THE CLIMATOLOGY OF THE ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM STUDY AREA

prepared by

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ABSTRACT

In many respects, the climate of northeastern Alberta resembles that of the central portions of the province. It is generally somewhat cooler, especially in winter, and precipitation is slightly less. The area has a very definite continental climate and its distance from the Pacific Ocean and the mountains result in the almost complete absence of winter chinooks which are often thought of as an integral part of Alberta climate.

Winters are cold with relatively little snow. Heavy snowfalls such as are common in the mountains and foothills are rare. Intense cold outbreaks can last from several days to a few weeks.

Summers are relatively short and cool, although the occasional warm spell can cause temperatures to rise above 30°C. About two-thirds of the precipitation falls in the summer months with several major rainstorms generally accounting for much of the seasonal rain.

Northeastern Alberta cannot be considered windy. High winds do occur but they are infrequent and rarely last longer than 12 to 24 hours.

Although the topography does not have a major impact on the weather patterns, certain terrain features are significant in establishing windflow patterns that must be understood and considered in assessing the impact of climate on the development of the Athabasca Oil Sands.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

Increased human activity associated with the development of the Athabasca Oil Sands has stimulated an active interest in the climate of northeastern Alberta. Climatological information is required not only for the planning and assessment of various industrial projects, but also people considering residence in the area are interested in knowing what to expect in the way of weather and climate.

In the past there has not been a widespread interest in the climate of this area and consequently the detailed information that is now required is not available. This report, prepared for the Alberta Oil Sands Environmental Research Program (AOSERP), attempts to synthesize the available climatological data and identify information gaps. Since data are somewhat sparse the report cannot be considered definitive and it may be desirable to revise it in a few years as more data become available from the area.

The report attempts to present an overview of the climate of northeastern Alberta and, although much of the information may be of general interest, there is a great deal of specific information that will be useful for the planning of industrial, recreational, municipal, and highway projects. The basic information contained in this report should meet the needs of those users requiring long-term temperature and precipitation data. However, the detailed information required by those users interested in air pollution and atmospheric dispersion is lacking because historical wind data are available from only a few stations.

The repeated emphasis in the report is to extract as much information as possible from the available data. In general, the approach has been to establish principles relating Fort McMurray airport (Fort McMurray A) data to other parts of the AOSERP study area (Figure 1).

SI units are used throughout the report except in a few instances where reference is made to historical data that were

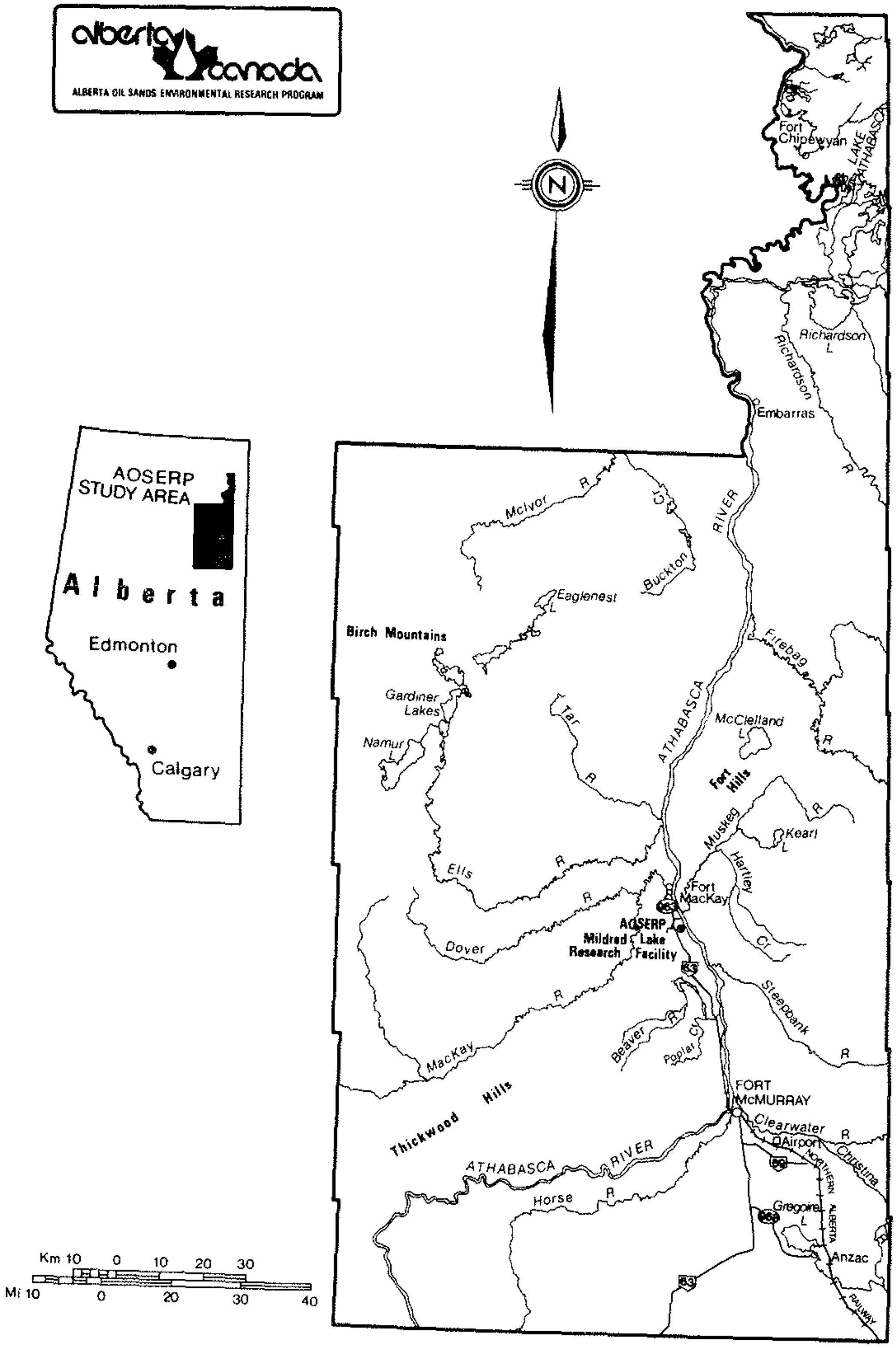


Figure 1. The AOSERP study area.

collected in Imperial units. Unless specifically noted, all time reference is to Mountain Standard Time.

1.2 DATA BASE AND ITS LIMITATIONS

The data base for this report comprises all the historical climatological data available from within the AOSERP study area. Reference is also made to stations lying just outside the boundaries of the area, and for comparison purposes, to some well known communities in western Canada.

The earliest known weather observations from northeastern Alberta date back to the early 1800's when explorers such as Mackenzie, Thompson and Franklin described the weather in their journals. According to Powell (1974:9), the earliest known data to be used in a climatological study were collected at Fort Chipewyan by Lefroy in the winter of 1843-1844. Records compatible with our present-day observational procedures and of sufficient length to calculate averages began at Fort Chipewyan in 1883 and continued with breaks until 1940.

Climatological records from the AOSERP study area fall into three categories depending on the type and frequency of observations:

1. Ordinary climatological records--daily precipitation (both type and amount). Most ordinary climatological stations also report daily maximum and minimum temperatures.
2. Synoptic records--observations of temperature, wind, pressure, weather, and cloud at synoptic hours (see Glossary). Records of daily precipitation and maximum and minimum temperatures are also made. These records are not completely compatible with those of category "1" because of the definition of the "day".
3. Hourly records--observations of wind, temperature, pressure, cloud and weather on an hourly basis. Within the AOSERP area such records are available only from stations established at airports.

Table 1 summarizes the stations used in the preparation of this report and indicates the category to which each station belongs. It will be noted that the lookout stations (Lo) have summer data only. These stations were established by the Alberta Forestry Service primarily for the purpose of forest fire detection but regular climatological observations have been an integral part of this program.

Climatologists have examined the need for data upon which to base a description of the climate of an area. To obtain a reliable sample of the varying types of weather, the climatologist concludes that in temperate climates observations taken over a period of 30 years are needed. Such records are usually referred to as "normals" and are usually recalculated every 10 years. The latest set of normal values for Canada is based on the period 1941 to 1970 (see Section 10.2).

An examination of Table 1 reveals that according to this criterion only Fort McMurray A has a record of sufficient length for inclusion in this latest set of normals. Because Fort McMurray A is the only long-term station in the area, one must consider it as a reference point and use its records as a starting point in assessing the climate. Climatic data for Fort McMurray A are found in Section 10.2. The area has a varied topography (Section 2.2) which results in variations of climate within the area. Examination of the records from the other stations in and around the area and comparison with those from Fort McMurray A and each other, permit one to estimate these climatic variations. The results may be used, but with a recognition of their tentative nature until records for a longer period provide more reliable values for the measures of climate.

The records from Embarras where an airport was maintained from 1943 until 1962, and Stoney Mountain (radar site 1957 to 1963) were useful in determining wind patterns and elevational relationships of temperature and precipitation. The lookout stations were invaluable in establishing summer precipitation and temperature patterns.

Table 1. Weather stations in the AOSERP study area and other stations to which reference is made.

Name	Lat.		Long.		Elevation (m)	Began[b]		Ended		Category[c] of Record
						Yr.	Mo.	Yr.	Mo.	
Algar Lo[a]	56	07	111	47	700	1959	04			C
Anzac	56	28	111	02	500	1972	12			C
Birch Mountain Lo	57	43	111	51	853	1960	05			C
Bitumount Lo	57	22	111	32	350	1962	05			C
Buckton Lo	57	52	112	06	790	1965	06			C
Calgary A	51	06	114	01	1079	1939	01			H
Edmonton Ind. A	53	34	113	31	677	1937	10			H
Edra Lo	57	51	113	15	790	1966	06			C
Ells Lo	57	11	112	20	560	1961	04			C
Embarras A	58	12	111	23	236	1943	02	1962	09	H
Fort Chipewyan	58	46	111	07	228	1962	10			H
Fort McMurray A	56	39	111	13	371	1944	01			H
Fort Smith A	60	01	111	58	203	1943	09			H
Fort Vermilion	58	23	116	03	280	1908	07			C
Gordon Lake Lo	55	37	110	30	490	1964	04			C
Grande Lo	56	18	112	13	530	1965	08			C
Johnson Lake Lo	57	35	110	20	550	1965	05			C
Keane Lo	58	19	110	17	460	1964	05			C
Legend Lo	57	27	112	53	850	1962	05			C
Livock Lo	56	28	113	11	580	1965	09			C
Mildred Lake	57	02	111	36	310	1973	07			C
Muskeg Lo	57	08	110	54	550	1959	06			C
Muskwa Lo	56	05	114	39	600	1967	05			C
Richardson Lo	57	55	110	58	300	1960	04			C
Saskatoon A	52	10	106	41	502	1941	04			H
Seaforth Lo	57	14	113	21	820	1961	04	1969	08	C
Stoney Mountain	56	23	111	16	780	1957	11	1963	12	S
Stoney Mountain Lo	56	23	111	14	760	1954	05			C
Tar Island	56	59	111	28	288	1970	06			C
Thickwood Lo	56	53	111	39	520	1957	04			C
Wabasca	55	58	113	50	545	1965	08			C

[a] All lookout stations (Lo) have summer data only.

[b] Indicates beginning of uninterrupted record. For complete station history see Milgate (1978).

[c] C - ordinary climatological data--daily precipitation or daily precipitation and maximum, minimum temperatures.
S - synoptic--cloud, weather, temperature, humidity, pressure wind at synoptic hours (see Section 10.1).
H - hourly--similar to synoptic but on hourly basis.

Researchers, faced with a paucity of climatological data from the study area, are often tempted to use Fort McMurray A data as being representative of the area. In the long term this may be valid for certain weather elements. For instance, the long-term temperature extremes, the mean monthly temperature, and the mean monthly precipitation values for most of the area can be estimated by applying appropriate adjustments to the Fort McMurray A values. The Fort McMurray A wind regime, as shown in Section 5 of this report, is far from being representative of the study area. Data on other climatic elements, such as sunshine and fog, are lacking so one must base any conclusions related to these to the data from Fort McMurray A and reports from stations outside the AOSERP area.

2. PHYSIOGRAPHY AND CLIMATIC CONTROLS

2.1 THE AOSERP STUDY AREA

The boundaries of the AOSERP study area as defined in Figure 1 are generally acceptable for the purposes of this climatic study. However, use is made of stations outside the area for comparison and to derive a broad picture of the variation of the climatic elements. These stations are listed in Table 1, Section 1.2 along with the stations in the study area.

The present extraction plants are located near the centre of the study area. Because the weather elements, such as temperature and wind, near these plants, are affected by their surroundings, the study must not be limited to the immediate vicinity. The hills on either side of the river form a basin which is open to the north. The weather on the sides of this basin influences that along the river valley. The study area then must include the surrounding hilltops. The major interest is directed to that area within the boundaries of the river basin. To the south, it extends to the top of the Stoney Mountain ridge. To the east the limit is the Alberta-Saskatchewan boundary. (No weather stations are east of the boundary for many kilometres.) The plateau of the Birch Mountains with its series of lakes form the western boundary. Lake Athabasca and Lake Claire limit our interest to the north.

2.2 TOPOGRAPHY OF THE STUDY AREA

The area of study is part of the drainage basin of the Athabasca River which rises in the Columbia Ice Fields in the Rocky Mountains. It flows northward to Jasper, and leaves the mountains at Entrance. From here it flows generally in a northeasterly direction, gathering water from other streams in its path, until it reaches Fort McMurray. Through the last part of this journey, it flows in a deep canyon with the Thickwood Hills to the north and the Stoney Mountains to the south.

At Fort McMurray it is joined by the Clearwater River which rises in Saskatchewan and flows from the east through a valley between Stoney Mountain to the south and the Muskeg Mountain to the north. Downstream from the confluence, the water flows northward at a slow pace toward Lake Athabasca. The drop in 200 km is less than 40 m. At the northern end it broadens out into a wide delta plain before it enters the lake. The topography of the area is shown in Figure 2.

To the east, south, and west of the valley are high hills. The rate of rise from the town of Fort McMurray (250 m) south to the high point at Stoney Mountain (780 m) is rapid. The elevation of the mountain complex drops as it extends east and west and particularly south.

Northeast of Fort McMurray and east of the Syncrude Plant near Mildred Lake lies the Muskeg Mountain uplands, where the hills reach about 600 m. The drop to the Clearwater River to the south is quite rapid, but the land slopes gently northwestward toward the Athabasca River. The Steepbank, Muskeg and Firebag rivers carry water off the uplands to the Athabasca River. Farther north, water from the uplands flows via the Richardson River into the delta plain of Lake Athabasca. West of the Athabasca River lies the Birch Mountain Plateau, with an elevation of about 700 m. Near 58°N the rate of rise from the river to the top at Birch Mountain Lookout (elevation 853 m) is rapid. South of Birch Mountain Lookout, the gradient is more gradual. A series of lakes lie in a saucer-shaped depression at the top of this plateau and drain via the MacKay and Ells rivers, at first southeastward and then northeastward into the Athabasca River. The northwestern part of the Birch Mountain Plateau drains into Lake Claire and the Peace River. The Thickwood Hills, rising to about 600 m, lie between the MacKay River and the Athabasca River west of Fort McMurray and so to its junction with the Clearwater River.

North of the district lie Lake Athabasca, Lake Claire, and extensive swamp areas, forming the Peace-Athabasca Delta. This large

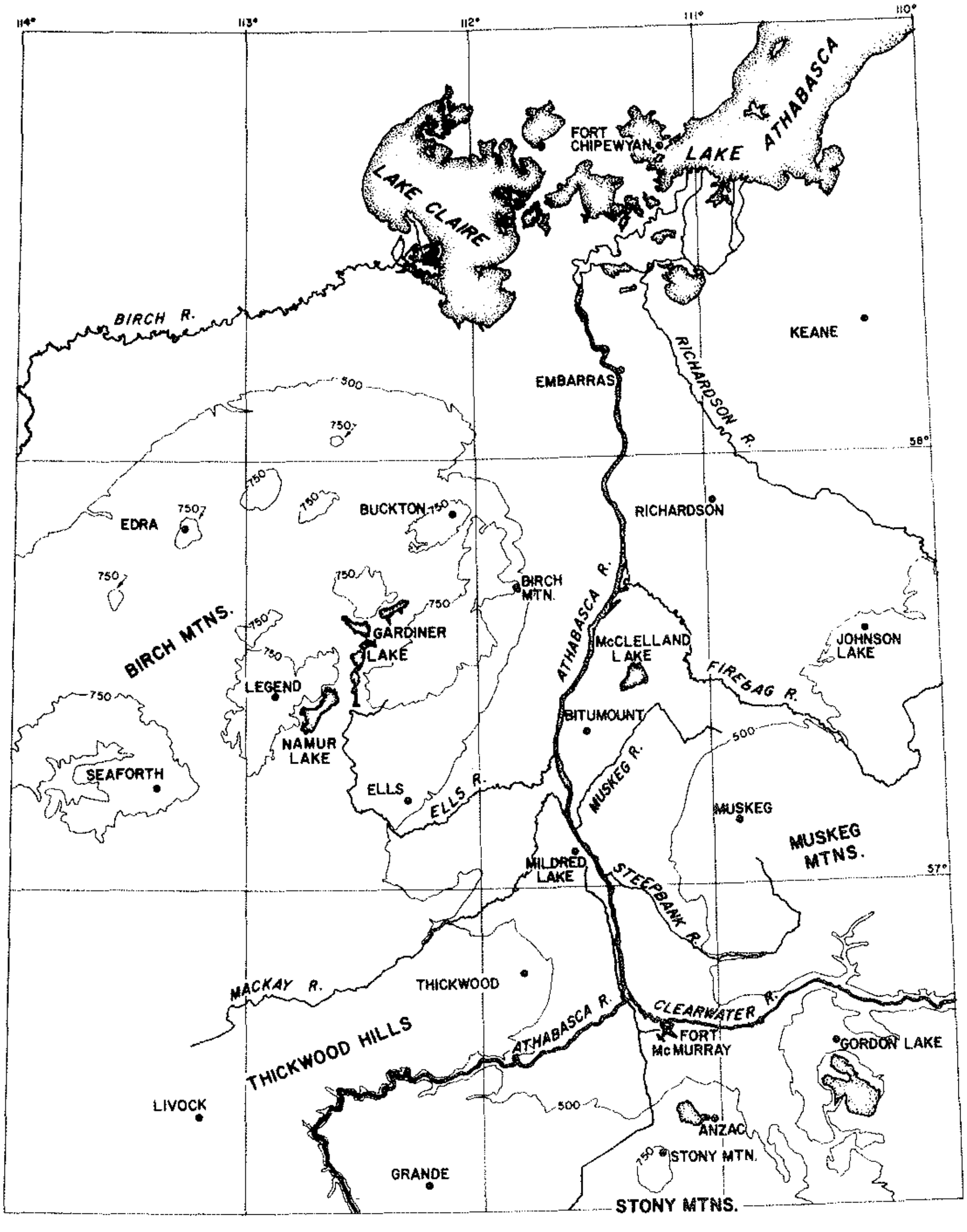


Figure 2. Topography of the AOSERP study area and surroundings.

area of water modifies the climate, particularly during the spring period between the time when the temperature rises above freezing and ice is almost gone and again in fall during the period between the time when the air temperature drops to freezing and when ice once again covers the water. In springtime, the loss of heat to melt the ice and warm the water tends to keep surrounding areas cooler. In the autumn, the heat stored in the water and released when freezing tends to keep surrounding areas somewhat warmer. These influences are felt in the immediate vicinity.

The area under study is not large on a world scale. Most major weather systems tend to influence the total area more or less uniformly. This is not always true for meso-systems, such as individual thunderstorms. Even with these, the conditions conducive to thunderstorms will generally exist over the whole district so that all parts of the area may be affected.

2.3 CLIMATIC CONTROLS

The climate of the earth has its origin in the sun and the radiative solar energy that the earth intercepts. Terrestrial influences cause the climate to vary from one district to another. These climatic factors or controls are discussed at length in most textbooks on climatology. Miller (1964) lists the following:

1. Latitude;
2. Altitude;
3. Proximity of oceans;
4. Prevailing winds;
5. Ocean currents;
6. Lakes;
7. Physical features; and
8. Soils.

When consideration is given only to the large-scale climatic factors of latitude, distance from the ocean, and the general circulation of the atmosphere or the prevailing winds, one is led to conclude that the climate over the area should be uniform.

Other climatic factors listed by Miller are more local in their influence. In particular, for the study area, elevation, topography and proximity to bodies of water are significant. Because of these, there are small but significant differences in the climate. Some of these differences can be detected from available data, and are revealed in this study. Other differences may be inferred from general principles, but must await further data collection to be confirmed.

2.3.1 Latitude

The study area lies between 56° 20' and 59°N. The change in latitude from equator to pole results in a change in the amount of incident radiation from the sun. If we consider the radiation at the top of the atmosphere, at the summer solstice the long hours of daylight result in more radiation at the latitude of Fort McMurray than at the equator. At the time of the winter solstice, the daily amount is less than 15% of that at the equator. For the year as a whole, radiation above Fort McMurray is about 60% of that above the equator.

The reference to the top of the atmosphere is misleading. There is significant energy loss between the top of the atmosphere and the ground. Reflection by clouds, and absorption of the heat as it passes through the atmosphere are major factors in reducing the solar radiation reaching the ground. Based on average solar radiation values (Titus and Truhlar 1969), and that computed by Melankovitch (List 1963) for the top of the atmosphere, the atmosphere reduces the solar radiation by about 50% at the latitude of Fort McMurray.

In winter, the solar input at the earth's surface is small for three reasons. The low angle of the sun results in a small amount of intercepted energy. Because it travels by a long path through the atmosphere, it loses a considerable amount of its initial energy. Third, the snow surface reflects as much as 80% of the solar radiation reaching it. The greatest amount of energy is lost from the earth by long-wave terrestrial radiation from the snow surface. This is relatively small because of the low surface temperature, but it is greater than the absorbed solar energy. The net result is a cooling until mid-January. This cooling would be more rapid if winds aloft did not result in a net influx of heat from southern latitudes. Before the end of January, the higher sun and longer daylight hours increase the solar input sufficiently that incoming energy exceeds outgoing energy, and the land begins to warm slowly. The maps from Titus and Truhlar indicate that the net incoming radiation for the three months, November, December and January is approximately 190 langleys for the southern boundary of the district, and 140 langleys for the northern boundary (see Section 10.1). The difference results in slightly lower mean temperatures in the north than in the south.

In summer, the different items of energy flow differ considerably from winter values. Solar input is large because of longer days, higher sun, and more absorption of the energy reaching the ground. The variation because of the latitudinal differences is slight. Titus and Truhlar show that for the three months of highest sun, May, June, and July, Fort McMurray receives 1,575 langleys, and the northern boundary 1,610 langleys. Mean summer temperatures in the northern portions of the study area are not significantly different from those in southern portions.

Visitors or newcomers to the area soon notice the effect of latitude on the length of day. At the height of summer there is an almost complete absence of darkness and there are almost 18 hours of daylight. Conversely, in winter the days are short with less than seven hours of daylight at the end of December.

2.3.2 Elevation and Climate

Mankind has recognized that usually the weather becomes colder as one climbs mountains. Records of rainfall have shown clearly that the mountain ranges change the precipitation patterns. Most of such studies have examined the effects of high mountains ridges on climate.

In the study area the greatest difference in elevation is about 600 m. This is small compared to the differences in elevation in, say, British Columbia. Nevertheless, the same principles are still valid. The studies of the temperature and precipitation regimes (Sections 3 and 4) show that temperature and rainfall are influenced by the differences in elevation within the study area. The differences are not great in comparison with differences found in mountainous areas, but are significant.

2.3.3 Proximity to Oceans

Next to latitude, the most significant factor in determining the variation of climate over the earth's surface is the proximity of the ocean. The high thermal capacity of the ocean waters dampens fluctuations of temperature. Also water surfaces are sources of moisture through evaporation when the water temperature is higher than the dew point of the air. The additional moisture provides vapour to form cloud and fog droplets and rain drops if the weather processes are favourable.

The study area lies some 1,000 km from the Pacific Ocean and is separated from it by several major mountain ranges. Thus the modifying influences of the Pacific Ocean reach the area with difficulty. On the other hand, the absence of a significant west-east mountain barrier between northeastern Alberta and the Arctic Ocean permits the frequent incursion of cold Arctic air originating over the polar icepack. The climate of the study area is thus definitely "continental."

2.3.3.1 The continental climate of the AOSERP area. The differences between marine climates and continental climates can be seen in both temperature and precipitation. Continental climates have greater variability in temperature, a variability that is revealed in the daily range, the annual range, the variation from day to day, and from year to year. Regarding precipitation, continental climates tend to have the maximum during the warm parts of the day or year. It often falls in convective showers or thundershowers. In contrast, marine climates have more uniformity of occurrence and amount.

Climatologists have sought some method by which they can indicate the continentality of a climate. Landsberg (1958) favoured a formula developed by Johansson (1931) as giving a good representation. The formula is:

$$K = \frac{1.6\ A}{\sin \phi} - 14$$

where K is the desired index, A the mean annual range of temperature ($^{\circ}$C), and ϕ is the latitude. Values of K on the world scene vary from near 0 for a marine climate to about 100 for some places in Siberia. MacKay and Cook (1963) used this formula to obtain the variation through Canada. The highest values, slightly over 65, were found in a band from western Keewatin south into northern Saskatchewan and then southeastward across Manitoba into northwestern Ontario. For Fort McMurray, the index is 59 and Fort Chipewyan has an index of 65. Thus the area has a high index of continentality. In comparison, Edmonton has an index of 47.

The continentality of the climate of the study area can be readily recognized in the data for Fort McMurray A (Section 10.2). Summer is the season when precipitation is highest whereas places with maritime climates, such as Victoria, have highest precipitation in winter. At Fort McMurray about two-thirds of the annual precipitation falls in summer, often in the form of showers. The continental nature of the climate is also revealed in several aspects of the temperature regime. The range between the absolute maximum and absolute minimum reached at Fort McMurray A is about 87°C whereas at Victoria, B.C. this range is only 51°C. In maritime climates the maximum and minimum temperatures usually remain fairly close to the long-term averages throughout the year. In northeastern Alberta the summer values can be expected to lie near the long-term averages only during the summer. Winter temperatures are characterized by rather large swings from the average. Cold periods and mild periods alternate at irregular intervals. Thus reference to average temperatures for the winter period is of little significance because on any given day the temperature may be considerably above or below the long-term average.

3. TEMPERATURE

3.1 DAILY AND ANNUAL REGIME OF TEMPERATURE AT FORT McMURRAY

The AOSERP study area is one of the coldest areas of Alberta. The plateau areas of Alberta's northland, such as the Caribou Mountains and the Birch Mountain Plateau, may be colder but, because the data in winter are lacking, one cannot be sure. According to Longley (1972), the area is about 4°C cooler in July than the warm areas along the U.S. boundary and the South Saskatchewan River. In spring and autumn, the difference is about 5°C. The contrast is greatest during the winter when Lethbridge is 13°C warmer than Fort McMurray.

The clearest picture of the temperature regime for the AOSERP area is found by examining the records for the only long-term station of the area, Fort McMurray A. The mean curves of daily temperature by months are given in Figure 3. Climatic data for the station are given in Section 10.2. Data are available from the Hourly Data Summaries (Canada, Department of Transport 1968b) for Fort McMurray A. Mean temperatures are available for eight individual hours of the day.

Using the data from which Figure 3 is derived, one discovers that the difference in January between the mean value at the coldest time of the day and that at the warmest time of the day is 4.2°, and in July 11.0°. The warmest time of the day is between 1400 and 1700 MST. It is warmer at 1700 for the months of February to June, and at 1400 for September to January. The coldest time of day normally is about 30 minutes after sunrise, and from the curves given in Figure 3, one would expect that this is true at Fort McMurray A. The mean daily range, i.e., the difference between the mean maximum and the mean minimum, varies between 9.3°, the November value, and 14.6°, the June value.

Figure 4 gives six curves related to the annual trend of temperature for Fort McMurray through the year. Curves c and d (Environment Canada 1975a) give, respectively, the mean daily maximum and minimum temperatures. The other four curves use data

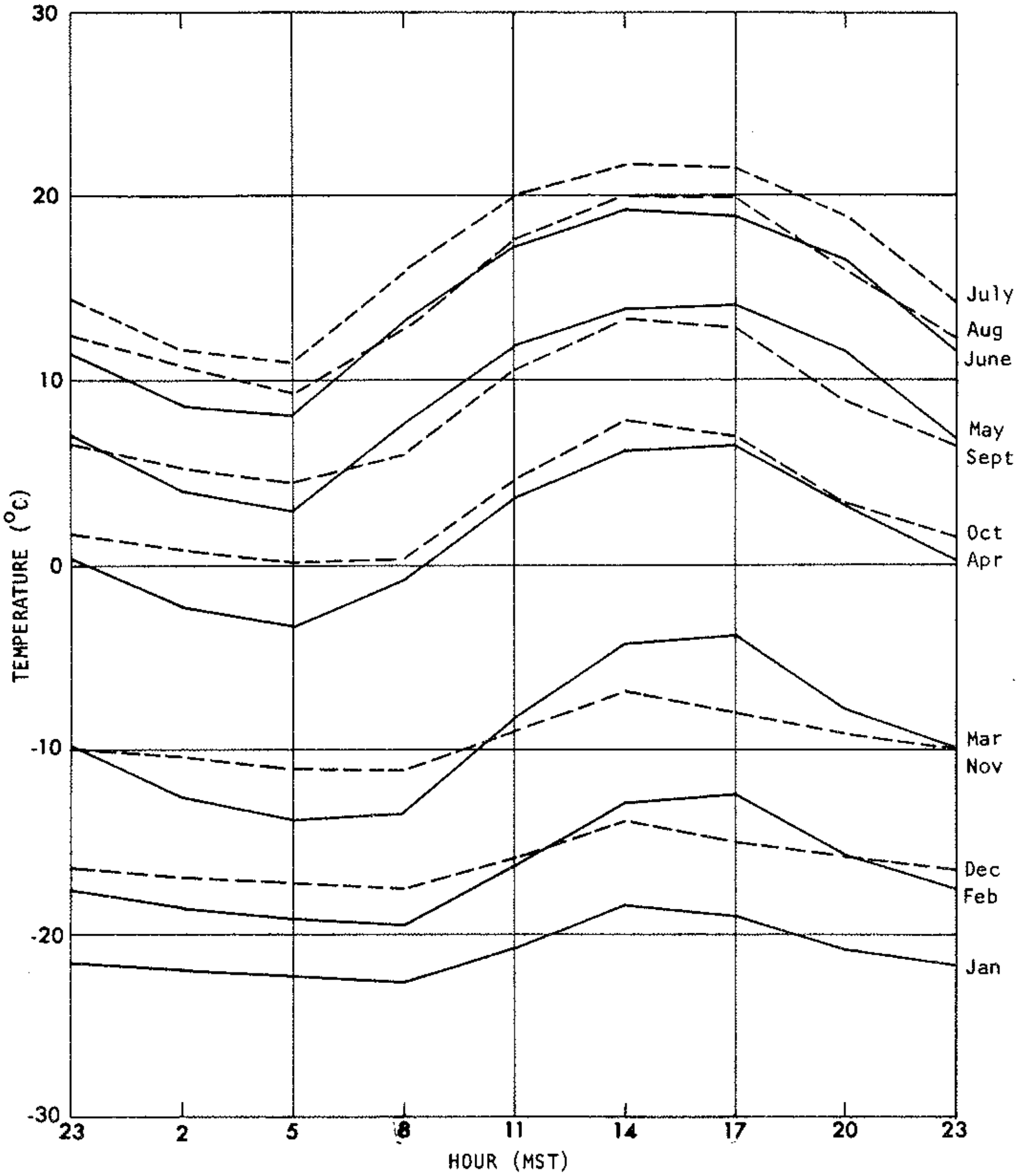


Figure 3. Mean temperatures during the day, Fort McMurray A. Curves are based on means at 3-hour intervals. (Data Source: Canada, Department of Transport 1968b).

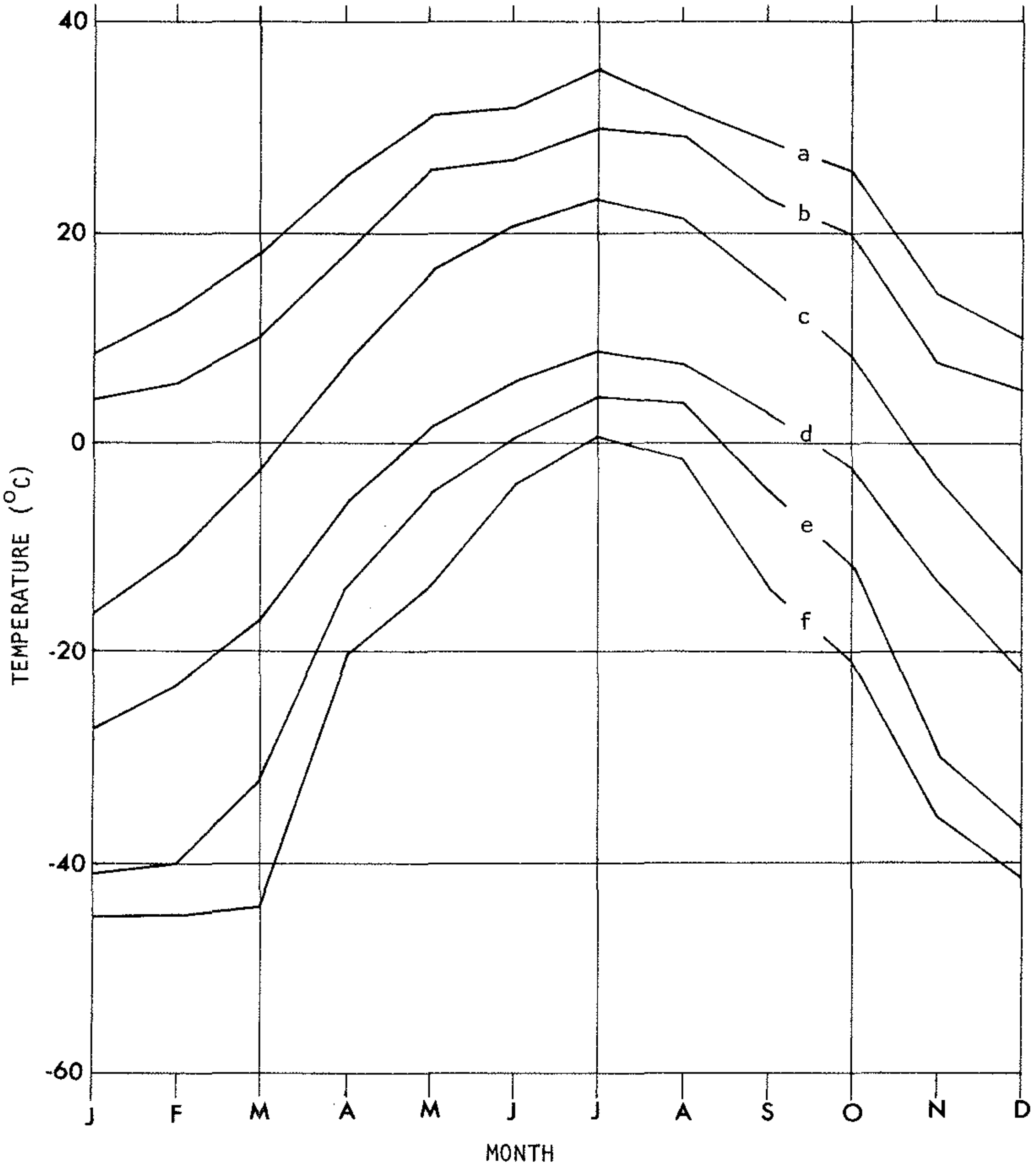


Figure 4. Monthly temperatures, Fort McMurray A.
a. Absolute maximum, 1957-1966
b. 90th percentile of hourly values, 1957-1966
c. Mean maximum, 1941-1970
d. Mean minimum, 1941-1970
e. 10th percentile of hourly values, 1957-1966
f. Absolute minimum, 1957-1966.

(Data source: Environment Canada 1975a)

from Hourly Data Summaries and are based on the 10 years, 1957 to 1966 (Canada, Department of Transport 1968b). Curves a and f give, respectively, the highest and lowest temperatures recorded in each month. Curve b gives the 90th percentile of recorded hourly temperatures; only one observation in 10 lies above this curve. Similarly, curve e gives the tenth percentile; one record in 10 lies below this curve.

Curves c and d show again that the range of temperature is highest in May and lowest in November. The mean annual range is 37.8°. The data from which curves a, b, e and f are derived show that the mean values come from a broad distribution of temperatures. The absolute range of temperature in January during the 10 years was 53°; in April, 49°; in July 35°; and in October, 47°. No frost was recorded in July but there was a temperature of 0.5°C recorded. Every other month recorded frost, with June having 48 observations and August, eight, during the 10-year period. Because some of these records might have occurred during the same night, this does not give the number of days with frost.

3.2 SPATIAL VARIATIONS IN THE STUDY AREA

3.2.1 Computation of Normal Temperatures

A study of the temperature distribution in the study area is hampered by lack of data. To make use of the incomplete records, available data from 1958 to 1976 were examined and compared to corresponding data for Fort McMurray A. For example, December mean maximum temperatures were available for Stoney Mountain for six years. For those six years, the averages showed that Stoney Mountain was 1.4°C warmer than Fort McMurray A. The mean 1941-1970 maximum temperature at Fort McMurray A is -12.2°C. So a tentative Stoney Mountain normal December temperature is -10.8°C.

The method outlined was used for any station and month when the records were available for four months. For many of the values, the method permitted the use of data not included in published normals which used data only until December, 1970

(Environment Canada 1975a). It also made allowance for the possibility that the periods of observations did not have normal temperatures. Table 2 gives the mean maximum and Table 3 the mean minimum temperatures for the different stations in the region. Normals for stations surrounding the area are also given.

3.2.2 Winter Temperatures in the Study Area

An examination of the January mean minimum temperatures in Table 3 shows that there is a gradual decrease as one moves north from Fort McMurray, with $-26.9^{\circ}C$ to Fort Smith at $-32.1^{\circ}C$. The normal south-north gradient of temperature is apparent, but from Fort McMurray to the south shore of Lake Athabasca the variation is less than $3^{\circ}C$. Stoney Mountain, $3^{\circ}C$ warmer than Fort McMurray A, is an anomaly in this picture. It shows that the winter temperatures on the hills are higher than in the river valley. This is the only hill station with winter records available. The extent of the warming on the other hills is unknown. Because of this lack of information, January isotherms for the area can be drawn only approximately. Figure 5 gives normal January temperatures for the study area. The normal range is about $10^{\circ}C$ and so mean maximum or minimum temperatures may be estimated by adding or substracting 5° from the map value.

3.2.3 Summer Temperatures in the Study Area

With the forestry station records, the distribution of summer temperatures is better known. As representative of summer temperatures, Figure 6 presents the mean July maximum and minimum temperatures. Data are given in Tables 2 and 3.

The south-north gradient of maximum temperatures, noted for winter data, is almost non-existent in the high summer. Fort Chipewyan is colder than other stations, but this could easily be a result of a cold lake. In August and September, Fort Chipewyan and Fort Smith have approximately the same mean maximum temperatures, and in October and November, Fort Chipewyan is warmer.

Table 2. Mean maximum temperatures ($^{\circ}$C), 1941-1970. Part 1 values are taken from published normals.[a] In Part 2 mean values for available data from 1958-1976 are adjusted as described in the text.[a]

Station	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
PART 1												
Embarras A	-16.9	-12.7	-3.9	6.2	15.1	20.5	23.7	21.8	14.4	6.9	-4.8	-13.6
Fort McMurray A	-16.0	-10.2	-2.3	7.8	16.3	20.8	23.4	21.7	15.2	8.5	-3.8	-12.2
Fort Smith A	-21.8	-15.5	-7.6	3.2	13.6	20.0	22.8	20.9	12.9	4.8	-7.7	-16.8
Fort Vermilion	-18.3	-12.7	-3.9	6.9	16.4	21.3	23.5	21.6	14.8	6.8	-6.7	-15.4
Uranium City	-22.6	-16.9	-8.9	1.8	11.6	18.9	21.3	19.9	11.3	4.2	-7.6	-16.7
Wabasca	-13.1	- 7.4	-0.9	8.8	15.6	20.1	22.5	21.1	15.3	9.2	-1.9	- 9.3
PART 2												
Algar Lo					12.9	17.5	20.2	18.8	12.3			
Anzac	-14.9	-10.0	-2.6	7.0	15.5	20.1	22.7	21.1		8.5	-3.9	-11.0
Birch Mtn. Lo					11.3	16.4	19.1	17.2	10.8			
Bitumount Lo					15.9	20.3	22.8	21.1				
Buckton Lo					10.9	15.8	18.8	17.6				
Edra Lo					11.7	16.9	19.4	17.6				
Ells Lo					14.9	19.1	21.8	20.1				
Fort Chipewyan	-20.7	-15.5	-7.2	3.2	13.4	19.4	22.6	20.6	13.1	5.7	-6.3	-14.5
Gordon Lake Lo					15.3	19.8	22.3	20.2				
Grande Lo					15.1	19.5	22.2	20.3				
Johnson Lake Lo					13.2	18.6	21.1	19.0				
Keane Lo					14.6	20.1	22.8	20.9				
Legend Lo					12.4	16.8	19.6	17.7	11.6			
Livock Lo					13.8	18.7	21.2	19.5				
Mildred Lake							24.0	22.2	15.4			-12.3
Muskeg Lo					13.3	18.5	21.1	19.0	12.7			
Richardson Lo					15.2	20.7	23.4	21.6	13.8			
Seaforth Lo						17.5	19.7	18.1				
Stoney Mtn.	-14.0	-10.7	-3.4	5.1	13.2	17.8	20.8	19.3	12.8	6.1	-4.6	-10.8
Stoney Mtn. Lo					13.0	17.5	20.1	18.4	12.0			
Tar Island	-16.4	-11.3	-2.9	7.4	16.5	21.3	23.9	22.9	15.4	8.2	-4.3	-11.9
Thickwood Lo					14.9	19.1	21.6	20.0	13.7			

[a] Data Source: Environment Canada 1975a.

Table 3. Mean minimum temperatures (°C), 1941-1970. Part 1 values are taken from published normals.[a] Part 2 mean values for data available from 1958-1976 are adjusted as described in the text.[a]

Station	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
PART 1												
Embarras A	-27.9	-25.6	-18.4	- 6.9	2.0	7.3	10.8	9.2	4.2	-2.1	-13.2	-23.2
Fort McMurray A	-26.9	-23.0	-16.4	- 5.4	1.7	6.2	9.1	7.6	2.8	-2.4	-13.1	-21.7
Fort Smith A	-32.1	-28.7	-21.6	- 9.7	0.6	6.2	9.3	7.6	2.4	-3.8	-16.0	-25.9
Fort Vermilion	-28.4	-24.2	-17.3	- 5.2	2.8	6.9	9.6	7.8	2.6	-3.3	-15.0	-23.9
Uranium City	-32.3	-28.4	-22.7	-10.1	-0.3	7.4	11.1	10.0	3.6	-2.7	-15.3	-18.6
Wabasca	-24.1	-21.5	-15.4	- 4.8	3.8	8.4	11.2	9.6	4.1	-0.9	-10.9	-18.6
PART 2												
Algar Lo					1.6	6.2	8.9	7.7	2.5			
Anzac	-24.8	-21.3	-15.4	- 5.5	1.7	6.1	8.7	7.5		-1.8	-12.1	-20.0
Birch Mtn. Lo					1.4	6.2	9.1	7.9	2.4			
Bitumount Lo					2.1	6.4	9.3	7.4				
Buckton Lo					0.4	5.3	8.2	6.8				
Edra Lo					0.2	5.2	8.2	6.5				
Ells Lo					1.8	6.2	8.9	6.8				
Fort Chipewyan	-31.7	-27.7	-20.2	- 8.6	1.2	7.2	10.3	8.6	3.3	-3.8	-14.7	-24.3
Gordon Lake Lo					1.3	6.5	9.3	7.8	3.7			
Grande Lo					1.6	5.8	8.4	7.0	3.2			
Johnson Lake Lo					1.5	6.8	9.8	8.1				
Keane Lo					2.5	7.7	10.4	8.8				
Legend Lo					0.7	5.6	8.6	6.6	2.4			
Livock Lo						6.5	9.1	7.9				
Mildred Lake							9.1	7.9	2.6			-23.9
Muskeg Lo					1.3	7.7	9.1	7.7	2.6			
Richardson Lo					1.9	7.8	10.8	9.1	3.7			
Seaforth Lo					1.7	5.8	8.5	7.1				
Stoney Mtn.	-23.6	-19.3	-14.0	- 4.8	2.9	7.7	10.8	9.6	4.0	-1.3	-11.6	-18.9
Stoney Mtn. Lo					1.9	6.8	9.6	8.3	3.1			
Tar Island	-27.5	-24.6	-17.6	- 5.2	2.9	8.3	10.6	9.0	3.9	-2.1	-12.7	-22.1
Thickwood Lo					1.9	5.9	8.7	7.2	2.5			

[a] Data Source: Environment Canada Monthly 1975a.

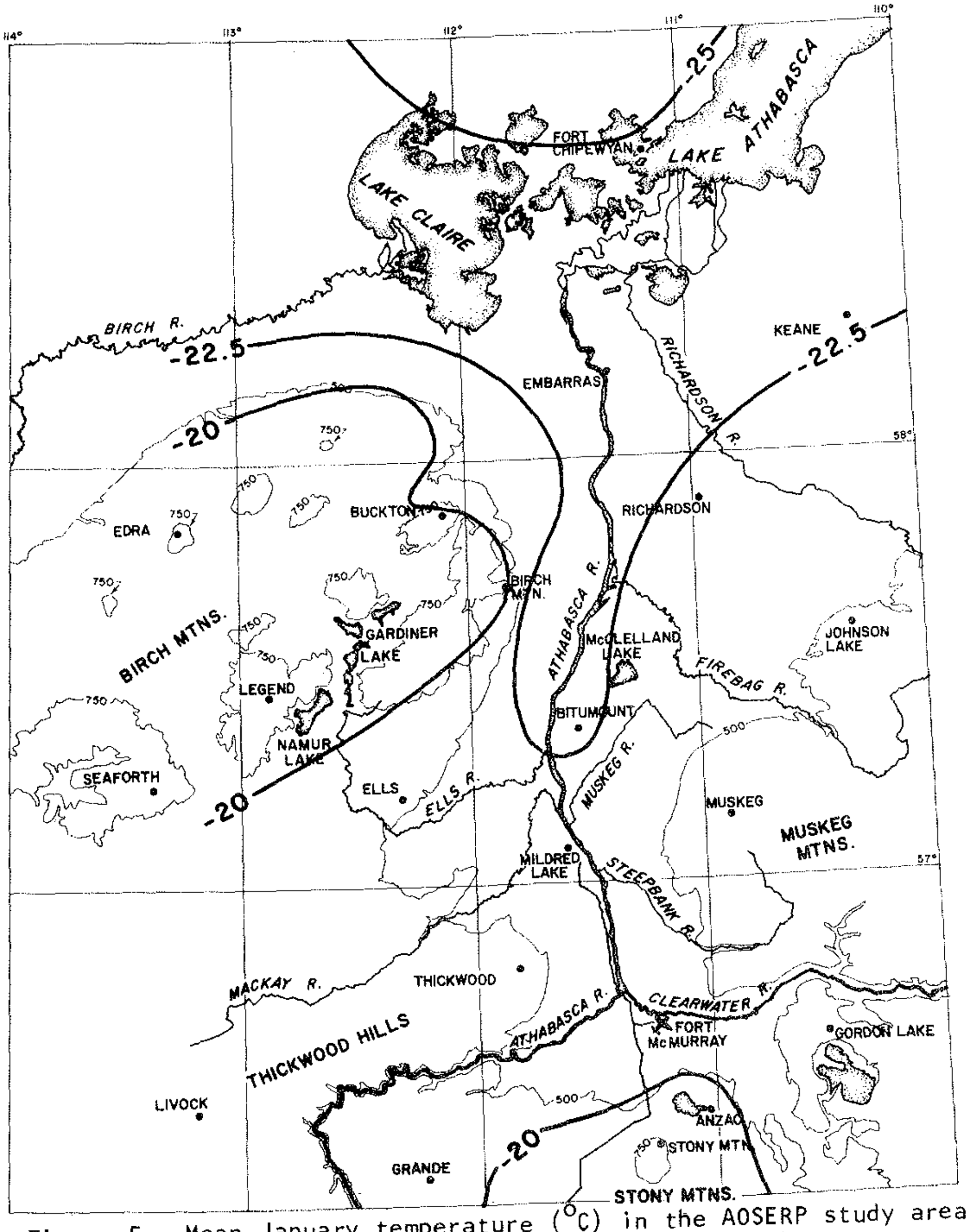


Figure 5. Mean January temperature ($^{\circ}C$) in the AOSERP study area and surroundings (based on Tables 2 and 3).

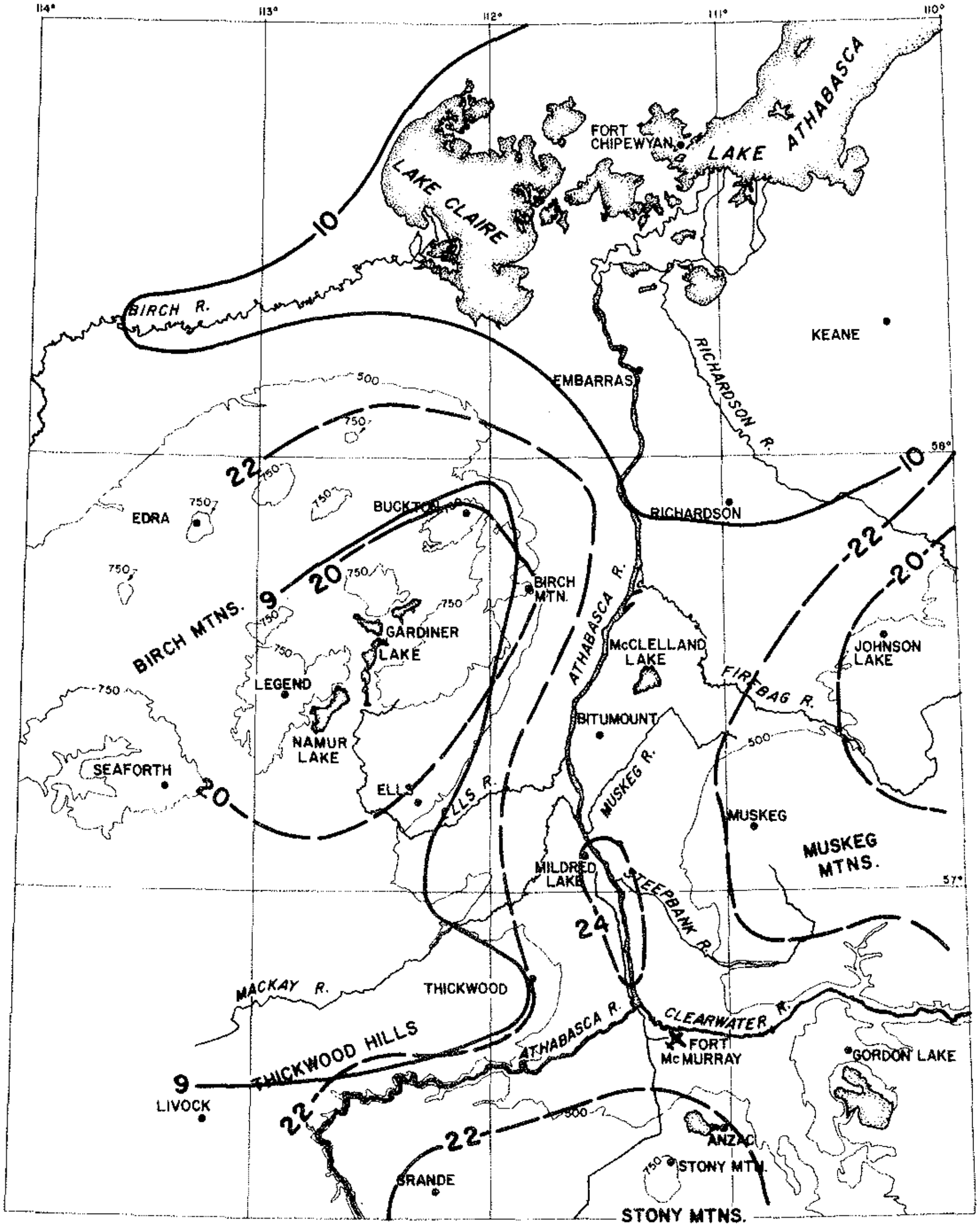


Figure 6. Mean July maximum and minimum temperatures ($^{\circ}C$) in the AOSERP study area and surroundings (based on Tables 2 and 3).

Although the south-north gradient of temperature is slight during the summer season, the gradient with elevation is not. The data of Table 2 show clearly that the warmest spots in June and July are the stations in the low areas near the Athabasca River: Tar Island, Bitumount Lo, Richardson Lo, and Anzac. To evaluate this tendency for individual months the mean maximum temperatures were correlated with elevation. Sixty values of the rates of decrease of temperature (i.e., the lapse rates, see Glossary) were determined for the months May to September, inclusive. Of these, 37 had correlation coefficients above 0.90. Only five were below 0.81, and these were in May and September. The average lapse rates are given in Table 4.

With the high lapse rates, given in Table 4, the variation of maximum temperature is closely related to elevation. This is apparent in the isotherms of July maximum temperatures in Figure 5. The greatest lapse rate occurs in June, a value close to the dry adiabatic. By September, when the solar radiation has decreased considerably, the lapse rate is 2° lower.

The relationship between elevation and minimum temperatures is less clear than with maximum. Of the 58 computed correlation coefficients, only eight were above 0.70, and five were zero or negative. Minimum temperatures are influenced greatly by local topography. Cold air flows off hillsides and into low-lying areas. In such situations, the lower location is the colder. The average lapse rates for minimum temperature are given in Column 3 of Table 4. These are clearly low compared with those for maximum temperatures. The decrease from June and July till September continues during the autumn so that in winter the minimum temperatures are lowest in the bottom of the valley.

As during the winter, the values for Fort McMurray's summer temperature give a first approximation to temperatures in the study area. These should be adjusted for elevation, with a drop of about $8^{\circ}C$ per km for maximum temperature and about $2^{\circ}C$ for minimum temperature. The value obtained for maximum temperature is

Table 4. Average lapse rate (°C per km) of temperature in the study area, May to September.

	Maximum	Minimum
May	8.0	2.3
June	8.2	2.4
July	8.0	2.4
August	7.6	1.7
September	6.3	1.2

probably reliable. For minimum temperatures, consideration of the surrounding topography or the proximity to a lake area would suggest an adjustment to the value obtained.

3.3 FROST-FREE PERIOD IN THE AOSERP STUDY AREA

Data on the occurrence of late spring and early fall frosts are sought by farmers because of the effect of frosts on crops. Other people whose occupations take them out-of-doors also wish to know about the occurrence of frosts. Hemmerick and Kendall (1972) present frost data for Fort McMurray A.

According to Hemmerick and Kendall, the average frost-free period at Fort McMurray A lasts from 15 June until 24 August, or for 69 days. Such a period of growth is too short for wheat and other grains, but does permit the maturing of some vegetables. Farming can be carried on with care, particularly because of the longer summer days of that latitude. But frosts may occur any time of the year. The shortest frost-free period was eight days, from 9 to 18 July. On the other hand, one year had no frost between 24 May and 17 September, or for 115 days.

It is difficult to generalize for the area from the Fort McMurray A data. The occurrence or non-occurrence of frost is a function of the topography and the proximity of water. Embarras, farther north but at a lower elevation, has a frost-free period of 89 days, three weeks longer than at Fort McMurray A. At least part of the reason is the fact that the Athabasca River is near, and, on a cold night, warms the air so that it is not so likely to reach the frost point.

As noted in Section 3.2.3, the minimum temperature in summer tends to be lower at higher elevations. This would result in more frequent frosts. Some locations on the sides of hills would keep warm on these critical nights because the cold air would drain past them into the valley below. Because of the various factors, it is difficult to draw a pattern of the length of the frost-free period.

Some evaluation was done by examining the number of occurrences of frost recorded at stations in the study area during the five months, May to September, inclusive. The normal for the season for Fort McMurray A is 26 days. The average number for most of those for which data are available were within three days of this figure. No station had over 29. Richardson Lo, one of the lower stations had 18, and Tar Island, also a low station, 19. Stoney Mountain Lo, one of the highest stations, had 22. Certainly the pattern is not well defined.

The data for Fort McMurray may then be taken as a first approximation, and the data adjusted considering the topography of the district and the occurrence of bodies of water in the vicinity.

3.4 BREAKUP AND FREEZEUP OF RIVERS

Another result of the annual cycle of temperature is the freezing and thawing of water bodies. The rate at which these occur depends upon other factors, such as the movement of the water, the depth of the pond or lake, the strength of the wind, and the depth of snow on the ice. No general picture can be established for an area.

The occurrence and thickness of ice on the Athabasca River at Fort McMurray has been recorded for over 20 years, and at

Embarras while the weather observations were taken. The median date for an ice cover on the river is about mid-November. The date has varied, at Fort McMurray, from 27 October in 1958 to 31 December in 1953 (Allen and Cudbird 1971). Normally, the maximum thickness is 85 cm. Ice begins to break up in late April and is gone during the first week in May. Data for Embarras are similar. Small ponds and shallow lakes freeze sooner than the flowing river, usually two to three weeks after the mean minimum reaches freezing.

3.5 INVERSIONS AND STABILITY

3.5.1 Inversions

Normally, in the free atmosphere, temperature decreases with height. Occasionally this tendency is reversed and an inversion occurs. An inversion is a condition in which the temperature aloft is higher than it is below.

The significance of inversions is related to their effect on air quality. With an inversion, there is very little vertical mixing, and so any gas released below the inversion is not readily dispersed. If the release continues, the concentration of the gas may reach critical levels.

Inversions are identified by temperature profiles in the atmosphere. These are determined by radiosondes, or minisondes by captive balloons, and by temperature measurements on a tower. Until recently, none of these had been done in the AOSERP study area on a routine basis. Therefore, we have no long series of measurements to determine accurately the frequency of inversions.

3.5.2 Lapse Rates Based on Surface Observations

It is possible to learn something of the frequency of inversions from surface observations if the stations are suitably located. It is fortunate that the Stoney Mountain and Fort McMurray Airport stations were so located. The horizontal distance is only about 25 km, and Stoney Mountain is 409 m above the airport. A comparison was made of the daily maximum and daily minimum temperatures at the two stations to learn about the variation in lapse rate over the 409 m. Table 5 gives the frequencies of inversion based on these values, i.e., the percentage of time when Stoney Mountain was warmer than Fort McMurray.

Table 5. Frequency (percent) of inversions, based on Fort McMurray A and Stoney Mountain temperatures.[a]

	J	F	M	A	M	J	J	A	S	O	N	D
					Maximum Temperatures							
Freq.	48	32	21	7	14	4	6	6	11	12	37	53
					Minimum Temperatures							
Freq.	68	65	61	50	53	60	67	61	54	60	58	64

[a] Data Source: Environment Canada, Monthly Record.

The data in Table 5 show that inversions were common at night ranging from a low of one night in two in April to two nights in three in January and July. These would be minimum frequencies. On many occasions, an inversion would be found above the airport, with the warmest temperature below the level of Stoney Mountain where the temperature would be lower than at Fort McMurray A.

Data on maximum temperatures show that inversions during a summer afternoon are rare, but in mid-winter, the inversion may persist through the afternoon on one day out of two.

Another comparison was made, using data from Fort McMurray Airport and Tar Island. The stations are not so well situated for the purpose, particularly because of the influence of the river temperatures on the Tar Island values. In general, the results supported the conclusions based on Stoney Mountain.

3.5.3 Stability Over the River Valley

Information about surface temperatures is available from a number of places within the area. To understand some weather phenomena, it is necessary to know, or to be able to estimate, the temperatures above the ground. When the temperature aloft is decreasing at a rate near to or greater than the adiabatic, the air is unstable. Vertical currents readily develop, carrying moisture and also pollutants aloft. At such times, cumulus clouds may develop and showers possibly occur. When the lapse rate is small or negative, vertical currents are dampened, winds near the surface are generally lighter, and gases released into the atmosphere disperse slowly.

In Section 3.5.2, an attempt was made to obtain the frequency of stable and unstable conditions using temperatures at Fort McMurray A and Stoney Mountain. Vertical temperature profiles taken at Mildred Lake during 1975, 1976, and 1977 permit further examination. These observations were taken by minisondes several times each day. The data were analyzed by hour of the day and by season of the year. Stability classes followed the pattern laid down in a pamphlet prepared by Environmental Research and Engineering (1976). They identified five classes according to the lapse rate of temperature for the layer from the surface to 255 m as follows:

	Lapse rate $^{\circ}C/km$
Unstable	≥ 1.15
Neutral	$1.15 > \alpha \geq 0.75$
Isothermal	$0.75 > \alpha \geq -0.10$
Weak inversion	$-0.10 > \alpha \geq -1.22$
Moderate inversion	$-1.22 > \alpha \geq -2.03$
Strong inversion	$-2.03 > \alpha$

Table 6 gives the relative frequency of the different classes for those observations taken at Mildred Lake before 0900, and for those taken between 1200 and 1500.

Table 6. Relative frequency of stability classes at Mildred Lake (percent).[a]

	16/11 - 15/3		16/3 - 15/5		16/5 - 31/8		15/09 - 15/11	
	Before 0900	1200-1500	Before 0900	1200-1500	Before 0900	1200-1500	Before 0900	1200-1500
Unstable	6	27	2	79	3	63	-	59
Neutral	8	21	11	18	5	31	3	30
Isothermal	16	30	18	1	27	4	29	7
Weak Inv.	27	13	25	1	30	2	33	-
Mod. Inv.	14	3	20	1	19	-	19	1
Strong Inv.	29	6	24	-	16	-	16	3
No. of Obs.	86	119	99	80	165	188	68	95

[a]Source: AOSERP unpublished data, 1975, 1976, 1977.

The data presented in Table 6 cannot be considered as valid for all times. There were times when no observation was taken, sometimes for weather reasons. There may thus be a bias. Yet, they do illustrate the changes that occur in stability during the day and during the year.

Before 0900, there is an inversion on most days. The frequency of moderate and strong inversions is less during the summer and autumn than during the six months, mid-November to mid-May. Even during summer unstable or neutral conditions are rare.

During the early afternoon from mid-March till mid-November the air is usually unstable. Conditions isothermal or more stable are very uncommon. But the data for winter show that in these months, the inversion of the early morning disappears by early afternoon except for one day in four. In terms of the implications for air quality, it would seem desirable to examine these days when the inversion persists. These are the times when pollutants released into the air will remain near the surface during the day, and then be augmented the following night. This can result in high concentrations of pollutants. Care to restrict the release of offending gases when such conditions exist, would, perhaps, reduce the risk of pollution becoming a serious hazard.

Analysis of five and one half months of tall tower data located on the Syncrude lease confirms the general conclusions expressed in the previous paragraphs. Temperatures near the base of the tower (10 m) were compared with those at the top of the tower (152 m) for two periods of the day, 0000-0800 and 1200-1800. The percentage frequency of inversions (i.e., temperature of top > temperature of bottom) are shown in Table 7.

The significant features to note are as follows:

1. In the Athabasca Valley inversions occur frequently during night-time hours. Even in mid-summer, there is an inversion in one out of three hours between midnight and 0800. During fall and winter, this increases to at least one hour in two.
2. In summer, the inversions break up by mid-afternoon but during fall and winter inversions may persist throughout the day. The December period covered a very cold outbreak.

Table 7. Percentage frequency of inversions in the Athabasca River Valley.[a]

	Frequency of Inversions	
Month	0000-0800	1200-1800
July	35	1
August	46	1
September	80	12
October	56	25
November	54	15
December (1 - 10)	65	41

[a] Source: AOSERP Tall Tower: 1 July 1977 to 10 December 1977.

3.6 PERMAFROST

The annual cycle of air temperatures is reflected in the annual cycle of temperatures of the top layers of the soil. During the period when the soil is warming, heat is passed downward to lower layers. This stored heat returns to the surface during the fall and early winter.

In some areas the flow of solar heat during the spring is not great enough to melt the ice of the previous winter before freezing comes again. This creates a layer underground which is permanently frozen, permafrost. The southern boundary of the area of continuous permafrost lies north of the oil sands area (see Brown 1967). There are regions within the area where permafrost exists. These areas are areas under muskeg, a composite of water, soil, and decaying vegetation. The conductivity of heat is small, and this is why some of the soil underneath never thaws during the summer.

4. PRECIPITATION

4.1 ANNUAL REGIME OF PRECIPITATION IN THE STUDY AREA

As with temperature, one must look to the records from Fort McMurray to learn and understand the precipitation regime of the study area. The data gathered from the surrounding stations may be used as guides to spatial variations. But the periods of records are too short to permit normal values to be determined with assurance.

The continental climate of the three prairie provinces is a determining factor for the precipitation regime. The maximum occurs in the warmer months of the year, and there is little winter precipitation. This characteristic is brought out clearly by Longley (1972) in his treatment of the climate of the three provinces. Figure 7, giving the annual trend of precipitation for Fort McMurray and four surrounding stations in Alberta and Saskatchewan, illustrates this tendency.

Figure 7 shows that during the seven coldest months, October to April inclusive, the monthly precipitation normally lies between 15 and 30 mm. There is a rapid rise in spring to a maximum in June or July, and a rapid fall between August and September. At Fort McMurray and Fort Smith, the spring rise occurs between May and June. The fall decrease is also delayed and September is wetter at Fort McMurray than at any of the other four locations.

4.2 SPATIAL DISTRIBUTION OF PRECIPITATION

To determine the spatial distribution of precipitation for the study area, use was made of the records of the various stations for the period 1958 to 1976. To allow for the variation of precipitation from year to year, for each station, the average for the months for which records were available was compared with the average for the same months at Fort McMurray A. The mean for the station being considered was then adjusted to give an estimate of the normal for the station for the month. This method is similar to the one mentioned in Section 3.2.1 dealing with temperature.

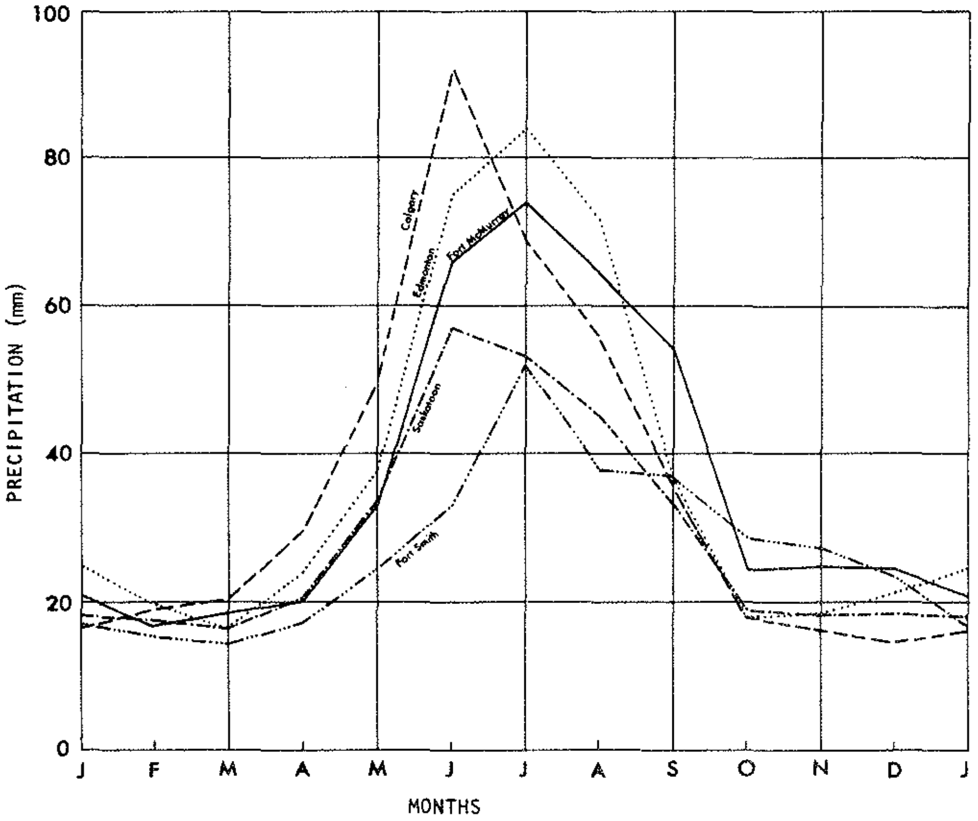


Figure 7. Mean monthly precipitation, 1941-1970. (Climatic Normals, 1941-1970, Environment Canada 1975b).
Totals: Calgary 437, Edmonton 446, Fort McMurray 435, Fort Smith 335, Saskatoon 353.

The results are given in Table 8. This method of adjustment cannot be considered precise, although the accuracy should increase with the length of record.

To illustrate the spatial pattern of precipitation, totals were calculated for the warm months, May to September. These were the months when most forestry stations were open, and so meaningful totals could be obtained. The values were plotted, and isohyets drawn (Figure 8).

The map emphasizes the large differences in summer precipitation given also in Table 8. The values range from 230 mm at Mildred Lake, a short-term station, and 243 at Richardson Lo, a long-term station, to 414 at Stoney Mountain Lo and 447 at Stoney Mountain. Such differences prompt a search for causes.

4.3 CAUSES FOR SPATIAL VARIATION

One explanation for the variation in precipitation over the region is the general south-north gradient in rainfall. As seen from Table 8, Fort Chipewyan and Fort Smith both have less summer precipitation than any station in the area south of Lake Athabasca. In this latter area, although the south-north gradient may be present, it is overshadowed by other factors.

One cause for local variations in rainfall is the topography of the land. It has long been known that when rain-bearing winds are forced to rise over a slope, the rainfall is increased on the windward facing slope. Janz and Storr (1977) examined this effect on the eastern slopes of the Rocky Mountains. They discovered an increase in annual precipitation with altitude, and determined regression equations relating the annual total to the elevation.

A slightly different method of analysis was used to check the relationship between elevation and precipitation in this study. There were 69 months when the number of stations reporting precipitation was great enough to make the evaluation of a coefficient of correlation worthwhile. Of the 69 values, 21 or nearly one-third of the total number were zero or negative. On the other hand, 12

Table 8. Mean monthly precipitation[a] (mm) 1941-1970 based on Fort McMurray A. Part 1 values taken from established normals.[a] Part 2 values based on Fort McMurray A as described in the text.[a]

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year
PART 1													
Fort McMurray A	21.1	17.3	18.3	20.3	33.0	61.5	73.7	64.0	53.1	24.1	24.9	24.1	435.4
Fort Smith A	17.5	15.5	14.5	17.5	24.6	33.8	52.8	37.8	37.6	28.7	27.7	23.1	331.1
Fort Vermilion	20.3	21.1	20.8	16.8	31.2	41.1	61.7	46.2	30.7	22.4	22.9	24.9	360.1
PART 2													
Algar Lo					48	84	103	82	66				
Anzac	21	19	20	22	41	64	82	50		17	27	33	
Birch Mtn. Lo					32	83	90	75	54	28			
Bitumount Lo					34	63	77	73					
Buckton Lo					39	99	100	59					
Edra Lo					28	81	89	65					
Ells Lo					34	68	74	64	38				
Embarras A	10	9	14	14	36	53	73	52	52	25	22	11	371
Fort Chipewyan A	23	15	22	21	26	45	59	45	42	26	23	21	368
Gordon Lake Lo					33	76	79	67					
Grande Lo					34	80	84	60					
Johnson Lake Lo					47	68	86	64					
Keane Lo					28	55	58	71	68				
Legend Lo					31	68	91	62	35				
Livock Lo					43	87	80	60					
Mildred Lake							63	48	41	13	13	22	
Muskeg Lo					35	69	85	75	62				
Richardson Lo					26	54	61	59	43	27			
Seaforth Lo					25	61	100	68	38				
Stoney Mtn.	17	25	25	38	56	99	109	81	102	18	33	25	628
Stoney Mtn. Lo					50	91	104	85	84	45			
Tar Island	19	12	12	13	30	62	57	44	59	21	28	25	382
Thickwood Lo					39	77	92	68	61				

[a] Data Source: Environment Canada 1975b.

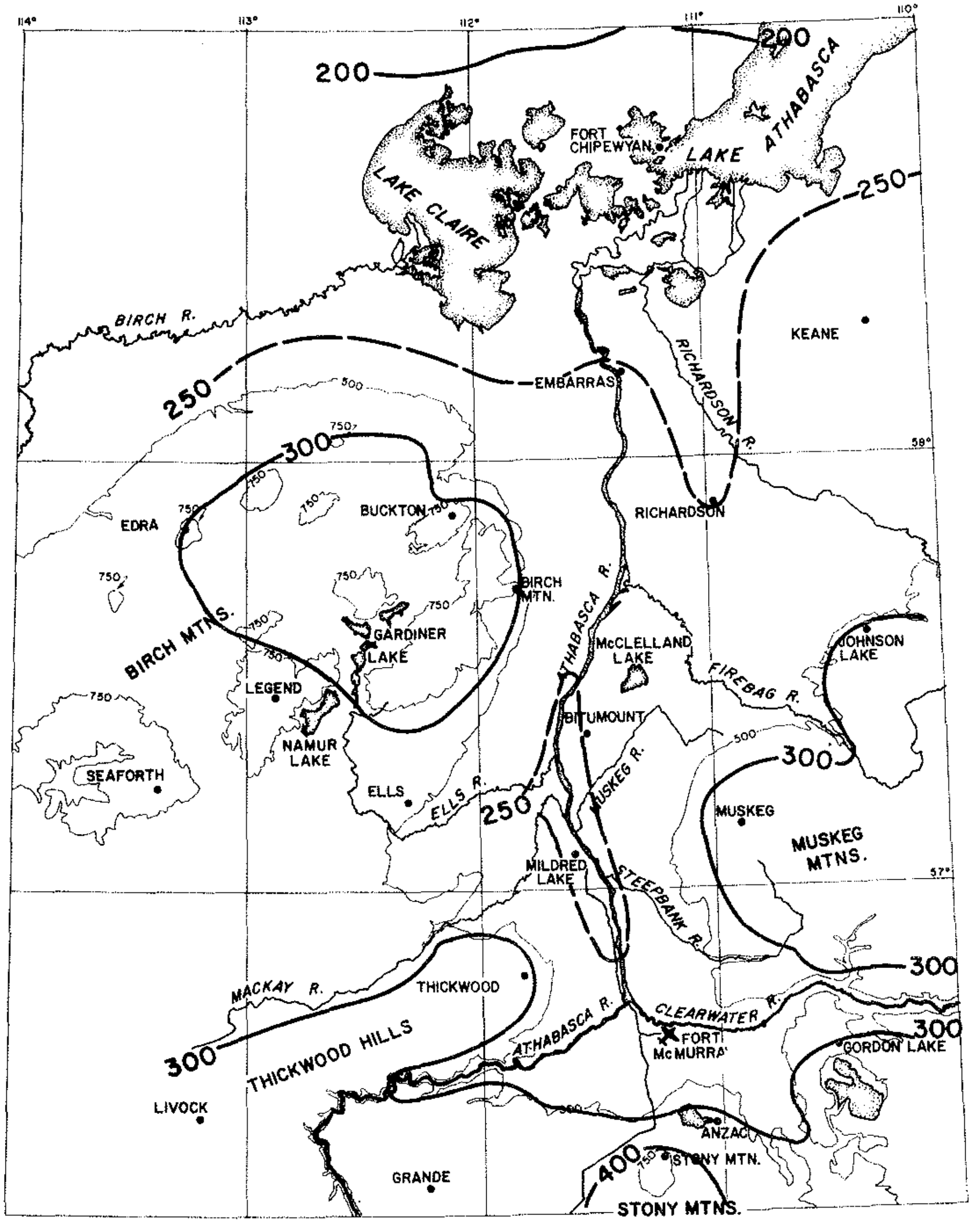


Figure 8. Mean precipitation (mm) in the AOSERP study area and surroundings, May to September, 1941-1970 (based on Table 8).

only had values above 0.50, and two in the range 0.71 to 0.80. The median value is 0.25. With such results, one may conclude that there is a positive correlation but the relationship is weak. When the adjusted means were correlated with elevation, correlations tended to be somewhat higher, although still not great.

An examination of the locations of the stations gives a clue to the reason for the low correlation. In contrast to the eastern slopes of the Rockies, there is no general trend to the land. As described in Section 2.2, it is very irregular. With the variation in aspect, as well as in elevation, the effect of elevation on the amount of rain varies greatly with the direction from which the rain-bearing winds are blowing.

Yet Figure 8 does show that in general the high points of the country tend to have the greatest summer precipitation. This principle is clearly shown in a comparison of the precipitation at Fort McMurray A with that of Stoney Mountain and Stoney Mountain Lookout. According to the figures of Table 8, during the seven months October to April, Stoney Mountain had greater precipitation in five. But the amounts at this time of year are small and the totals are not greatly different: Fort McMurray A, 149 mm; and Stoney Mountain, 181 mm. During the five summer months, May to September, both the Stoney Mountain observing stations have greater means than Fort McMurray. Stoney Mountain has 55% more precipitation, and Stoney Mountain Lookout 45% more precipitation that Fort McMurray. The contrast is also seen when comparing the values for individual months. Out of 28 summer months, Stoney Mountain had more precipitation in 24 months. And out of 90 summer months, Stoney Mountain Lookout had 79 with more precipitation.

A contrast appears when we examine the records for stations along the river. These are Embarras, Bitumount Lo, and the new stations Tar Island and Mildred Lake. The precipitation at each of these four stations is less than that found to the east and west on either side of the river. This may be caused by the gorge of the river, an effect that Longley (1974) examined for four different locations in Saskatchewan and Alberta. He examined the precipitation reported at the bottom of river gorges with that reported on the land on either side of the gorge. The results showed that the mean precipitation in the gorge and even along the edge, but at the level of the surrounding country, was 5% to 20% less than in the general vicinity. The difference varied with the slope of the land on the sides of the gorge.

4.4 DAYS WITH PRECIPITATION

The average number of days with measurable precipitation at Fort McMurray A is 131 (Environment Canada 1975b), with little variation from month to month. April has the fewest number of days, with eight. December, January, and July have the greatest number of days with 13.

In considering the number of days of precipitation over the study area, it was again necessary to adjust short-period data by using the Fort McMurray long-period normals. This is seen particularly when one compares the mean number for the five warmest months for Fort McMurray A for the period 1961 to 1975 with the value as given by the normals (1941 to 1970). The first value is 64, the second 55 days. The 1961 to 1975 period had more frequent precipitation than the 1941 to 1970 period.

An examination of the total for the five warm months, May to September, shows a south-north gradient similar to that for precipitation noted in Section 4.1. Fort McMurray A has 55 days precipitation while Embarras, Fort Chipewyan, and Fort Smith, 47 days. In general, over the area south of Lake Athabasca, the total lies between 50 and 55 days. Richardson Lo presents an anomaly with only 44 days. On the plateau of the Birch Mountains, over Stoney Mountain, and also at Muskeg Lo, the total is near 60 days. These were areas where precipitation during these months was high.

4.5 MAXIMUM ONE-DAY PRECIPITATION

The occurrence of a period of high rainfall has at times an adverse effect on the activities of people whose activities take them out-of-doors. Rainfall data are important in the design of drainage systems, highways, etc. Some information on the frequency of heavy rainfall is desirable.

Storr (1963) studied the frequency of heavy rainfall over Alberta, and from his study determined the highest amount that would probably occur in 5 years, 10 years, and 25 years. His data for Fort McMurray are given in Table 9.

Table 9. Maximum one-day rainfall (mm), Fort McMurray (after Storr 1963)

Return Period (yrs.)	May	June	July	August	Season
5	18	25	37	33	50
10	24	32	51	46	64
25	32	41	71	64	81

To compute reliable values of probable maximum rainfall, such as given in Table 9, from original records requires a long period of observations. Such periods are not available for the stations of the study area except for Fort McMurray. Yet some guidance may be obtained from the short series of records available if these are compared with Fort McMurray. For example, consider the series from Stoney Mountain Lo. For this station we have records for 15 years. For the 60 months, May, June, July and August 1961 to 1976 for which records are available, there were 47 months when the highest one-day rainfall at Stoney Mountain was greater than at Fort McMurray A, 12 when Fort McMurray A had the higher maximum one-day rainfall, and one month when the values were the same. Obviously, the probability of high intensity rainfall is greater at Stoney Mountain Lo than at Fort McMurray A. If the highest one-day rainfalls for all Mays for both stations are added, and divided one by other, we discover that the average one-day maximum at Stoney Mountain Lo is 40% higher than the Fort

McMurray value. Similarly a ratio was determined for the three other months, giving 1.78, 1.26 and 1.44. The seasonal average is 1.46. One may conclude that the seasonal maximums of one-day rainfall for Stoney Mountain Lo are about 1.5 times the corresponding values for Fort McMurray A.

There are, of course, many assumptions implied in the above calculations, but the resultant values should give some guide to the maximum rainfall expected at Stoney Mountain Lo. Similar calculations were made for other stations of the study area. The ratios are given in Table 10.

Based on the results given in Table 10, one concludes that heavy rains in the low lands east of Embarras are approximately the same as at Fort McMurray. Over most of the higher country, the amounts are about 20% greater than at Fort McMurray and, as noted above, at Stoney Mountain over 40%.

Table 10. Ratio of totals of monthly maximum one-day summer rainfall at Forestry Lookout stations in northeastern Alberta with corresponding values for Fort McMurray A.[a]

Station	Ratio	Station	Ratio
Algar	1.31	Johnson Lake	1.19
Birch	1.25	Keane	0.94
Bitumount	1.13	Legend	1.07
Buckton	1.21	Muskeg	1.20
Ells	1.13	Richardson	0.94
Gordon Lake	1.26	Stoney Mtn.	1.46
Grande	1.21	Thickwood	1.25

[a] Data Source: Environment Canada, Monthly Record of Meteorological Observations.

4.6 SHORT-DURATION RAINFALL-FREQUENCY DATA

Short-duration rainfall information, both intensity and amounts, is necessary in the design of various structures such as culverts, drainage systems, etc. These data are much more difficult to obtain than the 24-hour rainfall discussed in the previous section. In the study area, the only data available are from Fort McMurray Airport. Return periods calculated on the basis of eight years' records are presented in Table 11. They should be used with caution as the length of record is shorter than usually considered sufficient for such calculations.

4.7 HEAVY STORM-RAINFALL EVENTS

Heavy rainfalls of two or three days duration occurring in and upstream of the study area can have significant impacts on river and lake levels. For instance, about 250 mm of rain fell over the Pelican Mountains during the period 27 June to 2 July 1970. Richardson Lake rose about one metre as a result of the runoff. Recorded storms yielding in excess of 100 mm of precipitation are listed in Table 12.

Several features, both interesting and significant emerge from this table:

1. Two storms occurred in the same year (1960);
2. The apparent increase in frequency of heavy storms after 1960 is probably a reflection of the increased number of forestry lookout stations; and
3. There is a definite tendency for higher elevations to have heavier and more frequent rainstorms yielding in excess of 100 mm.

The majority of heavy rainfalls of the kind listed in Table 12 are associated with "cold lows" (see Section 10.1). The synoptic patterns giving rise to the 1977 storm are depicted in Section 10.3.

4.8 SNOW AND RAIN

In high latitudes, the precipitation falls as snow during the cold season, and as rain during the summer. This is true of the study area. Table 13 gives normal values for Fort McMurray for the different months.

Table 11. Short-duration rainfall-intensity data for Fort McMurray A.[a]

Part 1
Rainfall Rates in mm/h

Return Period Years	5 min	10 min	15 min	30 min	1 h	2 h	6 h	12 h	24 h
2	63.5	46.5	37.1	22.9	13.5	8.8	4.6	2.8	1.7
5	82.3	62.0	55.2	32.8	19.0	13.5	6.8	4.2	2.4
10	94.5	72.4	65.5	39.4	22.6	16.7	8.2	5.2	2.9
25	110.2	85.6	79.0	47.8	27.2	20.6	10.0	6.4	3.6

Part 2
Rainfall Amounts (mm)

Return Period Years	5 min	10 min	15 min	30 min	1 h	2 h	6 h	12 h	24 h
2	5.3	7.8	9.3	11.5	13.5	17.6	27.6	33.6	43.2
5	6.9	10.3	13.8	16.4	19.0	27.0	40.8	50.4	61.0
10	7.9	12.1	16.8	19.7	22.6	33.4	49.2	62.4	73.7
25	9.2	14.3	19.8	23.9	27.2	41.1	60.0	76.8	91.4

[a] Data Source: Environment Canada 1977.

Table 12. Heavy rainfall events in or near the AOSERP study area.[a]

Date	Duration (h)	Rainfall (mm)	Area of Heaviest Rainfall
1935, Jul 28-29	?	105	Fort McMurray
1960, Jul 22-24	66	180	Stoney Mtn.
1960, Sep 4- 7	66	127	Pelican Mtn.
1962, Jun 3- 6	90	133	Cowpar
1967, Aug 4	?	105	Primrose Lo
1970, Jun 27-Jul 2	120	250	Pelican Mtn.
1971, June	?	133	Buckton Lo
1973, Aug 4- 8	96	155	Cowpar
1976 Aug 24-26	60	134	Stoney Mtn. Lo.
1977, Jul 2- 3	36	107	Birch Mtn. Lo

[a] Data Source: Environment Canada ND, monthly.

Table 13. Mean monthly precipitation, Fort McMurray A.[a]

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Rain (mm)	0.5	0.3	1.0	7.1	31.0	61.5	73.7	64.0	49.5	13.2	2.5	0.5	304.6
Snow (cm)	22.1	19.1	19.3	12.7	2.0	T			2.8	11.2	24.6	25.9	139.7
Total precipitation (mm)	21.1	17.3	18.3	20.3	33.0	61.5	73.7	64.0	53.1	24.1	24.9	24.1	435.4
Percentage rain	2	2	5	35	94	100	100	100	93	54	10	2	70

[a] Data Source: Environment Canada 1975b.

As Table 13 shows, during the deep winter, December, January, and February, almost all of the precipitation falls as snow although light rain is occasionally recorded. March is similar although the possibility of rain increases slightly by the end of the month.

During the mid-summer months, June, July, and August, snow is almost unknown, although it does fall at times briefly in June. Some snow is probable in May and September, but the amount is normally less than 10% of the total monthly precipitation. During the other months, April, October, and November, the precipitation is sometimes rain, sometimes snow, but the probability of rain in November is low.

Except for the period June 1958 till December 1963 when observations were taken at Stoney Mountain, there is no available information on precipitation on the hilltops by which to compare the snow at these levels with that at lower elevations. During the period when observations were available at both locations, precipitation was almost entirely snow from 1 November until

31 March. During June, July, and August, only traces fell at Fort McMurray A, and also at Stoney Mountain except in June 1960. During that month Stoney Mountain recorded 15 cm of snow. During Septembers, snow fell at both locations in five years out of six, but amounts were slight. During the other three months, the proportion of the total precipitation falling as snow was significantly greater at Stoney Mountain than at Fort McMurray A. In April the ratios were 94% at Stoney Mountain, 73% at Fort McMurray A. Corresponding values for May were 35% and 20%; for October 59% and 55%.

The comparison of records leads us to the conclusion that the proportion of snow increases with elevation between Fort McMurray A and Stoney Mountain during the transition months of spring and autumn. It would appear that the differences in spring are greater than in autumn, but further data are necessary to confirm this hypothesis.

4.9 SNOW COVER

Low winter precipitation is reflected in the lack of a thick snow cover in the AOSERP study area. Statistics given by Potter (1965) provide data for Embarras and Fort McMurray based on the period from 1941 until the date of publication. Table 14 gives significant data from this report.

The data from the table show clearly that there is considerable variation from year to year in all aspects of snow cover. The means of the maximum recorded depths are approximately equal at the two locations. The range of values at Embarras is smaller, but that may be a result of the shorter period of observations. The duration is over two weeks longer at the northern location.

Preliminary results from a snow survey program being conducted for AOSERP suggest that snowpack distribution is consistent with the principle of increasing precipitation with increasing elevation. Thus, the higher ground in the study area has, in general, deeper snow during middle and late winter than

Table 14. Snow cover (2.5 cm or more) statistics for Fort McMurray A and Embarras. [a]

	Fort McMurray A			Embarras		
	Date of first snow cover	Days with snow cover	Date of last snow cover	Date of first snow cover	Days with snow cover	Date of last snow cover
Earliest or least	5 Oct.	127	27 Mar.	11 Sep.	127	3 Apr.
Mean	31 Oct.	154	17 Apr.	17 Oct.	171	28 Apr.
Latest or most	2 Dec.	186	12 May	1 Dec.	199	27 May
	Least	Mean	Maximum	Least	Mean	Maximum
Maximum depth	23	46	104	28	48	66

[a] Data Source: Potter 1965.

the areas at lower elevations. It appears that the region where the present extraction development is taking place has, on the average, the shallowest snow cover in the study area.

4.10 24-HOUR SNOWFALL

Heavy snowfalls are unusual in northeastern Alberta. The heaviest 24-hour fall on record is 33 cm on 22 March 1942. A fall of 25 cm in 24 hours must be considered heavy. There are only four recorded snowfalls of this magnitude in the Fort McMurray area. Heavy snowfalls are likely more frequent over higher ground such as Stoney Mountain and the Birch Hills.

4.11 THUNDERSTORMS

The frequency and severity of thunderstorms are of interest to a number of agencies within the study area. Not only are the short term high intensity precipitation events associated with thunderstorms but lightning may disrupt electrical facilities and start forest fires.

Thunderstorms pose a threat to the forest because of the danger of lightning starting forest fires. This danger is greater in an area like Alberta than in a well-watered area. In the latter, the surface fuels may not get dry enough for ignition by lightning strikes. Because of the risk from lightning, the Alberta Forest Service initiated Forestry Lookouts where observers are posted each summer to report lightning in sight of the station. The weather reports taken at these stations provided much needed information on weather throughout northern Alberta.

The average number of days with thunderstorms for the six-year period 1972 to 1977, supplied by the Alberta Forest Service, is given in Figure 9. This shows that the average for those years varied considerably over the area. The period is too short to accept the pattern as giving the normal picture of the spatial distribution. Yet it does indicate that one may expect about 20 days with thunderstorms during the summer. June and July see the largest number of storms, six to eight days each month, with frequency dropping off in August when the solar radiation has dropped from its peak value.

The data on stability (Sections 3.5.2 and 3.5.3) showed that unstable air frequently developed along the Athabasca River during summer afternoons. In this unstable air, vertical currents develop, producing cumulus clouds. These at times become shower clouds and under extreme conditions, thunderclouds. Although the air is unstable almost every afternoon of June and July, only on one day of four or five do the vertical currents produce a thunderstorm.

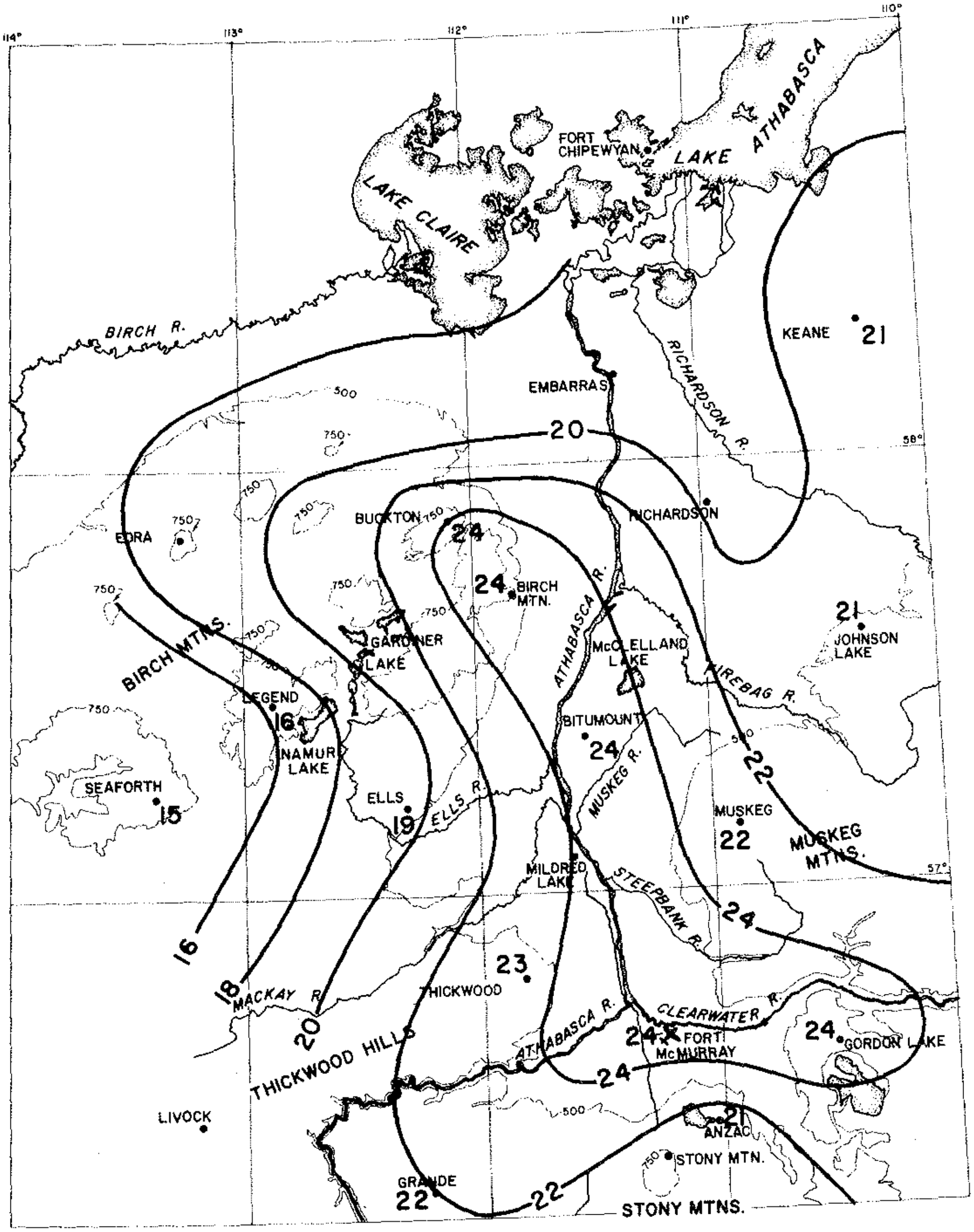


Figure 9. Average number of days with thunderstorms in the AOSERP study area and surroundings, May to September, 1972-1977 (Alberta Forest Service 1977).

5. WIND

5.1 INTRODUCTION

Winds are an important feature of weather and climate. Because of them, air is carried from one area of the earth's surface to another. This flow may bring warmer, colder, drier or moister air to an area. The winds may also carry pollutants such as dust, smoke, noxious gases, etc. Small eddies in the currents of air redistribute these components and so reduce their concentration with time. The concentration may, eventually, become small enough to pass unnoticed.

Winds are also a factor in determining the comfort of mankind. Strong winds during winter make people feel cold when otherwise the temperature may not be unpleasant. In a hot, humid period in summer, a breeze will remove saturated air from around a person, permitting more evaporation into the fresh air and so cooling of the individual.

5.2 WIND VARIATION

Winds are a common feature of the weather and climate of any location. Frequently we experience a wind and do not stop to realize that others not far distant may not be experiencing the same wind as we. The most rapid change occurs with height. At ground level there may be no air movement while we have a slight breeze on our faces and a flag on top of a nearby building may show a strong wind. The difference arises because earth-bound objects, such as grasses, rocks, trees and buildings exert a drag on the air to slow it down. The effect of this frictional force varies, depending upon the stability of the air and other factors, but is usually present through a depth of 200 to 300 m.

The slope of the land can influence wind direction and speed. When the sun is shining and warming the ground, rising air will follow the slope to produce an up-slope wind. During a clear night, air will subside along the valley sides to create a down-slope wind. At the bottom of the valley, the winds from the two sides tend to join to form a down-valley wind. We shall see examples of the influence of temperature patterns in determining the winds through the Athabasca River Valley.

When air rises it cools. The rate of cooling if no other changes are occurring is 1°C/100 m, the adiabatic lapse rate. If air rising comes in contact with air with the same temperature as its new temperature it tends to remain at that level. The air column is said to have neutral stability. If the lapse rate in the free air is greater than adiabatic, the rising air, even though cooling, remains warmer than its surroundings. Buoyancy forces then tend to keep it rising until it meets air of the same or warmer temperatures. In a summer afternoon, vertical movements are common. The surface air rising carries moisture aloft which forms clouds which sometimes give showers. The turbulent currents distribute foreign material over a great depth and assist any high concentrations to disappear through dispersion.

With inversion situations (Section 3.5), vertical currents are inhibited, and pollutants are not dispersed. Also the lack of exchange of air between surface layers and the rapidly moving air aloft reduces the movement of energy downward. Winds under an inversion tend to be light. Often in winter, plumes may be observed to rise slightly, and then flow horizontally. They rise until they meet a stable layer or inversion and then remain at that level. On the other hand, in an unstable atmosphere, winds tend to be stronger and gusty and plumes disperse readily.

5.3 WIND OBSERVATIONS IN THE STUDY AREA

In the study of temperature and precipitation, much use was made of the observations at Fort McMurray A to interpret the other data available and reach conclusions on the distribution of these two weather elements over the AOSERP study area. A similar method is more difficult with wind data. The observations of wind at Fort McMurray A provide the best set found in the area, but some data are available for Embarras A and Stoney Mountain.

Mean monthly wind speeds for Embarras A for the period 1955 to 1962 and for Fort McMurray A for 1955 to 1972 (Environment Canada 1975c) are given in Table 15.

Table 15. Mean monthly wind speeds (km/h) for Embarras A and Fort McMurray A (Environment Canada 1975c).

	J	F	M	A	M	J	J	A	S	O	N	D
Embarras A	10.3	9.8	10.1	11.9	12.4	11.1	11.0	10.5	11.9	12.2	11.4	10.3
Fort McMurray A	8.9	9.2	10.3	11.6	11.8	10.1	9.3	9.2	10.0	10.8	9.5	8.7

The wind speeds at these two locations are relatively low. In comparison with a mean wind speed for the year of 11.1 at Embarras A and 10.0 at Fort McMurray A, the value for Grande Prairie is 14.3, for Wagner, 14.8 and for Edmonton International 14.0 km/h. The low speed in the AOSERP stations is a result of the protected locations in the saucer of the Athabasca River Valley.

There is a variation of mean wind speeds during the year. The windiest months are the transition months, April and May, and again September and October. Midwinter has the lowest mean speeds, but there is a secondary minimum in August. This annual fluctuation is found for many observing points on the prairies.

Although wind observations were taken at Stoney Mountain during its period of weather observations, there are very few data available from its records. The Monthly Records for the period give, for 1100 and 1700 only, the number of occurrences during each month of calms and of winds in the ranges 1-20 and 21-61 km/h. Even so a comparison with similar data from Fort McMurray A and Embarras A for the same period does provide some evidence that the winds on the higher parts of the area are stronger than in the river valley.

The frequency of calms shows an annual rhythm with low values, 3%, in July, and values near 10% in the winter months. The mean for all months is the same, 6%, for Embarras A and Stoney Mountain but is 10% for Fort McMurray. Calms and light winds occur near the centre of an area of high pressure or underneath a strong inversion. Anticyclones formed by polar continental air are common during the months with a snow cover, but high pressure areas over the district are rare in summer.

The frequencies of winds in the two classes, 1-20 and 21-61 km/h, at the stations show clearly the effect of altitude. Of all the winds reported, Stoney Mountain had 32% in the 21-61 km/h class while Embarras A had 15% and Fort McMurray A had 12%. For the 1-20 km/h class, the corresponding figures are 62%, 79%, and 78%, respectively. Clearly, at many times when the winds in the valley were below 20 km/h, the winds on the higher hills were above that value.

More information from AOSERP is now becoming available which will permit a fuller analysis of the winds at higher elevations of the area. An analysis of these data will give a much clearer picture of the variation of wind speed with elevation.

5.4 WIND DIRECTIONS AT THE SYNOPTIC STATIONS

Of the three stations, Fort McMurray A, Stoney Mountain and Embarras A, Stoney Mountain is the highest and so is the one best situated to represent the general flow over the area. It is at 780 m, on a narrow ridge running east-west south of Fort McMurray. The period of six years of observations is not sufficiently long to establish a reliable normal. Nevertheless, the information the data provide will give a guide to upper air flows.

When the Stoney Mountain data for the two observing times 1100 and 1700 for the twelve months are examined, it is discovered that west is the predominant wind direction. Southwest winds tend to be almost as frequent for the five months, August to December. The percentage frequency of these two directions drops below 30 for the months, March, April, May, and June. During these latter months winds with an easterly component, northeast, east, and southeast, were relatively frequent with the combined frequency reaching 30% in June. During the other months, winds with an eastward component were low, usually between 10 and 20%. The wind roses for Stoney Mountain for three separate times, shown in Figure 10, illustrate the tendencies described.

To obtain data with which to compare the wind directions at Fort McMurray A and Embarras A, use was made of statistics (Environment Canada, Monthly) for the years 1961 to 1976 for Fort McMurray A and for 1947 to 1962 for Embarras A.

When one compares wind roses for Fort McMurray A and Embarras A with Stoney Mountain, as seen in Figure 10, one notices marked differences. These are seen most clearly in the comparison of the wind roses for January 1700 and April 1100. At these two times, Embarras had a high frequency of winds from the southeast, with west and northwest winds common and few winds from other directions. In the vicinity of the old airstrip, the river is flowing northwestward to a flat area west and northwest of Embarras. The surface winds, then, reflect the local topography.

The wind roses for Fort McMurray A at these same two times show a high frequency of east winds. To the east of the Fort McMurray Airport the Clearwater River flows from the east in a narrow valley, turning to the northwest near the airport to join the Athabasca River at the town of Fort McMurray. Many of the east winds are then drainage winds down the gorge during cold periods of the day. This tendency for east wind is seen again in the wind rose for October, 0500 MST (Figure 10).

During summer afternoons, the air tends to be unstable and vertical movements are common. Under these circumstances, the winds are not influenced so greatly by topography. The wind roses for the three stations for July 1700 are similar, as seen in Figure 10.

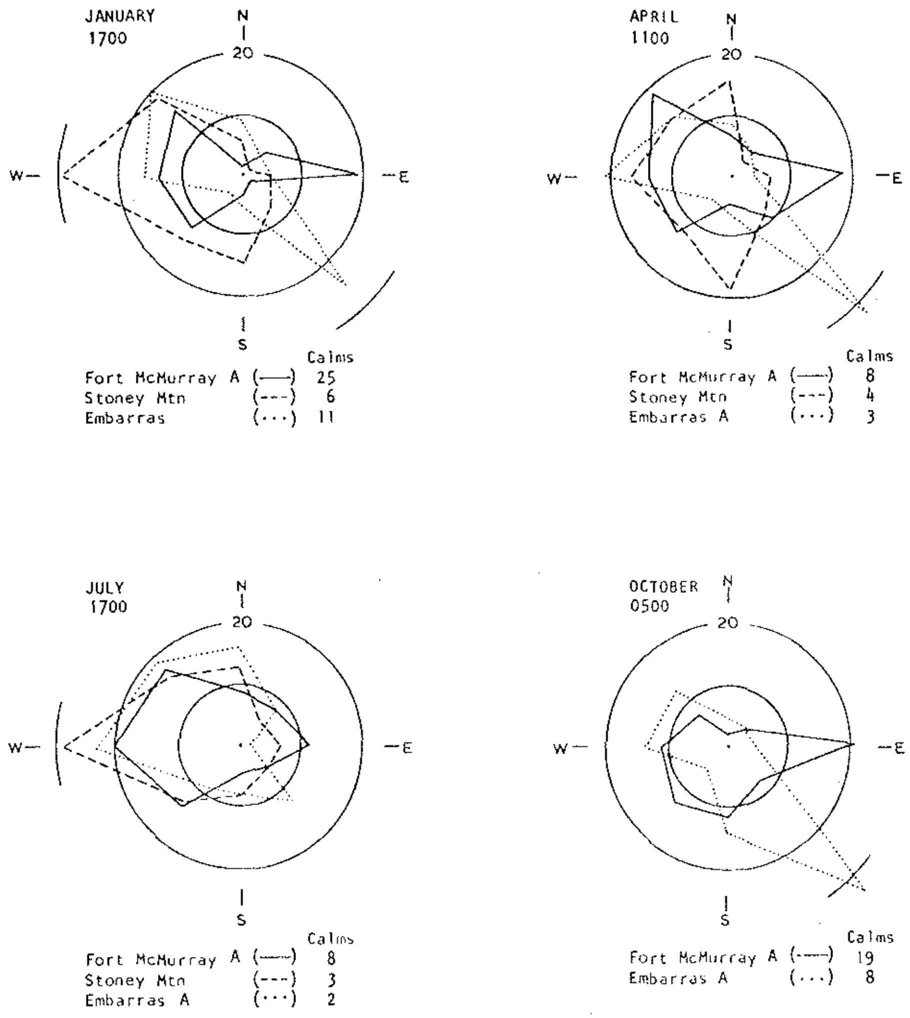


Figure 10. Wind roses for Fort McMurray A, Stoney Mountain, and Embarras A. The polygons around the centre are drawn such that the distance from the centre gives the relative frequency (%) of the wind from that compass point. The percentage of calms is given separately. (Data from Environment Canada, Monthly.)

As noted in Section 5.2, the diurnal heating causes changes in the surface air flow. The drainage winds noted above are an example. Figure 11 shows the wind roses for Fort McMurray A for June for the four synoptic hours. There is considerable similarity between the wind roses for 1100 and 1700. During the daytime, west and northwest winds flowing up the slope from the town predominate. Drainage winds flowing downward from off the Stoney Mountain ridge or down the valley of the Clearwater are most common at 0500 and 2300.

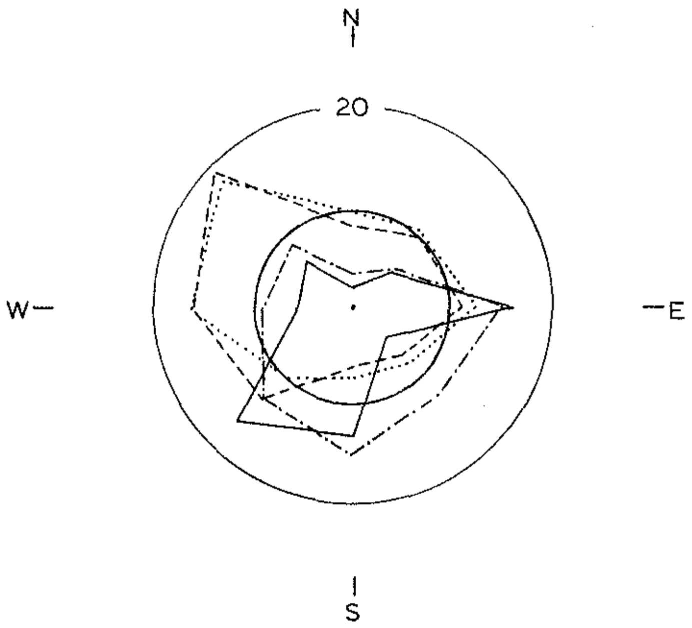
The foregoing analysis shows clearly that the winds at both airports are greatly influenced by the topography within 50 km of the observing points. The same will be true for other locations within the valley. But the topography of the area varies so much that it is impossible to generalize with any hope for accuracy for any point without a careful analysis of the local topography.

5.5 GENERAL COMMENTS ABOUT WINDS IN THE AOSERP STUDY AREA

Generally speaking, winds in the entire area must be considered light--certainly by the standards of southern Alberta. Strongest winds occur over higher land such as Stoney Mountain and the Birch Mountains where winds of the order of 80 km/h have been reported. Maximum observed speeds at Fort McMurray A and Embarras A (Environment Canada 1975c) are 72 and 64 km/h, respectively. Winds associated with snowstorms generally do not reach such speeds and consequently blizzards, such as occur over the prairies, are virtually unknown in the area.

Reports from the AOSERP telemetry stations and minisonde observations near Mildred Lake indicate that strongest winds are almost invariably westerly. Such winds usually are associated with an unstable westerly flow. Stable conditions are usually accompanied by light southerly surface winds over the main part of the valley.

These observations also indicate that in stable situations there may be a considerable difference in speed and direction between winds near the surface and those at several hundred metres above the



		Calms
0500 MST	(——)	29
1100 MST	(----)	8
1700 MST	(········)	7
2300 MST	(-·-·-)	17

Figure 11. Diurnal variation of wind in June at Fort McMurray A. The wind rose is drawn such that the percentage frequency from 8 compass points is given by the distance from the centre. The percentage of calms is given separately.

surface. This is also confirmed by plume observations during cold weather which suggest that surface emissions and stack emissions are often governed by different wind regimes. In stable conditions, on the other hand, vertical transfer of energy tends to encourage more uniform wind speed and direction in the lower few hundred metres.

These data show that there is a definite preference for the winds in the vicinity of the Athabasca River between Fort McMurray and latitude 58°N to be northerly or southerly. The stations further west, such as Birch Mountain, Ells, and Stoney Mountain show more of a preference for westerly winds.

This tendency for the lighter winds to blow up and down the valley has, of course, important implications insofar as air quality considerations are concerned. Frequently, in the regions of current development, the combination of light winds, stable atmospheric conditions and topography create less than ideal ventilation conditions.

A very important fact deserves repeating: namely, that within the AOSERP study area wind data cannot be transposed from one locality to another. Wind data are valid only for the locality where they were taken.

6. SUNSHINE, CLOUD, FOG, AND BLOWING SNOW

6.1 SUNSHINE

Data on the duration of sunshine in the study area are too few to give normal values. The only record comes from Fort McMurray A which has not been continued long. Records are available for Fort Smith, north of the study area, and Fort Vermilion on the Peace River and west of the area. Figure 12 gives the normal hours of sunshine at these locations (source, Yorke and Kendall 1972).

Under similar conditions, Fort Smith will have more hours of sunshine when the sun is north of the equator and less during the winter six months. This is in general the situation. But the difference is large in September and October. During these months, water surfaces tend to be warmer than land areas. This leads to rapid evaporation from lakes and rivers and condensation into cloud. Because of the greater extent of water surfaces near Fort Smith than near Fort Vermilion, there is less sunshine there during this period of the year.

Five years' data, 1972 to 1976, for Fort McMurray A permit a comparison with the two other stations. The totals of the monthly averages for the period for Fort Vermilion, 2,091 hours and Fort McMurray, 2,117 hours, would suggest that the two places are about equally sunny. For the months of November, December, and January, Fort McMurray A had 39 more hours sunshine than Fort Vermilion, and for the months of July, August and September, 21 less hours. The period is too short to permit the conclusion that these differences are representative. One concludes that Fort Vermilion and Fort McMurray are less sunny than most places in the prairie provinces but sunnier than many other areas of Canada.

6.2 CLOUD COVER

The extent of cloud cover is another climatic element which affects man's activities, although the effect is less than that of temperature and precipitation. Data on the cloud cover

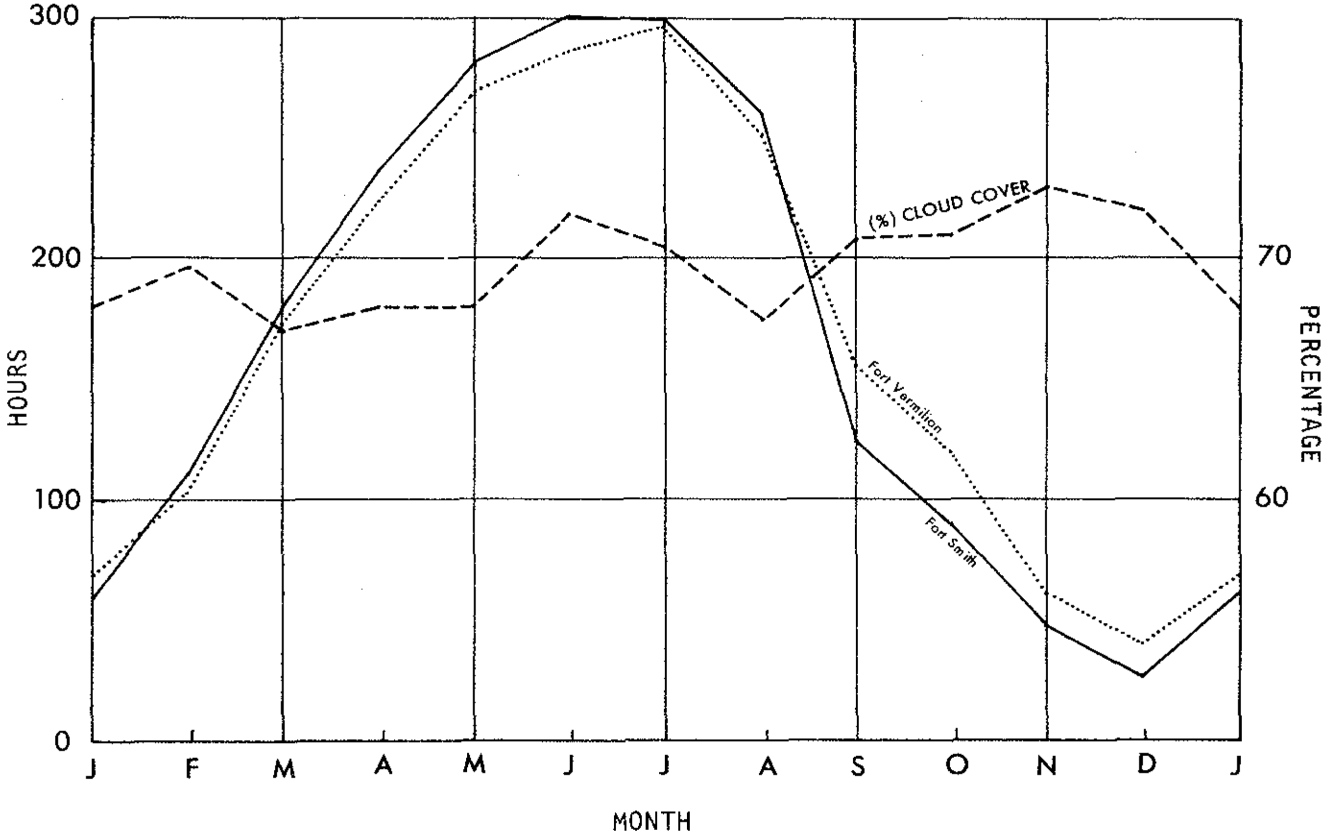


Figure 12. Mean monthly sunshine (hours), Fort Smith A and Fort Vermilion, and mean cloud cover, Fort McMurray A, 1100 and 1700. (Data source: Yorke and Kendall 1972).

are obtained from hourly observations taken at airports and sometimes elsewhere.

Data for 16 years, 1961 to 1976 inclusive, were examined to learn the extent of cloud cover at Fort McMurray A for the synoptic hours, 0500, 1100, 1700 and 2300 MST. The mean values for 1100 and 1700 were averaged, and the curve is given in Figure 12. The data for these two sets were taken as being representative of daytime conditions. Also, the data are more reliable than for 0500 and 2300. Study has shown that high, thin clouds are often not noted at night because they do not obscure the starlight.

The variation through the year of daytime cloudiness does not vary greatly, going from 67% in March to 73% in November. During the summer months, from May to August, inclusive, the afternoon is more cloudy than the morning, the result of the development of convective clouds during the afternoon. During the other months, the morning mean is 0 to 4% higher than the afternoon mean. There is some burning off of cloud through the heating of the sun. The means for the year are 70% for both times of observation.

The difference between reported daytime cloudiness and nighttime cloudiness results partially because of the difficulty of observing thin cloud in the darkness. The December means for the four synoptic hours illustrate this difference: 0500, 59%; 1100, 74%; 1700, 70%; and 2300, 61%. In June and July, there is very little darkness because of the high northern latitude. The reported values can then be considered valid. These show that cloudiness during the summer night is less than during the day. The means for June for the day are: 0500, 65%; 1100, 70%; 1700, 74%; and 2300, 61%.

Two other stations reported cloud cover in the area. Embarras closed in 1962 and Stoney Mountain, which took daytime observations only, in 1963. A comparison was made of the cloudiness at synoptic hours at each of these stations and Fort McMurray A. Stoney Mountain was definitely less cloudy than Fort McMurray A. The average for the year for the 1100 observation was 62% in contrast to 70% for Fort McMurray A, and for 1700, 63% in comparison with 70% at Fort McMurray A. The difference between Embarras A and Fort McMurray A was less, but the monthly means for the synoptic hours were all less at Embarras A than at Fort McMurray A, except for October when the means were slightly higher.

The relative increase in cloudiness in October at Embarras may be a result of evaporation from the warm river water in the proximity causing cloud to move over the airport at times. The Stoney Mountain results seem less easy to understand. Normally one expects clouds on mountain peaks during the season of convective cloud. Yet mean cloudiness at 1700 in July was 63% and at Fort McMurray A 73%. The difference may be because the years after Embarras A and Stoney Mountain closed had more cloud and rain than prior to that date.

The analysis has shown that the AOSERP study area has considerable cloudiness throughout the year. There are not sufficient data to estimate any variation in cloudiness over the area, although what data are available suggests that cloudiness over Fort McMurray is slightly more extensive than at other stations.

6.3 FOG

Fog exists when cloud droplets near the surface of the earth restrict visibility. To produce fog, the air must be close to the saturation point. With some types of material in the atmosphere, e.g., salt crystals or sulphur dioxide, fog will form at relative humidities under 100%. The cooling and the formation of fog happen most frequently in continental areas when the nocturnal cooling reduces the temperature to the dew point. Air can also become saturated when evaporation from a body of warm water adds moisture to the air so that the moisture in the air passes the saturation point of the ambient air temperature. Fog can be reported on a hill or mountain when the hill becomes enveloped in a cloud formed from rising air. All three processes are active at times in the study area.

Data on fog occurrence are found in Hourly Data Summaries for Fort McMurray A (Canada, Department of Transport 1968b). Figure 13 gives the number of days per month when fog is expected to occur at Fort McMurray A. It is based on the 10-year period of observations 1957 to 1966. For Figure 13, fog is said to occur when water droplets reduce the visibility below 10 km. Also given is the curve which shows the time of sunrise at Fort McMurray.

It will be noted in the diagram that the month with the most fog is August, followed by September. The diagram also shows that fog is often closely associated with sunrise. This, of course, occurs because the time of minimum temperature normally is just after sunrise.

The diagram also gives evidence that evaporation from water is a contributing factor to the fog at Fort McMurray. In the fall months, the waters of the rivers and lakes tend to remain warm. Evaporation from the warm water produces vapour which, when it meets cold air aloft, results in "steam fog." Fog is much more common in September than in May, and in August than in June because of the water temperature.

The fog of the winter season is usually ice fog. Although this is more common during the morning than during the afternoon, the diurnal variation is slight compared to that of the summer months.

According to Croft et al. (1977), ice fog is usually found when the temperature drops to -30°C although with a fresh supply of moisture the fog may occur at -20°C. The moisture in the study area is usually sufficiently high that the air will become saturated at the lower temperature. The probability of ice fog is then closely related to the frequency of -30°C temperature or below. This may occur in November and March, but is more probable in the mid-winter months. Naturally, one may expect more ice fog in a frost hollow than on the surrounding hills. With such low temperatures, any open pools or river will supply water vapour rapidly to the air to form the fog.

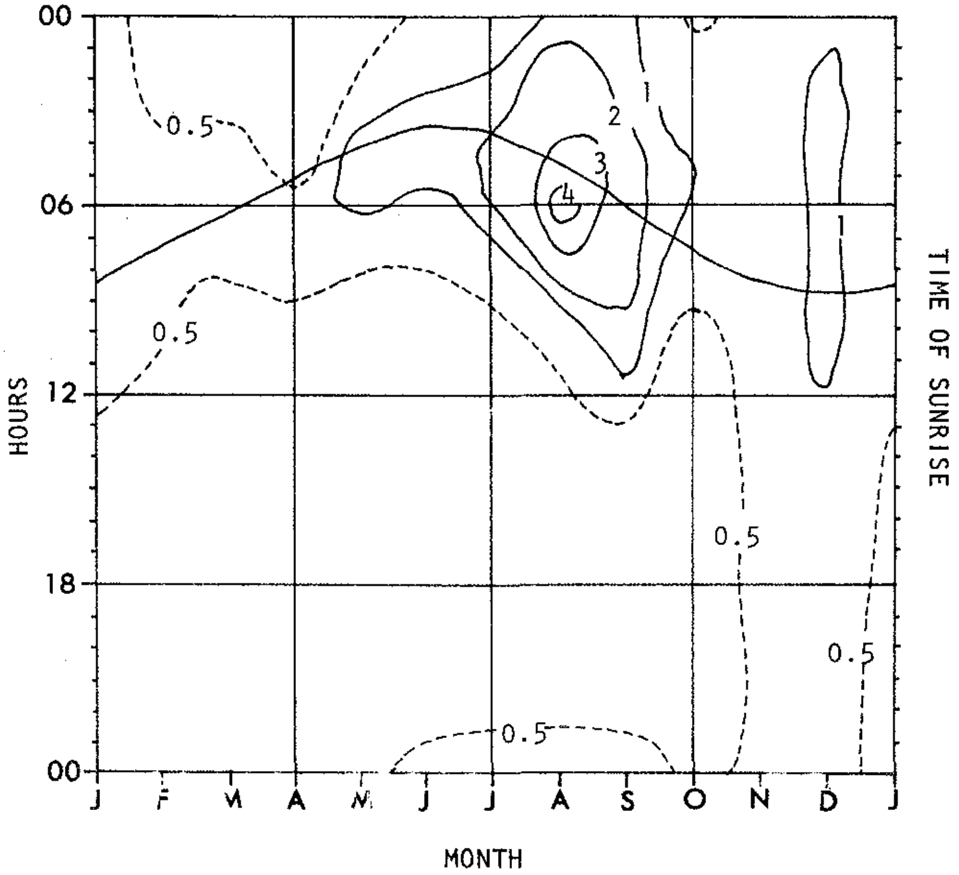


Figure 13. Number of days per month when fog (visibility < 10 km) is expected at Fort McMurray. Also given is the time of sunrise.

Although -30°C is considered a necessary temperature for the formation of ice fog, it does not follow that ice fog will necessarily form if this temperature is attained. Surface winds, even quite light, may disperse the available moisture sufficiently to prevent fog formation.

Fog, and particularly ice fog, is sometimes classified as air pollution (Murray and Kurtz 1976). Whether or not this classification is accepted depends on one's definition of air pollution. However, the confusion probably arises because ice fog and air pollution events often occur under similar meteorological conditions, namely low temperatures, inversions, and light winds.

An interesting phenomenon observed in the study area is the "snow out" of the GCOS plume. Under certain conditions when temperatures at plume level drop to -30°C the moisture in the plume condenses and falls out as "light snow" rather than dispersing as it does at higher temperatures. This "snow out" may deposit several centimetres of "snow" over a period of several hours. This phenomenon is usually confined to the downwind region within about 3 to 4 km from the source.

Records of fog occurrence are available from Embarras A and the Stoney Mountain station of 1956 to 1962. Embarras A is the only station in the valley. A comparison of the records for 1946 to 1962 with similar records from Fort McMurray A shows no significant difference, except that the frequency of fog at Fort McMurray A is more than double that at Embarras A at 0500, July and August. This is over one hour after sunrise, when solar heating can be noted. It may be that during the period after sunrise, gusts of wind carry fog and saturated air from the valley of the Athabasca River up the slope to the Fort McMurray Airport.

It is impossible to generalize on the extent of fog in the valley of the Athabasca. Fog occurrence, like minimum temperatures, is closely related to topography. In dips in the land, particularly, if a lake is present, fog is more probable than in flat country or on a hillside.

Records are available for Stoney Mountain for daytime only. Reduced visibility was more common in November than at other times, but the number of occurrences is below the corresponding number for Fort McMurray A . The number is larger at Stoney Mountain at 1700, July, August, and September. During this season of the year and time of day, convective clouds are common. These will envelop high hills such as that on which Stoney Mountain observing point was located. For this reason, fog will sometimes occur at Stoney Mountain when no fog is reported in the valley below.

6.4 BLOWING SNOW

Visibility is at times reduced by blowing snow. This results in severe conditions in the open prairies such as found near Regina. Climatological records indicate that this does not occur as frequently nor with such severity in the AOSERP study area.

For winds to produce blowing snow, they must be strong and the snow recently deposited. A wind of 30 km/h will pick up fresh light snow and carry it along. For older snowflakes which have lost their star-like formations, the wind should be above 40 km/h. Such winds are rare at Fort McMurray. In 10 Januarys, 1957 to 1966, of hourly observations, there were only 12 observations of winds 40 km/h or above, and such winds were less frequent during the other months. Under such circumstances, one can understand why there were only 122 times in 10 years when blowing snow reduced the visibility below 10 km. Annual totals for other places are: Calgary, 24; Lethbridge, 43; North Battleford, 84; Moose Jaw, 167; and Regina, 216 hours. The phenomenon at Fort McMurray was most frequent in January with 68 of the reported observations occurring in that month.

As indicated in Section 5, the frequency of high winds at Stoney Mountain and similar high elevations is much greater than at Fort McMurray. Exposed areas around such hills likely have a higher frequency of blowing snow than the wooded areas surrounding them.

7. CLIMATE AND HUMAN ACTIVITIES

7.1 AGRICULTURE

Section 3.3 discussed the frost-free period for the AOSERP study area. Frosts may occur at any time of the year and the average frost-free period is only about 10 weeks. Such conditions do not encourage agricultural activities. Some vegetables have been grown with equally poor climatic conditions at Fort Simpson and other locations along the Mackenzie River. But the grey-wooded and peat bog soils of the area are extremely acid and are thus unsuitable for farming. The combination has resulted in a lack of agricultural activity.

A small area near the confluence of the Clearwater and Athabasca Rivers has been cleared for market gardening, and this activity may be expanded slightly using the suitable soil on the river bank. An experiment is being conducted by Alberta Agriculture to grow grasses near Fort McMurray but the results so far have been discouraging (Per. comm., Larry Gareau, Alberta Agriculture). The lack of suitable fodder for cattle and the plague of flies discourages the development of cattle ranching in the area.

7.2 WINTER RECREATION

Masterton et al. (1975) have studied the recreational potential of the prairie provinces. The discussion here and in section 7.4 is based largely on their analysis. Some data for Edmonton are included for comparison.

Major outdoor winter recreation in Canada is found in skiing and snowmobiling. The analysis by Masterton et al. (1975) considers these two activities. Other activities that might be considered are skating and tobagganing but the conclusions about the relative merits of different areas would not change much by the expansion.

Based on subjective criteria about suitable temperatures, wind speed, and snow cover, the study concluded that there are normally 118 days at Fort McMurray and 113 days at Embarras that are suitable for snowmobiling. For skiing, the numbers were less: 80 for Fort McMurray, and 82 for Embarras. Corresponding numbers for Edmonton are 89 for snowmobiling and 70 for skiing.

Much of the advantage that the Athabasca Valley has over the Edmonton district is a result of the more reliable snow cover of the area. There are many days suitable for outdoor activities in late March and early April when the snow around Edmonton is disappearing. The snow pack within wooded areas and on higher levels is greater and less liable to disappear. There should, then, be better opportunities for skiing and snowmobiling in such areas than near the airport and at the bottom of the river valley.

The mean temperature is below freezing at Fort McMurray from late October until early in April. During this period the temperatures seldom rise above 5°C (see Section 10.2, Tables 24, 25 and 26). With the long period of sub-freezing temperatures it is possible to plan curling rinks and hockey rinks where the need for artificial cooling is minimal.

7.3 WINTER HEATING

The long and cold winters of the AOSERP study area result in need for much heating of homes, offices, etc. The Climatological Division of Environment Canada provides a measure of the amount of heat required by giving the number of heating degree days below 18°C for the different stations across Canada (Environment Canada 1976).

Table 16 gives the annual total degree-days for Fort McMurray and selected other stations. Monthly values, particularly during the colder months, are closely related to mean temperatures.

The table clearly points out that Fort McMurray is colder than any well-populated parts of Canada. Heating requirements are nearly double those in Toronto and more than double those of Vancouver. These data merely emphasize what

Table 16. Heating degree-day annual normals, below 18°C, based on the period 1941-1970.[a]

Station	Annual degree-days	Station	Annual degree-days
Fort McMurray	6778	Winnipeg	5889
Vancouver	3007	Churchill	9213
Fort Smith	7852	Toronto	4082
Inuvik	10,174	Ottawa	4673
Edmonton	5589	Quebec	5080
Medicine Hat	4874	Halifax	4123
Regina	5920	St.John's	4804

[a] Source: Environment Canada 1976.

has been brought out in other parts of this study, that northeastern Alberta has a very cold climate, with a long winter season.

7.4 SUMMER RECREATION

In their study, Masterson et al. (1975) examined summer recreation in Canada by determining the frequency of summer days suitable, first, for passive activities such as walking; vigorous activities, such as soccer or canoeing; and activities on the beach and for swimming. Vigorous activity may be enjoyed in cooler weather than passive activity, but cannot be enjoyed by most people when the weather is hot. The combination results in almost equal number of days for the two types of activities, 73 summer days at Embarras and 75 to 78 at Fort McMurray. Edmonton has approximately 20% more days with 91 for passive activity and 88 for vigorous activity.

A vacationer needs higher temperatures to enjoy lying on the beach and swimming in the water. The criteria reduce the frequency of such days to 42 in the AOSERP area, and to 47 at Edmonton.

Most people enjoy swimming only when the water temperature reaches 20°C. In Fort McMurray (see Figure 2), the mean air temperature rises above 15°C only for brief periods of the day during June, July, and August, and only in July does it reach 20°C. Under such conditions, bodies of water will stay cooler than most people enjoy for swimming. Masterton et al. (1975) report that the mean July temperature of large lakes is 18°C and of small lakes 19°C. Swimming is enjoyed by some residents during high summer, but most people will prefer to lie on the beaches.

7.5 CLIMATOLOGICAL FACTORS IN CONSTRUCTION AND HOUSING

Design engineers and architects are becoming increasingly aware of the importance of climatology in the design of buildings, bridges, roads and dams. It is not within the purview of this report to discuss the problems of building design in detail. The reader is referred to a comprehensive treatment of the subject by Page (1976).

Insofar as building design is concerned the significant factor to bear in mind is the temperature extremes that must be taken into account. According to the design information given by the National Research Council (NRC 1975) the July design temperature (2½%) is 28°C and the January temperature (2½%) is -41°C. This is a wider range than is given for southern parts of Canada. Yet in spite of the fairly high design temperature for July, there is a heating requirement every month of the year in the AOSERP study area.

The design snow loading given by NRC for the AOSERP area is about 200 kg/m^2. This is somewhat higher than in central parts of the province because there is relatively little ablation of the snowpack during the winter months.

Research is currently underway to investigate the feasibility of alternate energy sources, such as wind and solar, in Alberta. Special data will be gathered from the Fort McMurray area in support of this project. Preliminary reports (Hay 1977; Hawrelak et al. 1976) indicate that with current technology wind power does not appear very promising for the area. However, solar power is certainly feasible for a number of specific applications.

8. CONCLUSIONS

8.1 ADEQUACY OF DATA

Several significant generalizations emerge from this report. Firstly, the study of temperature relationships suggest that, on the basis of present knowledge, fairly reasonable estimates of the areal temperature distribution can be made using Fort McMurray A as the key station. Annual means, monthly means, estimates of extremes should be reasonably accurate, but day to day values could be somewhat less accurate.

Similarly, estimates of mean annual precipitation, and the snow-rain distribution should be reasonably good. Day to day summer values, however, vary considerably and the relationships developed for annual means are not applicable.

Wind, the parameter which is of utmost significance in the development of the oil sands, is the very parameter about which we know least. Detailed knowledge of the topographical influences is lacking and the development of a relationship using Fort McMurray A data as a key is not a promising approach.

In summary, existing data yield sufficient information to make generally acceptable the estimates of temperature, precipitation, humidity, radiation, cloud cover and sunshine given in the report. However, vertical temperature distribution and surface and vertical wind patterns required for air pollution abatement require detailed observational data.

8.2 CLIMATE SUMMARY

Winter in the AOSERP study area can be considered to last six months, from mid-October until mid-April. This collapses the other three seasons into six months, two months each.

Spring in the area covers the period from mid-April until mid-June. The weather warms rapidly, and 25°C can occur by the middle of May. This is the windiest period of the year, but even so, winds are generally not high. Early spring is dry, with small amounts of precipitation occurring about twice a week. May has slightly more rain than April.

Summer is short, with an average frost-free period of only seven weeks. This, and the acid soil, hinders agriculture in the area. Temperatures have reached 30°C not only in June, July, and August, but also in late May and early September. But frosts are always a threat. Rainfall increases rapidly to reach normally its highest monthly value of 75 cm in July. Periods of three overcast days with rain in a row occur but infrequently. Rain normally falls in Fort McMurray on 13 July days, but, with the showery nature of the rain, some types of outdoor activity can proceed with little interruption. These can include recreational activities, but, except for high summer, water temperatures are usually too cool for swimming. August and September are still quite wet, a circumstance that would make harvesting difficult if there were many crops to harvest. The thunderstorm activity has decreased markedly by September. Winds have increased slightly from a summer minimum, but the average is below the May value mean.

Autumn gives way to winter and a snow cover before the end of October. Cooling is rapid between September and November, 17°C in two months. Six months of snow cover begin in late October. Monthly falls of snow are low, but little snow melts. Therefore the snow pack continues to accumulate until late March. Although amounts are low, the frequency of days with snow is high, measurable snow falling, on the average, two to three days per week through the winter. Temperatures can be very low, -35°C having occurred each of the six months, November to April. Winds in winter tend to be light and so the discomfort of being out-of-doors is relatively small in spite of the low temperatures. Also blowing snow is uncommon and the blizzard conditions of southern Saskatchewan and elsewhere are almost never experienced.

One exhilarating feature of the weather of northeastern Alberta is the amount of blue sky. Although the amount of cloud cover is high, nearly 70%, much of this cloud consists of high thin cirrus, or puffy altocumulus, or cumulus through which the sky can be seen. When the sun is above the horizon, these clouds permit the sunshine to reach the earth, at least intermittently. The result is that the area has more sunshine than most of Canada. The blue sky and sunshine with the light winds give a feeling of well-being that compensates somewhat for some of the unpleasant features of the climate.

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10. APPENDICES

10.1 GLOSSARY OF TERMS

Throughout this report, there are technical terms used in the discussion and analysis of data. Some terms are well known but the meanings that climatologists and meteorologists ascribe to others are not familiar to the average reader. The following is a brief glossary of such terms.

Adiabatic lapse rate: the rate at which a mass of air cools with ascent because of decrease in pressure. Its value is $1^{\circ}C/100$ m for dry air.

Cold low: a low pressure area characterized by an isolated pool of cold air within its vortex. In the AOSERP study area these features are responsible for many of the extended periods (two to three days) of rain. See Section 10.2.

Degree-day: a measure of the departure of the mean daily temperature from a given standard. One degree-day for each degree above (or below) the standard for one day. Used commonly for growing and heating applications. Example:

$$\text{Heating degree-days (daily)} = 18 - \left(\frac{\text{Max} + \text{Min}}{2}\right)$$

Dew point: the temperature at which the air will become saturated with no change in moisture.

Inversion: a situation with a negative lapse rate, i.e. a rise of temperature with height.

Lapse rate: the rate at which the temperature drops with altitude, given as $^{\circ}C$/km or per 100 m.

Langley: a unit of energy commonly employed in radiation theory; in cgs units one langley is equivalent to one gram-calorie per square centimetre. The SI unit is MJ/m^2. One langley = $0.04186\ MJ/m^2$.

Macroscale: referring to the large scale, i.e. of the order of 200 km or more.

GLOSSARY OF TERMS (CONTINUED)

Mesoscale: in this study refers to an area of about 20-200 km across. The AOSERP study area is considered a mesoscale area.

Microscale: refers to individual topographical features, generally less than 20 km across.

Minisondes: small portable instruments equipped with a thermometer and radio transmitter. They are carried aloft by balloons and provide information about air temperatures and winds above the station.

Neutral stability: occurs in an air column when the lapse rate equals the adiabatic lapse rate.

Normal: the average value of a meteorological element over any fixed period of years. Recommended international usage is to recalculate normals at the end of every decade using data from the previous 30 years. Thus the latest normals are for the period 1941 to 1970.

Percentile: when a series of numbers is put into order from least to the greatest, the x percentile is that number such that x % of the values are below the number and (100 - x) % are above the value. The 50th percentile is called the median, or middle number.

Radiation: the transfer of electromagnetic waves, or (as used in this report) the amount of energy transferred by this process.

Range: the difference between the highest and lowest values of a variable is its *range*. The *mean daily range* is the difference between the mean maximum and the mean minimum temperature. The *mean annual range* is the difference between the mean temperature of the warmest month and the mean temperature of the coldest month.

Return period: the average interval in which an event will recur.

GLOSSARY OF TERMS (CONCLUDED)

Super-adiabatic lapse rate: a lapse rate greater than the adiabatic lapse rate. An air column is *unstable* if the lapse rate is greater than the adiabatic lapse rate, i.e., has a super-adiabatic lapse rate.

Synoptic: refers to measurements of data simultaneously at specified times. The synoptic hours are 0000 GMT and every six hours thereafter.

10.2 CLIMATOLOGICAL DATA FOR SELECTED STATIONS IN THE AOSERP STUDY AREA

10.2.1 Introduction

This section contains climatological data for Fort McMurray A and selected normalized data for Embarras A and Fort Chipewyan. Tables 17 to 20 present data in a fairly standard format. Tables 21 to 25 are based essentially on the same data set as Tables 17 to 20 but the data are analyzed in terms of risk factors regarding the occurrence of certain events. These latter tables when properly understood and applied can be very useful for planning and operational purposes.

10.2.2 Explanation of Tables

Table 17	These data were calculated in accordance with the formula given in section 10.1. Line 1 relates to heating requirements, line 2 gives a measure of heat available for the growth of plants, and lines 3 and 4 relate to temperatures above or below freezing.
Table 18 to Table 20	These tables present normal (i.e. over 30 year period 1941-1970) data for three stations in the AOSERP area. The data set for Embarras and Fort Chipewyan were of less than 30 years and were normalized in accordance with standard procedures.
Table 21	For the week beginning 1 January, there is a 99% probability of the temperature dropping to -18.9°C at least once during the week. Similarly, there is only a 5% probability of the temperature dropping to -46°C during the same period (i.e. about one year in 20).
Table 22	For the week beginning 1 January, there is a 99% probability of the temperature rising to -27.2°C or higher during the week. There is a 10% probability that the temperature will rise to 7.2°C at least once during the week.
Table 23	Out of the total of 203 days of record during the first week of January, 1% of the minima were -43°C or lower, 10.8% of the minima were in the -31°C to -32°C range etc.

Table 24	Similar to Table 25, but gives data relating to maximum temperatures.
Table 25	Gives data concerning the probability of precipitation. For example, during the period of record there was no first week of January with NIL precipitation; 44.8% of the weeks had 0.25 to 2.5 mm, 48.3% had 2.6 to 10.0 mm etc.

Table 17. Degree-day data for Fort McMurray A.[a]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Heating degree-days (below 18.0°C)	1237	978	850	497	279	141	69	112	271	463	795	1086	6779
Growing degree-days (above 5.0°C)	0	0	1	24	140	255	350	300	135	38	1	0	1245
Thawing degree-days (above 0.0°C)	0	3	12	100	282	405	505	455	272	125	13	3	2172
Freezing degree-days (below 0.0°C)	680	472	304	57	2	0	0	0	2	30	268	550	2345

[a] Data Source: Environment Canada (1973).

Table 18. Climatological data for Fort McMurray A (1941-1970).[a]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
Mean Daily Temperature (°C)	-21.5	-16.6	- 9.4	1.2	9.0	13.5	16.3	14.7	9.0	3.1	- 8.4	-16.9	- 0.5
Mean Daily Maximum Temperature	-16.0	-10.2	- 2.3	7.8	16.3	20.8	23.4	21.7	15.2	8.5	- 3.8	-12.2	5.3
Mean Daily Minimum Temperature	-26.9	-23.0	-16.4	- 5.4	1.7	6.2	9.1	7.6	2.8	- 2.4	-13.1	-21.7	- 6.8
Extreme Maximum Temperatures	10.0	15.0	18.9	26.1	32.8	36.1	35.6	32.8	30.6	26.7	18.9	10.0	36.1
No. of Years of Record	27	27	27	27	27	27	27	27	27	27	27	27	
Extreme Minimum Temperatures	-50.0	-50.6	-44.4	-35.0	-13.3	- 4.4	- 3.3	- 2.8	-15.6	-22.8	-37.8	-47.2	-50.6
No. of Years of Record	27	27	27	27	27	27	27	27	27	27	27	27	
No. of Days of Frost	31	28	31	25	12	3	<1	2	9	22	29	31	223
Mean Rainfall (mm)	0.5	0.3	1.0	7.1	31.0	61.5	73.7	64.0	49.5	13.0	2.5	0.5	304.6
Mean Snowfall (cm)	22.1	19.1	19.3	12.7	2.0	T	0.0	0.0	2.8	11.2	24.6	25.9	139.7
Mean Total Precipitation (mm)	21.1	17.3	18.3	20.3	33.0	61.5	73.7	64.0	53.1	24.1	24.9	24.1	435.4
Greatest Rainfall in 24 h (mm)	6.4	4.8	6.1	10.9	38.4	46.0	51.6	55.1	60.5	21.8	13.0	3.8	60.5
No. of Years of Record	27	27	27	27	27	27	27	27	27	26	27	27	
Greatest Snowfall in 24 h (cm)	15.5	13.2	29.7	20.8	8.9	0.3	0.0	T	18.3	10.9	15.5	22.6	29.7
No. of Years of Record	27	27	27	27	27	27	27	27	27	27	27	27	
Greatest Precipitation in 24 h (mm)	15.5	13.2	29.7	20.8	39.4	46.0	51.6	55.1	60.5	22.9	15.7	22.6	60.5
No. of Years of Record	27	27	27	27	27	27	27	27	27	26	27	27	
No. of Days with Measureable Rain	<1	<1	1	4	8	11	13	12	10	6	2	<1	67
No. of Days with Measureable Snow	14	11	10	5	1	<1	0	0	1	5	12	13	72
No. of Days with M. Precipitation	13	11	10	8	9	11	13	12	10	9	12	13	131

[a] Data Source: Environment Canada 1975a,1975b.

Table 19. Climatological data for Embarras A (1941-1970).[a]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
Mean Daily Temperatures (°C)	-22.4	-19.1	-11.2	- 0.3	8.6	13.9	17.3	15.5	9.3	2.4	- 8.9	-18.4	- 1.1
Mean Daily Maximum Temperature	-16.9	-12.7	- 3.9	6.2	15.1	20.6	23.7	21.8	14.4	6.9	- 4.8	-13.6	4.7
Mean Daily Minimum Temperature	-27.9	-25.6	-18.4	- 6.9	2.0	7.3	10.8	9.2	4.2	- 2.1	-13.2	-23.2	- 7.0
Extreme Maximum Temperatures	11.7	12.8	12.8	22.8	32.8	33.3	33.9	33.9	32.2	26.1	15.6	11.1	33.9
No. of Years of Record	19	20	20	20	20	20	20	20	19	19	18	19	
Extreme Minimum Temperatures	-51.1	-52.8	-45.6	-39.4	-16.1	- 4.4	0.0	- 2.8	-10.6	-23.3	-40.6	-48.3	-52.8
No. of Years of Record	19	20	20	20	20	20	20	20	19	19	18	19	
No. of Days of Frost	31	28	31	25	11	2	<1	1	6	21	29	31	216
Mean Rainfall (mm)	T	0.3	0.3	5.8	31.8	44.7	56.4	53.8	56.1	13.2	3.3	0.3	266.0
Mean Snowfall (cm)	19.3	16.3	16.3	12.4	4.6	T	0.0	0.0	3.8	14.5	23.9	22.1	133.2
Mean Total Precipitation (mm)	19.3	16.5	16.5	18.3	36.3	44.7	56.4	53.8	59.9	27.7	27.2	22.4	399.0
Greatest Rainfall in 24 h (mm)	0.3	1.5	2.3	12.7	21.1	42.2	81.8	50.8	37.6	26.7	7.6	5.1	81.8
No. of Years of Record	19	20	20	19	20	20	20	20	19	19	18	19	
Greatest Snowfall in 24 h (cm)	17.3	12.7	15.0	23.1	18.3	T	0.0	T	12.4	19.8	13.2	17.5	23.1
No. of Years of Record	19	20	20	20	20	20	20	20	19	19	18	19	
Greatest Precipitation in 24 h (mm)	17.3	12.7	15.0	23.1	22.6	42.2	81.8	50.8	37.6	26.7	13.2	17.5	81.8
No. of Years of Record	19	20	20	19	20	20	20	20	19	19	18	19	
No. of Days with Measureable Rain	<1	<1	<1	3	6	10	10	10	9	5	2	<1	55
No. of Days with Measureable Snow	11	10	9	5	1	0	0	0	1	5	11	11	64
No. of Days with M. Precipitation	11	10	9	7	7	10	10	10	10	9	12	11	116

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[a] Data Source: Environment Canada 1975a, 1975b.

Table 20. Climatological data for Fort Chipewyan (1941-1970).[a]

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
Mean Daily Temperatures (°C)	-26.2	-21.6	-13.7	- 2.7	7.0	13.1	16.3	14.9	8.2	1.0	-11.1	-20.5	- 2.9
Mean Daily Maximum Temperature	-20.7	-15.6	- 7.2	3.2	13.3	19.6	22.6	21.1	13.2	5.5	- 6.8	-15.4	2.7
Mean Daily Minimum Temperature	-31.7	-27.7	-20.2	- 8.6	0.7	6.5	9.9	8.7	3.2	- 3.5	-15.3	-25.6	- 8.6
Extreme Maximum Temperatures	8.3	15.0	13.9	22.2	30.0	33.3	33.9	33.9	29.4	24.4	13.9	13.9	33.9
No. of Years of Record	50	56	54	58	50	50	52	53	48	49	55	53	
Extreme Minimum Temperatures	-50.0	-51.1	-47.8	-35.6	-25.6	- 8.9	- 5.0	- 6.7	-12.2	-25.0	-38.3	-49.4	-51.1
No. of Years of Record	54	56	54	57	49	49	50	49	46	49	54	54	
No. of Days of Frost	31	28	31	27	13	2	<1	1	9	23	30	31	226
Mean Rainfall (mm)	0.3	T	0.3	5.6	18.5	34.3	51.8	41.4	36.3	10.9	1.3	0.3	200.7
Mean Snowfall (cm)	18.0	17.8	17.5	13.7	4.1	T	0.0	0.0	1.3	11.2	23.1	21.1	127.8
Mean Total Precipitation (mm)	18.8	17.8	18.0	19.3	22.4	34.5	51.8	41.4	38.1	22.6	24.4	21.6	330.7
Greatest Rainfall in 24 h (mm)	3.3	1.8	5.6	25.7	31.0	38.1	76.2	44.5	44.2	15.2	15.2	8.9	76.2
No. of Years of Record	58	57	57	49	50	48	52	51	47	51	54	58	
Greatest Snowfall in 24 h (cm)	2.0	3.0	1.8	1.8	3.0	0.3	0.0	0.0	0.8	3.3	2.3	3.0	3.3
No. of Years of Record	45	44	45	41	50	56	57	56	48	45	52	46	
Greatest Precipitation in 24 h (mm)	20.3	30.5	17.8	26.9	31.8	38.1	76.2	44.5	44.2	33.0	22.9	30.5	76.2
No. of Years of Record	44	44	45	41	48	48	52	51	45	45	51	46	
No. of Days with Measureable Rain	<1	<1	<1	1	4	7	8	8	7	3	<1	<1	38
No. of Days with Measureable Snow	6	5	6	3	1	<1	0	0	<1	3	6	6	35
No. of Days with M. Precipitation	6	5	6	4	5	7	8	8	7	6	6	6	74

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[a] Data Source: Environment Canada 1975a, 1975b.

Table 21. Weekly minimum temperatures (^{o}C) at given percent risk levels, Fort McMurray A (Environment Canada 1978).

WEEK BEGINS	NO. OF YEARS	99%	95%	90%	75%	50%	25%	10%	5%	LOWEST OBSERVED
JAN 1	29	-18.9	-20.0	-26.1	-30.6	-35.6	-39.4	-42.2	-46.1	-46.1
8	29	-23.3	-26.7	-31.7	-32.2	-36.7	-42.2	-43.3	-49.4	-49.4
15	29	-17.2	-18.3	-25.0	-31.1	-38.3	-41.7	-45.0	-47.2	-47.2
22	29	-22.2	-22.2	-30.0	-32.2	-39.4	-43.9	-45.0	-50.0	-50.0
29	29	-16.1	-22.2	-25.0	-32.8	-37.2	-41.7	-44.4	-50.6	-50.6
FEB 5	29	-12.8	-12.8	-17.2	-22.8	-32.2	-40.6	-42.8	-43.3	-43.3
12	29	-18.9	-23.9	-28.3	-30.6	-35.0	-39.4	-41.1	-42.2	-42.2
19	29	-20.0	-20.6	-23.9	-28.3	-33.9	-37.2	-41.1	-43.9	-43.9
26	29	- 8.9	-13.3	-18.9	-23.3	-32.2	-36.7	-41.1	-45.0	-45.0
MAR 5	29	-11.7	-13.3	-19.4	-25.6	-30.6	-33.9	-38.3	-41.1	-41.1
12	29	-11.1	-11.7	-16.7	-19.4	-24.4	-32.8	-36.1	-38.9	-38.9
19	29	- 7.8	-10.6	-11.7	-17.2	-22.8	-29.4	-33.9	-37.2	-37.2
26	29	- 2.2	- 4.4	-10.6	-12.8	-18.9	-28.3	-32.2	-33.9	-33.9
APR 2	29	- 6.1	- 7.2	- 7.8	-10.0	-12.8	-21.1	-26.1	-34.4	-34.4
9	29	- 2.8	- 3.9	- 4.4	- 5.6	-10.0	-17.8	-22.2	-26.7	-26.7
16	29	- 2.8	- 2.8	- 3.3	- 4.4	- 7.8	-14.4	-19.4	-20.6	-20.6
23	29	- 0.6	- 0.6	- 2.2	- 4.4	- 5.6	-10.6	-17.8	-25.6	-25.6
30	29	3.9	0.6	- 0.6	- 2.8	- 4.4	- 7.2	-10.6	-20.0	-20.0
MAY 7	29	- 0.6	- 1.1	- 1.1	- 1.7	- 3.3	- 5.6	- 7.8	-12.8	-12.8
14	29	2.2	1.7	0.6	- 1.7	- 1.7	- 3.9	- 5.6	- 5.6	- 5.6
21	29	6.7	2.2	1.7	0.6	- 1.7	- 3.3	- 5.0	- 6.1	- 6.1
28	29	4.4	2.8	2.8	1.7	0.6	- 1.7	- 3.9	- 5.6	- 5.6
JUN 4	29	6.7	5.0	3.9	2.2	0.6	- 2.2	- 3.3	- 4.4	- 4.4
11	29	7.2	5.6	5.6	5.0	2.8	- 1.1	- 1.7	- 3.9	- 3.9
18	29	6.7	6.7	6.1	3.3	0.6	- 1.1	- 1.7	- 4.4	- 4.4
25	29	10.0	8.9	6.7	5.0	2.8	0.0	- 1.1	- 2.2	- 2.2
JUL 2	29	8.9	8.9	8.3	6.7	4.4	2.2	1.1	- 0.6	- 0.6
9	29	12.2	10.0	7.8	6.7	4.4	2.2	0.0	- 3.3	- 3.3
16	29	10.6	9.4	8.9	7.2	5.0	2.8	0.6	- 2.8	- 2.8
23	29	8.3	7.8	7.2	5.6	4.4	3.3	1.1	0.0	0.0
30	29	10.0	8.9	8.3	5.6	5.0	3.3	2.2	0.6	0.6
AUG 6	29	9.4	8.9	8.3	7.8	5.6	1.7	0.0	- 2.8	- 2.8
13	29	7.2	7.2	5.0	4.4	2.8	- 0.6	- 1.1	- 1.7	- 1.7
20	29	7.2	6.7	5.6	4.4	1.7	0.0	- 2.2	- 2.8	- 2.8
27	29	7.2	6.1	5.0	2.8	1.1	- 1.7	- 2.2	- 2.8	- 2.8
SEP 3	29	5.0	3.9	2.2	0.6	- 2.2	- 3.9	- 6.1	-11.7	-11.7
10	29	5.0	4.4	1.1	0.0	- 1.7	- 3.9	- 5.0	- 6.7	- 6.7
17	29	2.2	1.7	0.0	- 0.6	- 1.7	- 3.3	- 5.6	- 7.8	- 7.8
24	29	1.7	1.7	0.6	- 1.7	- 2.8	- 6.7	-11.7	-15.6	-15.6
OCT 1	29	1.7	0.0	- 1.7	- 3.9	- 5.0	- 7.2	- 8.3	-14.4	-14.4
8	29	- 0.6	- 0.6	- 1.7	- 2.8	- 5.0	- 7.8	-10.0	-15.0	-15.0
15	29	- 2.2	- 2.2	- 3.9	- 5.6	- 6.7	-10.6	-14.4	-21.7	-21.7
22	29	- 4.4	- 5.0	- 5.6	- 6.7	-10.0	-14.4	-20.0	-22.8	-22.8
29	29	- 2.8	- 4.4	- 6.1	- 9.4	-11.1	-18.3	-23.9	-29.4	-29.4
NOV 5	29	- 2.2	- 6.7	- 8.3	-10.0	-12.8	-22.8	-27.2	-30.0	-30.0
12	29	-11.7	-12.2	-12.8	-15.0	-18.3	-30.0	-32.2	-37.2	-37.2
19	29	-10.0	-12.2	-15.0	-17.2	-22.2	-30.0	-35.0	-36.7	-36.7
26	29	-13.3	-15.6	-18.3	-20.6	-27.8	-35.0	-36.7	-37.8	-37.8
DEC 3	29	-12.2	-15.0	-17.8	-21.7	-26.7	-32.8	-40.6	-41.1	-41.1
10	29	-13.9	-15.0	-16.1	-23.9	-31.7	-38.3	-40.6	-45.0	-45.0
17	29	-14.4	-17.8	-18.9	-23.9	-35.0	-39.4	-41.1	-47.2	-47.2
24	29	-16.7	-17.8	-22.8	-26.1	-35.0	-37.2	-40.0	-46.7	-46.7

Table 22. Weekly maximum temperatures ($^{\circ}$C) at given percent risk levels, Fort McMurray A (Environment Canada 1978).

WEEK BEGINS	NO. OF YEARS	99%	95%	90%	75%	50%	25%	10%	5%	HIGHEST OBSERVED
JAN 1	29	-27.2	-22.8	-20.6	-16.1	-1.7	3.3	7.2	8.9	8.9
8	29	-24.4	-23.9	-17.8	-15.6	-8.3	1.7	3.3	3.3	3.3
15	29	-26.7	-22.8	-20.6	-15.6	-6.7	-1.1	4.4	10.0	10.0
22	29	-25.6	-24.4	-20.6	-16.7	-10.0	1.7	4.4	10.0	10.0
29	29	-19.4	-17.2	-15.6	-10.6	-2.2	2.2	5.0	13.9	13.9
FEB 5	29	-16.1	-14.4	-13.3	-11.1	-1.1	5.6	8.9	13.3	13.3
12	29	-16.7	-16.1	-15.0	-11.1	-2.2	1.7	6.1	7.2	7.2
19	29	-19.4	-12.2	-10.0	-6.7	-1.7	6.1	8.9	9.4	9.4
26	29	-13.9	-12.8	-10.0	-5.0	1.7	7.2	12.8	15.0	15.0
MAR 5	29	-17.2	-7.2	-6.1	-1.1	2.2	7.8	9.4	12.8	12.8
12	29	-8.3	-7.2	-2.8	1.7	6.7	8.9	12.2	14.4	14.4
19	29	-9.4	-7.2	0.0	3.3	7.8	11.1	12.2	16.7	16.7
26	29	-6.7	-0.6	3.9	5.6	8.9	12.2	14.4	18.9	18.9
APR 2	29	0.6	1.1	2.8	8.3	12.2	13.9	15.6	20.6	20.6
9	29	2.8	3.3	7.2	9.4	13.9	16.7	18.9	22.2	22.2
16	29	2.8	6.7	8.9	10.6	13.9	17.8	19.4	22.2	22.2
23	29	-2.2	8.3	10.6	13.3	16.7	22.8	23.3	26.1	26.1
30	29	14.4	14.4	16.1	17.8	20.0	23.9	26.7	27.8	27.8
MAY 7	29	12.2	12.2	15.6	16.7	22.2	24.4	26.7	32.8	32.8
14	29	13.3	14.4	17.8	20.6	22.8	26.1	28.9	32.8	32.8
21	29	17.2	17.8	18.9	21.1	23.9	27.2	29.4	31.1	31.1
28	29	13.9	18.3	20.0	22.2	25.6	28.9	32.2	33.9	33.9
JUN 4	29	17.2	20.6	22.2	23.9	25.6	28.9	31.7	36.1	36.1
11	29	21.1	22.2	23.3	25.0	26.7	28.9	30.6	31.1	31.1
18	29	20.6	20.6	22.2	23.9	26.1	28.9	30.0	31.7	31.7
25	29	22.2	22.8	23.3	25.0	25.6	27.8	30.6	31.7	31.7
JUL 2	29	22.8	23.3	24.4	25.0	28.3	30.6	32.2	33.9	33.9
9	29	22.8	24.4	24.4	25.6	27.2	32.2	34.4	35.0	35.0
16	29	23.3	25.0	25.6	26.7	28.3	31.1	32.8	35.6	35.6
23	29	20.6	22.2	22.8	25.0	26.7	27.8	29.4	35.0	35.0
30	29	22.2	23.3	24.4	26.7	28.3	30.0	31.7	33.3	33.3
AUG 6	29	21.1	22.8	23.3	24.4	27.2	29.4	32.2	32.8	32.8
13	29	19.4	20.6	22.2	23.9	25.0	29.4	31.1	31.7	31.7
20	29	18.3	18.9	20.6	22.8	25.6	30.6	32.2	32.8	32.8
27	29	18.3	18.9	19.4	21.7	23.9	27.2	28.9	31.1	31.1
SEP 3	29	16.7	18.3	18.9	20.0	22.8	27.8	29.4	30.6	30.6
10	29	12.2	15.6	18.3	20.0	21.7	25.0	26.7	30.0	30.0
17	29	7.8	11.1	14.4	16.7	19.4	23.9	27.2	28.3	28.3
24	29	9.4	11.1	12.2	15.0	17.8	24.4	27.2	27.8	27.8
OCT 1	29	5.6	10.0	14.4	17.8	20.0	22.2	23.3	26.1	26.1
8	29	6.7	6.7	10.0	12.8	16.7	21.1	25.0	26.1	26.1
15	29	-2.2	4.4	6.1	11.1	13.9	19.4	25.6	26.7	26.7
22	29	3.9	4.4	5.6	7.8	12.2	17.8	19.4	22.2	22.2
29	29	-3.3	-1.1	2.8	6.1	8.9	11.7	13.9	18.9	18.9
NOV 5	29	-10.0	-6.1	-2.8	-0.6	6.7	10.0	13.3	15.6	15.6
12	29	-12.2	-10.0	-8.3	-1.7	1.1	6.7	9.4	15.0	15.0
19	29	-13.3	-12.2	-10.0	-4.4	1.7	6.1	10.6	12.8	12.8
26	29	-16.9	-15.0	-13.9	-7.8	-2.8	5.0	10.0	10.6	10.6
DEC 3	29	-18.9	-15.0	-13.3	-7.8	-3.9	2.2	5.6	10.0	10.0
10	29	-20.0	-18.9	-17.2	-11.7	-7.2	3.3	6.7	8.9	8.9
17	29	-23.3	-22.2	-16.7	-11.7	-5.6	0.6	3.9	10.0	10.0
24	29	-23.9	-19.4	-16.7	-11.1	-4.4	1.1	8.3	10.0	10.0

Table 23. Part 1: daily minimum temperatures (°C), percent frequency by week, Fort McMurray A (Environment Canada 1978).

WEEK BEGINS	TOTAL DAYS	<= -43	-42 -41	-40 -39	-38 -37	-36 -35	-34 -33	-32 -31	-30 -29	-28 -27	-26 -25	-24 -23	-22 -21	-20 -19	-18 -17	-16 -15	-14 -13	-12 -11	-10 -9	-8 -7	-6 -5	-4 -3	-2 -1
JAN 1	203	1.0	5.9	1.5	7.4	5.9	3.4	10.8	6.9	5.4	5.4	6.9	4.9	6.4	10.8	3.4	3.9	6.4	1.5	1.5		.5	
8	203	3.0	6.9	3.9	4.9	4.4	7.4	11.8	5.9	7.4	3.9	10.3	7.9	3.4	5.4	2.0	4.4	1.5	2.5	1.5	.5	.5	.5
15	203	2.5	5.4	5.4	7.9	6.9	6.4	5.9	5.9	5.9	6.9	4.4	7.4	5.9	6.4	3.9	4.4	3.4	3.0	.5	.5	.5	.5
22	203	7.4	6.4	4.9	10.8	4.4	5.9	13.3	4.9	4.9	4.4	2.5	6.4	4.4	6.9	3.4	3.4	3.0	1.5	.5		.5	
29	203	3.4	3.4	4.4	4.9	4.9	5.9	5.9	6.9	5.9	6.9	4.9	9.4	4.9	7.4	4.9	4.9	3.4	1.5	1.5	.5	2.0	1.0
FEB 5	203	2.0	3.0	1.0	7.4	3.4	3.0	4.4	5.4	3.9	9.4	8.4	8.9	3.9	7.9	4.4	5.9	3.9	5.4	3.9	1.0	2.0	1.0
12	203		3.0	3.4	4.4	4.4	5.4	8.4	5.9	5.9	5.9	9.9	8.4	6.9	6.4	4.9	5.4	5.4	3.0	2.5	.5		
19	203	.5	1.5	2.0	1.5	4.9	6.9	8.4	3.4	8.9	5.4	5.4	7.9	5.4	6.4	8.9	9.9	3.4	2.5	2.0	2.5	1.5	1.0
26	203	2.5	1.5	1.0	2.5	2.0	5.9	6.4	4.4	4.4	4.4	7.4	11.3	8.9	5.4	3.9	8.4	6.4	3.0	3.4	2.5	1.5	2.5
MAR 5	203		1.0		2.0	1.0	2.0	7.4	7.4	5.4	6.9	6.4	5.9	7.4	8.9	4.4	5.4	10.3	3.9	6.9	3.4	3.0	.5
12	203			.5	1.5	1.5	2.5	2.0	2.0	3.9	3.9	5.4	7.4	5.4	11.8	5.4	8.4	10.8	7.4	5.9	5.9	4.9	3.0
19	203				.5	1.0	2.5	3.0	1.5	2.0	3.4	3.9	7.4	4.9	7.9	4.9	7.9	11.8	4.4	8.4	8.9	9.9	4.9
26	203						1.5	1.0	1.5	2.5	2.5	3.0	3.4	4.4	6.4	3.0	6.9	10.3	6.9	13.3	8.9	10.3	9.4
APR 2	203						.5	1.0			2.0	2.5	2.0	2.0	2.0	3.4	6.9	8.4	7.9	14.3	11.8	12.8	13.8
9	203									1.0		.5	1.5	2.5	3.4	3.9	2.0	4.4	3.9	6.4	9.9	25.1	17.7
16	202												.5	1.5	1.5	.5	4.5	4.0	4.5	9.9	9.4	22.3	20.8
23	203										.5	1.0	1.0	1.0	1.0	2.0	1.5	3.4	3.4	4.9	11.3	14.8	24.1
30	203													.5			.5	1.5	1.0	5.4	9.9	12.8	17.7
MAY 7	203																.5		1.5	2.5	6.9	10.3	19.2
14	203																				3.0	5.4	20.2
21	203																				1.5	7.4	11.8
28	203																				.5	3.0	6.4
JUN 4	203																					2.0	6.9
11	203																					1.0	3.9
18	203																					1.0	4.9
25	203																						3.9
JUL 2	203																						.5
9	203																					.5	.5
16	203																					.5	
23	203																						
30	203																						
AUG 6	203																					.5	.5
13	203																						6.4
20	203																					1.0	3.0
27	203																					1.0	7.4
SEP 3	203																	.5		.5	1.5	6.4	7.9
10	203																			1.0	1.0	5.4	9.4
17	203																			1.5	3.0	7.4	18.2
24	203															.5	.5	1.5	.5	2.5	3.0	15.8	19.2
OCT 1	203																.5		1.0	3.9	6.4	18.7	16.3
8	203															.5		.5	1.5	3.9	6.9	16.7	28.1
15	203												.5		1.0		1.5	3.4	4.4	6.9	11.8	20.2	24.6
22	203											.5	.5	.5	3.4	1.0	3.4	5.9	5.4	10.3	11.3	21.7	20.7
29	203								.5	.5	.5	.5	.5	2.0	3.4	1.0	5.9	8.4	6.9	8.4	14.3	22.7	15.8
NOV 5	203								.5	2.0	1.0	3.9	2.0	2.0	3.0	5.9	6.4	11.3	10.8	15.8	11.3	7.9	12.3
12	203				.5			2.5	2.0	2.5	1.0	5.4	6.4	4.9	8.4	4.9	9.4	11.8	5.9	11.8	8.9	9.9	3.0
19	203				1.0	1.0	2.0	2.5	3.9	1.5	3.0	5.4	6.4	4.9	11.8	10.8	5.9	9.4	10.8	8.4	1.5	4.4	3.0
26	202				2.0	2.5	2.5	4.5	4.5	4.0	8.4	4.0	8.4	7.4	10.4	9.4	10.4	4.0	5.9	3.0	3.0	3.0	2.0
DEC 3	203		1.5		1.0	1.0	3.0	6.4	6.4	3.4	1.5	10.3	8.4	8.9	10.3	7.9	9.4	6.4	6.9	3.4	1.5	2.0	
10	203	.5	2.0	2.5	5.4	3.9	6.9	4.4	3.0	5.4	5.4	5.4	8.9	6.9	5.9	6.4	10.3	5.9	3.0	5.4		2.0	.5
17	203	1.5	2.0	3.0	6.4	3.9	4.4	3.9	4.4	7.9	2.5	12.8	6.4	5.9	9.4	6.9	4.4	5.9	3.4	1.0	.5	1.0	.5
24	203	1.0	1.0	2.0	5.4	6.4	6.9	4.9	6.4	6.9	5.9	6.9	7.4	5.9	8.9	5.9	7.4	4.9	2.5	2.0	.5		.5

continued ...

Table 23. Part 2: daily minimum temperature (^{O}C), percent frequency by week, Fort McMurray A (Environment Canada 1978).

WEEK BEGINS	TOTAL DAYS	0 1	2 3	4 5	6 7	8 9	10 11	12 13	14 15	16 17	18 19	20 21	>= 22
JAN 1	203												
8	203												
15	203												
22	203												
29	203		.5		.5								
FEB 5	203	.5											
12	203												
19	203												
26	203	.5											
MAR 5	203	.5											
12	203		.5										
19	203		1.0										
26	203	4.4		.5									
APR 2	203	4.9	1.5	2.5									
9	203	9.9	6.4	1.0	.5								
16	202	12.9	5.9		1.0	1.0							
23	203	15.3	7.9	3.0	3.0	1.0							
30	203	20.2	11.8	11.3	4.4	1.5	1.5						
MAY 7	203	19.2	16.3	12.3	6.4	3.0	2.0						
14	203	14.8	25.1	13.3	11.8	3.9	.5	2.0					
21	203	15.3	18.2	11.8	12.8	12.8	5.9	2.5					
28	203	12.3	14.3	15.3	22.7	13.8	6.4	4.9	.5				
JUN 4	203	9.9	19.2	10.8	19.7	15.3	7.9	5.4	1.5	1.5			
11	203	4.4	9.9	10.3	26.1	21.2	15.8	6.4	1.0				
18	203	6.9	10.3	14.3	20.7	22.2	10.8	7.4	1.5				
25	203	3.9	7.9	11.3	20.2	23.2	14.3	12.8	1.5	1.0			
JUL 2	203	1.5	5.4	10.3	16.7	25.6	19.2	15.3	4.4	1.0			
9	203	.5	4.9	8.9	12.3	22.7	19.7	21.2	6.4	2.0	.5		
16	203	1.5	4.4	4.4	14.8	18.2	23.2	23.2	6.4	3.0	.5		
23	203	1.5	5.4	6.9	18.7	22.7	26.1	12.8	3.9	1.5	.5		
30	203	1.0	5.9	4.4	24.1	19.7	22.2	17.2	3.0	2.5			
AUG 6	203	3.0	5.9	3.9	12.3	23.6	18.2	23.2	8.4	.5			
13	203	3.0	7.9	6.4	23.6	25.1	13.3	11.3	1.5	1.5			
20	203	7.4	8.4	10.3	18.7	21.2	16.3	10.3	2.5	1.0			
27	203	5.4	14.8	15.3	18.7	20.7	11.3	4.4	1.0				
SEP 3	203	14.3	16.3	13.3	16.7	14.3	4.4	3.9					
10	203	16.2	13.8	12.8	16.7	15.8	4.4	1.5					
17	203	11.8	24.6	16.3	11.3	4.9		.5		.5			
24	203	13.3	18.7	12.3	7.9	2.5	1.5	.5					
OCT 1	203	17.2	16.3	12.8	5.9	.5	.5						
8	203	16.3	12.3	8.4	4.4		.5						
15	203	10.3	9.9	2.5	2.5	.5							
22	203	10.3	3.4	1.5									
29	203	5.4	2.5	.5	.5								
NOV 5	203	2.5	.5	.5	.5								
12	203		1.0										
19	203	2.5											
26	202	.5	.5										
DEC 3	203	.5											
10	203												
17	203	1.0	1.0										
24	203		.5										

Table 24. Part 1: daily maximum temperature (°C), percent frequency by week, Fort McMurray A (Environment Canada 1978).

WEEK BEGINS	TOTAL DAYS	<= -25	-24 -23	-22 -21	-20 -19	-18 -17	-16 -15	-14 -13	-12 -11	-10 -9	-8 -7	-6 -5	-4 -3	-2 -1
JAN 1	202	19.8	8.4	7.4	5.9	5.4	2.0	9.4	5.0	3.0	7.9	3.5	5.0	5.4
8	203	23.2	10.8	7.4	5.4	12.3	7.4	5.9	4.9	1.5	4.4	4.9	2.0	3.0
15	203	21.7	9.9	7.4	4.9	6.9	6.9	7.4	8.9	4.9	4.4	2.5	4.9	3.0
22	203	24.1	11.3	12.3	4.4	7.4	5.9	6.4	5.4	4.9	6.9	1.0	1.5	1.0
29	203	12.8	7.4	5.4	5.9	10.8	4.4	8.4	12.8	3.4	7.4	2.0	2.5	4.9
FEB 5	203	3.4	4.4	9.4	5.4	8.4	6.4	9.9	6.9	6.9	4.9	4.4	4.9	8.4
12	203	3.4	6.9	7.9	6.4	14.3	6.4	7.4	8.9	3.9	6.9	4.9	7.9	4.4
19	203	1.5	2.0	4.4	4.9	7.9	7.4	6.4	10.8	6.4	7.9	6.9	6.9	5.9
26	203	1.0	2.5	3.4	3.0	3.4	5.9	8.9	14.8	9.4	4.9	8.9	4.9	6.4
MAR 5	203	.5	1.0	1.5	1.5	2.5	3.4	7.4	8.9	7.4	11.3	8.9	10.8	8.4
12	203					1.5	3.0	4.9	5.9	5.9	6.9	6.4	7.9	12.8
19	203					2.5	2.5	3.4	4.9	3.9	4.4	3.9	9.9	13.3
26	203			.5		.5	.5	1.0	1.5	3.0	5.4	3.4	8.9	7.9
APR 2	203						.5	1.0	.5	3.4	.5	1.5	7.4	7.4
9	203								1.0		3.0	2.0	1.5	5.4
16	203											2.0	2.5	3.9
23	203									.5	.5	.5	4.9	2.0
30	203												1.5	.5
MAY 7	203													1.0
14	203													
21	203													
28	203													
JUN 4	203													
11	203													
18	203													
25	203													
JUL 2	203													
9	203													
16	203													
23	203													
30	203													
AUG 6	203													
13	203													
20	203													
27	203													
SEP 3	203													
10	203													
17	203													1.0
24	203													2.0
OCT 1	203													3.4
8	203											.5	1.5	2.5
15	203										.5	1.0	3.9	4.4
22	203									1.0	3.4	1.0	4.4	7.9
29	203								.5	2.5	5.4	2.5	6.9	11.3
NOV 5	203				.5			6.4	3.0	2.5	5.4	6.9	13.3	11.3
12	203			1.0	1.5	4.4	4.9	4.4	7.9	5.9	9.4	7.4	11.8	11.8
19	203	.5	1.5	2.5	.5	4.9	4.4	8.9	12.3	3.9	10.8	7.4	8.4	7.9
26	202	2.5	4.0	3.5	5.9	7.4	6.4	7.9	8.9	5.4	12.9	6.9	6.9	4.0
DEC 3	203	5.9	3.9	4.4	4.9	7.4	5.9	9.4	4.4	7.4	11.8	6.4	10.3	4.4
10	203	12.8	5.4	6.4	6.9	6.9	6.4	7.4	6.4	4.4	6.4	5.4	7.9	6.9
17	203	15.3	5.9	5.4	2.0	11.8	4.9	4.4	10.8	7.4	9.9	6.4	3.4	3.4
24	203	14.3	8.9	6.4	5.9	6.9	2.5	11.8	10.3	7.4	8.4	1.5	2.5	4.9

continued ...

Table 24. Part 2: daily maximum temperatures (°C), percent frequency by week, Fort McMurray A (Environment Canada 1978).

WEEK BEGINS	TOTAL DAYS	0 1	2 3	4 5	6 7	8 9	10 11	12 13	14 15	16 17	18 19	20 21	22 23	24 25	26 27	28 29	30 31	32 33	34 35	36 37	38 39	40 41	>= 42
JAN 1	202	3.0	2.5	3.5	2.0	1.0																	
8	203	2.0	4.9																				
15	203	1.5	1.5	2.5		.5	.5																
22	203	1.0	3.4	2.0	.5		.5																
29	203	1.5	4.9	2.0		3.0			.5														
FEB 5	203	3.0	4.9	2.0	2.5	2.5	.5	1.0															
12	203	3.4	2.5	2.5	2.0																		
19	203	2.5	3.4	6.9	5.4	2.5																	
26	203	3.9	4.4	6.4	3.4	1.5	1.5	1.0	.5														
MAR 5	203	6.4	4.4	4.9	4.9	4.4	1.0	.5															
12	203	7.9	14.3	6.4	6.9	6.4	1.0	1.0	1.0														
19	203	7.9	10.8	6.9	9.9	6.4	4.9	3.4	.5	.5													
26	203	6.4	10.3	11.3	14.8	11.8	5.4	4.4	2.5		.5												
APR 2	203	7.9	12.3	8.4	10.3	14.3	8.9	10.8	2.5	2.0		.5											
9	203	4.9	8.4	7.9	13.3	11.3	9.9	14.8	6.4	5.9	3.0	1.0	.5										
16	203	3.9	11.3	8.9	10.8	11.8	8.9	14.3	9.4	6.4	4.9	.5	.5										
23	203	1.5	7.4	5.4	7.4	8.9	10.8	14.8	9.4	7.4	9.9	3.0	4.9		1.0								
30	203	1.0	3.4	3.9	6.9	5.4	6.9	16.3	12.8	20.2	8.4	3.4	4.9	2.0	2.0	.5							
MAY 7	203		1.0	3.4	5.4	8.9	6.9	11.3	7.9	13.8	15.8	9.4	8.9	4.9	2.0	.5		1.0					
14	203		.5		3.4	4.4	5.9	13.8	10.3	14.8	12.8	13.3	11.8	2.0	3.0	2.5	1.0	.5					
21	203	.5		1.0	1.0	3.9	5.9	6.9	6.9	14.3	16.7	12.8	11.8	4.9	7.9	3.9	1.5						
29	203			.5	1.0	4.9	4.9	4.9	9.9	14.3	14.3	10.3	15.3	4.4	8.4	4.9	1.5	2.0	.5				
JUN 4	203					1.5	3.0	5.9	6.9	12.3	9.9	12.8	19.2	11.8	8.9	4.4	2.0	1.0		.5			
11	203					.5	3.0	8.4	4.4	11.8	13.3	10.3	18.2	10.8	11.8	5.4	2.0						
18	203					.5		3.4	3.9	10.3	12.3	15.3	23.6	11.8	9.9	6.9	1.5	.5					
25	203				.5	1.0	1.0	2.5	3.4	9.9	10.3	16.7	21.7	15.3	8.9	6.4	1.5	1.0					
JUL 2	203						.5	.5	1.5	5.4	10.3	10.3	22.2	16.7	15.8	9.9	4.4	2.0	.5				
9	203							1.5	2.5	2.5	7.9	13.3	25.6	17.2	16.5	6.9	2.0	3.0	1.5				
16	203							1.0	1.5	4.9	7.9	8.9	20.2	14.8	22.7	10.3	4.9	2.0	.5	.5			
23	203							2.5	1.5	7.4	14.3	16.7	17.7	13.8	16.7	7.4		1.0	1.0				
30	203							1.5	1.0	4.4	9.4	7.4	22.2	15.3	19.2	13.3	4.9	1.5					
AUG 6	203						.5	1.0	2.5	9.9	11.8	9.4	20.7	18.7	11.8	7.9	2.5	3.4					
13	203				.5		.5	5.4	4.9	6.4	12.8	12.8	22.7	12.3	8.4	8.4	3.9	1.0					
20	203			.5			1.5	3.9	4.4	15.8	13.8	13.3	17.7	11.3	5.9	6.4	3.4	2.0					
27	203				1.5	1.5	1.5	6.9	5.9	12.3	21.7	13.8	18.2	7.9	5.4	2.0	1.5						
SEP 3	203				3.0	7.9	9.9	5.9	9.9	13.8	18.2	9.9	13.8	2.5	1.0	3.4	1.0						
10	203	.5	1.5	1.5	3.9	4.9	6.4	11.8	14.3	14.3	11.3	10.3	8.4	5.9	2.5	2.0	.5						
17	203	1.5	1.5	1.5	6.9	14.3	11.3	12.8	8.9	12.3	9.9	6.9	6.4	1.5	2.5	1.0							
24	203	2.0	7.9	8.4	12.3	12.8	8.4	10.8	6.9	8.9	6.9	4.9	3.4	2.0	2.0	.5							
OCT 1	203	4.4	5.4	5.4	8.9	8.9	8.9	12.3	12.8	10.8	9.9	3.4	4.9		.5								
8	203	5.4	9.4	10.3	9.4	8.9	8.4	11.8	7.4	9.9	5.9	3.4	2.5	2.0	1.0								
15	203	5.4	8.9	7.4	5.4	15.3	13.8	15.8	5.4	6.9	1.5	2.0	1.0		1.5								
22	203	10.3	11.3	9.9	12.3	10.3	4.9	11.8	4.4	3.4	2.5	.5	.5										
29	203	8.4	17.2	10.3	8.4	13.3	5.9	4.4	1.5		1.5												
NOV 5	203	10.8	17.2	7.9	5.4	4.4	2.5	1.0	1.0	.5													
12	203	10.3	7.4	3.4	4.9	3.0			.5														
19	203	4.9	9.4	4.4	3.4	2.5	.5	1.0															
26	202	4.5	2.5	3.0	2.5	3.5	1.5																
DEC 3	203	5.4	3.9	2.0	1.0	.5	.5																
10	203	2.5	3.0	2.5	2.0	.5																	
17	203	2.5	2.0	1.0	1.0	2.0	.5																
24	203	2.5	2.5	1.0	1.5	.5	.5																

Table 25. Weekly precipitation amounts (mm), percent frequency by classes, Fort McMurray A (Environment Canada 1978).

WEEK BEGINS	TOTAL DAYS	0	0.25 TO 2.5	2.6 TO 10	11 TO 20	21 TO 30	31 TO 40	41 TO 50	51 TO 60	61 TO 70	71 TO 80	81 TO 90	91 OR MORE	MAX REPORTED
JAN 1	203		44.8	48.3	6.9									18.5
8	203	6.9	31.0	51.7	3.4	3.4	3.4							30.5
15	203	3.4	31.0	48.3	17.2									16.5
22	203	10.3	41.4	41.4	6.9									18.8
29	203	6.9	20.7	65.5	6.9									12.7
FEB 5	203	6.9	48.3	34.5	10.3									17.5
12	203	3.4	34.5	44.8	17.2									17.0
19	203	17.2	41.4	20.7	20.7									19.8
26	203	10.3	51.7	31.0	6.9									15.0
MAR 5	203	10.3	44.8	41.4		3.4								22.1
12	196	14.3	42.9	28.6	10.7			3.6						47.2
19	203	3.4	41.4	37.9	17.2									19.8
26	203	20.7	34.5	37.9	6.9									16.8
APR 2	203	6.9	34.5	37.9	17.2		3.4							33.8
9	203	24.1	34.5	27.6	6.9	6.9								27.9
16	203	10.3	55.2	24.1	3.4	6.9								22.1
23	203	27.6	31.0	24.1	13.8	3.4								21.8
30	203	17.2	31.0	31.0	17.2	3.4								28.4
MAY 7	203	20.7	37.9	31.0	3.4	3.4	3.4							32.5
14	203	10.3	17.2	51.7	13.8	3.4		3.4						41.1
21	203	10.3	31.0	31.0	20.7	3.4			3.4					54.9
28	203	13.8	20.7	31.0	13.8	17.2		3.4						41.7
JUN 4	203	13.8	10.3	51.7	13.8		6.9					3.4		81.3
11	203	6.9	6.9	24.1	24.1	24.1	3.4	6.9	3.4					56.1
18	203	10.3	13.8	27.6	27.6	10.3	3.4	3.4				3.4		86.9
25	203	6.9	6.9	13.8	31.0	24.1		6.9	6.9	3.4				60.7
JUL 2	203	6.9	6.9	37.9	27.6	6.9	6.9	3.4	3.4					50.8
9	203		6.9	37.9	24.1	17.2		3.4	3.4	6.9				69.6
16	203	6.9	3.4	44.8	20.7	13.8	6.9		3.4					52.1
23	203		3.4	27.6	31.0	24.1	6.9	3.4			3.4			80.0
30	203		3.4	48.3	20.7	10.3	6.9	3.4	3.4		3.4			77.5
AUG 6	203	6.9	3.4	20.7	44.8	13.8	6.9	3.4						48.3
13	203	3.4	24.1	27.6	20.7	10.3	3.4	3.4	6.9					56.4
20	203	10.3	20.7	34.5	10.3	13.8	3.4	3.4	3.4					58.4
27	203	17.2	17.2	31.0	17.2	6.9				10.3				64.8
SEP 3	203	6.9	34.5	13.8	24.1	13.8	3.4	3.4						48.0
10	203	13.8	13.8	37.9	17.2		6.9	6.9			3.4			73.2
17	203	13.8	20.7	6.9	37.9	3.4	6.9	6.9	3.4					54.1
24	203	13.8	27.6	27.6	17.2	6.9	3.4	3.4						46.5
OCT 1	203	13.8	34.5	41.4		3.4		3.4	3.4					50.8
8	203	10.3	24.1	48.3	13.8	3.4								23.4
15	196	21.4	42.9	21.4	10.7	3.6								21.6
22	203	13.8	27.6	37.9	17.2	3.4								25.4
29	203	17.2	31.0	27.6	17.2	6.9								27.4
NOV 5	203	13.8	31.0	31.0	20.7	3.4								20.8
12	203	6.9	24.1	55.2	10.3	3.4								24.9
19	203	3.4	20.7	58.6	13.8		3.4							32.0
26	196	17.9	21.4	53.6	7.1									13.0
DEC 3	203		41.4	51.7	6.9									15.5
10	203	13.8	24.1	48.3	13.8									15.5
17	203	17.2	10.3	58.6	10.3	3.4								26.9
24	203	10.3	24.1	41.4	17.2	6.9								30.0

10.3 SYNOPTIC PATTERNS AND SOME EXTREME EVENTS IN THE AOSERP STUDY AREA

10.3.1 Introduction

Much of the information in the main body of this report deals with long-term averages of the various meteorological elements. However, extreme events such as heavy rainfalls, and cold and hot spells are part of the climatological picture and may have profound impacts on the activities within the study area.

The synoptic patterns giving rise to some of these events are described in this section. The patterns are illustrated with a surface chart and an upper air chart (500 mb--approximately 5500 metres).

10.3.2 The storm of 1-3 July 1977

This storm, illustrated by Figures 14 to 16, is an example of a "cold low" mentioned in the text and defined in section 10.1. In this particular storm the main precipitation band was closely associated with the 500 mb centre (Figure 15). This centre entered Alberta in the vicinity of Grande Prairie and moved northeastwards toward the AOSERP area. The centre moved across the Birch Mountains where a record 24-hour rainfall was recorded (87 mm on 2 July).

The heavy precipitation associated with this storm was confined to higher ground and a relatively small portion of the AOSERP area (Figure 16), and it should be noted that southern portions of the area received relatively little precipitation.

10.3.3 The cold spell of 6-8 December 1977

The AOSERP area with its continental climate is subject to extended cold spells in winter. The synoptic patterns associated with a fairly typical outbreak are shown in Figures 17 and 18.

The essential features to note in Figure 17 are the high pressure area over the Northwest Territories and the position of the low pressure area well south of the AOSERP area. It will also be noticed that there is a flat gradient (isobars widely separated) over northeastern Alberta. This implies light winds, usually a necessary condition for extremely low temperatures.

At 500 mb (Figure 18) the gradient over most of Alberta and the southern parts of the Northwest Territories is weak. This implies little motion of the high pressure system lying north of the AOSERP area. The combination of surface and upper air circulation in this particular situation was such that the cold spell lasted several days.

10.3.4 An example of a winter mild spell, 21 January 1977

The synoptic conditions favoring mild winter weather in the AOSERP study area are depicted in Figures 19 and 20. Such mild spells occur when upper air conditions are such that the surface low pressure areas are steered through northern Alberta. Note that in Figure 19 the low pressure area lies north of the AOSERP study area whereas in the cold outbreak (Figure 17) the low pressure area lies in southeastern British Columbia. Similarly there is a difference at the 500 mb level. In the cold outbreak (Figure 18) the gradient is weak over most of Alberta, whereas in the mild spell (Figure 20) there is a high pressure ridge over British Columbia which has steered the surface low into northern Alberta.

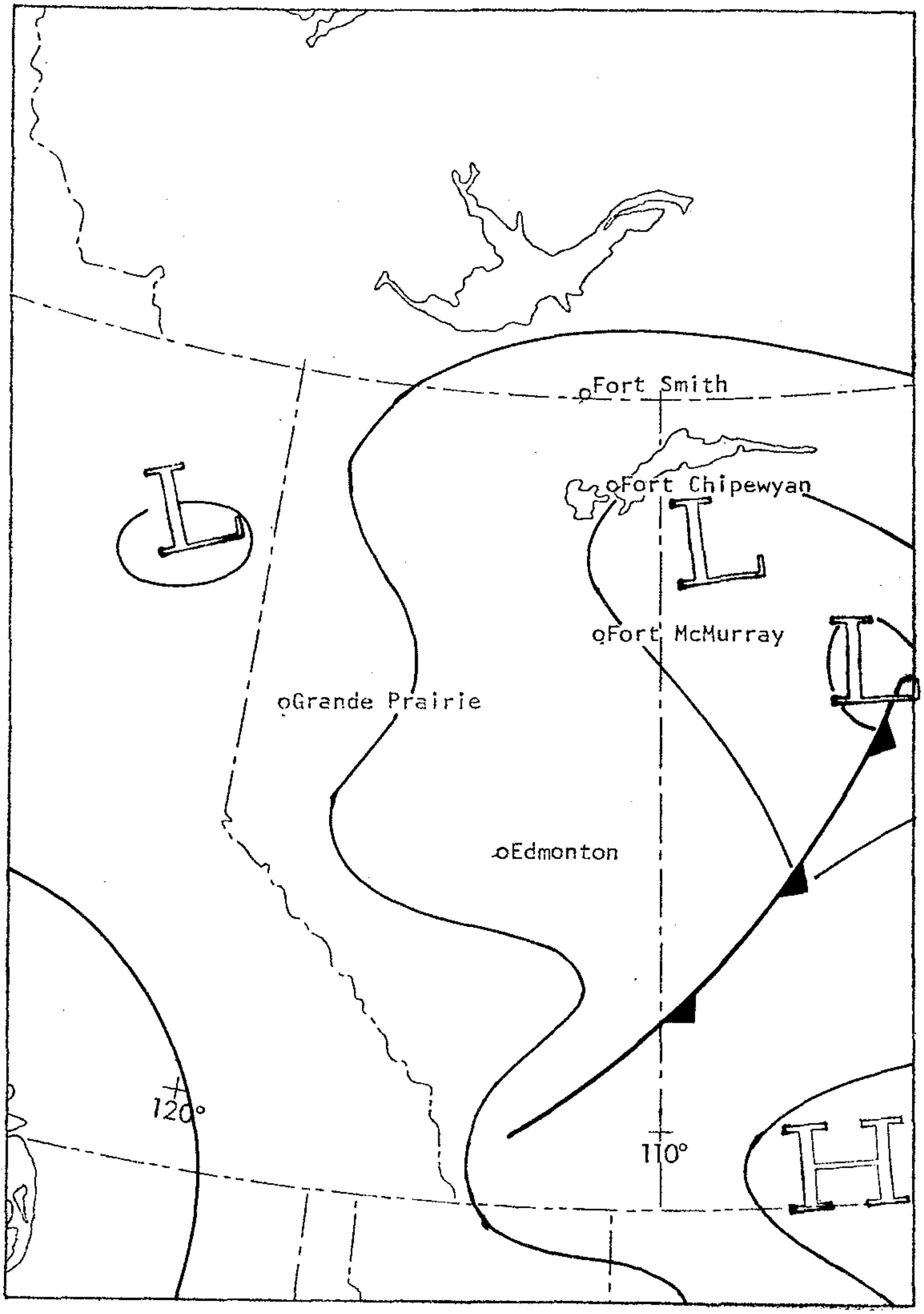

Figure 14. Surface chart for 1700, 3 July 1977.

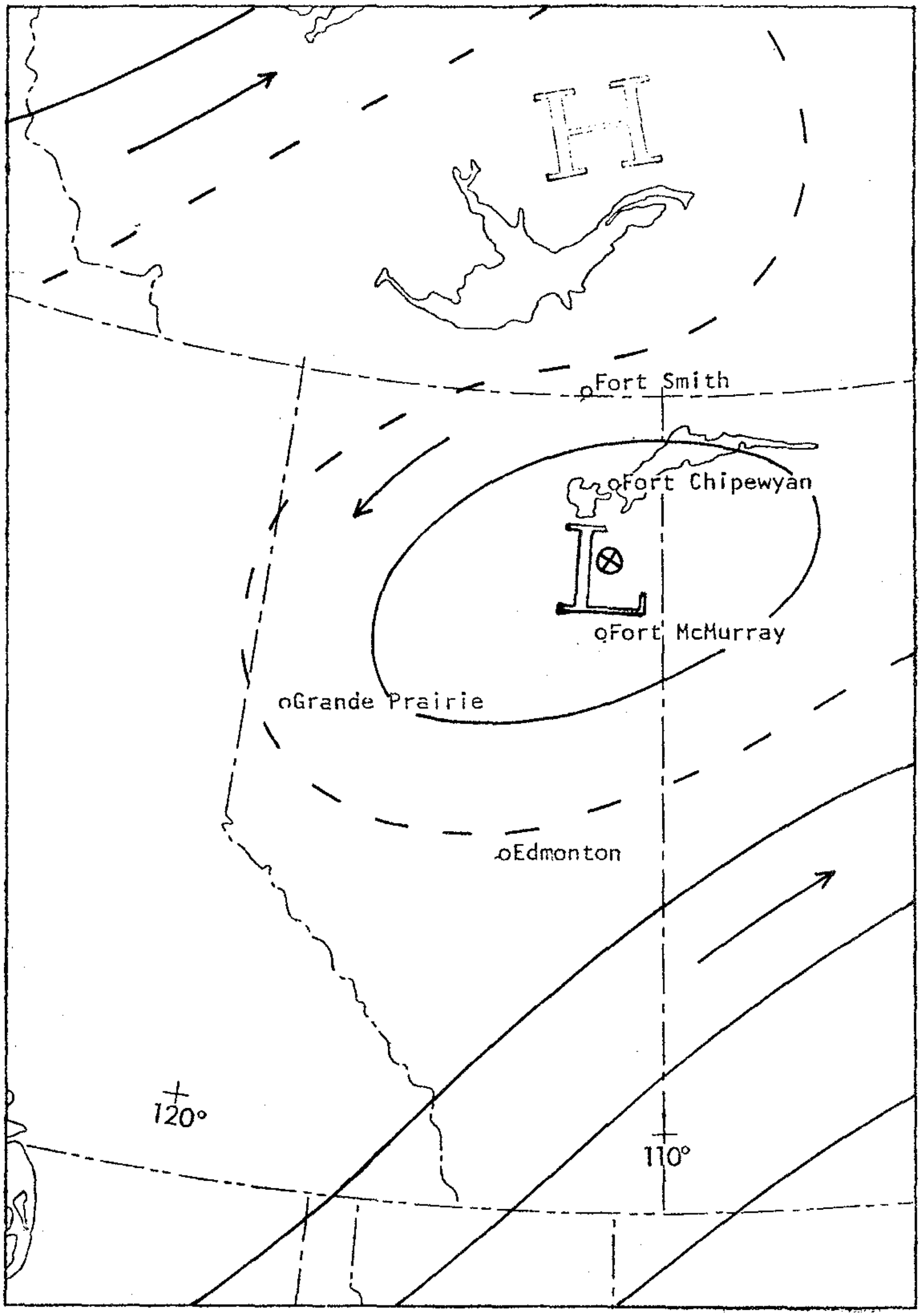

Figure 15. Upper air 500 mb chart for 1700, 3 July 1977.

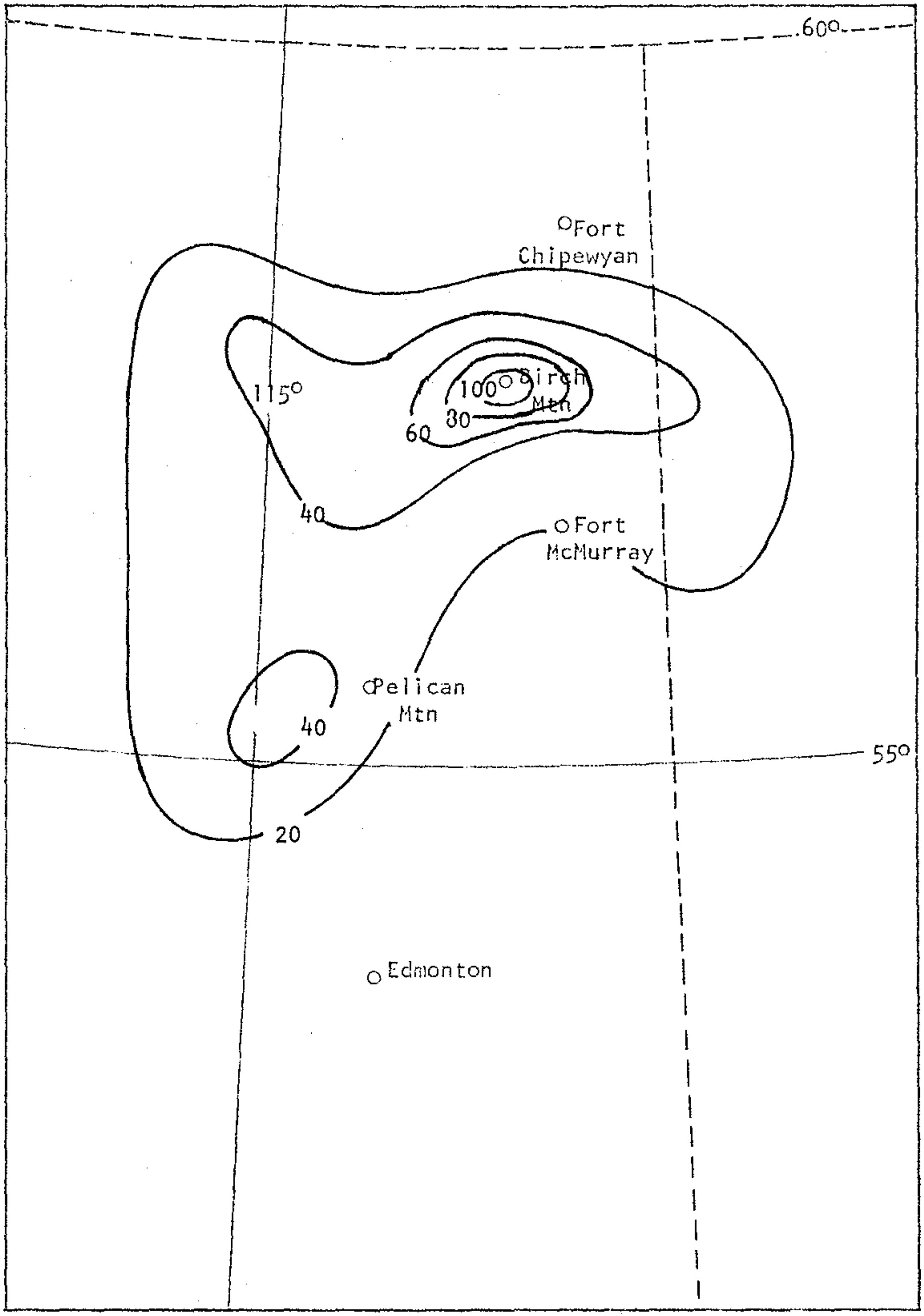

Figure 16. Isohyets (20 mm intervals) for storm of 1-3 July 1977.

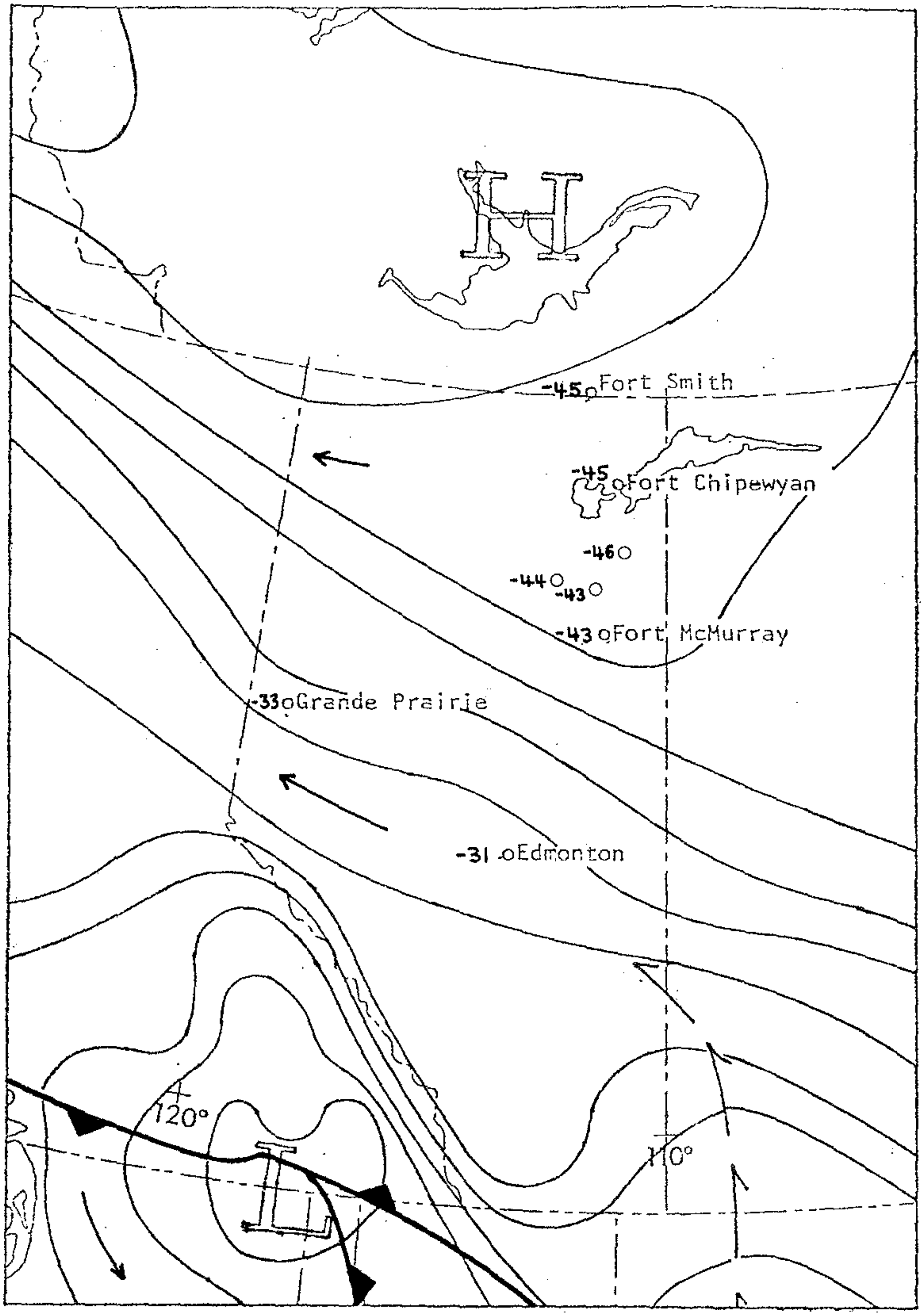

Figure 17. Surface chart for 0500, 7 December 1977. Numbers to left of station circle are temperatures in °C.

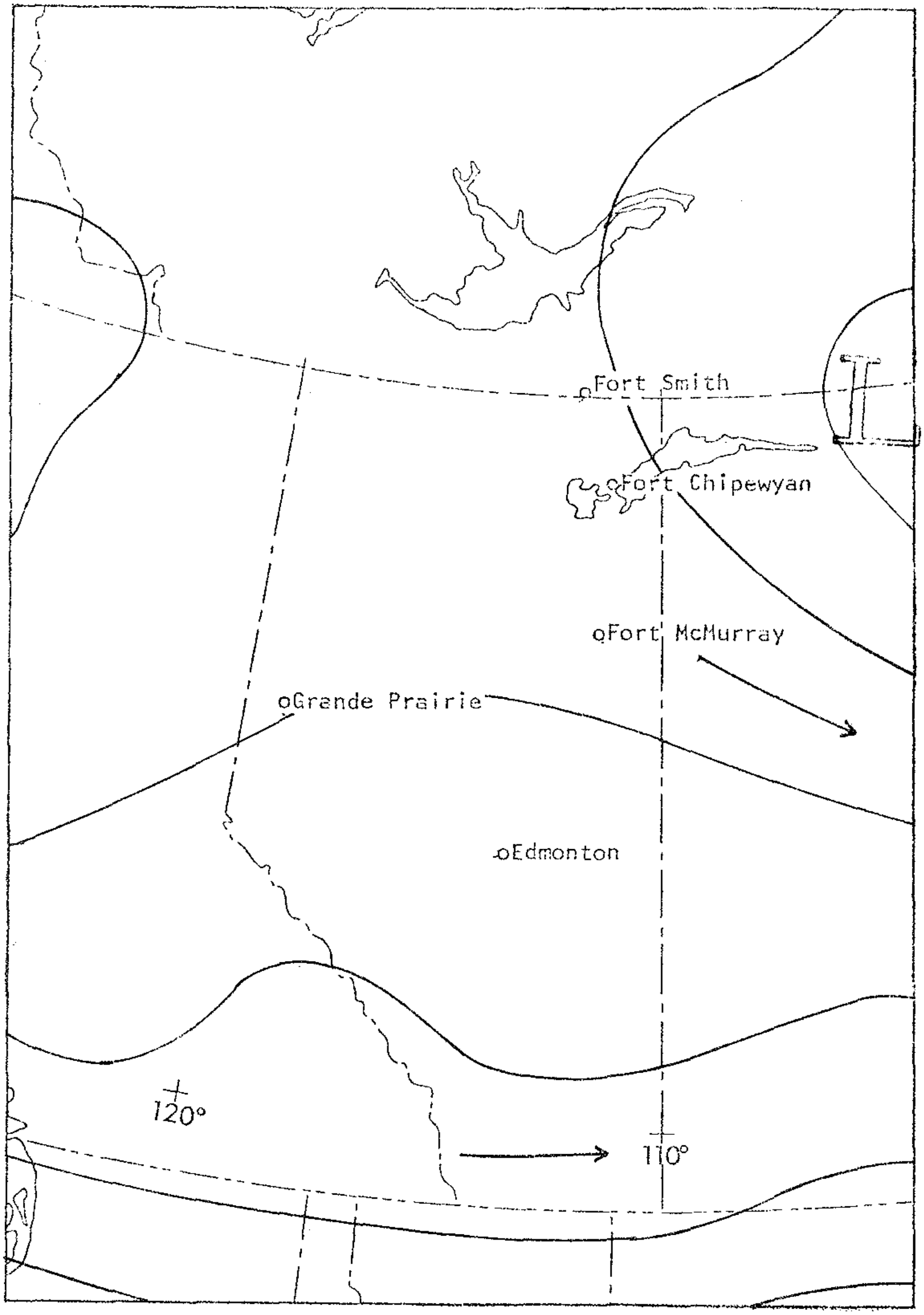

Figure 18. Upper air 500 mb chart for 0500, 7 December 1977.

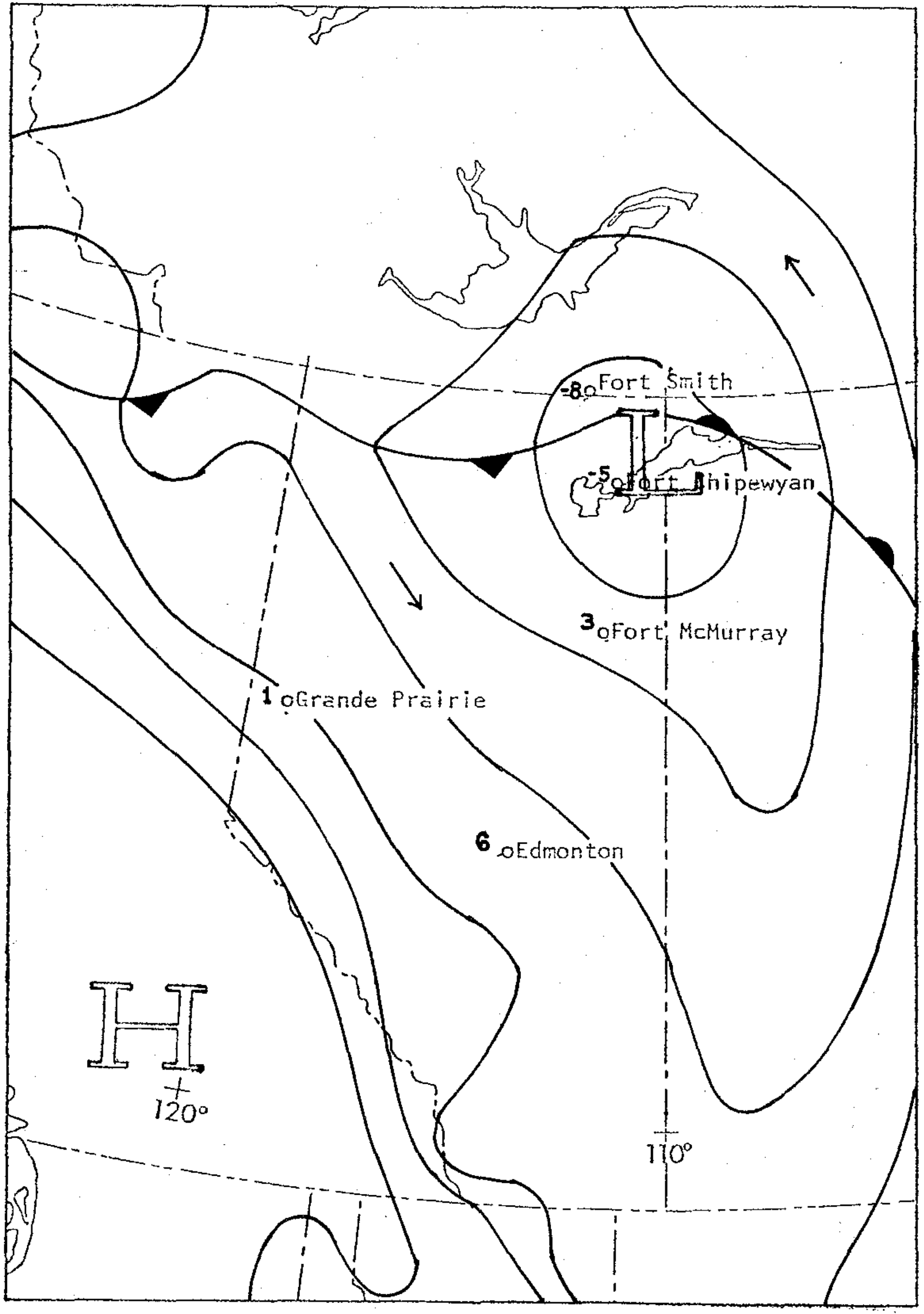

Figure 19. Surface chart for 1700, 21 January 1977.
Numbers to left of station circle are temperatures in °C.

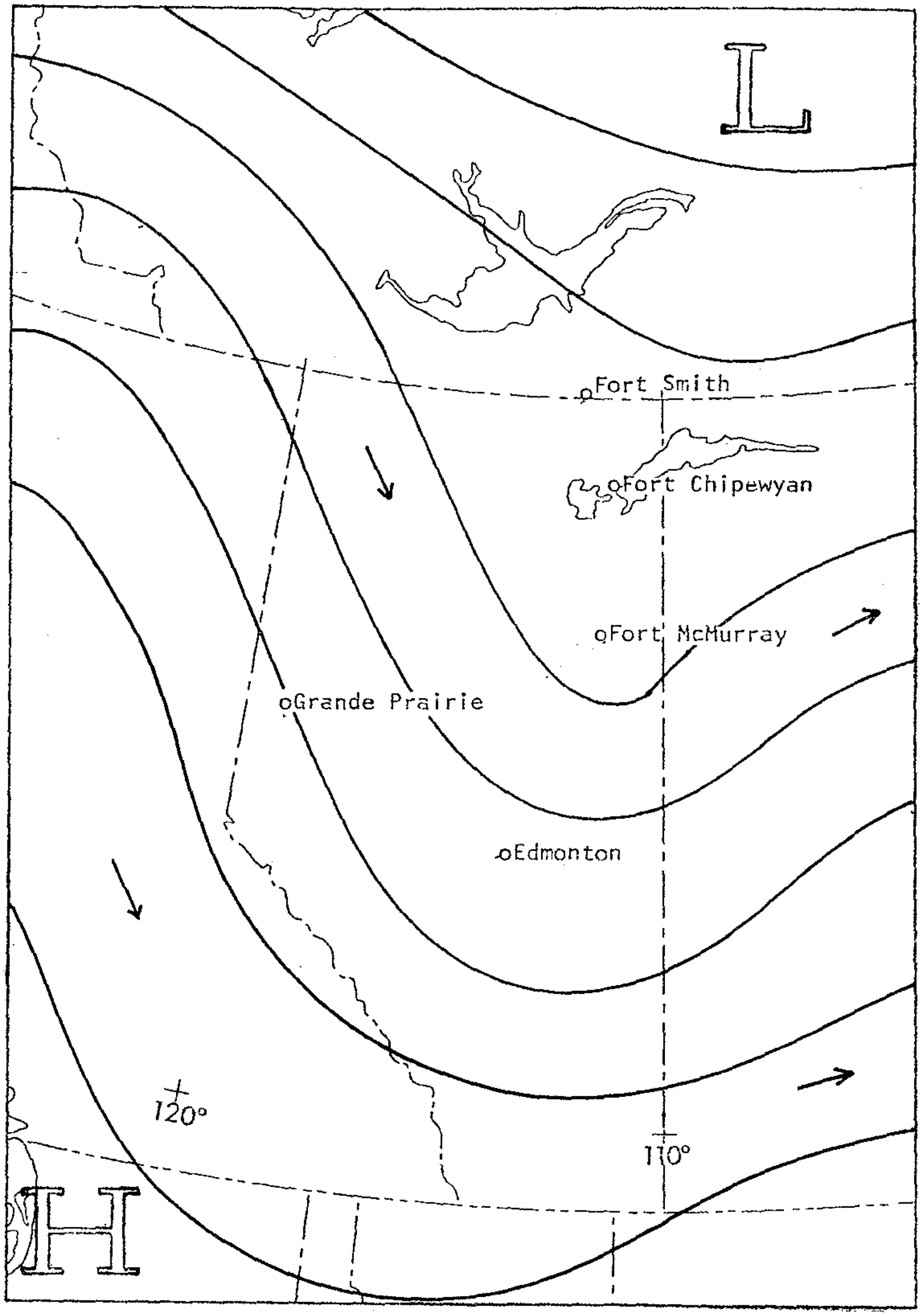

Figure 20. Upper air 500 mb chart for 1700, 21 January 1977.

11. AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
7.	AF 3.1.1	A Synopsis of the Physical and Biological Limnology and Fisheries Programs within the Alberta Oil Sands Area
8.	AF 1.2.1	The Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography)
9.	ME 3.3	Preliminary Investigations into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10.	HE 2.1	Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11.	AF 2.2.1	Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12.	ME 1.7	Very High Resolution Meteorological Satellite Study of Oil Sands Weather: "a Feasibility Study"
13.	ME 2.3.1	Plume Dispersion Measurements from an Oil Sands Extraction Plant, March 1976
14.	HE 2.4	Athabasca Oil Sands Historical Research Design (3 Volumes)
15.	ME 3.4	A Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area
16.	ME 1.6	The Feasibility of a Weather Radar near Fort McMurray, Alberta
17.	AF 2.1.1	A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18.	HY 1.1	Interim Compilation of Stream Gauging Data to December 1976 for the Alberta Oil Sands Environmental Research Program
19.	ME 4.1	Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area
20.	HY 3.1.1	Characterization of Organic Constituents in Waters and Wastewaters of the Athabasca Oil Sands Mining Area

21.		AOSERP Second Annual Report, 1976-77
22.	HE 2.3	Maximization of Technical Training and Involvement of Area Manpower
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 4.2.1	Review of Dispersion Models and Possible Applications in the Alberta Oil Sands Area
25.	ME 3.5.1	Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area
26.	AF 4.5.1	Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
27.	ME 1.5.1	Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976
28.	VE 2.1	Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29.	ME 2.2	An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30.	ME 2.1	Ambient Air Quality in the AOSERP Study Area, 1977
31.	VE 2.3	Ecological Habitat Mapping of the AOSERP Study Area: Phase I
32.		AOSERP Third Annual Report, 1977-78
33.	TF 1.2	The Relationship Between Habitats, Forages, and Carrying Capacity of Moose Range in the AOSERP Study Area
34.	HY 2.4	Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area
35.	AF 4.9.1	The Effects of Sedimentation on the Aquatic Biota
36.	AF 4.8.1	Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
37.	HE 2.2.2	Community Studies: Fort McMurray, Anzac, Fort MacKay
38.	VE 7.1.1	Techniques for the Control of Small Mammals: A Review
39.	ME 1.0	The Climatology of the Alberta Oil Sands Environmental Research Program Study Area

These reports are not available upon request. For further information about availability and location of depositories, please contact:

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