

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TABLE 21 - Conversion Factors

English Unit	x	Multiplier	=	S.I. Unit
acre		0.004047		km^2
cu. ft.		0.0283		m^3
ft.		0.3048		m
°F		0.5555 (°F-32)		°C
gal (Imp)		0.004546		m^3
gpm (Imp) of H_2O		6545.5		kg/day of H_2O
in.		2.54		cm
lb. (mass)		0.4546		kg
lb/1000 cu.ft.		16.02		g/m_3
long ton		1.016		t
mile		1.609		km
sq. mile		2.588		km^2
ton		9072		kg
ton		0.9072		t